CSA A23.1:19/CSA A23.2:19

National Standard of Canada

Concrete materials and methods of concrete construction/Test methods and standard practices for concrete



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Contents

Technical Committee on Concrete Materials and Construction *9*

Preface *15*

CSA A23.1:19, *Concrete materials and methods of concrete construction*

0 Introduction *18*

1 Scope *18*
1.1 General *18*
1.2 Exclusions *18*
1.3 Precasting of concrete in the field *18*
1.4 Parking garages *19*
1.5 Supplementary specifications *19*
1.6 Terminology *19*

2 Reference publications *19*

3 Definitions *47*

4 Materials and concrete properties *55*
4.1 Requirements for concrete and alternative methods for specifying concrete *55*
4.1.1 Durability requirements *55*
4.1.2 Alternatives for specifying concrete *59*
4.2 Materials *60*
4.2.1 Cements and supplementary cementitious materials *60*
4.2.2 Water *61*
4.2.3 Aggregates *61*
4.2.4 Admixtures *66*
4.2.5 Fibres *67*
4.2.6 Pigments for integrally coloured concrete *67*
4.3 Concrete properties *67*
4.3.1 Mix proportions *67*
4.3.2 Workability *68*
4.3.3 Air entrainment *69*
4.3.4 Density *70*
4.3.5 Strength *70*
4.3.6 Volume stability considerations *70*
4.3.7 Chloride ion penetrability *71*
4.4 Quality control *71*
4.4.1 Responsibilites *71*
4.4.2 Concrete acceptance *73*

5 Production and delivery *75*
5.1 Storage of materials *75*
5.1.1 General *75*
5.1.2 Cementitious materials *75*

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5.1.3 Aggregate *76*
5.1.4 Admixtures *76*
5.2 Production of concrete *76*
5.2.1 General *76*
5.2.2 Measurement of materials *77*
5.2.3 Batching plant *78*
5.2.4 Mixing *79*
5.2.5 Delivery *81*

6 Formwork, reinforcement, and prestressing *84*
6.1 Reinforcement *84*
6.1.1 Reinforcing steel *84*
6.1.2 Bend test *84*
6.1.3 Special reinforcement *85*
6.1.4 Dissimilar metals *85*
6.1.5 Prestressing steel *85*
6.1.6 Surface condition of reinforcement *85*
6.1.7 Protective coating *86*
6.2 Hardware and miscellaneous materials *86*
6.2.1 Hardware and ferrous inserts *86*
6.2.2 Nonferrous inserts *86*
6.2.3 Protective coating *86*
6.2.4 Miscellaneous materials *86*
6.2.5 Vapour retarder *87*
6.3 Storage of reinforcement *87*
6.3.1 General *87*
6.3.2 Special storage requirements *87*
6.4 Construction tolerances for cast-in-place concrete *88*
6.4.1 General *88*
6.4.2 Cross-sectional dimensions and tolerances *88*
6.4.3 Plumbness *89*
6.4.4 Relative alignment *90*
6.4.5 Levelness *90*
6.4.6 Variations from a reference system and general dimensions *90*
6.5 Formwork *91*
6.5.1 General *91*
6.5.2 Drawings for formwork *91*
6.5.3 Construction *91*
6.6 Fabrication and placement of reinforcement *93*
6.6.1 General *93*
6.6.2 Hooks and bends *93*
6.6.3 Spirals *94*
6.6.4 Ties *95*
6.6.5 Spacing of reinforcement *96*
6.6.6 Concrete cover *96*
6.6.7 Support of reinforcement *97*
6.6.8 Tolerances for location of reinforcement *99*
6.6.9 Splices of reinforcement *100*
6.6.10 Welding of reinforcement *100*

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6.6.11 Inspection *100*
6.7 Fabrication and placement of hardware and other embedded items *100*
6.7.1 General *100*
6.7.2 Placing of hardware *100*
6.7.3 Tolerances for placing anchor bolts and hardware *101*
6.7.4 Welding of hardware *101*
6.7.5 Conduits and pipes embedded in concrete *102*
6.8 Post-tensioning *103*
6.8.1 General *103*
6.8.2 Unbonded tendons *104*
6.8.3 Bonded tendons *106*
6.8.4 Cement grout for bonded tendons *107*
6.8.5 Preparation for post-tensioning *109*
6.8.6 Application and measurement of prestressing force *112*
6.8.7 Grouting *113*

7 Placing, finishing, and curing concrete *115*
7.1 Preconstruction quality planning *115*
7.1.1 General *115*
7.1.2 Concrete mixes for interior concrete floors *115*
7.2 Hot and cold weather concreting *116*
7.2.1 Hot weather concreting — Job preparation *116*
7.2.2 Cold weather concreting *116*
7.3 Jointing *117*
7.3.1 Construction joints *117*
7.3.2 Contraction joints *118*
7.3.3 Isolation joints *119*
7.3.4 Expansion joints *120*
7.3.5 Joint filling *120*
7.4 Storage of materials used for placing, finishing, and curing *120*
7.4.1 General *120*
7.4.2 Fabricated and proprietary materials *120*
7.5 Placing of concrete *120*
7.5.1 General *120*
7.5.2 Handling *121*
7.5.3 Depositing *122*
7.5.4 Consolidation *124*
7.5.5 Concreting underwater *124*
7.5.6 Concrete placed by tremie *125*
7.5.7 Concreting tubular piles and drilled shafts *125*
7.6 Protection of plastic concrete *126*
7.6.1 General *126*
7.6.2 Initial curing for high-strength and high-performance concrete *127*
7.6.3 Mass concrete *127*
7.7 Finishing of concrete floor surfaces *129*
7.7.1 Surface tolerances *129*
7.7.2 Correction of floor flatness deficiencies *130*
7.7.3 Initial finishing of horizontal surfaces *130*
7.7.4 Final finishing *131*

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7.7.5 Abrasion and wear resistance *133*
7.7.6 Nonslip surfaces *133*
7.7.7 Scratch finish *133*
7.7.8 Grinding *133*
7.7.9 Moisture condition of concrete floors *134*
7.8 Curing *134*
7.8.1 General *134*
7.8.2 Methods and materials *134*
7.8.3 Curing for special requirements *135*
7.9 Bonded toppings *136*
7.9.1 Types *136*
7.9.2 Special concrete mixtures for toppings *136*
7.9.3 Monolithic toppings *137*
7.9.4 Bonding systems *137*
7.9.5 Bonding fresh concrete to rock *138*
7.9.6 Tensile bond *138*
7.9.7 Testing frequency *138*
7.9.8 Finishing bonded toppings *138*
7.9.9 Curing *139*
7.10 Finishing of formed surfaces *139*
7.10.1 General *139*
7.10.2 Formed surface finishes *139*
7.10.3 Patching *140*
7.10.4 Rubbed finishes *141*

8 Concrete with special performance or material requirements *142*
8.1 General *142*
8.1.1 Application *142*
8.1.2 Purpose *142*
8.1.3 Criteria *142*
8.1.4 Relevant clauses *142*
8.1.5 Performance evaluation *143*
8.1.6 Materials *143*
8.1.7 Mix proportions *143*
8.1.8 Placing and curing *143*
8.2 High-performance concrete and ultra-high performance concrete *143*
8.3 Architectural concrete *143*
8.3.1 General *143*
8.3.2 Reference samples *144*
8.3.3 Mock-up field samples *144*
8.3.4 Formwork for special architectural finishes *144*
8.3.5 Placing of architectural cast-in-place concrete *145*
8.3.6 Special finishes *146*
8.4 Pervious concrete *146*
8.5 High-strength concrete *147*
8.5.1 General *147*
8.5.2 Aggregate *147*
8.5.3 Mixing *147*
8.5.4 Trial mixes *147*

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8.5.5 Temperature *147*
8.5.6 Consolidation *147*
8.5.7 Curing and protection *147*
8.5.8 Strength testing *148*
8.6 Self-consolidating concrete *148*
8.6.1 General *148*
8.6.2 Materials *149*
8.6.3 Performance requirements for SCC *149*
8.6.4 Mixture proportions *149*
8.6.5 Delivery and placing *150*
8.6.6 Finishing *150*
8.6.7 Formwork *150*
8.6.8 Curing *150*
8.7 Concrete made with high-volume supplementary cementitious materials *150*
8.7.1 Proportion of SCM *150*
8.7.2 Materials *151*
8.7.3 Trial mixes *151*
8.7.4 Curing requirements *151*
8.8 Low-shrinkage concrete *152*
8.8.1 General *152*
8.8.2 Qualification testing *152*
8.8.3 Qualification of the mixture proportions *152*
8.9 No-slump concrete *152*
8.9.1 General *152*
8.9.2 Trial mixtures *153*
8.9.3 Concrete mix design *153*
8.9.4 Field testing of no-slump concrete *153*
8.9.5 Consolidation *153*
8.9.6 Slump and air content tests *153*
8.9.7 Contractor co-operation *153*
8.9.8 Pre-construction meeting *154*
8.10 Roller-compacted concrete *154*
8.11 Controlled low-strength materials (CLSM) *154*
8.11.1 General *154*
8.11.2 Unshrinkable fill *154*
8.12 Concrete made with alternative supplementary cementitious materials *156*
8.12.1 General *156*
8.12.2 Materials *156*
8.12.3 Use in concrete *156*
8.13 Shotcrete *156*
8.13.1 General *156*
8.13.2 Materials *157*
8.13.3 Performance requirements for shotcrete *157*
8.13.4 Mixture proportions *158*
8.13.5 Delivery *159*
8.13.6 Placing *159*
8.13.7 Consolidation considerations *159*
8.13.8 Hardened shotcrete testing *160*

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9 Concrete for housing and small buildings (R class concrete) *160*
9.1 General *160*
9.2 Formwork and formed sections *161*
9.3 Requirements for concrete *161*
9.4 Chloride exposure of R class concretes *161*
9.5 Sulphate exposure of R class concretes *161*

Annexes
Annex A (informative) — Special cements *189*
Annex B (informative) — Alkali-aggregate reaction *191*
Annex C (informative) — Tolerances: Principles, preferred sizes, and usage *220*
Annex D (informative) — Guidelines for curing and protection *224*
Annex E (informative) "Reserved" — Concrete surface tolerances: Elevation, slope, and waviness *226*
Annex F (informative) — Abrasion resistance of concrete surfaces *227*
Annex G (informative) — Sample grouting record *231*
Annex H (informative) — Fibre-reinforced concrete *233*
Annex I (informative) — High-performance concrete *237*
Annex J (informative) — Guide for selecting alternatives when ordering concrete using Table 5 *243*
Annex K (informative) — Concrete made with high-volume supplementary cementitious materials *255*
Annex L (informative) — Mineral filler as an aggregate for concrete *259*
Annex M (informative) — Sustainable development, construction, and concrete *262*
Annex N (informative) — Requirements for pervious concrete *273*
Annex O (informative) — Aggregate made from recycled concrete for use in hydraulic cement concrete *278*
Annex P (informative) — Impact of sulphides in aggregate on concrete behaviour and global approach to determine potential deleterious reactivity of sulphide-bearing aggregates *288*
Annex Q (informative) — Simple method to optimize combined aggregate gradation *341*
Annex R (informative) — Residential concrete construction *351*
Annex S (informative) — Concrete made with carbon dioxide as an additive *360*
Annex T (informative) — Mass concrete *364*
Annex U (informative) — Ultra-high performance concrete (UHPC) *376*

CSA A23.2:19, *Test methods and standard practices for concrete*

1 Scope *411*
1.1 General *411*
1.2 Hazards *411*
1.3 Dimensions *411*
1.4 Terminology *411*

2 Reference publications *412*

3 Definitions *412*

4 Reporting *412*

Test methods

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A23.2-1A — Sampling aggregates for use in concrete *413*
A23.2-2A — Sieve analysis of fine and coarse aggregate *421*
A23.2-3A — Clay lumps in natural aggregate *427*
A23.2-4A — Low-density granular material in aggregate *431*
A23.2-5A — Amount of material finer than 80 µm in aggregate *436*
A23.2-6A — Relative density and absorption of fine aggregate *440*
A23.2-7A — Test for organic impurities in fine aggregates for concrete *447*
A23.2-8A — Measuring mortar-strength properties of fine aggregate *450*
A23.2-9A — Soundness of fine and coarse aggregate by use of magnesium sulphate *457*
A23.2-10A — Bulk density of aggregate *465*
A23.2-11A — Surface moisture in fine and coarse aggregate *470*
A23.2-12A — Relative density and absorption of coarse aggregate *478*
A23.2-13A — Flat and elongated particles in coarse aggregate *485*
A23.2-14A — Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C) *495*
A23.2-15A — Petrographic examination of aggregates *509*
A23.2-16A — Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine *547*
A23.2-17A — Resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine *554*
A23.2-23A — Test method for the resistance of fine aggregate to degradation by abrasion in the Micro-Deval apparatus *558*
A23.2-24A — Test method for the resistance of unconfined coarse aggregate to freezing and thawing *568*
A23.2-25A — Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars *579*
A23.2-26A — Determination of potential alkali-carbonate reactivity of quarried carbonate rocks by chemical composition *588*
A23.2-27A — Standard Practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete *594*
A23.2-28A — Standard Practice for laboratory testing to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete *611*
A23.2-29A — Test method for the resistance of coarse aggregate to degradation by abrasion in the Micro-Deval apparatus *619*
A23.2-30A — Standard Practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes *627*
A23.2-1B — Testing for properties of flowable grout *636*
A23.2-2B — Determination of sulphate ion content in groundwater *643*
A23.2-3B — Determination of total or water-soluble sulphate ion content of soil *646*
A23.2-4B — Sampling and determination of water-soluble chloride ion content in hardened grout or concrete *650*
A23.2-6B — Determination of bond strength of bonded toppings and overlays and of direct tensile strength of concrete, mortar, and grout *658*
A23.2-7B — Random sampling of construction materials *666*
A23.2-8B — Determination of water-soluble sulphate ion content of recycled aggregates containing crushed concrete *674*
A23.2-1C — Sampling plastic concrete *677*
A23.2-2C — Making concrete mixes in the laboratory *681*

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A23.2-3C — Making and curing concrete compression and flexural test specimens *688*
A23.2-4C — Air content of plastic concrete by the pressure method *702*
A23.2-5C — Slump of concrete *708*
A23.2-6C — Density and yield of plastic concrete *713*
A23.2-7C — Air content of plastic concrete by the volumetric method *719*
A23.2-8C — Flexural strength of concrete (using simple beam with third-point loading) *729*
A23.2-9C — Compressive strength of cylindrical concrete specimens *733*
A23.2-10C — Accelerating the curing of concrete cylinders and determining their compressive strength *748*
A23.2-11C — Water content, density, absorption, and voids in hardened concrete, grout, or mortar *756*
A23.2-12C — Making, curing, and testing compression test specimens of no-slump concrete *760*
A23.2-13C — Splitting tensile strength of cylindrical concrete specimens *766*
A23.2-14C — Obtaining and testing drilled cores for compressive strength testing *774*
A23.2-15C — Evaluation of concrete strength in place using the pullout test *778*
A23.2-16C — Determination of steel or synthetic fibre content in plastic concrete *790*
A23.2-17C — Temperature of freshly mixed hydraulic cement concrete *794*
A23.2-18C — Determination of total water content of normal weight fresh concrete *797*
A23.2-19C — Slump flow of concrete *802*
A23.2-20C — Passing ability of self-consolidating concrete by J-ring and slump cone *807*
A23.2-21C — Test Method for length change of hardened concrete *812*
A23.2-22C — Scaling resistance of concrete surfaces exposed to deicing chemicals using mass loss *819*
A23.2-23C — Electrical indication of concrete's ability to resist chloride ion penetration *827*
A23.2-24C — Standard Practice for sampling, testing, and inspection of concrete for qualification purposes *839*
A23.2-25C — Standard Practice for sampling, testing, and inspection of concrete for acceptance purposes *846*
A23.2-26C — Bulk electrical resistivity of concrete *855*
A23.2-1D — Moulds for forming vertical concrete test cylinders *866*
Annex A (informative) — Nondestructive methods for testing concrete *871*
Annex B (informative) — Form for reporting compressive strength of concrete test cylinders *876*

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Preface

This is the thirteenth edition of the combined CSA A23.1/CSA A23.2, *Concrete materials and methods of concrete construction/Test methods and standard practices for concrete*. These Standards are part of the CSA A23 series on concrete and supersede the previous editions published in 2014, 2009, 2004, 2000, 1994, 1990, 1977, 1973, 1967, 1960, 1942, and 1929.

There have been many technical, editorial, and formatting changes throughout this edition; the most significant technical changes are the following:

a) Requirements and guidance for materials qualification and for quality assessment, previously included in Clause 4 of A23.1, have been extensively reorganized and clarified into the following new standard practices:
   i) A23.2-30A, *Standard Practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes;*
   ii) A23.2-24C, *Standard Practice for sampling, testing, and inspection of concrete for qualification and acceptance purposes;* and
   iii) A23.2-25C, *Standard Practice for sampling, testing, and inspection of concrete for acceptance purposes.*
b) Additional provisions have been added for mass concrete including the submission of a thermal control plan for controlling and monitoring temperature.
c) There is a new requirement for the slump of concrete for interior concrete floors, partly for reasons of health and safety.
d) Annex P on the potentially deleterious impact of sulphide minerals in concrete aggregate has been substantially updated, including a new performance evaluation protocol, revised criteria on maximum sulphur content of aggregates, and three new preliminary test methods for the determination of the sulphide content of aggregate and for assessing the potential for deleterious oxidation of sulphide-bearing aggregates.
e) Annex S, which was first published as an amendment to the 2014 edition, provides information on concrete made with carbon dioxide in either a gaseous or liquid form as an additive to reduce the carbon footprint of cement and concrete.
f) The new Annex T on mass concrete has been added providing information on material properties and their effect on the temperature rise, measures to control and monitor temperature, temperature limits for maximum concrete temperature and maximum temperature difference for concrete in mass placements, and best practices to protect and cure mass concrete.
g) The new Annex U has been added to provide information for materials and methods of construction for the use of ultra-high performance concrete (UHPC) with minimum strengths of 120 and 150 MPa.
h) The new test method has been added to CSA A23.2: A23.2-26C, *Bulk electrical resistivity of concrete.* This test provides an indication of resistance of concrete to the penetration of fluids and aggressive ions.

The Technical Committee includes representatives from most geographical areas of Canada and from all sectors of the industry: concrete producers, specifying and regulatory authorities, materials consultants, concrete testing laboratories, researchers, and teachers. The Technical Committee intends to review and update these Standards on a continuing basis and to maintain a close liaison with the CSA Technical Committees on Design of Concrete Structures and Cementitious Materials.

CSA Group acknowledges that the development of these Standards were made possible in part by the financial support of the Canadian Ready Mixed Concrete Association.

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These Standards were prepared by the Technical Committee on Concrete Materials and Construction, under the jurisdiction of the Strategic Steering Committee on Concrete and Related Products, and have been formally approved by the Technical Committee.

These Standards have been developed in compliance with Standards Council of Canada requirements for National Standards of Canada. They have been published as National Standards of Canada by CSA Group.

Notes:

1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*
2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*
3) *This Standard was developed by consensus, which is defined by* CSA Policy governing standardization — Code of good practice for standardization *as "substantial agreement. Consensus implies much more than a simple majority, but not necessarily unanimity". It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of this Standard.*
4) *To submit a request for interpretation of this Standard, please send the following information to inquiries@csagroup.org and include "Request for interpretation" in the subject line:*
   a) *define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;*
   b) *provide an explanation of circumstances surrounding the actual field condition; and*
   c) *where possible, phrase the request in such a way that a specific "yes" or "no" answer will address the issue.*

   Committee interpretations are processed in accordance with the CSA Directives and guidelines governing standardization *and are available on the Current Standards Activities page at standardsactivities.csa.ca.*
5) *This Standard is subject to a review within five years from the date of publication. Suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to inquiries@csagroup.org and include "Proposal for change" in the subject line:*
   a) *Standard designation (number);*
   b) *relevant clause, table, and/or figure number;*
   c) *wording of the proposed change; and*
   rationale for the change.

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National Standard of Canada

CSA A23.1:19

Concrete materials and methods of concrete construction



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CSA A23.1:19
Concrete materials and methods of concrete construction

0 Introduction

This Standard is intended to be used in its entirety. Caution should be exercised in extracting individual clauses and using them in project specifications, since taking them out of context can change their meaning.

A number of notes and several annexes, inserted for guidance, can in some cases be made mandatory by appropriate references in contract documents.

Many clauses provide alternatives and require choices to be made by the user of this Standard. The actual choices should be clearly identified in contract documents.

1 Scope

1.1 General

This Standard provides the requirements for materials and methods of construction for

a) cast-in-place concrete and concrete precast in the field; and
b) residential concrete used in the construction of buildings conforming to Part 9 of the *National Building Code of Canada (NBCC)*.

1.2 Exclusions

This Standard does not specify the following:

a) requirements for the design of concrete structures, which are provided in CSA A23.3 and CSA S6;
b) designs of specialty concrete products, which are described in separate CSA Group Standards;
c) test methods for concrete, which are provided in CSA A23.2;
d) design provisions governing the fire resistance of reinforced concrete structures, which are set out in the *NBCC*;
e) requirements for the plant production of precast concrete, which are provided in CSA A23.4; and
f) use of proprietary materials or methods of construction.

Note: *Proprietary materials or methods of construction may be permitted by the owner under a separate specification, provided that the quality of the resulting construction meets the minimum requirements of this Standard.*

1.3 Precasting of concrete in the field

1.3.1

At the option of the owner, precasting of concrete in the field or in a plant (temporary or permanent) is governed by this Standard or by CSA A23.4, except as limited by Clauses 1.3.2, 1.3.3, and 1.3.4 of this Standard.

Note: *Guidelines for such a choice are provided in CSA A23.4.*

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1.3.2
Precast products that may be produced in accordance with this Standard include conventionally reinforced elements of structures, such as tilt-up walls, stair flights, landings, balcony slabs, lintels, and sills. Products requiring prestressing or post-tensioning are produced in accordance with CSA A23.4.

Note: *For references to tilt-up construction, see PCA PA163 and ACI 551R.*

1.3.3
If tolerances equivalent to the requirements of CSA A23.4 are desired, then CSA A23.4 is specified for all precasting operations.

1.3.4
The requirements of CSA A23.4 are applicable to pretensioned concrete and precast concrete used in segmental construction.

1.4 Parking garages
For parking garages, the additional requirements of CSA S413 are applicable.

1.5 Supplementary specifications
In addition to the requirements of this Standard, the owner may elect to include supplementary specifications to address proprietary materials and methods of construction, or any other elements not dealt with in this Standard, in order to ensure that the desired quality level is maintained.

1.6 Terminology
In this Standard, “shall” is used to express a requirement, i.e., a provision that the user is obliged to satisfy in order to comply with the Standard; “should” is used to express a recommendation or that which is advised but not required; and “may” is used to express an option or that which is permissible within the limits of the Standard.

Notes accompanying clauses do not include requirements or alternative requirements; the purpose of a note accompanying a clause is to separate from the text explanatory or informative material.

Notes to tables and figures are considered part of the table or figure and may be written as requirements.

Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

2 Reference publications
This Standard refers to the following publications, and where such reference is made, it shall be to the edition listed below, including all amendments published thereto.

CSA Group

CAN/CSA-ISO 9001:16
Quality management systems — Requirements

A23.2:19
Test methods and standard practices for concrete

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A23.3-14
Design of concrete structures

A23.4-16
Precast concrete — Materials and construction

A283:19
Qualification Code for concrete testing laboratories

A371-14
Masonry construction for buildings

CAN/CSA-A438-00 (R2004) (withdrawn)
Concrete construction for houses and small buildings

A864-00 (R2005)
Guide to the evaluation and management of concrete structures affected by alkali-aggregate reaction

A3000-18, Cementitious Materials Compendium:

A3001-18
Cementitious materials for use in concrete

A3004-18
Test methods for cementitious materials for use in concrete and masonry

A3005-18
Test equipment and materials for cementitious materials for use in concrete and masonry

G30.18-09 (R2014)
Billet-steel bars for concrete reinforcement

G40.20-13/G40.21-13 (R2018)
General requirements for rolled or welded structural quality steel/structural quality steel

Multi-laboratory study of proposed new test for determination of sulphide sulphur content of concrete aggregates, 2019
https://www.csagroup.org/article/multi-laboratory-study-of-proposed-new-test-for-determination-of-sulphide-sulphur-content-of-concrete-aggregates/

S6-19
Canadian Highway Bridge Design Code

S269.1-16
Falsework and formwork

S413-14
Parking structures

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CAN/CSA-S474-04 (R2014)
Concrete structures

S478-95 (R2007)
Guideline on durability in buildings

S806-12 (R2017)
Design and construction of building structures with fibre-reinforced polymers

W47.1-09 (R2014)
Certification of companies for fusion welding of steel

W59-13
Welded steel construction (metal-arc welding)

W186-M1990 (R2016)
Welding of reinforcing bars in reinforced concrete construction

CAN/CSA-Z234.1-00 (withdrawn)
Metric practice guide

AASHTO (American Association of State Highway and Transportation Officials)

M 182-91 (1996)
Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats

T 26-79 (2008) (withdrawn)
Standard Method of Test for Quality of Water to be Used in Concrete

T 105-14
Standard Method of Test for Chemical Analysis of Hydraulic Cement

T 336-11
Standard Test Method for Determining the Coefficient of Thermal Expansion of Hydraulic Cement Concrete

T 358-17
Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Penetration

ACI (American Concrete Institute)

117-10
Specification for Tolerances for Concrete Construction and Materials (ACI 117-10) and Commentary

201.2R-16
Guide to Durable Concrete

207.1R-05
Guide to Mass Concrete

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207.2R-07
Report on Thermal and Volume Change Effects on Cracking of Mass Concrete

207.5R-11
Report on Roller-Compacted Mass Concrete

211.1-91 (R2009)
Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete

211.2-98 (R2004)
Standard Practice for Selecting Proportions for Structural Lightweight Concrete

211.3R-02 (R2009)
Standard Practice for Selecting Proportions for No-Slump Concrete

211.7R-17
Guide for Proportioning Concrete Mixtures with Ground Limestone and Other Mineral Fillers

214R-11
Guide to Evaluation of Strength Test Results of Concrete

214.4R-10
Guide for Obtaining Cores and Interpreting Compressive Strength Results

222R-01 (R2010)
Protection of Metals in Concrete Against Corrosion

223R-10
Guide for the Use of Shrinkage-Compensating Concrete

224R-01 (R2008)
Control of Cracking in Concrete Structures

228.1R-03
In-Place Methods to Estimate Concrete Strength

228.2R-98 (R2004)
Nondestructive Test Methods for Evaluation of Concrete in Structures

229R-13
Report on Controlled Low-Strength Materials

237R-07
Self-Consolidating Concrete

301-16
Specifications for Structural Concrete

302.1R-15
Guide to Concrete Floor and Slab Construction

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302.2R-06
Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials

303R-12
Guide to Cast-in-Place Architectural Concrete Practice

304R-00 (R2009)
Guide for Measuring, Mixing, Transporting, and Placing Concrete

304.2R-96 (R2008)
Placing Concrete by Pumping Methods

305R-10
Guide to Hot Weather Concreting

306R-16
Guide to Cold Weather Concreting

308R-16
Guide to External Curing of Concrete

309R-05
Guide for Consolidation of Concrete

309.2R-98 (R2005)
Identification and Control of Visible Effects of Consolidation on Formed Concrete Surfaces

309.5R-00 (R2006)
Compaction of Roller-Compacted Concrete

318-14
Building Code Requirements for Structural Concrete and Commentary

327R-14
Guide to Roller-Compacted Concrete Pavements

336.1-01
Specification for the Construction of Drilled Piers

347R-14
Guide to Formwork for Concrete

360R-10
Guide to Design of Slabs-on-Ground

363.2R-11
Guide to Quality Control and Assurance of High-Strength Concrete

503R-93 (R2008)
Use of Epoxy Compounds with Concrete

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506R-16
Guide to Shotcrete

506.1R-08
Guide to Fiber-Reinforced Shotcrete

522R-10
Report on Pervious Concrete

522.1-13
Specification for Pervious Concrete Pavement

544.2R-17
Report on the Measurement of Fresh State Properties and Fiber Dispersion of Fiber-Reinforced Concrete

544.3R-08
Guide for specifying, proportioning, mixing, placing, and finishing FRC

544.4R-18
Guide to Design with Fiber-Reinforced Concrete

544.5R-10
Report on the Physical Properties and Durability of Fiber-Reinforced Concrete

544.6R-15
Report on Design and Construction of Steel Fiber-Reinforced Concrete Elevated Slabs

544.7R-16
Report on Design and Construction of Fiber-Reinforced Precast Concrete Tunnel Segments

544.8R-16
Report on Indirect Method to Obtain Stress-Strain Response of Fiber-Reinforced Concrete

544.9R-17
Report on Measuring Mechanical Properties of Hardened Fiber-Reinforced Concrete

551R-92
Tilt-Up Concrete Structures

CT-18
ACI Concrete Terminology

ACI Collection Online
https://www.concrete.org/publications/collectiononline.aspx

SP-004, 2014 (8th Edition)
Formwork for Concrete

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SP-131, 1992
Durability of Concrete — G.M. Idorn International Symposium — Calcium Chloride in Type V-Cement Concrete

AFNOR (Association française de normalisation)
P15-315-1991
Liants hydrauliques — Ciment alumineux fondu

APHA/AWWA/WEF (American Public Health Association/American Water Works Association/Water Environment Foundation)
Standard Methods for the Examination of Water and Wastewater, 21st Edition, 2005

ASCC (American Society for Concrete Contractors)
Guide for Surface Finish of Formed Concrete, The Aberdeen Group, 1999

Association Française de Genie Civil
Betons Auto-Placants (Self-consolidating Concrete) (July 2000)

ASTM International
A53/A53M-18
Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless

A184/A184M-17
Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement

A185/A185M-07 (withdrawn)
Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete

A416/A416M-18
Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete

A421/A421M-15
Standard Specification for Stress-Relieved Steel Wire for Prestressed Concrete

A704/A704M-18
Standard Specification for Welded Steel Plain Bar or Rod Mats for Concrete Reinforcement

A722/A722M-18
Standard Specification for High-Strength Steel Bars for Prestressed Concrete

A767/A767M-16
Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement

A775/A775M-17
Standard Specification for Epoxy-Coated Reinforcing Steel Bars

A820/A820M-16
Standard Specification for Steel Fibers for Fiber-Reinforced Concrete

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A1064/A1064M-18a
Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

C25-17
Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime

C33/C33M-18
Standard Specification for Concrete Aggregates

C39/C39M-18
Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

C109/C109M-16a
Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in or [50-mm] Cube Specimens)

C114-18
Standard Test Methods for Chemical Analysis of Hydraulic Cement

C117-17
Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

C123/C123M-14
Standard Test Method for Lightweight Particles in Aggregate

C136/C136M-14
Standard Test Method for Sieve analysis of Fine and Coarse Aggregates

C142/C142M-17
Standard Test Method for Clay Lumps and Friable Particles in Aggregates

C151/C151M-18
Standard Test Method for Autoclave Expansion of Hydraulic Cement

C171-16
Standard Specification for Sheet Materials for Curing Concrete

C173/C173M-16
Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C174/C174M-17
Standard Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores

C227-10 (withdrawn)
Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

C231/C231M-17a
Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

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C260-10
Standard Specification for Air-Entraining Admixtures for Concrete

C289-07 (withdrawn)
Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)

C293/C293M-16
Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

C294-12(2017)
Standard Descriptive Nomenclature for Constituents of Concrete Aggregates

C305-14
Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

C309-11
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C330/C330M-17a
Standard Specification for Lightweight Aggregates for Structural Concrete

C342-97 (withdrawn)
Standard Test Method for Potential Volume Change of Cement-Aggregate Combinations

C403/C403M-16
Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance

C457-16
Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C469/C469M-14
Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

C490/C490M-17
Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

C494/C494M-17
Standard Specification for Chemical Admixtures for Concrete

C496/C496M-17
Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

C511-13
Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

C512/C512M-15
Standard Test Method for Creep of Concrete in Compression

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C597-16
Standard Test Method for Pulse Velocity Through Concrete

C617/C617M-15
Standard Practice for Capping Cylindrical Concrete Specimens

C627-18
Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson-Type Floor Tester

C666/C666M-15
Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C672/C672M-12
Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

C685/C685M-17
Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing

C702/C702M-18
Standard Practice for Reducing Samples of Aggregate to Testing Size

C803/C803M-18
Standard Test Method for Penetration Resistance of Hardened Concrete

C805/C805M-18
Standard Test Method for Rebound Number of Hardened Concrete

C856-18a
Standard Practice for Petrographic Examination of Hardened Concrete

C873/C873M-15
Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Moulds

C900-15
Standard Test Method for Pullout Strength of Hardened Concrete

C939/C939M-16a
Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)

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C979-16
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C1017/C1017M-13e1
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C1064/C1064M-17
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C1074-17
Standard Practice for Estimating Concrete Strength by the Maturity Method

C1084-10 (withdrawn)
Standard Test Method for Portland-Cement Content of Hardened Hydraulic-Cement Concrete

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C1260-14
Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

C1362-09 (withdrawn)
Standard Test Method for Flow of Freshly Mixed Hydraulic Cement Concrete

C1383-15
Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method

C1437-15
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C1542/C1542M-16a
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Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

C1579-13
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C1581/C1581M-18a
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Volume 04.02-18
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3 Definitions

The following definitions shall apply in this Standard:

Admixture — a material other than water, aggregate, cementitious material, and fibre reinforcement used as an ingredient in concrete, mortar, or neat cement grout and added to the batch immediately before or during its mixing in order to purposely modify its usual characteristics and behaviour.

Air-entraining admixture — an admixture that causes the development of a system of microscopic air bubbles in concrete or mortar during mixing.

Chemical admixtures —

a) a water-reducing, cement-dispersing agent having a neutral, accelerating, or retarding effect on setting time and giving water reduction in low, mid-, or high range for strength development and enhancement of slump of the concrete; and
b) set-modifying admixtures (i.e., accelerators, retarders, and hydration stabilizers) that affect setting time.

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Corrosion-inhibiting admixture — a chemical compound mixed into concrete that impedes the initiation and kinetics of the electrochemical corrosion process at the reinforcement surface.

Lithium-based admixture — an admixture (usually based on lithium nitrate) that prevents deleterious alkali-silica reaction.

Shrinkage-reducing admixture (SRA) — an admixture for concrete that reduces shrinkage due to drying.

Viscosity-modifying admixture (VMA) — a material composed of long-chain polymer molecules that, when added to concrete, affects the viscosity (cohesiveness) of the mixture. VMAs are typically used in self-consolidating concrete (SCC) or as an anti-washout admixture in underwater concrete.

Aggregate — a natural, processed, or manufactured granular material having physical, chemical, and mineralogical characteristics suitable for use in concrete (or in mortar).

High-density aggregate — aggregate of high relative density from which high-density concrete can be produced.

Low-density aggregate — aggregate of low relative density from which low-density structural concrete can be produced.

Normal-density aggregate — any suitable aggregate from which normal-density concrete can be produced.

Note: *Examples of suitable aggregate are natural sand, manufactured sand, gravel, crushed gravel, crushed stone, and air-cooled iron blast-furnace slag.*

Air-cooled iron blast-furnace slag — the material resulting from solidification of a molten non-metallic product consisting essentially of silicates and aluminosilicates of calcium and other bases, developed simultaneously with iron in a blast furnace.

Alkali-aggregate reaction — the chemical reaction in either concrete or mortar between hydroxyl ions (OH^-) of the alkalis (sodium and potassium) from hydraulic cement or other sources and certain constituents of some aggregates.

Note: *Under certain conditions, deleterious expansion of concrete or mortar can result.*

Alkali-carbonate reaction — the chemical reaction in either concrete or mortar between hydroxyl ions (OH^-) of the alkalis (sodium and potassium) from hydraulic cement or other sources and certain carbonate rocks, particularly calcitic dolostone and dolomitic limestones, present in some aggregates.

Note: *The reaction causes dedolomitization and expansion of the affected aggregate particles, leading to abnormal expansion and cracking of concrete in service.*

Alkali-silica gel — the reaction product formed in some concretes or mortars when certain susceptible silica/silicate minerals or rocks react with hydroxyl ions (OH^-) in the pore solution to form a gelatinous sodium/potassium/calcium silicate hydrate.

Note: *The composition of the gel varies depending on the composition of the alkaline pore solution and the age of the gel.*

Alkali-silica reaction (ASR) — the chemical reaction in either concrete or mortar between hydroxyl ions (OH^-) of the alkalis (sodium and potassium) from hydraulic cement or other sources and certain

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siliceous rocks and minerals, such as opal, chert, micro-crystalline quartz, and acidic volcanic glass, present in some aggregates.

Note: *This reaction and the development of the alkali-silica gel reaction product can, under certain circumstances, lead to abnormal expansion and cracking of the concrete.*

Alternative supplementary cementitious materials (ASCM) — constituents that show pozzolanic or hydraulic properties, or both.

Note: *ASCMs are not supplementary cementitious materials as defined in CSA A3001.*

Backup mix — the concrete that is cast into the formwork as a filler behind a face mix.

Blast-furnace slag — see **Granulated blast-furnace slag**.

Bleeding — the emergence of mixing water from plastic concrete or mortar.

Blended hydraulic cement — a product obtained by

a) blending Portland cement or Portland-limestone cement and up to three supplementary cementitious materials; or
b) intergrinding Portland cement clinker and up to three supplementary cementitious materials or two supplementary cementitious materials and granulated blast-furnace slag, to which the various forms of calcium sulphate, limestone, water, and processing additions may be added at the option of the manufacturer.

There are two classes of blended hydraulic cement: Portland cement based and Portland-limestone cement based.

Notes:

1) *Blended hydraulic cements may be produced by intergrinding or blending, or a combination of both. The attainment of a homogeneous blend, in the dry state, of all materials is important. Appropriate equipment and controls should be provided by the manufacturer.*
2) *Material proportions are indicated in Table 9 of CSA A3001.*
3) *The requirements for limestone used in a Portland cement based blended cement (limestone content ≤ 5% based on the Portland cement fraction) are found in Clauses 4.4.2 and 4.4.3 of CSA A3001.*
4) *The requirements for limestone used in Portland-limestone based blended cement (limestone content > 5% and ≤ 15% based on the Portland-limestone cement fraction) are found in Clause 4.4.4 of CSA A3001.*
5) *Portland-limestone cement is by itself a cementitious material and is not considered to be a blended hydraulic cement.*

There are three types of blended hydraulic cement: binary, ternary, and quaternary.

Binary blended hydraulic cement — a blended hydraulic cement containing a single supplementary cementitious material. The proportions are indicated in Table 9 of CSA A3001.

Quaternary blended hydraulic cement — a blended hydraulic cement containing three supplementary cementitious materials. The proportions are indicated in Table 9 of CSA A3001.

Ternary blended hydraulic cement — a blended hydraulic cement containing two supplementary cementitious materials. The proportions are indicated in Table 9 of CSA A3001.

Bundling — the placing of several parallel elements of reinforcement in contact with each other.

Camber — the upward curvature built into the framework system to compensate for the anticipated deflection of the structure after formwork is removed.

Cement — hydraulic cement or blended hydraulic cement.

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Cementitious material — hydraulic cement with or without a supplementary cementitious material.

Chloride ion penetrability — the charge passed, in coulombs, during the 6 h test period specified in CSA A23.2-23C.

Concrete — a composite material consisting essentially of a mixture of cementitious material and water within which are embedded particles of fine and coarse aggregate.

Air-entrained concrete — concrete in which air, in the form of minute bubbles, has been incorporated during the mixing period as a result of the use of an air-entraining admixture.

Architectural concrete — concrete that is exposed to view as an interior or exterior surface in the completed structure and specifically designated as such in contract documents.

Flowing concrete — a homogeneous concrete having a slump greater than 180 mm.

High-density concrete — concrete having an air-dry density exceeding 2500 kg/m^3.

High-performance concrete (HPC) — concrete that meets performance requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices.
Note: *The requirements can involve enhancements of placement and compaction, long-term mechanical properties, early-age strength, toughness, volume stability, or service life in severe environments.*

High-strength concrete — concrete having a specified compressive strength of at least 70 MPa at a specified age not exceeding 91 d.

High-volume supplementary cementitious materials (HVSCM) concrete — concrete that contains a level of supplementary cementitious materials above that typically used for normal construction.
Note: *See Clause 8.7 for requirements and further information on HVSCM concrete.*

Mass concrete — a body of concrete for which consideration is given to temperature rise caused by the hydration of the cement.

Normal concrete — concrete as described in Table 1, without special performance or material requirements.

Normal-density concrete — concrete having an air-dry density between 2150 kg/m^3 and 2500 kg/m^3.

Pervious concrete — an open-graded, no-slump concrete designed to be free draining.

Precast concrete — concrete elements cast in a location other than their final position in service.

Prestressed concrete — concrete in which internal stresses have been initially introduced so that the subsequent stresses resulting from dead load and superimposed loads are counteracted to a desired degree. This can be accomplished by the following:

Post-tensioning — a method of prestressing in which the tendons are tensioned after the concrete has hardened.

Pretensioning — a method of prestressing in which the tendons are tensioned before the concrete is placed.

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Reinforced concrete — concrete in which reinforcement is embedded in such a manner that the two materials act together in resisting forces.

Roller-compacted concrete (RCC) — a zero slump mixture of aggregate, cementitious materials, water, and admixtures that is compacted in place by vibratory rollers or plate compaction equipment.

Self-consolidating concrete (SCC) — a highly flowable, yet stable, concrete that can spread readily into place, fill the formwork, and encapsulate the reinforcement, if present, without any mechanical consolidation and without undergoing any significant separation of material constituents.

Structural concrete — concrete for structures designed in accordance with CSA A23.3 and CSA S6.

Structural low-density concrete — concrete having a specified 28 d compressive strength of 20 MPa or greater and an air-dry density not exceeding 1850 kg/m^3.

Structural semi-low-density concrete — concrete having a specified 28 d compressive strength of 20 MPa or greater and an air-dry density between 1850 kg/m^3 and 2150 kg/m^3.

Superplasticized flowing concrete — flowing concrete obtained by the use of a superplasticizing admixture.

Concrete cover — the distance from the concrete surface to the nearest deformation (or surface, for smooth bars or wires) of the reinforcement.

Consistency — the degree of fluidity of freshly mixed concrete or mortar.

Contractor — an individual or firm responsible for the construction of all or part of the structure.

Curing — the maintenance of a satisfactory moisture content and temperature in concrete for a period of time immediately following placing and finishing so that desired properties can develop.

Delayed ettringite formation (DEF) — a late internal sulphate attack in hardened concrete caused by the formation of ettringite after early hydration and formed from sulphur-containing compounds that were present in the concrete at the time of casting.
Note: *This phenomenon has been particularly noted in heat-treated concrete.*

Engineer — a person in the engineering profession who is licensed to practice in a jurisdiction in Canada, with specific expertise in either or both of
a) concrete materials and methods of concrete construction; or
b) principal test methods for hardened and freshly mixed concrete and for concrete materials.

Face mix — the exposed (visible) face of an architectural component behind which is a different type of concrete which can be a less costly or less visually attractive mix.

Fibre-reinforced polymers (FRP) — a composite material formed from continuous fibres impregnated with a fibre-binding polymer, then hardened and moulded in the form of reinforcement or concrete.

Field-cured specimens — concrete test specimens cured as nearly as practicable in the same manner as the concrete in the structure.

Filling ability — the ability of self-consolidating concrete to flow into and fill completely all spaces within the formwork.

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Fineness modulus (FM) — an empirical factor equal to 1% of the sum of the cumulative percentages by mass of a sample of aggregate retained on each of a specified series of sieves. The sieves used are adopted from ISO 3310-1 as follows: 160 µm, 315 µm, 630 µm, 1.25 mm, 2.5 mm, 5 mm, 10 mm, 20 mm, 40 mm, and 80 mm.

Fines — a material of particle size smaller than 80 µm.

Finishability — the subjective property of a concrete that allows leveling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete to produce desired appearance and service.

Flatness — the degree to which a surface approximates a plane.

Floating — working the unformed surface of fresh concrete to produce a relatively even, but still open texture.

Flowability — the tendency of concrete to move away from the site of discharge under its own weight and the force of gravity without any additional external energy being applied.

Granulated blast-furnace slag (GBFS) — the glassy granular material formed when molten blast-furnace slag is rapidly chilled.

Notes:

1) *Granulation may be achieved by immersing the molten slag in water, by the pelletizing process, or by other satisfactory methods that will ensure a high percentage of glass or vitrification. Granulation may be accomplished in the initial melt or after remelting air-cooled slag.*
2) *Small percentages of silica and alumina may be added while the slag is molten, to enhance desired characteristics.*

Honeycomb — voids left in concrete due to failure of the mortar to effectively fill the spaces between coarse aggregate particles.

Hydraulic cement — a type of cement that sets and hardens through a chemical reaction with water and is capable of setting and hardening under water.

Note: *Blended hydraulic cement, Portland cement, Portland-limestone cement, mortar cement, and masonry cement are examples of hydraulic cement.*

Joint —

Cold joint — a joint or discontinuity formed when a concrete surface hardens before the next batch of concrete is placed against it.

Construction joint — a joint used to delineate the limits of an individual concrete placement.

Contraction joint — a joint intended to encourage cracking due to shrinkage at a specific location.

Expansion joint — a separation provided between adjoining parts of a structure to allow movement.

Isolation joint — a joint that allows relative movement to take place between adjoining parts of a structure to prevent spalling of the concrete.

Laitance — a layer of weak material containing cement and fines from aggregates, brought to the top of the concrete by bleeding water.

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Levelness — the degree to which a line or surface parallels the horizontal plane.

Mineral filler — finely divided inorganic material, such as limestone powder, that may be used in concrete in some applications and exposure conditions, after its suitability is determined through physical, chemical and mineralogical testing.

Note: *An example of such an application is self-consolidating concrete.*

Mortar — a mixture consisting essentially of cementitious material, fine aggregate, and water which may also contain chemical admixtures.

Mudsill — a temporary plate or board set in place on grade to transfer vertical loads from shores or falsework.

Mud slab — a layer of concrete placed over soft, wet soil to provide a level surface beneath a structural concrete floor or footing, typically 50 to 150 mm thick.

Neat cement grout — a mixture consisting of cementitious materials and water that may contain chemical admixtures.

Nominal maximum size of aggregate — the standard sieve opening, which is one size smaller than the smallest sieve through which all of the aggregate must pass. For combined aggregate gradations, if more than 15% is retained on the standard sieve opening that is one size smaller than the smallest sieve through which all of the aggregate passes, the nominal size is the smallest sieve size through which all material passed.

Note: *This definition applies only to concrete that contains coarse aggregate.*

Owner — the administrator of the requirements of this Standard or the designated representative, usually an engineer, a member of the Ordre des ingénieurs du Québec, or an architect.

Passing ability — the capacity of aggregate to flow around formwork and through reinforcement without separation from the mortar or paste fraction of the concrete.

Placing — the handling, deposition, and consolidation of freshly mixed concrete in the place where it is to harden.

Plumbness — the degree of closeness to a vertical direction radiating from the centre of the earth and commonly determined by a suspended mass.

Portland-limestone cement (PLC) — a product obtained by intergrinding Portland cement clinker and limestone, to which the various forms of calcium sulphate, water, and processing additions can be added at the option of the manufacturer.

Notes:

1) *Limestone is designated with the suffix L. The proportions to be used are determined in accordance with Clause 4.3.1 of CSA A3001.*
2) *Portland-limestone cement is by itself a cementitious material and is not considered to be a blended hydraulic cement.*

Proportioning — the selection of proportions of ingredients to produce concrete of the required properties and performance.

Quality assurance (QA) — activities taken by or on behalf of the owner to independently validate the results of the quality control (QC) program and to confirm that the QC measures are effectively controlling the quality of the constructed work.

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Quality control (QC) — activities undertaken by or on behalf of a contractor, producer, or supplier to control and document the quality of the work to ensure that the materials produced or work completed comply with the requirements of this Standard.

Service life — the time during which the structure performs its design function without unforeseen maintenance or repair.

Slurry water — a fluid derived from concrete reclaiming processes containing constituents of returned concrete, such as aggregate fines, cementitious materials, and admixtures.

Stability — the ability of a concrete mixture to resist segregation of the paste from the aggregates.

Steel slag — the material produced in the steel-refining process consisting of oxides of calcium (free lime), magnesium (periclase), and iron (wustite), as well as dicalcium silicate and complex aluminosilicates.

Supplementary cementitious material (SCM) — material that, when used in conjunction with hydraulic cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both.

Supplier — the individual or firm responsible for the production and supply of concrete.

Suspended slabs — concrete floors that are not supported on ground.

Sustainable development — meeting the needs of the present without compromising the ability of future generations to meet their own needs. See Annexes M and S.

Tolerance — the difference between the permissible limits of size. The tolerance is an absolute value without sign and is specified as T. Allowable variation is normally specified as $\pm T/2$.

Treated wash water — the water that is collected from recycling operations at the concrete plant and treated to reduce suspended solids prior to use in concrete.

Tremie concrete — concrete deposited underwater through a pipe or tube fitted with a hopper at its upper end.

Trowelling — the working of the unformed surface of fresh concrete to produce a smooth and dense finish.

Vapour retarder — a membrane or sheet material that will reduce the transmission of water vapour from the soil support system through a slab.

Water, potable — water suitable for human consumption.

Water-to-cementitious materials ratio (w/cm) — the ratio by mass of the amount of water to the total amount of cementitious material in a freshly mixed batch of concrete or mortar, stated as a decimal. The amount of water does not include that absorbed by the aggregate.

Wet-sieving — the process of removing aggregates larger than a designated size from the fresh concrete by sieving it on a sieve of the designated size.

Workability — the property of freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, compacted, and finished.

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4 Materials and concrete properties

4.1 Requirements for concrete and alternative methods for specifying concrete

4.1.1 Durability requirements

4.1.1.1 General

4.1.1.1.1

Concrete that will be subjected in service to weathering, sulphate attack, a corrosive environment, or any other process of deterioration covered by this Standard shall meet the requirements of Clauses 4.1.1.1 to 4.1.1.11 and 7.5, Tables 1 to 4 and 19, and CSA A23.2-24C, CSA A23.2-25C, and CSA A23.2-30C, as appropriate.

Notes:

1) *Although minimum requirements for concrete durability are specified, it should be stressed that a durable concrete also depends upon the use of high-quality materials, an effective quality control program, and good quality of work in producing, placing, finishing, and curing the concrete.*
2) *Requirements and guidance for materials qualification and for quality assessment are found in the following standard practices: CSA A23.2-30A on sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes; CSA A23.2-24C, on sampling, testing, and inspection of concrete for qualification and acceptance purposes; and CSA A23.2-25C on sampling, testing, and inspection of concrete for acceptance purposes.*
3) *For exposure conditions not covered by this Standard and for general information on concrete durability, see ACI Collection Online, ACI 201.2R, and PCA IS001.*
4) *For parking structures, highway bridges, and offshore structures, see CSA S413, CSA S6, and CAN/CSA-S474, respectively.*
5) *For concrete cover required to address the durability of reinforced concrete related to corrosion of reinforcing steel in concrete, see Clause 6.6.6.2.*

4.1.1.1.2

Certain measures, methods, systems, or materials (e.g., epoxy-coated reinforcing bars, cathodic protection systems, polymer impregnation, corrosion-inhibiting admixtures, sealants, membranes, and coatings) shall not be used to replace, either partially or totally, the requirements of Clause 4.1.1 unless their equivalency or superiority can be proven to the satisfaction of the owner.

4.1.1.1.3

Where more than one exposure condition defined in Table 1 applies to a specific concrete, of the requirements specified in Table 2 the concrete shall be designed to meet

a) the highest minimum compressive strength;
b) the lowest maximum water-to-cementitious materials ratio;
c) the highest range in air content; and
d) the most stringent cement type requirement of all the exposure conditions being considered.

4.1.1.1.4

The owner shall specify the minimum compressive strength, which shall be determined at an age of 28 d unless otherwise specified by the owner or this Standard.

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4.1.1.1.5

When combinations of hydraulic cement and supplementary cementitious materials are used, the combinations shall have been proven, to the satisfaction of the owner, to produce concrete resistant to the exposure conditions outlined in Clauses 4.1.1.3, 4.1.1.4, 4.1.1.5, 4.1.1.6, and 4.1.1.8.

4.1.1.1.6

Where a concrete element is not an integral part of the final structure and has a specified compressive strength of less than 10 MPa, the aggregates shall meet the requirements of Table 24, but the requirements of Clause 4.2.3 and Tables 10 to 12 are not mandatory.

Note: *This Clause is intended to allow the use of recycled concrete as aggregates (see Annex O) or aggregates that do not meet concrete gradation limits to reduce the demand on quality aggregates, a non-renewable resource [e.g., for fill concretes such as controlled low-strength material (CLSM)].*

4.1.1.2 Limits on chloride ion content

4.1.1.2.1

The water-soluble chloride ion content by mass of the cementitious material in the concrete before exposure shall not exceed the following values for the indicated applications:

a) for prestressed concrete: 0.06%;
b) for reinforced concrete exposed to a moist environment or chlorides, or both: 0.15%; and
c) for reinforced concrete exposed to neither a moist environment nor chlorides: 1.0%.

Notes:

1) *Quarried carbonate coarse aggregates from the Niagara Escarpment of southern Ontario contain sufficient chloride ions to cause concrete to exceed the values specified in this Clause. Experience has shown that this chloride remains within the aggregate and does not participate in the corrosion process. Thus, concrete made with these aggregates can be safely used, provided that chloride ion contributed by other concrete components by themselves does not cause the concrete to exceed the limits specified in this Clause. For background information, see Rogers and Woda, 1992, and Manning, 1991.*
2) *In cases where the raw materials contribute excessive levels of soluble chloride ion to the concrete and limits are exceeded, the owner may allow the use of a corrosion inhibitor. Recommendations on dosage rates of corrosion inhibitors for this application should be provided by the manufacturer.*
3) *The water-soluble chloride ion content as determined by CSA A23.2-4B and expressed as a percentage by mass of concrete should be converted to a percentage by mass of the cementitious material when checking against the limits specified in Clause 4.1.1.2.1.*

4.1.1.2.2

Measurements of total or acid-soluble chlorides shall be made either on the separate constituents of the concrete or on the concrete itself. See Clause 8.2.1 j) of CSA A23.2-24C.

4.1.1.2.3

Since total or acid-soluble chloride content is higher than water-soluble chloride content, if the total or acid-soluble chlorides are measured in accordance with Clause 8.2.1 j) of CSA A23.2-24C and are less than the permissible limits for water-soluble chloride ions stated in Clause 4.1.1.2.1, testing of the water-soluble chloride content in accordance with Clause 8.2.1 j) of CSA A23.2-24C shall not be required.

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4.1.1.3 Freezing and thawing (F class)

For concrete that might be subjected to freezing and thawing in service, the specified 28 d compressive strength, the water-to-cementitious materials ratio, and the air content shall be in accordance with Tables 2 and 4.

4.1.1.4 De-icing chemicals (C class) (chlorides)

For concrete that will be subjected directly or indirectly to de-icing chemicals, the specified compressive strength, the water-to-cementitious materials ratio, the chloride ion penetrability, and the air content shall be in accordance with Tables 2 and 4. See Clause 4.1.1.1.

Notes:

1) *The most common factors leading to corrosion of the reinforcement, resulting in delamination, spalling, and deterioration of the concrete, are high permeability and insufficient thickness of concrete cover over the reinforcement. Hence, particular attention should be paid not only to the quality of the concrete, as required by Clause 4.1.1.1, but also to ensure that the required cover, as specified in Clause 6.6.6, is obtained. See ACI 222R.*
2) *See also CSA S6, CSA S413, and CAN/CSA-S474.*

4.1.1.5 Sea water (C and S classes)

Concrete that will be exposed to sea water or sea water spray (i.e., marine exposure) shall be in accordance with the requirements of Tables 2, 3, and 4 that are appropriate for the exposure classes selected from Table 1. In addition to meeting the requirements of the appropriate chloride exposure (C-1 or C-3), concrete that will be exposed to sea water or sea water spray shall meet the requirements of S-3 exposure.

Notes:

1) *The severity of exposure in a sea water environment will vary depending on whether the concrete is subject to any of the following conditions:*
   a) *repeated wetting and drying cycles and/or freezing and thawing cycles, in the tidal or splash zone, where a structure is most vulnerable. The best possible protection should be provided to increase the resistance of concrete to weathering, sulphate attack, corrosion of reinforcement, and abrasion;*
   b) *total and permanent submersion. Under this condition the concrete becomes saturated but does not freeze. Furthermore, the risk of corrosion of the reinforcement is reduced because of the low level of oxygen in the water; and*
   c) *being in an area above the tidal zone and not exposed to sea water spray. In this area the concrete does not become saturated and attack is minimized.*
2) *As the C_3A content of the cement increases, the resistance to chloride-ion penetration of hydraulic-cement concrete increases but the resistance to sulphate attack decreases. Thus, moderate levels of C_3A (4% to 8%) or SCMs should be used.*

4.1.1.6 Sulphate attack (S class)

4.1.1.6.1

A concrete structure that is in contact with sulphates can be subjected to varying degrees of attack. Sulphates can occur in bedrock, in rock fill, in soil, in groundwater, in recycled aggregate, or in industrial wastes. Each structure shall be treated as a special engineering problem requiring individual diagnosis and treatment.

Notes:

1) *When structures are only partially immersed or are in contact on only one side with sulphate water or soils, the continuing evaporation can build up a very high concentration of sulphates within the concrete. Thus, a severe sulphate attack can occur even where the sulphate content is not initially high. Concretes buried in soil*

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or completely immersed in water are under static conditions in which sulphate attack is confined to surfaces and normally is negligible.

2) *Flowing water and groundwater under a hydraulic head can lead to a more severe sulphate attack than static water containing the same concentration of salts.*
3) *Concrete wholly or permanently above the water table can be subjected to sulphate attack as a result of the migration of salts through the capillaries of the subsoil.*
4) *Additional information on sulphate attack can be found in Skalny et al. (2002).*
5) *A severe form of low-temperature sulphate attack related to thaumasite formation has been identified in the Canadian Arctic. See Balinski et al. (1993) and Thaumasite Expert Group (1999).*
6) *Sulphates can also be created by oxidation of sulphide minerals that are in bedrock that is disturbed or broken during the construction process. A Canadian example is that presented by Grattan-Bellew and Eden (1975). The Building Research Establishment Special Digest 1 (2005) gives an extensive description of the issues related to oxidation of sulphides in disturbed bedrock and the effect on concrete and means of mitigation.*

4.1.1.6.2

For concrete subject to potential sulphate attack, the specified 56 d compressive strength, the water-to-cementitious materials ratio, and the cement type shall be in accordance with Tables 2 and 3. Supplementary cementitious materials may be used in combination with a hydraulic cement or a blended cement, provided that the mixture of cementitious materials meets the relevant performance requirements in Table 3, for S-1, S-2, or S-3 exposure.

Mineral fillers, as described in Annex L, composed of calcium or magnesium carbonate shall not be used in concrete proportioned for exposure classifications S-1, S-2, and S-3, as defined in Table 3.

4.1.1.6.3

Calcium chloride or any admixture formulation containing chloride shall not be used in concrete proportioned for exposure classifications S-1 and S-2, as defined in Table 3.

Notes:

1) *Other calcium salts used as accelerating admixtures should also be avoided, as they might also increase the severity of the sulphate attack.*
2) *The combined effect of chloride and sulphate in the concrete system is uncertain. One of the possible effects is that sulphates decompose chloroaluminates to release previously chemically-bound chlorides; thus, there is the potential to increase the amount of chlorides available for corrosion of reinforcement (ACI SP-131; Shideler, 1952).*

4.1.1.6.4

The methods of testing the sulphate content of groundwater and soils shall be those specified in CSA A23.2-2B and CSA A23.2-3B, respectively.

4.1.1.7 Abrasion/erosion

4.1.1.7.1

For horizontal concrete exposed to mechanical abrasion and scouring action, specialty treatments should be used as noted in Clause 7.7.5 and Annex F.

4.1.1.7.2

For formed and vertical surfaces subjected to moderate abrasion, 35 MPa concrete containing a durable aggregate shall be used. For some heavy-duty applications, steel plates might be required.

Note: *See ASTM STP 169D for further information.*

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4.1.1.8 Exposure to aggressive agricultural chemicals, acids, and acidic sewer wastes (A class)

4.1.1.8.1 General

Special provisions shall be implemented to improve the durability of concrete exposed to aggressive industrial chemicals, fertilizers, agricultural wastes, acids, and other chemicals. Such provisions shall include the use of supplementary cementitious materials, protective coatings, penetrating sealers, or other means.

Note: *Information on protective treatment is contained in PCA IS001. This document includes information on the aggressiveness of industrial chemicals, fertilizers, agricultural wastes, and other chemicals.*

4.1.1.8.2 Acidic sewer wastes

Concrete that will be subjected to sulphuric acid attack caused by microbially induced corrosion shall meet the requirements of Tables 2 and 4 that are appropriate for the exposure class selected from Table 1.

Note: *The resistance of hydraulic cement concrete in such exposures is largely dependent on the resistance to penetration of acids.*

4.1.1.9 Concrete cover

Concrete cover shall conform to Clause 6.6.6.

4.1.1.10 Cracking

Concrete cracking can compromise the durability of concrete by allowing ingress of water and aggressive agents. Extra care and attention shall be exercised during the design stage and during all stages of concrete construction to prevent cracking and to improve durability of concrete structures.

Note: *Guidelines for prevention of concrete cracking can be found in CSA A23.3 and in the following Clauses and Annexes of this Standard:*

a) *pre-construction stage:*
   i) *concrete cover — Clause 6.6.6.2; and*
   ii) *volume stability considerations — Clause 4.3.6;*
b) *use of fibres — Annex H;*
c) *construction stage: joints — Clause 7.3; and*
d) *post-construction stage: curing and protection — Clause 7.5 and Clause I.3.13. Additional information on cracking and its prevention can be found in ACI 224R and ACI 308R.*

4.1.1.11 Chloride ion penetrability

Chloride ion penetrability shall be determined as a qualification test in accordance with CSA A23.2-23C on concretes of classes C-XL, A-XL, C-1, and A-1. Chloride ion penetrability shall be in accordance with the requirements specified in Table 2. The owner may also specify chloride ion penetrability as an acceptance test.

Note: *For parking structure requirements, see CSA S413.*

4.1.2 Alternatives for specifying concrete

4.1.2.1

The owner shall select one of the specifying alternatives given in Table 5.

Note: *When specifying concrete, the following items should be considered:*

a) *class of exposure [water-to-cementitious materials ratio, air-void system, chloride ion penetrability, curing (see Table 2)];*

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b) *minimum specified strength at age;*
c) *intended application;*
d) *aggregate properties [i.e., size, special grading, alkali aggregate reaction (see Clause 4.2.3)];*
e) *architectural properties [colour, finish, appearance (see Clause 8.3)];*
f) *sustainable development (i.e., use of supplementary cementitious material);*
g) *volume stability;*
h) *quality control plan;*
i) *qualification (i.e., trial batch, historical data, material conformance);*
j) *finishability and finish requirements;*
k) *thermal control of mass concrete in accordance with Clause 7.6.3; and*
l) *any special requirements of the owner.*

4.1.2.2

Project specifications shall be reviewed by the contractor prior to ordering concrete.

Note: *Successful specifications and supply of concrete are a collaborative effort between the owner, contractor, and supplier. There should be a high level of communication, including provision and review of applicable documents, and pre-construction meetings.*

4.1.2.3

When ordering concrete, the following items, depending upon the method in Table 5 selected by the owner, shall be designated:

a) intended application, exposure class (from Table 1), and corresponding mix designation;
b) method and rate of placement;
c) quantity of concrete required;
d) compressive strength at age;
e) nominal maximum size of aggregate;
f) air content for air-entrained concrete;
g) required slump at point of discharge;
h) finishability and finish requirements; and
i) other characteristics as required.

4.2 Materials

4.2.1 Cements and supplementary cementitious materials

Note: *Not all hydraulic cements and supplementary cementitious materials are readily available in a given region and specifiers should take this into account during the design process.*

4.2.1.1 Hydraulic cement

4.2.1.1.1 General

Hydraulic cements shall conform to the requirements of CSA A3001.

4.2.1.1.2 Types

Hydraulic cement shall be specified by one or more of the types described in Table 6, as required.

Note: *For explanation of cement types, see CSA A3001.*

4.2.1.2 Blended hydraulic cements

Blended hydraulic cements shall conform to the requirements of CSA A3001 and shall be specified by one or more of the types described in Table 7.

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4.2.1.3 Supplementary cementitious materials

Supplementary cementitious materials shall conform to the requirements of CSA A3001 and shall be specified by one or more of the types described in Table 8.

4.2.1.4 Other cements and supplementary cementitious materials

4.2.1.4.1

Cements other than those described in Tables 6 and 7 are beyond the scope of this Standard (see Annex A).

4.2.1.4.2

Alternative supplementary cementitious materials meeting the requirements of CSA A3004-E1 may be used with the consent of the owner (see Clause 8.12).

4.2.2 Water

4.2.2.1

Water for the production of concrete shall meet the requirements of Clause 4.2.2.2, 4.2.2.3, or 4.2.2.4.

Note: *For further information, see Chapter 5 of CAC EB101 and Chapter 39 of ASTM STP 169D.*

4.2.2.2

Any potable water is suitable for use in the production of concrete.

4.2.2.3

Water deemed not potable may be used in the production of concrete provided that a satisfactory history of strength and durability of concrete made with the water has been demonstrated.

4.2.2.4

Water of unknown quality, including treated wash water and slurry water, shall not be used in concrete unless it produces 28 d concrete strengths equal to at least 90% of a control mixture. The control mixture shall be produced using the same materials, proportions, and a known acceptable water. The mixing water in question shall be assessed on a semi-annual basis or more frequently if any change in water quality is suspected. The mixture used to assess the mix water shall be designed for a strength of 25 MPa or greater at 28 d, and utilize a representative sample of the water in question. The mixture comparison shall be produced in accordance with the provisions of CSA A23.2-2C.

Notes:

1) *Some excessive impurities in mixing water can also cause efflorescence, staining, corrosion of reinforcement, and durability problems.*
2) *The owner may specify the optional limits of Table 9, where appropriate.*
3) *The total chloride ion content in the concrete should not exceed the limits specified in Clause 4.1.1.2, including any chlorides in the mixing water.*
4) *The total alkali content in the concrete should follow CSA A23.2-27A, including any alkalis in the mixing water.*

4.2.3 Aggregates

4.2.3.1 General

Normal-density fine and coarse aggregates shall meet the requirements of Clauses 4.2.3.3 and 4.2.3.4, respectively, and Clauses 4.2.3.5 to 4.2.3.9. Structural low-density aggregate shall conform to the

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requirements of ASTM C330/C330M. Aggregate properties for high-density concrete shall be specified by the owner (see Clause 4.3.4.3)

Notes:

1) *Special requirements for aggregates for architectural concrete are provided in Clause 8.3.*
2) *Mineral filler used as aggregate should be evaluated in accordance with Annex L.*
3) *Information concerning aggregate made from recycled concrete is given in Annex O. If recycled-concrete aggregate is to be used in concrete, particular attention should be given to assessing*
   a) *durability characteristics;*
   b) *deleterious materials;*
   c) *potential alkali-aggregate reactivity;*
   d) *chloride contamination; and*
   e) *the workability characteristics of concrete made with the material.*
4) *Annex P provides a comprehensive description of the impact of sulphides in concrete aggregate on concrete behaviour.*

4.2.3.2 Sampling and testing

4.2.3.2.1

Sampling, testing, and acceptance of aggregates for use in concrete shall be carried out in accordance with CSA A23.2-30A.

4.2.3.2.2

Where multiple sources of coarse or fine aggregates are blended, the owner shall specify whether

a) each individual source of the blend shall individually meet the deleterious limits and physical requirements of this Standard; or
b) the blended aggregate shall, in the combined blended proportions, meet the deleterious limits and physical requirements of this Standard.

When there is no specification by the owner, Item b) shall apply.

4.2.3.2.3

Products falling outside the grading limits of Table 10 or 11 shall meet the requirements of the appropriate Clause 4.2.3.5.1, 4.2.3.5.2, or 4.2.3.5.3.

4.2.3.3 Normal-density fine aggregate

4.2.3.3.1 General characteristics

Normal-density fine aggregate shall consist of natural sand, manufactured sand, or a combination thereof. Mineral fillers are considered fine aggregates that have a special grading (see Clause 4.2.3.5.2 and Annex L).

4.2.3.3.2 Grading

4.2.3.3.2.1 Sieve analysis

Fine aggregate (FA) shall be graded within the limits specified in Table 10. Not more than 45% of the fine aggregate shall pass any sieve and be retained on the next consecutive sieve of those shown in Table 10.

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Individual sands that are combined to meet the requirements of Table 10 need not individually meet the requirements of Table 10 provided that the final blend meets the specified requirements of Table 10.

Notes:

1) *When fine aggregate is to be used in concrete that will be placed by pumping methods, the grading characteristics of the fine aggregate in some cases requires special attention. For additional information, see ACI 304R and 304.2R.*
2) *FA2 is intended to be used in conjunction with FA1 in order to optimize the particle size distribution of the coarse and fine aggregate components of a mix. See Shilstone, 1991.*
3) *If FA2 is used as the sole component of fine aggregate in the concrete mixture, attention to both workability and bleeding should be considered.*

4.2.3.3.2.2 Uniformity

To control the grading of fine aggregate from any one source, the fineness modulus of any shipment made during the progress of the work shall not vary more than ±0.20 from the initially approved value. If the variation exceeds the mentioned tolerance, a request to the owner to adjust the concrete mix proportions shall be made.

4.2.3.3.3 Organic impurities

4.2.3.3.3.1

Fine aggregate shall be free from injurious amounts of organic impurities.

4.2.3.3.3.2

Fine aggregate producing a colour darker than standard colour No. 3, when tested in accordance with CSA A23.2-7A, shall be considered to have failed to meet the requirements of this Standard, except as provided in the following:

a) A fine aggregate failing the test may be used, provided that the discoloration is due principally to the presence of particles of coal or lignite (which are normally brownish-black or black) in amounts not exceeding 0.5%, as determined in accordance with CSA A23.2-4A.
b) A fine aggregate failing the test may be used, provided that when tested in accordance with the requirements of CSA A23.2-8A, the mortar develops a compressive strength at 7 d and 28 d of not less than 95% of that developed by a similar mortar made from another portion of the same sample that has been washed in a 3% solution of sodium hydroxide and then thoroughly rinsed in water. This treatment shall be sufficient to produce a colour lighter than the standard colour with the washed material.

For Items a) and b), concrete made with the fine aggregate shall meet the specified concrete strength.

4.2.3.3.3.3

Fine aggregate that causes entrainment of excessive amounts of air so that the requirements of Clause 4.3.3 cannot be met shall be considered to have failed to meet the requirements of this Standard, unless corrective measures that are acceptable to the owner are applied.

Note: *Organic impurities not detected by the colour test can entrain excessive amounts of air. For further information, see MacNaughton and Herbich (1954).*

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4.2.3.4 Normal-density coarse aggregate

4.2.3.4.1 General characteristics

Normal-density coarse aggregate shall consist of crushed stone, gravel, air-cooled iron blast-furnace slag, or a combination of these materials conforming to the requirements of this Standard.

4.2.3.4.2 Grading

The sizes of coarse aggregate shall be selected from the standard sizes given in Table 11, in accordance with the criteria of Clauses 4.3.2.2 and 4.3.6.

4.2.3.4.3 Particle shape

Where required by the owner, particle shape shall meet the requirements of Table 12, when determined in accordance with CSA A23.2-13A, Procedure A or Procedure B.

Note: *For further information, see Galloway (1994).*

4.2.3.5 Other aggregate types

4.2.3.5.1 Mineral fillers

Mineral fillers are not cementitious materials and shall not be used to replace cementitious materials in concrete. Mineral fillers shall not be included in the calculation of the water-to-cementitious materials ratio (w/cm) of the concrete. Mineral fillers containing calcium or magnesium carbonate shall not be used in the production of concrete that will be exposed to sulphate exposure classes (S-1, S-2, or S-3). Mineral fillers shall be non-plastic, with less than 1% clay to meet the requirements of Table 12, and shall be added as a separate ingredient to the mix. Mineral fillers shall be tested for alkali-aggregate reactivity.

Notes:

1) *See Annex L for information on mineral filler requirements.*
2) *Information on proportioning concrete mixtures with mineral fillers can be found in ACI 211.7R.*

4.2.3.5.2 Special grading

When a fine aggregate with a grading falling outside the limits of Table 10 or a coarse aggregate with a grading falling outside the limits of Table 11 is proposed for use by the supplier, the supplier shall provide the owner with test data in accordance with CSA A23.2-24C to demonstrate that the material will produce concrete of acceptable quality that meets all the relevant requirements of this Standard. Assessment of performance should include, but not be limited to, compressive strength, drying shrinkage, and durability tests applicable to the specified exposure class.

4.2.3.5.3 Combined aggregate gradation

4.2.3.5.3.1

The combined aggregate gradation may be optimized for all of the aggregate in the concrete mix, rather than for the individual aggregate components. Each of the fine- and coarse-fractions of the combined aggregate shall meet all the requirements of this Standard with the exception of the individual grading requirements of Tables 10 and 11 (see CSA A23.2-30A, Clause 6.2, for requirements for establishing compliance). Each of the fine- and coarse-fractions of the combined-aggregate shall be handled and weighed separately to maintain uniformity. The supplier shall provide the owner with test data in accordance with CSA A23.2-24C to demonstrate that the material will produce concrete of acceptable quality that meets all the relevant requirements of this Standard. Assessment of performance shall

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include, but not be limited to, compressive strength, durability tests applicable to the specified exposure class, and if specified by the owner, drying shrinkage.

Notes:

1) *This Clause is intended to provide the user with the opportunity to improve concrete performance, sustainability, and economy by optimizing the aggregate envelope for the whole mix and not the individual components. Individual aggregates being considered for use as part of the mix may contain significant proportions of both coarse and fine material.*
2) *There is no single method that optimizes a mix for all applications. Annex Q provides guidance on one such method, the "Fuller" power curves.*
3) *Aggregate components may be individual size fractions or separate material with a range of gradation.*
4) *Aggregate should be proportioned to minimize water demand and drying shrinkage, consistent with other performance requirements.*

4.2.3.5.3.2

Where the combined aggregate is used for the purpose of demonstrating compliance with Clause 6.2 of CSA A23.2-30A or with the physical requirements of Table 12, the producer shall develop data that show conformance over the range of aggregate proportions to be used.

4.2.3.6 Deleterious reactions of aggregates

4.2.3.6.1 Alkali-aggregate reactivity

Aggregate for use in concrete shall not react with alkalis contained within the concrete to an extent that results in excessive expansion or cracking, or both, of the concrete. When potentially reactive aggregates are to be considered for use, preventive measures acceptable to the owner shall be applied. Evaluation of the potential for alkali-aggregate reactivity and the selection of preventive measures shall be performed in accordance with CSA A23.2-27A.

Notes:

1) *Alkali-aggregate reactivity primarily depends upon the amount of alkali in the cementitious materials, the cementitious materials content of the concrete, the composition of the aggregate, the presence or absence of supplementary cementitious materials, and the amount of moisture in the environment. Some aggregates that will react in concrete having a high alkali content may be satisfactory if the alkali content of the concrete is reduced.*
2) *Annex B discusses methods for evaluating the reactivity of aggregate and the application of preventive measures.*

4.2.3.6.2 Other reactions

Aggregates that produce excessive expansion in concrete through reactions other than alkali reactivity shall not be used for concrete unless preventive measures acceptable to the owner are applied.

Note: *Although rare, significant expansions can occur due to reasons other than alkali-aggregate reaction. Such expansions might be due to the following:*

a) *the presence of sulphides, such as pyrite, pyrrhotite, and marcasite, in the aggregate that might oxidize and hydrate with volume increase or the release of sulphate that produces sulphate attack upon the cement paste, or both (see Annex P for a comprehensive description of the impact of sulphides in concrete aggregate on concrete behaviour);*
b) *the presence of sulphates, such as gypsum, in the aggregate, resulting in sulphate attack on the cement paste;*
c) *the presence of free lime (CaO) or free magnesia (MgO) in the cement or aggregate, which can progressively hydrate and carbonate, with consequent expansion that leads to disruption of the cement paste and hence the concrete. CaO and MgO are found in steel slags and can also occur in other aggregates; and*
d) *the presence of finely-divided carbonate in mineral fillers can react with calcium-silicate hydrates (C-S-H) in the presence of sulphates to form thaumasite. This reaction can lead to the loss of cohesion in the cement*

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paste and degradation of the concrete. Mineral fillers containing carbonates should not be used in the production of concrete that will be exposed to sulphate exposure classes (S-1, S-2, S-3).

4.2.3.7 Deleterious substances and physical properties

Results of tests on separate samples that comply with the grading requirements of Table 10 or 11 shall not exceed the limits for standard requirements specified in Table 12.

4.2.3.8 Petrographic examination

When required by the owner, petrographic examination shall be made in accordance with CSA A23.2-15A. Guidance on the interpretation of petrographic number (PN) is given in Attachment A2 of CSA A23.2-15A.

Notes:

1) *ASTM C294 is a useful guide to the identification of many deleterious substances, including alkali-reactive components.*
2) *Petrographic examination should be conducted by suppliers and made available at the request of the owner.*
3) *Useful references relating to petrographic examination of aggregates are Dolar-Mantuani (1983) and Poole and Sims (2016).*

4.2.3.9 Concrete-making properties

When required by the owner, evidence shall be provided indicating that concrete produced using the proposed aggregates will have the specified strength, density, durability, and volume stability.

4.2.3.10 Aggregate acceptance

Sampling, testing, and acceptance of aggregates for use in concrete shall be carried out in accordance with CSA A23.2-30A.

4.2.4 Admixtures

4.2.4.1 General

Admixtures shall conform to the requirements of Clause 4.2.4.2 or 4.2.4.3.

4.2.4.2 Air-entraining admixtures

Air-entraining admixtures shall conform to the requirements of ASTM C260.

4.2.4.3 Chemical admixtures

Chemical admixtures shall conform to the requirements of ASTM C494/C494M, or ASTM C1017/C1017M when flowing concrete is applicable.

Note: *ASTM C494/C494M refers to a superplasticizing admixture as a "water-reducing, high range admixture".*

4.2.4.4 Powdered admixtures

Powdered admixtures shall be used in accordance with the manufacturer's recommendations.

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4.2.5 Fibres

4.2.5.1 Steel fibres

Each lot of steel fibre reinforcement shall be identified and accompanied by a certificate of compliance and test reports in accordance with ASTM A820/C820M or CE EN14889-1.

Notes:

1) *Prior to the commencement of fibre use, the owner may perform testing for conformance with ASTM A820/C820M or CE EN14889-1 through an accredited test laboratory.*
2) *For further information, see Annex H.*

4.2.5.2 Synthetic fibres

Micro-fibre reinforcement shall meet the requirements of ASTM C1116/C1116M, Type III (Clause 4.1.3). Polyolefin chop strand fibre reinforcement shall meet the requirements of ASTM D7508/D7508M.

Note: *For further information, see Annex H.*

4.2.6 Pigments for integrally coloured concrete

Pigments for integrally coloured concrete shall conform to the requirements of ASTM C979.

4.3 Concrete properties

4.3.1 Mix proportions

Mix proportions shall be selected to provide

a) workable concrete consistent with placement and finishing requirements (see Clause 4.3.2);
b) durable concrete meeting the requirements of Clause 4.1.1;
c) the specified range of air content and quality of air entrainment (see Tables 2 and 4 and Clause 4.3.3);
d) the required density (see Clause 4.3.4);
e) the specified strength (see Clause 4.3.5), which shall be such that both durability and structural requirements are met (see Clauses 4.1 and 4.4.2.2);
f) volume stability (see Clause 4.3.6);
g) measures to prevent deleterious expansion of concrete (see Clause 4.2.3.6); and
h) special properties specified by the owner.

Notes:

1) *The compatibility of concrete materials meeting the requirements of this Standard should be ascertained when selecting the mix proportions. For example, a combination of certain materials, such as certain combinations of cement and admixture, might cause excess bleeding, erratic setting times, loss of workability, or an unsatisfactory air-void system.*
2) *As a guide for determining mix proportions, see CAC EB101 or ACI 211.1 and ACI 211.2. Where used, the dry-rodded density of the coarse aggregate should be determined in accordance with CSA A23.2-10A.*
3) *Selecting proportions for concrete that is to be pumped might require special consideration. For more information on this subject, see ACI 304.2R.*
4) *Because of its unusually high fineness and resultant increased water demand in concrete, silica fume or silica fume blended cements should only be used together with water-reducing or high-range water-reducing admixtures, or both.*
5) *For guidance on pre-concreting procedures for high-performance concrete, see Annex I.*

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4.3.2 Workability

4.3.2.1 General

Inadequate mixing, transporting, or placing equipment shall not impose limitations on proportions, consistency, and workability.

4.3.2.2 Nominal maximum size of aggregate

4.3.2.2.1

The nominal maximum size of aggregate shall not be larger than

a) 1/5 of the narrowest dimension between sides of forms;
b) 3/4 of the minimum clear spacing between reinforcing bars;
c) 1/3 of the depth of the slabs;
d) the specified cover for concrete not exposed to earth or weather (see Clause 6.6.6.2);
e) 2/3 of the specified cover for concrete exposed to earth or weather (see Clause 6.6.6.2 and Table 17); or
f) 1/2 of the specified cover for concrete exposed to chlorides (see Clause 6.6.6.2 and Table 17).

4.3.2.2.2

For concrete that is to be placed by pump, the nominal maximum size of the coarse aggregate shall be limited to 1/3 of the smallest internal diameter of the hose or pipe through which the concrete is to be pumped or 40 mm, whichever is smaller.

4.3.2.2.3

The limitations specified in Clause 4.3.2.2.1, Items a) to d), may be waived if, in the judgment of the owner, workability and methods of consolidation are such that the concrete can be placed with a larger nominal maximum size aggregate.

4.3.2.3 Slump or slump flow

4.3.2.3.1 General

Slump or slump flow shall be consistent with the placement and consolidation methods, equipment, and site conditions. Slump requirements shall be identified and reviewed by the contractor and concrete supplier prior to construction. When the slump is specified, the acceptance of the concrete in the field shall be subject to the tolerances specified in Clause 4.3.2.3.2.

Notes:

1) *Flowing concretes, such as self-consolidating concrete mixtures, require slump flow methods of measurement for testing consistency. For more information, see Clause 8.6.3.1.*
2) *Alternative devices and methods to measure workability are available. For more information on this subject, see ASTM C1362.*
3) *For general guidance in mix proportioning, see ACI 211.1 and ACI 302.1R.*
4) *For guidance on selecting appropriate slumps, see ACI 211.1 and ACI 302.1R; ASTM STP 169D; Neville (1995); and CAC EB101.*

4.3.2.3.2 Tolerances in slump or slump flow

Tolerances for slump shall be within the following applicable ranges:

a) when the specified slump is less than 80 mm, the allowable variation shall be ±20 mm;
b) when the specified slump is 80 mm to 180 mm, the allowable variation shall be ±30 mm; and

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c) when the specified slump is greater than 180 mm, the allowable variation shall be ±40 mm.

Tolerance for slump flow shall be ±70 mm.

Note: *The control of slump before and after the addition of superplasticizer is discussed in Clause 5.2.5.3.3.*

4.3.3 Air entrainment

4.3.3.1 General

The air content of plastic concrete shall be as shown in Table 4 or as specified by the owner. In selecting the air content, consideration shall be given to the exposure conditions to which the concrete will be subjected.

Notes:

1) *In addition to improved resistance to freezing and thawing, intentionally entrained air can improve workability, decrease bleeding, increase resistance to scaling from de-icing chemicals, and increase watertightness.*
2) *Air contents less than those shown in Table 4 might not give the required resistance to freezing and thawing or scaling from the application of de-icing salts, which is the primary purpose of air entrainment. Air contents higher than the levels shown might reduce strength without contributing further improvement to durability.*

4.3.3.2 Air-void system

Concrete of air content Category 1 in Table 4 shall meet the requirements of Clause 4.3.3.3. The air-void spacing factor ($\bar{L}$) of the air-void system shall be determined in accordance with ASTM C457, using a magnification factor between 100 and 125.

Notes:

1) *Using an air-entraining admixture and measuring the air content of the plastic concrete in accordance with standard procedures does not in itself guarantee a satisfactory air-void system. A satisfactory air-void system is one in which the air voids are of the proper size and spacing in the paste fraction of the concrete.*
2) *The magnitude of variations in the air content and in the air-void parameters depends on how well the materials, the concrete production, and the testing are controlled.*
3) *The concrete supplier may adjust the required air content in the plastic concrete if it can be shown that the adjusted air content will produce a spacing factor meeting the requirements of this Clause.*
4) *The Materials Engineering and Research Office of the Ontario Ministry of Transportation maintains concrete reference samples, available to laboratories for internal quality management.*
5) *A useful reference relating to air-void determinations is Pleau et al. (1990).*

4.3.3.3 Air-void parameters

For the category of concrete defined in Clause 4.3.3.2, the air-void system shall meet the following requirements:

a) the average spacing factor ($\bar{L}$) determined on samples of the same mix design shall not exceed 230 µm, with no single value greater than 260 µm; and
b) air content shall be greater than or equal to 3.0% in the hardened concrete.

For concrete with a water-to-cementitious materials ratio of 0.36 or less, the average spacing factor shall not exceed 250 µm, with no single value greater than 300 µm.

Notes:

1) *Considering that the ASTM C457 test is subject to large variations, the target spacing factor ($\bar{L}$) should be less than 170 µm to have reasonable assurance that the 230 µm requirement of this Clause is met.*
2) *See Clause I.3.8 for additional information on air void parameters of high-performance concrete.*
3) *For mix qualification purposes, the average value should be calculated on the basis of the three most recent tests conducted on the same mix design within three years of the qualification date, with at least one test conducted within one year of the qualification date.*

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4) *For quality control purposes during construction, the moving average of three tests should be used.*
5) *For mix qualification and for quality control purposes, where fewer than three test results are available, all test results should meet the specified average value.*

4.3.4 Density

4.3.4.1 Normal-density concrete

Normal-density concrete shall be proportioned to meet the minimum density of the plastic concrete if specified by the owner.

4.3.4.2 Structural low-density and semi-low-density concrete

Structural low-density and semi-low-density concrete shall be proportioned to meet the maximum air-dry density of the concrete specified by the owner.

Note: *Suppliers of low-density aggregate should be consulted to establish the concrete densities obtainable with their aggregates.*

4.3.4.3 High-density concrete

High-density concrete shall be proportioned to meet the minimum density of the plastic concrete specified by the owner.

Note: *Suppliers of high-density aggregate should be consulted to establish the concrete densities obtainable with their aggregates.*

4.3.5 Strength

4.3.5.1 Combinations of materials previously evaluated

The water-to-cementitious materials ratio shall be selected on the basis of test data that have established a relationship between strength and water-to-cementitious materials ratios for the materials to be used.

Note: *Refer to ACI 214R for further information.*

4.3.5.2 Combinations of materials to be evaluated by trial mixes

4.3.5.2.1

Where previous data are not available, concrete trial mixes using project materials that have proportions and consistency suitable for the work shall be made in accordance with CSA A23.2-2C.

4.3.5.2.2

Where different combinations of materials are to be used for different portions of the work, each combination shall be evaluated separately.

4.3.6 Volume stability considerations

Where required, the owner shall specify volume stability criteria. To minimize creep and drying shrinkage of the concrete, the maximum aggregate-to-paste ratio that is practicable shall be used, consistent with placement procedures and equipment.

Note: *Creep and drying shrinkage are minimized when concrete*
a) *contains the maximum permissible nominal size of aggregate (see Clause 4.3.2.2);*
b) *has the lowest permissible water content; and*

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c) *has a combined grading of the fine and coarse aggregate fractions that will require the minimum amount of water for a given degree of workability.*

4.3.7 Chloride ion penetrability

Notes:

1) *For mix qualification purposes, the average value should be calculated on the basis of the three most recent tests conducted on the same mix design within three years of the qualification date, with at least one test conducted within one year of the qualification date.*
2) *For quality control purposes during construction, the moving average of three tests should be used.*
3) *For mix qualification and for quality control purposes, where results of fewer than three tests are available, all test results should meet the specified average value.*

4.3.7.1

To satisfy the maximum permeability index requirement of 1500 coulombs for Exposure Classes C-1 and A-1 (Table 2), the average of three test results shall be equal to or less than this limit, with no single result greater than 1750 coulombs. In cases where less than three test results are available, all results shall meet the limit for the average test result.

4.3.7.2

To satisfy the maximum permeability index requirement of 1000 coulombs for Exposure Class C-XL and A-XL (Table 2), the average of three test results shall be equal to or less than this limit, with no single result greater than 1250 coulombs. In cases where less than three test results are available, all results shall meet the limit for the average test result.

4.4 Quality control

4.4.1 Responsibilites

4.4.1.1 General

Responsibilities for concrete quality shall be assigned following one of the alternatives described in Table 5. Additional guidance is found in Annex J.

Note: *Table 5 and Clause 4 of CSA A23.2-24C provides a description of roles and responsibilities of the various parties involved in a typical concrete construction project. They are intended to provide guidelines to ensure that all necessary responsibilities are delegated appropriately. They are not intended to cover all possible scenarios, and it is acknowledged that other scenarios are common. The contracts among the various parties will define the actual responsibilities, and will govern in the event of disputes.*

4.4.1.2 Submittals

Submittals shall be prepared and submitted in accordance with the requirements of Table 5 and CSA A23.2-24C.

4.4.1.3 Procedures

Procedures for qualification and acceptance of concrete shall be carried out in accordance with CSA A23.2-24C and CSA A23.2-25C, respectively.

4.4.1.4 Responsibilities

The owner shall be responsible to ensure that the requirements of this Standard are met and to clearly specify all qualification, acceptance testing, and submittal requirements for the project. The owner may

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delegate through contractual arrangements the necessary roles and responsibilities. Reasonable access for purposes of inspection and for the selection of samples shall be available to the owner.

Note: *The owner should implement an effective quality assurance program.*

4.4.1.5 Assignment of responsibilities

The owner shall assign the responsibilities to the most appropriate party:

a) submittals, including, as appropriate
   i) provincial or regional concrete association concrete production facility certification if specified;
   ii) concrete mix data submittal form for concrete supplied under Alternative 1, Table 5;
   iii) qualification data as required in the specification and Table 5;
   iv) ACI Flatwork certification or an equivalent industry recognized program if specified; and
   v) other relevant certifications (e.g., Pervious Pavement Certification);
b) pre-construction and pre-placement meetings including all stakeholders;
c) regular schedule for project update meetings;
d) concrete ordering and scheduling;
e) concrete supply;
f) concrete performance requirements at the point of discharge from the delivery equipment (see Table 5);
g) placing, finishing, curing, and protection of concrete in accordance with specification requirements;
h) in-place concrete performance requirements;
i) quality control for acceptance; and
j) designated areas for environmentally responsible disposal of excess concrete and truck washout.

Notes:

1) *Requirements for submittals and certification should be stated in the project specifications.*
2) *When concrete performance verification is provided by the concrete supplier the owner should implement an effective quality assurance program.*

4.4.1.6 Testing laboratory responsibilities

The testing laboratory shall be responsible for the following:

a) Laboratory and field personnel shall meet the requirements of CSA A283 to the appropriate category, or CAN/CSA-ISO 9001 with equivalent scope to CSA A283, or other equivalent certification approved by the owner.
b) All testing to the applicable test methods and standard practices of CSA A23.2, reports distributed (see CSA A23.2-25C, Clause 6), and all related records available for audit by the certification agency.

Note: *All sampling, specimen preparation, and testing (in both the field and laboratory) should be provided by the same laboratory meeting the requirements of CSA A283 to the appropriate category, or CAN/CSA-ISO 9001 with equivalent scope to CSA A283, or other equivalent certification approved by the owner. The owner may also choose to specify a quality management plan including concrete acceptance criteria and authority. Information on quality management plans is found in Annex J.*

4.4.1.7 Field testing

Field sampling and test procedures undertaken to assess concrete quality shall be carried out in accordance with the requirements of CSA A23.2 by personnel certified under an industry-recognized program.

Note: *Examples of industry-recognized programs include*

a) *CSA A283 or CAN/CSA-ISO 9001 with equivalent scope to CSA A283; and*
b) *ACI Concrete Field Testing Technician Grade 1.*

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4.4.1.8 Contractor responsibilities

To facilitate testing, the contractor shall provide and maintain, for the sole use of the testing agency, adequate facilities for safe storage and proper curing of concrete test specimens on the project site for the initial curing period. Adequate facilities shall include a protected and temperature-controlled designated area to comply with CSA A23.2-3C.

4.4.2 Concrete acceptance

4.4.2.1 General

4.4.2.1.1

Sampling and testing of concrete and constituent materials for qualification purposes shall be carried out in accordance with CSA A23.2-24C. Subject to the requirements of this Standard and project specifications, the owner may accept or reject proposed materials and mix designs on the basis of information provided in the qualification submittal.

4.4.2.1.2

Sampling, testing, and inspection of concrete for acceptance purposes shall be carried out in accordance with CSA A23.2-25C.

4.4.2.1.3

Concrete testing used as the basis for acceptance shall comply with all aspects of the applicable CSA A23.2 field and laboratory test methods and standard practices. Acceptance of the concrete shall be subject to the procedures and criteria in CSA A23.2-25C.

4.4.2.2 Compressive strength acceptance

4.4.2.2.1 Standard-cured cylinders

4.4.2.2.1.1

The strength level of concrete shall be considered satisfactory if for a given strength-class the following two criteria are met for concrete produced from a single mix design:

a) each individual strength test equals or exceeds the acceptable test result (ATR), where ATR = specified strength – 3.5 MPa when the specified compressive strength is 35 MPa or less; or where ATR = 0.90 × specified strength when the specified compressive strength is above 35 MPa; and
b) the moving average of three consecutive strength tests in the same concrete equals or exceeds the specified strength.

These requirements shall not apply to field-cured specimens.

Notes:

1) *With the standard deviation, designated "s", these criteria can be expected to be met with a high probability if the concrete is proportioned to produce an average strength as follows:*
   a) *1.4 times the standard deviation (1.4 s) above the specified strength when the standard deviation(s) is not more than 3.5 MPa; and*
   b) *2.4 times the standard deviation minus 3.5 MPa (2.4 s – 3.5 MPa) above the specified strength when the standard deviation(s) is more than 3.5 MPa.*
2) *The standard deviation used in Note 1) should be based on at least 30 consecutive strength tests, representing concrete made from a single mix design.*

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3) *Individual tests from concrete meeting these requirements can be expected to be below specified strength about 10% of the time.*
4) *For more detail about statistical analysis of the compressive strength of concrete, see ACI 318 and ACI 214R.*

4.4.2.2.1.2

The strength test result shall be the average of the strength of the specimens tested at the same age for concrete of a single mix design produced on the same day in accordance with Clause 7.2.3.3 of CSA A23.2-25C. If any test specimen shows distinct evidence of improper sampling, moulding, handling, curing, or testing, the test specimen shall be disregarded. The average strength of the remaining test cylinder(s) shall be considered the test result. However, if there are indications that there might have been a disruption to concrete quality control measures, the owner may make a distinction between specimens for testing.

4.4.2.2.1.3

If the results of tests indicate that the concrete is less than the specified strength, the owner shall have the right to require one or more of the following:

a) changes in the mix proportions for the remainder of the work;
b) additional curing on those portions of the structure represented by the test specimens that failed to meet specified requirements;
c) nondestructive testing (see Clause 4.4.2.2.4 and Annex A of CSA A23.2);
d) that cores be drilled from the portions of the structure in question and tested in accordance with Clause 4.4.2.2.2. Interpretation of the core test results shall take into consideration the placing and curing conditions and the age of the concrete;
e) load testing of the structure or structural elements in accordance with the requirements of CSA A23.3; and
f) such other tests as the owner might specify.

Notes:

1) *Cores should not be drilled from the tension zone of a structural member because the presence of cracks can adversely affect the measured compressive strength.*
2) *Additional information is contained in ACI 214.4R.*

4.4.2.2.1.4

If, after carrying out the appropriate requirements of Clauses 4.4.2.2.1 and 4.4.2.2.2, the elements are found not to comply with the requirements of this Standard, the owner shall require strengthening or replacement of those portions deemed to be non-compliant.

4.4.2.2.2 Cores from existing structures

4.4.2.2.2.1

Drilled cores shall be sampled and tested in accordance with CSA A23.2-25C.

4.4.2.2.2.2

The compressive strength of the concrete in the area of the structure represented by the core tests shall be considered adequate if

a) the average of each set of three cores from the portion of the structure in question is equal to at least 85% of the specified strength; and
b) no single core is less than 75% of the specified strength.

Notes:

1) *The figures of 85% and 75% in Items a) and b) are derived from Bloem (1965).*

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2) *Additional information for high strength concrete can be obtained from ACI 363.2R.*
3) *See Annex I for further information regarding high-strength concrete.*
4) *Additional information can be obtained from ACI 214.4R.*

4.4.2.2.3 Accelerated tests

The strength level of each class of concrete shall be considered satisfactory if the 28 d strength predicted from the accelerated tests meets the criteria in Clause 4.4.2.2.1.

4.4.2.2.4 Non-destructive in-place tests

The strength level to be reached for each class of concrete before form removal, post-tensioning, cessation of curing, or removal of reshores shall be specified by the owner.

4.4.2.2.5 Non-compliance

If, after carrying out the appropriate requirements of Clause 4.4.2.2.1, the elements are found not to comply with the requirements of this Standard, the owner shall require strengthening or replacement of those portions deemed to be non-compliant.

5 Production and delivery

5.1 Storage of materials

5.1.1 General

5.1.1.1

All materials shall be stored in a manner that will prevent contamination or deterioration. Access shall be provided to the storage facilities to allow for inspection.

5.1.1.2

Any material used in liquid or slurry form shall be protected from freezing. Powdered material shall be protected from moisture.

Note: *Liquid admixtures that have been frozen without impairment to their quality, as determined by the manufacturer, are acceptable, provided that they are thawed and agitated prior to use.*

5.1.1.3

Any material that has deteriorated, been damaged, or been contaminated shall not be used in the production of concrete.

5.1.2 Cementitious materials

5.1.2.1

Cement and supplementary cementitious materials shall be stored in a suitable bin or building that will provide protection against dampness and inclement weather.

Notes:

1) *A tightly sealed overhead silo, equipped with an air pollution control device, should be used for silica fume storage.*
2) *Underground containers may be used as temporary receivers for silica fume if they are properly installed and tightly sealed to meet local air pollution requirements.*

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5.1.2.2

If cementitious materials contain agglomerations owing to partial hydration or dampness, the cementitious materials shall not be used in the production of concrete unless it can be proven by testing, to the satisfaction of the owner that with corrective measures agglomerations will not have a detrimental effect on the quality and strength of the concrete.

5.1.3 Aggregate

Each nominal size of aggregate shall be separately stored in a freely draining stockpile in a manner that will prevent contamination, intermixing, and segregation. The equipment and methods of handling aggregate shall be such as to prevent degradation and contamination of the aggregate.

Note: *Additional information for stockpiling of aggregates can be found in ACI 304R.*

5.1.4 Admixtures

5.1.4.1

Adequate storage facilities shall be provided to ensure an uninterrupted supply of admixtures during batching operations.

5.1.4.2

The contents of all bulk storage tanks shall be clearly identified. Provision shall be made for venting and straining facilities and for flushing, draining, and cleaning these storage tanks.

5.2 Production of concrete

5.2.1 General

The owner is responsible for quality assurance processes to verify that the requirements for concrete are met. The concrete supplier is responsible for quality-control processes to ensure and verify that the requirements for concrete are met. Supply of concrete may be carried out by a facility that is certified in accordance with a recognized independent concrete organization which operates a formal facility certification program. Certification shall conform to a recognized standard, be completed by an engineer, and include periodic documentation that demonstrates compliance with the applicable certification standard.

Notes:

1) *The owner may accept an industry-recognized concrete facility certification program that is operated by members of the Canadian Ready Mixed Concrete Association.*
2) *The concrete producer may indicate that the facility, materials, and products it has selected for the supply of a project*
   a) *address sound and responsible environmental and sustainable development management and operations;*
   b) *utilizes manufacturing practices and protocols supporting the choice of responsible material procurement;*
   c) *identify environmental- and sustainable-development stewardship; and*
   d) *address the responsibility of the facility's processes to minimize the environmental footprint.*
3) *Refer to BNQ 2621-905 for information on certification in the Province of Québec.*

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5.2.2 Measurement of materials

5.2.2.1 General

Materials that are batched shall meet the allowable batching tolerances stated in Table 23. All batch weights shall be recorded and shall be available for audit.

5.2.2.2 Concrete

The concrete supplier shall add all materials that constitute the concrete mix. The volume of concrete as discharged from the supplier's equipment shall be expressed in cubic metres. The volume of concrete in a given batch shall be determined from the total mass of the batch divided by the density of the concrete.

The total mass of the batch shall be calculated either as the sum of the masses of all materials entering the batch, including all water added, or as the net mass of the concrete in the batch as delivered. The density shall be determined in accordance with CSA A23.2-6C.

5.2.2.3 Cementitious materials

Cementitious materials shall be measured by mass and shall meet the allowable batching tolerances stated in Table 23. The mass shall be measured on a scale and in a hopper that are separate and distinct from those used for aggregates. When supplementary cementitious materials are to be batched cumulatively with the Portland cement, they shall be batched only after the required amount of Portland cement has been weighed. When the quantity of cementitious material exceeds 30% of the full capacity of the scale, the measured quantity of the hydraulic cement shall be within ± 1% of the required mass, and the cumulative measured quantity of hydraulic cement plus supplementary cementitious materials shall also be within ± 1% of the required cumulative mass at each intermediate weighing. Under special circumstances, approved by the owner, cement may be batched using bags of known mass.

5.2.2.4 Supplementary cementitious materials

5.2.2.4.1

When supplementary cementitious materials are to be batched cumulatively with the cement, they shall be batched only after the required amount of cement has entered the weigh hopper. Under special circumstances, approved by the owner, supplementary cementitious materials may be batched using bags of known mass.

5.2.2.4.2

When cementitious materials are batched in slurry form, both the cementitious material and the water shall be measured and shall conform to the respective allowable variation stated in Table 23 and the amount of this water shall be deducted from the amount of the concrete mix water.

5.2.2.5 Aggregate

Aggregate shall be measured by mass. Batch masses shall be based on the required mass of saturated surface-dry aggregate corrected for the moisture conditions of the aggregate at the time of batching.

5.2.2.6 Mixing water

Mixing water shall consist of all water in the batch, including water occurring as surface moisture on the aggregate, water contained in admixture solutions, wash water, slurry water and ice used as a concrete

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coolant. Ice shall be measured by mass. Added liquid water may be measured by mass or volume, as permitted in Clause 5.2.3.3.

Note: *Variations in aggregate moisture content, especially of the finer materials, can be significant. Frequent checks, followed by any required adjustments to the batch quantities of aggregate and water, are necessary for achieving good quality control.*

5.2.2.7 Admixtures

Powdered admixtures shall be measured by mass and liquid admixtures by mass or volume.

5.2.2.8 Other batching methods

Consideration may be given by the owner to methods and procedures, such as volumetric batching and continuous mixing, provided the accuracy limitations of Table 23 are met.

Note: *Additional information on volumetric batching and continuous mixing is contained in ASTM C685/C685M.*

5.2.2.9 Fibre reinforcing

Fibre reinforcing (FR) shall be measured by mass or bag of known mass so that no less than the specified dosage expressed in kg/m^3 will be added to a given volume of concrete. Following the addition of the FR, the mixer drum shall be rotated at mixing speed for an additional 30 revolutions or in accordance with the manufacturer's recommendations.

5.2.3 Batching plant

5.2.3.1 Storage

Bins or silos with adequate separate compartments for cement, fine aggregate, each required size of coarse aggregate, and supplementary cementitious materials, if used, shall be provided in the batching plant. Storage and handling facilities shall be designed to prevent intermingling of different materials, contamination, segregation, and breakage, and shall provide for free movement of materials to discharge openings. Each batcher-charging mechanism shall be capable of stopping the flow of material within the allowable tolerances specified in Table 23. Hoppers shall be constructed so that they eliminate accumulations of materials and discharge fully for every batch.

5.2.3.2 Scales

Scales or other mass-measuring devices shall be accurate to ±0.4% of the total capacity of the device when static-load-tested. All necessary facilities, including an adequate number of standard test masses, shall be provided by the concrete supplier for calibrating the weighing and volumetric batching devices.

A certificate of accuracy not more than 180 d old shall be provided for the scales or measuring devices by a company using weights traceable to national standards. Where there is reasonable doubt concerning the accuracy of the scales or measuring devices, the owner may require calibration before or during progress of work. Recalibration shall be performed after plant relocation or major alterations.

All exposed fulcrums, clevises, and similar working parts shall be kept clean. When beam-type scales are used, provision shall be made for indicating to the operator that the required load in the hopper is being approached; the device shall indicate at least the last 100 kg of the target mass. All measuring and indicating devices shall be in full view of the operator while charging the hopper and the operator shall have convenient access to all controls.

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5.2.3.3 Volumetric measurement of water

If added water is to be measured by volume, the device shall be so arranged that measurements will not be affected by variable pressure in the water supply line. The device shall be fitted with such valves and connections as are necessary to divert the water measured for a batch so that accuracy of measurement can be easily verified.

5.2.3.4 Admixture measurement

All admixture batching systems, other than mass measuring systems, shall incorporate visual, volumetric measuring, or readout units. These units shall be clearly readable by the operator. Where a positive displacement system is used, a volumetric measuring unit shall be provided for periodic physical checks of dispenser accuracy. In remote-control plants and where batch cycles are timed, provision shall be made to ensure accurate filling and complete discharging of the measuring unit for each batch. Where a pressure dispensing system is used, the maximum pressure for discharging the units shall not exceed that designated for those units and positive ON-OFF-type valves shall not be installed except where safety precautions are taken. Pressure systems shall have a safety check-valve system to prevent admixtures from re-entering the storage system. Admixtures that can come into contact with each other prior to entry into the mixer shall be compatible. Admixture suspensions or solutions made from powdered materials shall be thoroughly agitated before being dispensed. A certificate of accuracy for the admixture batching system, not more than 180 d old, shall be provided.

5.2.3.5 Protection from freezing and settlement

If required, liquid admixtures and silica fume slurries shall be protected from freezing. They shall have a means for preventing settlement or separation of the admixture, as required by the manufacturer.

5.2.4 Mixing

5.2.4.1 Equipment

5.2.4.1.1

Mixers may be stationary mixers or truck mixers. The mixer shall carry the manufacturer's rating plate in a prominent place, indicating in standard metric units

a) the gross volume of the drum;
b) the rated maximum mixing capacity;
c) the rated maximum agitating capacity; and
d) the minimum and maximum mixing and agitating speeds for the drum, blades, or paddles.

5.2.4.1.2

The rated maximum mixing capacity denotes the size of a mixer. For stationary mixers, the gross volume shall conform to the limitations set forth in the *Concrete Plant Standards of the Concrete Plant Manufacturers Bureau*. Truck mixers shall conform to the limitations of TMMB 100. The owner may require that concrete uniformity tests be made in accordance with Table 13.

Notes:

1) *When satisfactory performance is found in one truck mixer, the performance of mixers of substantially the same design and blade condition may be regarded as satisfactory.*
2) *Use of equipment not meeting the above requirements may be considered when operation with a longer mixing time, a smaller load, or a more efficient charging sequence indicates that the requirements of Clause 5.2.4.5 are met.*

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5.2.4.1.3

When stationary mixers are used for the complete mixing of concrete, the concrete supplier shall determine the time of mixing. For truck mixers not equipped with revolution counters, the mixer shall be timed at full mixing speed and the time for 70 revolutions shall be posted in the truck cab.

5.2.4.1.4

Truck mixers and/or agitators furnished with a water tank shall be equipped with a water-measuring device that includes a sight gauge for each compartment. The gauge markings shall be visible through the entire range of the tank's capacity.

Note: *Gauge glasses can become inoperable during freezing conditions.*

5.2.4.2 Operation of mixers

All mixers shall be capable of combining the ingredients of the concrete within the time or the number of revolutions established in Clause 5.2.4.4 into a thoroughly mixed and uniform mass and of discharging the concrete so that the uniformity requirements of Clause 5.2.4.5 are met. The entire contents of the mixer shall be discharged before recharging.

5.2.4.3 Mixer maintenance

Mixers shall be examined routinely by the supplier to detect wear of blades and accumulations of hardened concrete or mortar. Mixers shall be maintained in accordance with the manufacturer's recommendations such that their operation, as described in Clause 5.2.4.2, is not impaired.

5.2.4.4 Time and rate of mixing

5.2.4.4.1 General

Mixers shall be rotated at the rate recommended by the manufacturer of the mixer.

5.2.4.4.2 Partial mixing (shrink mixing)

When a stationary mixer is used for partial mixing of concrete, the mixing time in the stationary mixer need be no more than is required to intermingle the ingredients. After transfer to a truck mixer, further mixing at the designated mixing speeds shall be undertaken as required to fully mix the concrete and meet the requirements of Clause 5.2.4.5. Additional turning of the mixer, if any, shall be at the designated agitating speed. The mixing and agitating speed shall be designated on the mixer by the manufacturer.

5.2.4.5 Testing for uniformity of mixed concrete

5.2.4.5.1 Sampling

Concrete samples for testing the uniformity of mixed concrete shall be obtained in accordance with the requirements of Clause 7.4 of CSA A23.2-1C.

5.2.4.5.2 Test procedures and requirements

5.2.4.5.2.1

The determination of within-batch uniformity (see Table 13) shall be based on concrete using normal-density aggregate with a nominal maximum size of not more than 40 mm. The samples shall be tested in accordance with the methods listed in CSA A23.2. Density, air content, and slump or slump flow tests

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for uniformity shall be carried out as a minimum prior to a decision on the acceptance of the equipment under test, as follows:

a) Where the range, in each test, is equal to or less than the acceptance limit of Table 13, the concrete shall be considered uniform.
b) Where the range of any single test is greater than the rejection limit, the concrete shall be considered non-uniform.
c) Where the range of any single test falls between the acceptance and rejection limits, additional tests shall be made on the next consecutive batch or load delivered by that mixer unit. If the range of any single test is then greater than the acceptance limit, the concrete shall be considered non-uniform.

5.2.4.5.2.2

If the concrete has been judged non-uniform, the equipment shall be rejected. This equipment shall not be used until it passes a retest, nor shall it be submitted for retesting unless the condition presumed to have caused the lack of uniformity has been corrected.

5.2.5 Delivery

5.2.5.1 Concrete mixed on-site

Concrete shall be transported or conveyed from the mixer to the point of delivery as rapidly as practicable. The methods and equipment used shall conform to the requirements of Clause 7.

5.2.5.2 Concrete mixed off-site

5.2.5.2.1 Delivery with agitating equipment

After mixing as specified in Clause 5.2.4, concrete shall be transported to the point designated by the purchaser by means of agitators or mixers. The equipment shall be operated at the agitating speed designated by the manufacturer, except for shrink-mixed concrete, in which case operation at both the designated mixing and agitating speeds shall be required. The concrete shall be delivered to the job site in a thoroughly mixed and uniform state and discharged with the degree of uniformity specified in Clause 5.2.4.5.

5.2.5.2.2 Delivery with non-agitating equipment

Concrete that is completely mixed in a stationary mixer and then transported in non-agitating equipment to the point designated by the purchaser shall be specifically proportioned for this purpose. The bodies of such equipment shall be smooth, clean, watertight, metal containers equipped with gates that permit control of the discharge of the concrete.

Covers shall be available to provide protection against inclement weather. The concrete shall be delivered to the job site in a thoroughly mixed and uniform mass and discharged with the degree of uniformity specified in Clause 5.2.4.5.

5.2.5.3 Control of slump or slump flow and air content

5.2.5.3.1 Time of delivery

A maximum time limit of 120 min from the time of initial mixing to complete discharge shall be observed. Exemptions to the maximum time limit, if required, shall be agreed upon by the owner and

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the concrete supplier prior to placement of the concrete. In some circumstances, set retarders or hydration stabilizers may be used to extend the discharge time as permitted by the owner.

Note: *The period during which concrete is workable is significantly affected by type and content of the cementitious materials, the type and dosage of the admixture, other added materials, and ambient and concrete temperatures. This period can be extended or reduced by the use of set-retarding or accelerating admixtures. If specific time limitations are desired, they should be clearly identified and included in project specifications.*

5.2.5.3.2 Addition of water on the job site

5.2.5.3.2.1

When the slump or slump flow of the concrete is determined to be less than that designated, water may be added on the following basis:

a) When the concrete is supplied on the basis of Alternative 1 (performance specification) in Table 5, the water shall be added on the instruction of the concrete supplier.
b) When the concrete is supplied on the basis of Alternative 2 (prescription specification) in Table 5, the water shall be added on the instruction of the owner.

5.2.5.3.2.2

For both situations described in Clause 5.2.5.3.2.1, the following requirements shall be met:

a) The specified water-to-cementitious materials ratio shall not be exceeded.
b) No more than the lesser of 16 L/m^3 or 10% of the mixing water shall be added.
c) No more than 60 min shall have elapsed from the time of batching.
d) The mixer drum shall be turned at mixing speed for at least 30 revolutions (or equivalent time limit) after the addition of water.
e) The amount of water added and by whose authority shall be recorded on the delivery ticket.

Note: *In some circumstances, set retarders or hydration stabilizers may be used to extend the time allowed for water addition, as permitted by the owner.*

5.2.5.3.3 Control of slump or slump flow of plasticized concrete on the job site

Prior to discharge, concrete incorporating ASTM C494/494M Type F or G water reducing admixture (i.e., plasticizer) may be retempered with water in accordance with Clause 5.2.5.3.2, provided the designed w/cm is not exceeded. When concrete incorporating ASTM C494/494M Type F or G water reducing admixture falls below the designated slump or slump flow after discharge has begun, it shall be retempered with those admixtures only, not water. The amount of additional admixture added shall be recorded on the delivery ticket. All retempering shall be done by the concrete supplier.

Notes:

1) *High-strength superplasticized mixes need extra care.*
2) *Variations in initial slump or slump flow, prior to the addition of superplasticizers, can affect performance. Initial slump or slump flow should be monitored where consistency of setting and finishing properties is of particular concern (e.g., flatwork).*

5.2.5.3.4 Control of slump or slump flow and air content on the job site

When the measured slump or slump flow of the concrete is less than designated it can be adjusted in accordance with Clause 5.2.5.3.2. When the concrete slump or slump flow of the concrete is higher than that designated, concrete shall not be adjusted on-site with the addition of dry materials. The air content of the concrete shall, if necessary, be adjusted to within the specified range by the concrete supplier by the addition of an air-entraining agent in the field. Mixing shall follow to ensure proper dispersion. The total air content shall be retested. When concrete is supplied for exposure classifications C-XL, A-XL, C-1, A-1, C-2, A-2 and F-1 and the 120 min time limit is in effect, the concrete shall be

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retested for conformance to air content requirements when more than 90 min have elapsed since batching. The amount of air-entraining agent added and air content test results shall be recorded on the delivery ticket.

5.2.5.4 Temperature control

5.2.5.4.1

Concrete delivered to the site shall conform to the temperature requirements in Table 14. Temperature shall be tested in accordance with CSA A23.2-17C.

5.2.5.4.2

To avoid the possibility of premature stiffening of the concrete when either the water or the aggregates are heated to a temperature in excess of 40 °C, the water and aggregates shall come together first in the mixer in such a way that the temperature of the combination is reduced to below 40 °C before the cement is added. Adequate heating of aggregate shall take place prior to mixing to avoid the likelihood of frozen material being incorporated in the concrete.

Notes:

1) *When concrete temperatures more restrictive than those outlined in Clause 7.5 are required, the conditions and manner of supply should be detailed in the project specifications.*
2) *Aggregates should not be heated above 80 °C and all lumps of frozen aggregates should be excluded from the mix.*
3) *Additional information is contained in ACI 305R.*

5.2.5.5 Delivery ticket

5.2.5.5.1

Before unloading each truck at the site, the supplier of the concrete shall furnish the purchaser, or the purchaser's representative, with a delivery ticket on which is printed, stamped, or written the following information:

a) name and location of the batch plant;
b) date and serial number of the ticket;
c) name of the contractor;
d) identification of the truck driver;
e) specific designation of the job (name and location);
f) specific class of exposure and mix identification of the concrete;
g) amount of concrete in cubic metres;
h) truck number, cumulative total, and/or load number;
i) time stamped when loaded or time of first mixing of the cement and aggregate; and
j) ordered slump or slump flow and air content.

5.2.5.5.2

The following shall be written on the delivery ticket after concrete discharge:

a) time that the load arrived on the project;
b) time that the discharge of load was started;
c) time that the discharge of load was completed;
d) amount of water added after batching and units used (see Clause 5.2.5.3.2); and
e) amount of admixture added after batching.

Note: *The following information should be provided, if available:*

a) *time when field testing commenced;*

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b) *name of testing and inspection company and on-site personnel performing the inspection;*
c) *location of test; and*
d) *slump or slump flow and air content test results.*

5.2.5.5.3

Additional information designated by the owner and required by the project specifications shall be furnished upon request.

6 Formwork, reinforcement, and prestressing

6.1 Reinforcement

6.1.1 Reinforcing steel

6.1.1.1

Reinforcement for concrete and methods of testing reinforcement shall conform to the requirements of one or more of the following Standards:

a) CSA G30.18; or
b) ASTM A184/A184M, ASTM A185/185M, ASTM A704/A704M, ASTM A775/A775M, or ASTM A1064/A1064M.

6.1.1.2

All reinforcement shall be of the grade specified on the construction drawings. Reinforcement without rolled-in grade identification marks shall be otherwise identified to the satisfaction of the owner.

6.1.1.3

The yield strength shall correspond to that determined by tests on full-size bars, unless an alternative test method is shown to correlate with tests on full-size bars.

6.1.1.4

All bars for concrete reinforcement shall be deformed bars, except that plain bars may be used for spirals or helical ties. Plain bars no larger than 10 mm in diameter may be used for stirrups or ties.

6.1.1.5

Welded wire mesh shall not be used for stirrup reinforcement, unless the transverse wires can develop a strain of at least 4% measured over a gauge length of at least 100 mm that includes at least one cross wire when tested in accordance with the tension test requirements of ASTM A1064/A1064M.

Notes:

1) *The effectiveness of welded wire mesh for crack control is greatest when a minimum 1% area is used (see WRI TF 705-R-03).*
2) *The placement location of welded wire mesh is difficult to maintain. Special attention should be directed to the type and spacing of welded wire mesh supports and the placement method for the concrete and its effect on the location of the welded wire mesh (see WRI TF 702-R2).*

6.1.2 Bend test

Plain reinforcing bars used for stirrups or ties shall meet the bend test requirement of 180° around a pin with a diameter of four bar diameters.

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6.1.3 Special reinforcement

6.1.3.1

Special reinforcement, such as epoxy-coated steel, galvanized steel, stainless steel, cadmium-plated steel, or other material not covered by Clause 6.1.1 or 6.1.5 shall be used only when specified or approved by the owner.

Note: *Such reinforcement should be selected with caution, based on the severity of the concrete exposure and the desired service life of the concrete component or structure. There is a body of knowledge suggesting that the benefits of epoxy coatings for long-term corrosion protection is not what was originally anticipated. Potential users should review the literature on the subject for further information (e.g., see Pianca et al., 2005; Weyers et al., 2006).*

6.1.3.2

Galvanized reinforcement shall meet the requirements of ASTM A767/A767M.

6.1.3.3

Epoxy-coated bars shall meet the requirements of ASTM A775/A775M and ASTM D3963/D3963M.

6.1.3.4

Fibre-reinforced polymer (FRP) components and FRP reinforcing materials shall meet the requirements of CSA S806.

6.1.4 Dissimilar metals

For all exposure classes (Table 1) where potential for corrosion of steel is significant, to prevent electrolytic action and corrosion between dissimilar metals or between steel and metal-coated components, dissimilar metals in concrete shall not be in contact, or shall be electrically separated by an electrical insulating dielectric material.

6.1.5 Prestressing steel

Prestressing steel shall conform to the requirements of ASTM A416/A416M, ASTM A421/421M, or ASTM A722/A722M.

6.1.6 Surface condition of reinforcement

6.1.6.1

Reinforcement, at the time concrete is placed, shall be free from mud, oil, or other contaminants that can adversely affect the bond.

6.1.6.2

Reinforcement with rust, mill scale, or a combination of both shall be considered satisfactory, provided that the minimum dimensions, including height of deformations, and mass of a wire-brushed test specimen are not less than the applicable specification requirements.

6.1.6.3

Prestressing steel shall be clean and free of rust, oil, dirt, scale, and pitting. Prestressing steel may have a light oxide coating.

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6.1.6.4
Coating damage on epoxy-coated bars shall be repaired in accordance with ASTM A775/A775M.

6.1.7 Protective coating
Where protective coatings for reinforcement or prestressing steel are required, the preparation of surfaces and methods of application shall be specified by the owner.

6.2 Hardware and miscellaneous materials

6.2.1 Hardware and ferrous inserts
Materials used in ferrous items embedded in the concrete for the purpose of connecting precast elements or attaching or accommodating adjacent materials or equipment shall conform to the requirements of CSA G40.20/G40.21.

6.2.2 Nonferrous inserts

6.2.2.1
Nonferrous inserts may be used if they have been proven to be resistant to electrolytic action and alkali attack, and are approved by the owner.

Note: *See Clause 6.7.5.5 for information on aluminum items.*

6.2.2.2
Wooden nailing strips or plugs shall be properly impregnated with preservative pressure treatment to minimize degradation due to decay and volume changes during concrete placing and curing and freezing weather.

Note: *For further information on the type of impregnating materials, see Wood Preservation Canada (woodpreservation.ca).*

6.2.3 Protective coating

6.2.3.1
Protective coating of hardware, preparation of surfaces, and methods of application shall be specified by the owner.

Note: *Damaged protective coating can require a final touch-up as prescribed by the owner.*

6.2.3.2
Bolts or portions of bolts not protected by embedment in concrete shall be protected against corrosion using a protective coating approved by the owner.

6.2.3.3
Hardware for precast concrete panel connections shall be protected from corrosion with a coating suitable for the service environment.

6.2.4 Miscellaneous materials
Form ties, inserts, bracing, spacers, pipes, conduits, and similar embedded items incidental to concrete construction shall comply with the requirements of Clause 6.7.

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6.2.5 Vapour retarder

Where a moisture-sensitive floor covering is to be applied, a minimum 0.25 mm (10 mil) thick vapour retarder conforming to ASTM E1745 Class A shall be installed directly below and in contact with the slab. The vapour retarder shall be protected from damage during construction and casting operations and shall be installed in accordance with ASTM E1643. The vapour retarder seams shall be lapped and sealed with a compatible sealant or tape product, in accordance with the materials manufacturer's instructions. All penetrations through the vapour retarder and perimeter joints shall also be taped and sealed.

Notes:

1) *Careful consideration should be given to the use of additional reinforcing, including increasing the slab thickness and reducing the contraction joint spacing, to minimize the potential for curling and cracking caused by the placement of the vapour retarder directly beneath the slab. In accordance with the recommendations of ACI 302.1R, the decision to include a vapour retarder should be made on a case-by-case basis.*
2) *Moisture vapour emissions have created significant problems with low permeability flooring materials that are applied to concrete slabs. The designer and constructor should review and consider the recommendations in ACI 302.2R prior to completion of design plans for the system.*
3) *When concrete is placed on an impermeable substrate, precautions should be taken to control the potential for excessive bleeding.*

6.3 Storage of reinforcement

6.3.1 General

All materials shall be stored in a manner that prevents contamination or deterioration. Access shall be provided to the storage facilities to allow for inspection.

6.3.2 Special storage requirements

6.3.2.1

Reinforcement shall be stored, in bundles with identifying tags or markings, on racks or sills that permit easy access for identification and handling and prevent the reinforcement from becoming coated with any material that would adversely affect bond.

6.3.2.2

Prestressing steel packs and coiled tendons shall be stored with identifying tags and shall be protected to prevent corrosion due to humidity, contamination, or electrolytic action.

Note: *Experience has indicated that where prestressing steel is exposed to wet weather or excessively humid conditions in storage, corrosion damage can occur within a few weeks. For acceptable surface conditions, see Clause 6.1.6.*

6.3.2.3

Special attention shall be given to protecting sheathing when unloading and storing coiled, sheathed tendons.

6.3.2.4

Epoxy-coated reinforcing steel shall be handled and stored so that damage to the epoxy coating is within the limits stated in ASTM D3963/D3963M.

Note: *Extended outdoor storage and exposure to sunlight and moisture should be avoided.*

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6.3.2.5

Handling and storage of fibre-reinforced polymer materials shall be done in accordance with the provisions of CSA S806.

6.4 Construction tolerances for cast-in-place concrete

6.4.1 General

6.4.1.1

The tolerances for concrete work as built shall conform to the requirements of Clauses 6.4.2 to 6.4.6. Elevated and suspended slabs shall be measured for as built tolerances (other than for flatness and levelness) at the top surface of the slab prior to formwork and reshore removal.

Notes:

1) *The measured elevated top surface profile of the slab includes any camber that might be specified in the project specifications.*
2) *According to ASTM E1155M, flatness and levelness are to be measured within the time constraints specified in Clause 7.7.1.2.*
3) *Cambers, deflections, and plan geometry tolerances are measured typically with a rod, level, or total station at discreet locations within a slab bay prior to formwork and reshore removal.*

6.4.1.2

For tolerance definitions, principles, and preferred sizes, see Annex C.

6.4.1.3

The surface tolerances of floor slabs and roof slabs shall be as specified in Clause 7.7.1 (see Figure 2).

6.4.1.4

Tolerances for location of reinforcement shall be as specified in Clause 6.6.8.

6.4.1.5

Tolerances for placing of hardware shall be as specified in Clause 6.7.3.

6.4.2 Cross-sectional dimensions and tolerances

6.4.2.1 Formed sections

Allowable variations for cross-sections of girders, beams, and columns and for the thickness of walls and suspended slabs shall be as follows:

a) 0.3 m and less: ±8 mm;
b) greater than 0.3 m but less than 1 m: ±12 mm; and
c) 1 m and greater: ±20 mm.

Note: *Local variations in unformed top surfaces of suspended slabs might cause these values to be exceeded.*

6.4.2.2 Slabs on grade

6.4.2.2.1 Slab on grade thickness

The thickness of a slab on grade shall be acceptable if the average thickness is not more than 10 mm less than the specified thickness and no individual measurement is more than 20 mm less than the specified thickness. When calculating the average thickness of the slab, samples with thicknesses

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greater than 20 mm more than the specified thickness shall be considered to have a thickness of 20 mm greater than the specified thickness.

If the slab thickness is in question, it shall be verified using either a calibrated impact-echo device or by coring, at a rate of one reading for every 100 m^2 of floor but at not less than five locations. Locations shall be representative, well distributed, and agreed upon with the owner. No thickness sample shall be taken closer than 1 m to any vertical obstruction such as columns and walls.

Impact echo testing shall be performed in accordance with ASTM C1383. The impact echo device shall be calibrated using a suitable core sample(s) extracted from each location. The length of the core shall be determined in accordance with ASTM C1542/C1542M. The variation of the impact echo device shall be stated on the test report. If the impact echo test results indicate the slab thickness exceeds the limitations noted herein, then coring shall be used to verify the impact echo result and to determine the extent of area requiring corrective action.

Notes:

1) *Thickness measurements should be taken within 7 d of each floor placement, or as soon as practicable, to permit any necessary corrective action.*
2) *The thickness measurements should not be closer than 1 m to any vertical obstruction because floor finishing operations on the plastic concrete tend to mound up the concrete in these locations.*

6.4.2.2.2 Curling

Owners shall specify low-shrinkage concrete mixes, appropriate curing, or suitable reinforcing, or a combination of these, as necessary to minimize curling to suit their intended usage.

Notes:

1) *Curling occurs because of differential drying shrinkage or temperature variations between the top and bottom of a slab on grade.*
2) *Tolerance losses of up to 50% in F-number measurements can occur in slab on grade floors due to normal drying shrinkage of concrete. Concrete mixes for slabs on grade should be carefully designed for reduced drying shrinkage including the use of shrinkage reducing and plasticizing admixtures (see also Clause 7.1.2). Proposed concrete mixes may be tested in accordance with CSA A23.2-21C over 120 d.*
3) *"As built" concrete floor tolerances can change significantly by the time of an applied finish application or owner occupancy. Unreinforced slabs on grade can exhibit curling of up to 25 mm at contraction joints which can significantly affect the application and appearance of applied finishes as well affecting foot and vehicular traffic.*
4) *Curling can be reduced through the use of adequate reinforcing to restrain the effects of shrinkage.*
5) *The consequences of curling can be reduced through the use of steel fibres or macro synthetic fibres at increasing dosage rates. Refer to Annex H for further information on fibres. Note that each fibre type/ configuration has unique performance and load carrying characteristics and are therefore not interchangeable on an equivalent dosage basis (refer to the manufacturer's written design instructions).*
6) *Further information is available from ACI 302, ACI 360R, and Suprenant (2002).*

6.4.2.3 Column offsets

Column offsets at floors and girder or beam offsets at columns or walls shall not exceed the allowable deviation for the appropriate section dimensions specified in Clause 6.4.2.1 in either direction. The offsets shall not be in the same direction for more than two consecutive floors or bays (see Figure 1).

6.4.3 Plumbness

Plumbness of columns, walls, and slab edges (when exterior cladding elements like curtainwall and precast are to be supported off of the slab edges) shall be within 1:400 measured at any one surface, but total variation shall be not more than 40 mm for the total height of the structure. For special

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conditions, such as elevator columns and external columns, if closer tolerances are required, the tolerance shall be specified by the owner (see Figure 1).

Notes:

1) *Depending on elevator requirements and wall cladding details, it might be necessary to specify closer tolerances for the columns involved, although it might not be considered practical to specify less than half of the deviations permitted.*
2) *Plumbness of slab edges is determined by defining a line or plane between two adjacent floor elevations. The plumbness is then the offset dimension or variation in plan location between the outermost points of the slab edge divided by the difference in elevation between the top surface of the two adjacent slabs.*

6.4.4 Relative alignment

Relative alignment (abrupt changes) between adjacent formed concrete surfaces shall be less than or equal to the following:

a) in areas designated as architectural concrete or exposed to view where appearance is of critical importance: 3 mm;
b) in areas exposed to view but not designated as architectural concrete: 5 mm;
c) in areas where applied finishes have a critical dependence upon the variation: 10 mm; and
d) for other concrete surfaces: 20 mm.

Note: *Depending on the owner's requirements regarding surface alignment, it might be necessary to specify tighter tolerances (e.g., where surfaces are exposed to flowing water).*

6.4.5 Levelness

The average slope of suspended floors, beams, and other horizontal units shall not exceed 1:400 with total variation not more than 40 mm over the total length of the structure (see Figure 1).

Note: *See Clause 7.7.1.4 for flatness tolerances. Slope in this context means the vertical distance between two points not less than 3 m apart.*

6.4.6 Variations from a reference system and general dimensions

6.4.6.1

The actual dimensions according to a vertical and horizontal reference grid system shall not vary from the dimensions on the drawings beyond the tolerances provided in Table 15.

Notes:

1) *Wherever possible, the nearest building lines should be designed to be a minimum distance of 30 mm from property lines. For practical reasons, this allowance should be increased wherever possible.*
2) *Elevations of finished floors are a function of both the construction tolerances and the design. The constructor can affect the camber and deflections of the flooring system through his formwork and falsework procedures. Once the forms are removed, the final deflection of the flooring system is dependent upon design camber, concrete strength, and reinforcement. See ACI 117 for construction tolerances and CSA A23.3 for design deflection.*

6.4.6.2

When unit masonry cladding is to be incorporated into the structure, tolerances shall be coordinated with the requirements for masonry construction tolerances in CAN/CSA-A371.

6.4.6.3

General dimensions, such as bay sizes, storey heights, and other dimensions not listed separately in Clause 6.4.2, shall be built to the tolerances listed in Table 15.

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6.5 Formwork

6.5.1 General

6.5.1.1
The design, fabrication, erection, and use of concrete formwork shall conform to the requirements of CSA S269.1.

6.5.1.2
Falsework for suspended concrete elements shall conform to CSA S269.1.

6.5.1.3
Formwork for special architectural finishes shall meet the requirements of Clause 8.3 of this Standard and the requirements of CSA A23.4.

6.5.2 Drawings for formwork

6.5.2.1
The erection drawings for formwork shall show the design criteria with respect to the following:

a) density of plastic concrete;
b) rate, sequence, and method of placing of concrete;
c) concrete slump or slump flow;
d) concrete admixtures;
e) concrete temperature;
f) specifications for formwork materials;
g) maximum member or panel deflection;
h) mass of components of formwork to be erected;
i) locations and details of proposed construction joints; and
j) camber.

6.5.2.2
Drawings for formwork for exposed concrete surfaces shall specify panel surface material, joint locations, panel sizes and supports, and tie types and locations, all of which shall be subject to the approval of the owner.

6.5.2.3
Camber shall be determined by the owner and shown on the construction drawings. Increased curvature or adjustment in the formwork system might be required to compensate for the anticipated deflection of the formwork system during concrete placement. These additional adjustments shall be determined by the contractor and be added to the camber specified by the owner.

6.5.3 Construction

6.5.3.1 General
Forms shall be constructed to meet the requirements for shape, dimensions, and tolerances specified in Clause 6.4. Immediately prior to concrete placement, all forms shall be inspected by the contractor to ensure that they have been erected in conformance with the shop drawings.

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Forms shall be constructed with temporary ports or openings at the bottom of all deep units, such as columns, deep beams, and walls, to facilitate cleaning and inspection.

Formwork for self-consolidating concrete (SCC) shall be designed to prevent loss of paste. Areas to consider include joints between panels, holes for ties, and sill plates supported on foundation footings or finished slab surfaces. Minor holes or joints can lead to significant leakage of the plastic flowing SCC. Design of the formwork shall assume that a full liquid head will be developed once placing is completed.

Note: *Research is currently underway to determine appropriate design procedures for forms containing SCC.*

6.5.3.2 Untreated forms

Untreated forms shall be thoroughly wetted prior to the placing of the concrete and shall be surface wet at the time of placing.

6.5.3.3 Preparation of formwork surfaces — Parting agents

For treated formwork surfaces, the materials used as a parting agent shall be nonstaining. The amount of material used shall be kept to a minimum and any that adheres to reinforcement shall be removed. When the concrete surface is to receive a permanent finish coating, the parting agent shall be compatible with the coating.

Notes:

1) *Some parting agents cause dusting of the surface and some increase the number or size of bug holes. While such conditions do not affect the structural properties of the concrete, they might be objectionable on the basis of appearance. If appearance is important, tests should be performed using the release agent in question, the forming material, and the concrete proposed for the work.*
2) *Care and attention are important when applying parting agents to ensure that a buildup of material or overspray does not develop. Parting agents are typically categorized as barrier, reactive, or reactive-barrier type products. Barrier products typically require a higher rate of application than do reactive agents.*

6.5.3.4 Alignment of forms during placing

6.5.3.4.1

Prior to placing concrete, a suitable means for checking the alignment and elevations of forms during placing shall be provided. These checks shall be made frequently during placing of the concrete and adjustments to the formwork and falsework shall be made by the contractor as required until all concrete is in place (see CSA S269.1).

Notes:

1) *Accommodations should be made for such factors as closure of form joints, settlement of mudsills, thread seating of screwjacks, shrinkage of lumber, dead load deflections, and elastic shortening of form members.*
2) *These adjustments may approach a slope of 1:500. This is in addition to a camber specified by the owner.*
3) *Care should be taken when placing falsework on mudsills where there is frozen ground. Any heating or thawing of the frozen ground can cause settlement of the falsework.*

6.5.3.4.2

Stay-in-place form spacers exposed to weather, earth, or moisture shall not be made from wood and shall be corrosion-resistant, dimensionally stable, and decay-resistant.

6.5.3.5 Formwork removal

Formwork shall be left in place until concrete has attained sufficient strength to support its own weight adequately, together with the construction loads likely to be imposed.

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The thickness and elevations of elevated slabs shall be measured prior to and after formwork removal to verify camber requirements.

Notes:

1) *A system of reshoring may be considered when the reshoring satisfies the curing, strength, and deflection requirements of CSA S269.1.*
2) *See ACI SP-004 for further information on stripping times and related concrete strengths. The minimum recommended stripping time of formwork for vertical surfaces is 12 h, provided that the curing is in accordance with Clause 7.6. When supplementary cementitious materials, special cements, retarders, or accelerators are used, this period might need to be adjusted.*

6.6 Fabrication and placement of reinforcement

6.6.1 General

The sizes and spacing of the reinforcement and its concrete cover shall be as shown on the construction drawings.

6.6.2 Hooks and bends

6.6.2.1 General

Unless otherwise stated on the construction drawings, fabrication and detailing of hooks shall be as specified in Clauses 6.6.2.2 to 6.6.2.5.

6.6.2.2 Standard hooks

The term “standard hook” as used herein shall mean

a) a semicircular bend plus an extension of at least four bar diameters but not less than 60 mm at the free end of the bar;
b) a 90° bend plus an extension of at least 12 bar diameters at the free end of the bar; or
c) for stirrup and tie anchorage only, either a 90° or 135° bend plus an extension of at least six bar diameters but not less than 60 mm at the free end of the bar. Hooks for stirrups or ties shall have a 135° bend, unless the concrete surrounding the hook is restrained from spalling (see CSA A23.3).

Hooks for crossties shall have a bend of at least 135° at one end and a standard tie hook with a bend of at least 90° at the other end. The hooks shall engage peripheral longitudinal bars. The 90° hooks of successive crossties engaging the same longitudinal bar shall be alternated end for end.

6.6.2.3 Minimum bend diameter

The diameter of the bend measured on the inside of the bar for standard hooks, except stirrup and tie hooks, shall be not less than the values in Table 16.

6.6.2.4 Stirrup and tie hooks

6.6.2.4.1

The inside diameter of bends and 90° hooks for stirrups and ties shall be not less than four bar diameters.

6.6.2.4.2

The inside diameter of 135° hooks shall be not less than 20 mm, four bar diameters, or the diameter of the bar enclosed by the hook, whichever is greater.

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6.6.2.4.3

The inside diameter of bends in welded wire fabric for stirrups or ties shall be not less than four wire diameters. Bends with an inside diameter less than eight wire diameters shall be not less than four wire diameters from the nearest welded intersection.

6.6.2.5 Bending

6.6.2.5.1

All bars shall be bent at temperatures greater than 16 °C, unless bending tests that are otherwise in accordance with CSA G30.18 confirm that bars bent at temperatures below 16 °C are acceptable.

Note: *See Stecich et al. (1984).*

6.6.2.5.2

No bars partially embedded in concrete shall be field bent except as shown on the drawings or as permitted by the owner.

Note: *See Stecich et al. (1984).*

6.6.2.5.3

The bending tolerances shall be sufficiently accurate to comply with the placing and protection tolerances specified in Clause 6.6.8.

6.6.3 Spirals

6.6.3.1

The size and spacing of spirals shall be as shown on the construction drawings.

6.6.3.2

Spiral reinforcement shall consist of evenly spaced, continuous, circular spirals held firmly in place and true to line by vertical spacers. Where the vertical reinforcement is to serve as the spacers, each loop of the spiral shall be securely tied.

6.6.3.3

The number of spacers shall be as follows:

a) for wires or bars less than 16 mm in diameter, a minimum of
   i) two spacers for spirals less than 500 mm in diameter;
   ii) three spacers for spirals 500 mm to 800 mm in diameter; and
   iii) four spacers for spirals larger than 800 mm in diameter; and
b) for wires or bars with a diameter 16 mm or larger, a minimum of
   i) three spacers for spirals up to 600 mm in diameter; and
   ii) four spacers for spirals larger than 600 mm in diameter.

6.6.3.4

The spirals shall be of such size and so assembled as to prevent them from being distorted from the specified dimensions during handling and placing.

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6.6.3.5
Anchorage of spiral reinforcement shall be provided by 1-1/2 extra turns of spiral rod or wire at each end of the spiral unit.

6.6.3.6
Splices in spirals shall have a minimum 50 bar diameter lap plus a 90° hook around a longitudinal bar at the free end or shall be welded in accordance with CSA W186.

6.6.3.7
The reinforcing spiral shall extend from the floor level in any storey or from the top of the footing to the level of the lowest horizontal reinforcement in the slab, drop panel, or beam above.

6.6.3.8
Where beams or brackets are not present on all sides of a column, ties shall extend above the termination of the spiral to the bottom of the slab or drop panel.

6.6.3.9
In a column with a capital, the spiral shall extend to a plane at which the diameter or width of the capital is twice that of the column.

6.6.4 Ties

6.6.4.1
The size, spacing, and arrangement of ties shall be as shown on the construction drawings. When welded wire mesh of random length is used as tie reinforcement, the required splice length shall be indicated on the drawings.

6.6.4.2
The ties shall be so arranged that every corner and alternate longitudinal bar shall have lateral support provided by the corner of a tie having an included angle of not more than 135° and no bar shall be farther than 150 mm clear, on either side, from such a laterally supported bar.

6.6.4.3
Where the bars are located around the periphery of a circle, a complete circular tie may be used, provided that the ends of the ties are bent at least 135° around a longitudinal bar or otherwise anchored within the core of the column.

6.6.4.4
Ties shall be located vertically not more than half a tie spacing above the floor or footing and shall be spaced as specified on the drawings to not more than half a tie spacing below the lowest horizontal reinforcement in the slab or drop panel above. Where beams or brackets provide enclosure on all sides of the column, however, the ties shall be terminated not more than 75 mm below the lowest reinforcement in such beams or brackets.

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6.6.4.5
When ties consist of continuously wound reinforcement in the form of a cylindrical helix enclosing the longitudinal reinforcement, each end shall be hooked around a vertical bar, or otherwise anchored in the core of the column.

6.6.5 Spacing of reinforcement

6.6.5.1
The spacing of bars shall be as shown on the construction drawings.

6.6.5.2
The clear distance between parallel bars or parallel bundles of bars shall be not less than 1.4 times the bar diameter, not less than 1.4 times the nominal maximum size of the coarse aggregate, and not less than 30 mm. This clear distance shall apply to the distance between a contact lap splice and adjacent splices or bars.

6.6.5.3
Where parallel reinforcement is placed in two or more layers, the bars in the upper layer shall be placed directly above those in the bottom layer unless otherwise permitted by the engineer.

Note: *The intention of this Clause is to provide adequate spacing for concrete to be placed in the presence of closely spaced mats of steel.*

6.6.5.4
Bars shall be bundled only when so shown on the drawings.

6.6.5.5
Where spacing limitations and clear concrete cover are based on bar size, a unit of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total cross-sectional area.

6.6.5.6
Spacing of post-tensioning ducts shall be as specified in Clause 6.8.

6.6.6 Concrete cover

6.6.6.1 General
Concrete cover shall be measured from the concrete surface to the nearest deformation (or surface, for smooth bars or wires) of the reinforcement. Reinforcement includes ties, stirrups, and main reinforcement. For textured architectural surfaces, concrete cover shall be measured from the deepest point of the textured surface.

6.6.6.2 Specified cover for reinforced and prestressed concrete

6.6.6.2.1
The specified cover for reinforcement shall be based on consideration of life expectancy, exposure conditions, protective systems, maintenance, and the consequences of corrosion.

Notes:

1) *The desired service life should be established early in the design process (see CSA S478).*

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2) *Requirements for corrosion protection can be influenced by the ease of access for inspection and repair and the feasibility and cost of repair or replacement.*
3) *Service life can be improved by*
   a) *increasing the cover and the duration of moist curing;*
   b) *reducing the water-to-cementitious materials ratio;*
   c) *adding supplementary cementitious materials, corrosion inhibitors, or membranes; and*
   d) *improving drainage.*
4) *As the positioning of reinforcement is not exact, in some cases it is advisable to increase the specified cover to ensure adequate protection. Service life can be extended by reducing the variability in placement of reinforcement.*

6.6.6.2.2

The specified cover for fibre-reinforced polymer bars, grids, and tendons in prestressed and reinforced concrete shall be in accordance with CSA S806.

6.6.6.2.3

The specified cover for steel reinforcement, tendon sheaths, and ducts in prestressed and reinforced concrete shall be not less than the largest of the limits for each relevant exposure condition in Table 17.

Note: *See Clause 6.6.8 for tolerances of concrete cover and Clause 6.8.2.4 for additional cover requirements.*

6.6.6.2.4

In corrosive environments, the concrete cover to the sheath shall be not less than 50 mm.

6.6.6.3 Cover for fire resistance

Where a structural concrete member is required to have a fire-resistant rating, the minimum cover for reinforcement shall be specified by the owner.

Note: *Information can be found in Appendix D of the* NBCC.

6.6.7 Support of reinforcement

6.6.7.1 General

Reinforcement shall be accurately positioned, secured, and supported, using bar supports, side form spacers, and internal spacers, to ensure proper concrete cover and spacing within allowable tolerances before and during placing of concrete.

Note: *Small movements in vertical placement of top bars can have significant effects on performance. Adequate support to ensure correct placement of reinforcement for slabs in relation to the top surface is important for shear and negative moment resistance.*

6.6.7.2 Securement

Unless otherwise approved by the owner, reinforcing bars shall be tied using black annealed, zinc coated, or polymer coated wire as applicable.

Note: *Approval of alternative materials such as plastic and/or metal clips should consider the amount of alternative materials used in relation to its effect on bond to the reinforcement and the overall structural performance of the section.*

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6.6.7.3 Bar supports

6.6.7.3.1
Bar supports shall have sufficient strength and stiffness to carry the loads from the reinforcement, construction crew, and concreting pressures without failure, displacement, or significant deformation. Bar supports shall be spaced so that any sagging between supports will not reduce the specified concrete cover significantly (see Clause 6.6.8).

6.6.7.3.2
The height of bar supports shall be determined by the specified concrete cover. The nominal height of a bar support shall be the distance from the bottom of the support at the form surface to the underside of the reinforcement. The height shall not vary more than 3 mm from the nominal height.

6.6.7.3.3
Bar supports shall be made of precast concrete, plastic, or steel. In humid or corrosive environments, bar supports should be non-corrosive (i.e., plastic or precast concrete).

6.6.7.3.4
Where concrete surfaces are to be exposed to weather, earth, sea water, de-icing salts, corrosive chemicals, or any exterior exposure to weather, the bar supports shall be nonconductive and have a geometry and bond characteristics that deter the movement of moisture from the surface to the reinforcement.

6.6.7.3.5
Supports in contact with the soil shall have an extended base area large enough to prevent unacceptable settlement.

6.6.7.3.6
Precast bar supports shall be made of concrete with a quality at least equal to that specified for the member in which they are used.

6.6.7.3.7
Supports for welded wire reinforcement shall take into account the diameter and spacing of reinforcement, the stability of the supporting substrate, and any construction loads that will be applied before and during concrete placement.

Notes:

1) *Suggested spacings are outlined in WRI TF 702-R2.*
2) *Welded wire mesh reinforcing sheets are recommended over rolls which are prone to edge curling.*

6.6.7.4 Side form spacers

6.6.7.4.1
Side form spacers shall be used for all vertical or steeply sloping forms, such as columns, walls, drilled shafts, and pipe piles, to secure the reinforcement against displacement and maintain the specified cover.

6.6.7.4.2
Side form spacers shall have provisions to enable them to be firmly secured to the reinforcement.

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6.6.7.4.3

Side form spacers shall meet the same requirements specified for bar supports in Clause 6.6.7.3.

6.6.7.5 Internal spacers

Spacers for maintaining the specified distance between layers of reinforcement shall be made from reinforcing bars or steel rods. Such spacers shall be positioned and securely fixed between the layers of reinforcement but shall not protrude into the cover.

6.6.7.6 Corrosion prevention

6.6.7.6.1

In architectural concrete and for concrete surfaces subject to Class C exposure (see Table 1), tie wires, form ties, bolts, hardware, and other embedded metal items shall not extend to within 40 mm of the concrete surface.

6.6.7.6.2

Epoxy-coated reinforcement shall be tied with plastic ties or plastic-coated wire.

6.6.7.6.3

Exposed reinforcing bars, inserts, and plates intended for bonding with future extensions shall be protected from corrosion.

6.6.8 Tolerances for location of reinforcement

Unless otherwise specified by the owner, reinforcement, prestressing steel, and post-tensioning ducts shall be placed within the following tolerances:

a) concrete cover: ±12 mm (however, the concrete cover shall in no case be reduced by more than 1/3 of the specified cover);

   Note: *See Table 17 for concrete cover.*

b) where the depth of a flexural member, the thickness of a wall, or the smallest dimension of a column is
   i) 200 mm or less: ±8 mm;
   ii) larger than 200 mm but less than 600 mm: ±12 mm; and
   iii) 600 mm or larger: ±20 mm;

c) lateral spacing of bars: ±30 mm (see Figure 4);

d) longitudinal location of bends and ends of bars: ±50 mm; and

e) longitudinal location of bends and ends of bars at discontinuous ends of members: ±20 mm.

In detailing the reinforcement spacing, consideration shall be given for locating structural anchors and other embedded items in the concrete

Notes:

1) *Where reinforcement is added to help provide a more rigid reinforcing mat or cage (e.g., in prefabricated reinforcing cage), such additional reinforcement is not subject to the tolerances of this Clause, except for the minimum cover requirements.*
2) *Shop drawings for the reinforcing steel contractor and the structural steel contractor should be coordinated to ensure that information is available to adequately sequence the work such that there is a provision of clear space to accommodate placing of the anchor bolt pattern within the tolerance guidelines of Figure 3.*

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6.6.9 Splices of reinforcement

Splicing of reinforcement shall be done only as permitted by the owner. The locations and the details of such splices shall be indicated on the construction drawings.

6.6.10 Welding of reinforcement

6.6.10.1

Welding of reinforcement shall conform to the requirements of CSA W186. Weldable grade bars shall be used.

6.6.10.2

Tack welding of reinforcing bars shall be performed in accordance with CSA W186.

6.6.10.3

Welding shall not be executed nearer than 3 m from any prestressing tendon unless effective screens are provided. The prestressing tendon shall not be exposed to splatter, direct heat, or short-circuited current flow.

Note: *The splatter can cause stress concentrations and the temperature due to the direct effect of welding heat or the indirect effect of current flow through the high-tensile prestressing steel can cause a sudden loss of tension.*

6.6.11 Inspection

The location and spacing of reinforcement, bar supports, and form spacers shall be inspected prior to concrete placement.

Note: *Cover meters may be used to verify that the specified cover has been attained in the completed structure. The prompt checking of the cover after casting will enable inadequacies in bar support and concrete placement procedures to be discovered so that such defects can be avoided in subsequent construction.*

6.7 Fabrication and placement of hardware and other embedded items

6.7.1 General

Clause 6.7 covers the fabrication and placement of hardware for concrete building structures that have been designed in accordance with CSA A23.3. The details and location of this hardware shall be shown on the construction drawings.

Note: *For reinforced concrete structures other than buildings, the owner should show clearly on the drawings and specifications any departures from the requirements of Clauses 6.7.2 to 6.7.5.*

6.7.2 Placing of hardware

6.7.2.1

Hardware shall be properly jigged, securely located prior to concrete placing, and placed within the tolerances specified in Clause 6.7.3.

6.7.2.2

Anchor bolts and bearing plates shall be properly aligned and locations verified before the concrete has taken its initial set.

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6.7.2.3
Threads and inserts shall be kept free from any deleterious materials. Care shall be taken to avoid damage that might adversely affect their function.

6.7.2.4
Proper anchorage within the concrete shall be maintained. Under no circumstances shall the main reinforcement as shown on construction drawings be eliminated or cut to accommodate hardware. If hardware or reinforcement cannot be located as specified, work shall not proceed until the necessary modifications have been approved by the owner.

6.7.2.5
Hardware shall be securely fastened to prevent movement during concrete placing and finishing.

6.7.3 Tolerances for placing anchor bolts and hardware

6.7.3.1
Unless otherwise specified by the owner, the location of anchor bolts and embedded items shall not vary from the dimensions shown on the erection drawings by more than the following (see also Figure 3):

a) 3 mm centre-to-centre of any two bolts within an anchor bolt group, where an anchor bolt group is defined as the set of anchor bolts that receives a single fabricated steel or precast concrete member;
b) 6 mm centre-to-centre of adjacent anchor bolt groups;
c) a maximum accumulation of 6 mm per 30 m along the established column line of multiple anchor bolt groups, but not to exceed a total of 25 mm. The established column line is the actual field line most representative of the centres of the as-built anchor bolt groups along a line of columns; and
d) 6 mm from the centre of any anchor bolt group to the established column line through that group.

The tolerances of Items b), c), and d) apply to offset dimensions, as shown on the construction drawings and measured perpendicular to the nearest column line.

6.7.3.2
Vertical alignment variations for anchor bolts shall not exceed 3 mm or 1 mm in 40 mm, whichever is larger.

6.7.3.3
Slope variations for hardware serving as bearing plates shall not exceed 1 mm in 40 mm, with a maximum of 3 mm for plates having side dimensions less than 300 mm and a maximum of 5 mm for plates having side dimensions of 300 mm or larger.

6.7.4 Welding of hardware

6.7.4.1
Welding of steel hardware shall conform to the requirements of CSA W59 and CSA W47.1.

Note: *Welding procedures should be such that no damage to the concrete will result.*

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6.7.4.2

Welding of reinforcing bars to hardware shall conform to the requirements of CSA W186 or CSA W59 and performed by a company complying with CSA W186 or CSA W47.1.

Note: *See Clause 6.6.10.1 for requirements for welding reinforcing bars to reinforcing bars.*

6.7.4.3

Material and equipment for stud welding of bars and anchors shall be compatible and shall be used in accordance with the recommendations of the manufacturers of the material and equipment.

Note: *See the Supplement to ANSI/AWS D1.1.*

6.7.5 Conduits and pipes embedded in concrete

6.7.5.1

Sleeves, pipes, or conduits of any material that does not react deleteriously with concrete, and within the limitations of this Standard, may be embedded in the concrete with the approval of the owner.

6.7.5.2

Conduits and other pipes or their fittings whose embedment is allowed shall not displace more than 4% of the area of the design cross-section for columns on which stress is calculated or which are required for fire protection. Special care shall be taken to ensure that the physical and chemical properties of nonferrous materials are not harmful to the concrete.

6.7.5.3

Sleeves, conduits, or other pipes passing through floors, walls, or beams shall be of such size or in such location as not to impair the required strength of the construction. Such sleeves, conduits, or pipes may be considered as replacing the displaced concrete structurally in compression, provided that they

a) are not exposed to corrosion or other deterioration;
b) are of uncoated or galvanized iron or steel not thinner than that specified in ASTM A53/A53M;
c) have a diameter not exceeding 50 mm; and
d) are spaced not less than 3 diameters on centres.

6.7.5.4

Except when approved by the owner, embedded pipes or conduits shall not be

a) larger in outside diameter than 1/3 the thickness of the slab, wall, or beam in which they are embedded;
b) spaced closer than 3 diameters on centres; or
c) so located as to impair the required strength of the structure.

Note: *To avoid induced cracking, conduits and pipes should not be embedded in exposed slabs on grade.*

6.7.5.5

Sleeves, pipes, or conduits of aluminum shall not be embedded in concrete unless they are effectively coated or covered to prevent aluminum-concrete reaction or electrolytic action between aluminum and steel.

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6.7.5.6

Pipes that will contain liquids, gas, or vapour may be embedded in concrete, subject to the following additional conditions:

a) Pipes and fittings shall be designed to resist the effects of the material, pressure, and temperature to which they will be subjected.
b) The temperature of the liquid, gas, or vapour shall not exceed 70 °C.
c) The maximum pressure to which any piping or fittings are subjected shall be 1.4 MPa above atmospheric pressure.
d) Immediately prior to concreting, all pipes shall be subjected to a leakage test in which
   i) the testing pressure above atmospheric pressure shall be 50% in excess of the pressure to which pipes and fittings might be subjected in service, but not less than 1.0 MPa above atmospheric pressure; and
   ii) the test pressure shall be held for 4 h with no drop in pressure except that which might be caused by temperature changes.
e) Pipes carrying liquid, gas, or vapour that is explosive or injurious to health shall again be tested, as specified in Item d), after the concrete has hardened.
f) No liquid, gas, or vapour, except water not exceeding 30 °C and 0.4 MPa pressure, shall be placed in the pipes until the concrete has attained its specified strength.
g) In solid slabs, the piping shall be placed between the top and bottom reinforcement, except piping used for radiant heating and snow melting.
h) The concrete covering of the pipes and fittings shall be in accordance with Clause 6.6.6.2.
i) Reinforcement with an area equal to at least 0.2% of the concrete cross-section shall be provided normal to the piping.
j) The piping and fittings shall be assembled by welding, brazing, solder-sweating, or other equally satisfactory methods, but threaded connections shall be prohibited.
k) The piping shall be so fabricated and installed that no cutting, bending, or displacement of the reinforcement will be required.

Note: *Drain pipes and other piping designed for pressures of not more than 7 kPa above atmospheric pressure need not be tested as required in Item d).*

6.8 Post-tensioning

6.8.1 General

6.8.1.1

Post-tensioning includes the placement of anchorages, sheaths and ducts, and tendons, stressing, and grouting. Placement and stressing shall be carried out with sufficient accuracy that deflections and factors of safety will be in accordance with the appropriate standards. Where specified, grouting shall be done to protect the steel against corrosion and to develop bond between the tendons and the concrete.

6.8.1.2

Post-tensioning steel shall conform to Clause 6.1.5.

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6.8.1.3

Post-tensioning anchorage zones and other areas of high stress should be examined to determine if any unanticipated cracking occurs. Such crack patterns shall be reported to the owner immediately.

Note: *In some cases unanticipated cracking can be indicative of insufficient reinforcement, or inadequate anchorage and development of the reinforcement. This might require redesign for subsequent portions of construction and an assessment of the adequacy of the portion already constructed.*

6.8.2 Unbonded tendons

6.8.2.1 Anchorages

Anchorages shall develop at least 95% of the minimum specified breaking strength of the tendon. The anchorage shall be considered satisfactory if tests under coated conditions as specified in Clause 6.8.2.5 show that the tendon, while anchored with the anchorage, reaches a strain of at least 2% measured over a gauge length of not less than 1 m. Anchorages shall retain their effectiveness under cyclic loading conditions or vibrations to which they might be subjected.

6.8.2.2 Couplings

Couplings shall be used only at locations specifically indicated or approved by the owner. Couplings shall not be used at regions of sharp tendon curvature. Couplings shall develop at least 95% of the minimum specified breaking strength of the tendon. Couplings shall not reduce elongation at rupture below that required for the tendon steel. Couplings shall be enclosed in housings that are long enough to permit the necessary movements. Coupling assemblies shall be completely protected against corrosion with a corrosion-resisting coating material prior to final encasement in concrete. Couplings shall retain their effectiveness under cyclic loading conditions or vibrations to which they might be subjected.

6.8.2.3 Sheaths

Sheaths shall be made of polypropylene, high-density polyethylene, or other plastic that is not reactive with concrete, coating, or steel. Polypropylene shall meet the requirements of ASTM D4101 and polyethylene shall meet the requirements of ASTM D4976. The material shall be watertight and have sufficient strength and durability to resist damage and deterioration during fabrication, transport, storage, installation, concreting, and tensioning. The material shall remain chemically and thermally stable throughout the service life of the structure. Sheaths shall be continuous between the two end anchorages and shall prevent the intrusion of water or cement paste and the escape of the coating material. The minimum wall thickness of sheaths shall be 1.5 mm.

6.8.2.4 Concrete cover to anchorage

6.8.2.4.1

The concrete cover to the anchorage, measured in a direction perpendicular to the tendon, shall be not less than 40 mm.

6.8.2.4.2

The stressing pocket shall be sufficiently deep so that the cover to the end cap, measured parallel to the tendon, will be at least 40 mm and the cover to the anchorage will be at least 60 mm.

6.8.2.5 Corrosion protection for unbonded tendons

Tendons shall be lubricated and protected against corrosion by a properly applied coating of grease or other approved material. Coatings shall remain ductile and free from cracks at the lowest anticipated

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temperature and shall not flow out from the sheath at the maximum anticipated temperature. Coatings shall be chemically stable and non-reactive to the tendon, the concrete, and the sheath. Coatings shall adhere to and be continuous over the entire unbonded tendon length and shall fill the annular space between the tendon and the sheath.

Note: *For performance specifications for coatings, see Table 1 of PTI Ad-Hoc Committee for Unbonded Single Strand Tendons (1985).*

6.8.2.6 Protection from moisture ingress

Penetration of water or moisture into the sheath through damaged areas, tendon anchorages, or along the exposed ends of the tendons shall be prevented before, during, and after construction. The entire assembly, including tendon, sheath, anchorages, and coupler housings, shall

a) contain no voids; and
b) be sufficiently watertight to resist a 1 m hydrostatic head for 24 h without leakage.

Note: *The requirements of this Clause can be met by using a sheath that is extruded onto the coated tendon, fitting the anchorage with a corrosion-resistant secured cap filled with the same coating material, extending the sheath through the anchor (and cutting it off within the anchor when the wedges are installed). If in lieu of extending the sheath through the anchor, the sheath is stopped short of the anchor and connected to the anchor with a trumpet connector, then the annular space within the trumpet connector would need to be filled by injecting coating material into this space.*
Special care should be taken because tendon corrosion and failures have resulted from rainwater that has entered during construction and collected in cavities near the anchorage and at low areas along the tendon profile.

6.8.2.7 Protection from corrosion

In corrosive environments, the entire assembly, including the anchorages, shall be electrically isolated from the concrete and other reinforcing or embedded materials.

Note: *Electrical isolation can be achieved by epoxy-coating the anchor.*

6.8.2.8 Inspection prior to concrete placement

Tendons shall be inspected prior to and during concrete placement by qualified personnel with expertise in this area.

6.8.2.9 Inspection of damaged tendons

Damaged areas shall be checked to determine whether water has entered the sheath. If any moisture is found in the sheath, the tendon shall be replaced. If the tendon is dry, the sheath shall be repaired by restoring the coating and the sheath's watertightness.

6.8.2.10 Preparation of cut tendon ends

The tendons shall be cut off and a watertight cap shall be securely installed immediately after stressing.

6.8.2.11 Preparation of anchor pockets after stressing

As soon as possible after the ends of the tendon have been cut to length and the watertight cap installed, the laitance shall be removed from the sides of the stressing pockets, the sides coated with bonding agent, and the pocket filled with a non-shrink grout. This grout shall not contain chlorides, or other chemicals known to be deleterious to the prestressing steel, in amounts greater than those specified in Clause 6.8.4.3.7.

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6.8.3 Bonded tendons

6.8.3.1 Anchorages

Anchorages shall develop at least 95% of the minimum specified breaking strength of the tendon when tested in an unbonded condition. However, 100% of the specified ultimate capacity of the tendons shall be developed after the tendons are grouted in the member. Anchorages shall be protected against corrosion as specified in Clause 6.8.3.5.

6.8.3.2 Couplings

Couplings shall be used only at locations specifically indicated or approved by the owner. Couplings shall not be used at regions of sharp tendon curvature. Couplings shall develop at least 95% of the minimum specified breaking strength of the tendon. Couplings shall not reduce elongation at rupture below that required for the tendon steel. Couplings shall be enclosed in housings that are long enough to permit the necessary movements. Fittings shall be provided to allow complete grouting of coupling components.

6.8.3.3 Ducts

Duct material for bonded tendons shall be strong enough to retain its shape, resist damage during construction, and prevent the entry of cement paste or water from the concrete. Duct material left in place shall not cause harmful electrolytic action or deteriorate. The inside diameter shall be at least 6 mm larger than the nominal diameter of single wire, bar, or strand tendons or, in the case of multiple wire, bar, or strand tendons, the inside cross-sectional area of the duct shall be at least twice the net area of the prestressing steel. Ducts shall be capable of transmitting forces from the grout to the surrounding concrete. Ducts shall have grout openings at each end and at all high points except where the degree of tendon curvature is small and the tendon is relatively level, such as in continuous slabs.

6.8.3.4 Sleeves or gaskets

Sheaths shall be connected at joints in segmental construction by leaktight sleeves or gaskets.

Note: *Sleeves may be*

a) *telescopic sleeves pushed over the protruding ducts;*
b) *screw-on sleeves; or*
c) *rubber or plastic sleeves.*

6.8.3.5 Stressing pockets

As soon as possible after the ends of the tendons have been cut to length, the laitance shall be removed from the sides of the stressing pockets, the sides coated with a bonding agent, and the pocket filled with a nonshrink grout or concrete. The grout or concrete used to fill these pockets shall be proportioned to meet or exceed the same durability requirements as the surrounding concrete. This grout or concrete shall not contain chlorides or other chemicals known to be deleterious to the prestressing steel in amounts greater than those specified in Clause 6.8.4.3.7. The nonshrink properties of this grout or material shall be verified by tests conducted in accordance with ASTM C1107/C1107M.

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6.8.4 Cement grout for bonded tendons

6.8.4.1 Materials

Cement, water, and admixtures for grout shall conform to the requirements of Clauses 4.2.1, 4.2.2, and 4.2.4, respectively.

Notes:

1) *The compatibility of different admixtures used in the grout should be assessed.*
2) *When approved by the owner, aluminum powder, thixotropic additives, supplementary cementitious materials, and other admixtures may be used to produce expansion, reduce bleeding, and increase the flow rate with reduced water content.*
3) *Vertical strand tendons might require admixtures that make the grout thixotropic to prevent excessive bleeding, which results from the filtering action of the strand. Grouting trials are considered good practice.*
4) *See* PTI Guide Specification for Grouting of Post-Tensioned Structures *for more guidelines on materials and construction of post-tensioning grout.*

6.8.4.2 Proportioning materials

Material proportions shall be based on the results of tests made on the grout before commencement of grouting. The water content shall be the minimum necessary for proper placement. The water-to-cementitious materials ratio shall not exceed 0.45.

Notes:

1) *At the discretion of the owner, material proportions may be selected based on prior documented experience with similar materials and equipment under comparable field conditions.*
2) *Colloidal mixers can produce a grout of a desired fluidity using a lower water-to-cementitious materials ratio than is possible with other types of mixers. Air entrainment can be used to reduce bleeding and increase the fluidity of grout.*

6.8.4.3 Properties of grout

6.8.4.3.1

Grout that might be subjected to freezing during the first two weeks shall contain entrained air. Unless a more detailed determination of air requirements is made, the percentage of air content, *A*, shall exceed

$$A > \left(24\frac{w}{c}\right) - 5\log_{10}\left[\frac{(T+10)h}{32}\right]$$

where

A = air content, %

w/*c* = the water-to-cement ratio

T = average temperature during *h*, °C

h = hours between grouting and freezing

Notes:

1) *Sufficient air entrainment prevents the grout from expanding during freezing, thereby preventing cracking of the member. See Loov, Hon, and Ward (1984).*
2) *The water-to-cement ratio is used in this equation rather than the water-to-cementitious materials ratio because the early frost resistance of grout containing supplementary cementitious materials has not been established.*
3) *The tabulated values of required air content in Table 18 have been calculated using the above equation.*
4) *Normally, if grouts can be critically saturated and subject to cyclic freezing and thawing, they must be air entrained.*

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6.8.4.3.2

The air content of the grout shall be determined in accordance with CSA A3004-C4 or CSA A23.2-4C.

6.8.4.3.3

Grout fluidity shall be determined in accordance with CSA A23.2-1B. The efflux time of the grout sample immediately after mixing shall be not less than 11 s nor more than 25 s unless specifically limited otherwise by the manufacturer's recommendations for proprietary prepackaged grouts for post tensioning ducts.

Note: *Further information on selection of grout properties based on efflux time can be seen in the PTI* Specification for Grouting of Post-Tensioned Structures by Post-Tensioning Institute.

6.8.4.3.4

The bleed water shall not exceed 2% and all separated water shall be absorbed within 24 h when tested in accordance with CSA A23.2-1B.

6.8.4.3.5

When an expansion agent is used, the unrestrained expansion shall be 3% to 8% when tested in accordance with CSA A23.2-1B.

The grout for vertical tendons shall not contain an expansion agent.

6.8.4.3.6

Minimum grout strength shall be 20 MPa at 7 d when tested in accordance with CSA A23.2-1B.

6.8.4.3.7

The concentrations of corrosion-inducing chemicals in the grout shall be kept as low as is reasonably possible. The chloride concentration shall not exceed 250 mg/kg of grout.

Chlorides shall be determined in accordance with CSA A23.2-4B. When testing for nitrates, the sampling procedure shall be in accordance with Clauses 9.1 and 9.2 of CSA A23.2-4B. The nitrates in water, extracted by boiling the grout samples, shall be determined in accordance with ASTM D4327.

Notes:

1) *When testing for nitrates, the atmosphere described in Clause 10 c) of CSA A23.2-4B should be free of HNO_3 fumes.*
2) *Materials conducive to the promotion of corrosion, such as fluorides, sulphites, and sulphides, should not be used in grout unless it can be proven that their presence is not detrimental.*

6.8.4.4 Production

6.8.4.4.1

Mix water should be added to the mixer first, followed by cementitious materials and admixtures.

Pre-packaged grout shall be mixed in accordance with the manufacturer's requirements. Mixing shall continue in accordance with the manufacturer's specifications or for a period of time until a uniform and thoroughly blended mixture of grout is obtained.

Note: *When the grout is to be air entrained, the use of a colloidal mixer will be beneficial. In some cases, a field trial might be necessary to determine the admixture dosage, mixing speed, and mixing time.*

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6.8.4.4.2

Grout shall be agitated continuously during the grouting operations. When not being pumped into the duct, the grout shall be re-circulated or agitated in the pump hopper or separate holding tank.

6.8.4.4.3

Grout shall pass through a screen with openings no larger than 5 mm before it enters the grout pump.

6.8.4.4.4

Grout shall be discarded when the flowability as measured by the flow cone exceeds 25 s. Retempering shall not be allowed.

Notes:

1) *Grout containing expanding agents sometimes has to be discarded sooner than indicated, in order to have the desired amount of expansion remaining after injection has been completed.*
2) *See reference document as published by the FHWA* Post-Tensioning Tendon Installation and Grouting Manual*.*

6.8.4.5 Testing

Control tests for strength and fluidity shall be conducted daily, and as specified in construction documents, for air entrainment. Control tests for bleeding, expansion, and chemical content shall be carried out as required by the owner.

6.8.5 Preparation for post-tensioning

6.8.5.1 Formwork and shoring

6.8.5.1.1

Concrete formwork and other structural elements shall not restrain the elastic shortening or the cambering of the member more than the normal frictional restraint imparted by forms properly treated with a release agent.

6.8.5.1.2

Unless otherwise specified by the owner, shoring that supports concrete to be prestressed shall not be removed until the prestressing steel has been stressed. The design of the falsework and reshores shall account for the post tensioning forces as supplied by the post-tensioning engineer in accordance with CSA S269.1.

Note: *Reshoring is not normally required for the temporary support of prestressed concrete but it might be required to support the weight of additional floors of unstressed concrete.*

6.8.5.2 Anchoring of tendons

6.8.5.2.1

The spacing between anchorages shall be sufficient to allow the operation of the stressing jacks to be unimpeded by adjacent stressed or unstressed tendons.

6.8.5.2.2

The axis of the tendon shall be in line with the anchorage for a minimum distance of 0.4 m or as approved by the owner.

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6.8.5.3 Prestressing tendons

6.8.5.3.1 Cover

Cover requirements shall be as specified in Clause 6.6.6.2.3.

6.8.5.3.2 Curved tendons

Where it is necessary to curve tendons in the horizontal plane in order to bypass an opening, the tendon offset shall not exceed one in five, and the clearance to the opening shall not be less than 150 mm. The portion of tendon that passes by the opening shall be straight.

6.8.5.3.3 Spacing

6.8.5.3.3.1

The clear distance between parallel ducts in a layer shall be not less than the largest of the following:

a) the diameter of the ducts;
b) 1-1/3 times the nominal maximum size of the coarse aggregate; or
c) 30 mm.

6.8.5.3.3.2

To provide access for concrete placement and the insertion of vibrators, at least 1/3 of the spaces between ducts shall exceed 60 mm.

6.8.5.3.3.3

Where parallel ducts are placed in two or more layers, the ducts in the upper layers shall be placed directly above those in the bottom layer, with the clear distance between layers not less than 30 mm or 1-1/3 times the nominal maximum size of the aggregate, whichever is larger.

6.8.5.3.4 Bundling

Individual strands may be bundled, provided that the

a) concrete can be placed satisfactorily;
b) strand, when tensioned, does not break into adjacent ducts; and
c) ducts, if grouted, can be grouted individually without the flow of grout into adjacent ducts.

6.8.5.3.5 Tolerances

Ducts shall be well secured to prevent flotation or displacement during concrete placement. Support shall be adequate so that the tolerances specified in Clause 6.6.8 are maintained. Ducts in segmental construction shall be placed with special care to ensure that the ducts in adjacent segments are aligned.

Note: *Sharp curvatures will make it difficult to thread tendons through the duct and will create high local stresses when the tendon is stressed.*

6.8.5.3.6 Marking

Prefabricated tendons shall be clearly marked so that each tendon can be placed in the correct location as shown on the approved drawings.

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6.8.5.4 Placing of concrete

6.8.5.4.1
Immediately before concrete is placed, the tendon profiles and alignment shall be checked and corrected where necessary. Sheaths and ducts shall be inspected and damage repaired to prevent concrete from bonding to the prestressing steel.

6.8.5.4.2
The placing of concrete shall be in accordance with Clause 7.5.

6.8.5.4.3
When concrete is placed, reinforcement, tendons, vent pipes, sheaths, and ducts shall not be displaced.

6.8.5.4.4
The concrete shall be vibrated with particular care at each post-tensioning anchorage location to ensure adequate consolidation in the anchorage zone.

6.8.5.4.5
Before stressing, the concrete strength, determined in accordance with CSA A23.2-14C or A23.2-15C, shall be not less than the specified transfer strength. The conditioning of the cores in the Test Method specified in CSA A23.2-14C for either dry condition or wet condition is not required when measuring for transfer strength. Cores shall be tested as they are received and results shall be recorded accordingly.

6.8.5.5 Jointing segmental sections

6.8.5.5.1
The joints of match-cast elements shall be coated with an approved adhesive before the separate elements are connected.

6.8.5.5.2
Joints 10 mm to 70 mm wide shall be filled with a sand/cement mortar.

6.8.5.5.3
Joints over 70 mm wide shall be filled with concrete.

6.8.5.5.4
The strength of the mortar or concrete used in joints shall be at least equal to the parent concrete, unless a lower strength is specified in the project documents.

6.8.5.5.5
To obtain the desired strength and durability, joints shall be protected so that the adhesive, mortar, or concrete is properly cured.

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6.8.6 Application and measurement of prestressing force

6.8.6.1

The required tendon elongation and jacking force shall be computed based on the required prestressing force and consideration of the stressing procedures and losses due to effects such as jack friction and anchorage set as well as strand friction, strand wobble.

6.8.6.2

Tendons shall be tensioned in sequence, as specified in the approved drawings.

6.8.6.3

A specified initial load shall be applied to the tendon to take up slack and to provide a starting point for elongation measurements before the final load is applied, as specified in the stressing procedure.

Notes:

1) *The initial load is usually 5 to 25% of the full load.*
2) *The owner may waive this requirement when the slack and dead-end anchorage set have a negligible effect, such as is normally the case for single-strand tendons.*

6.8.6.4

The rate of application of the prestressing force shall be consistent with proven procedures applicable to the particular type of post-tensioning as approved by the owner.

Note: *When tendons are jacked from two ends it is preferable to jack alternately from each end, in steps if necessary, to maintain adequate control. Additional information can be found in the U.S. Federal Highway Administration* Post-Tensioning Tendon Installation and Grouting Manual.

6.8.6.5

Both the tendon elongation and the jacking force or pressure shall be measured and recorded during the prestressing operation.

6.8.6.6

The stressing forces measured by jacking pressure shall be within 7% of the force calculated by measured elongation. If the results do not fall within this range, the procedures shall be examined and any sources of error determined. If the results cannot be reconciled within the required limits, remedial action shall be instituted as approved by the owner.

6.8.6.7

Pressure gauges shall be recalibrated at least every 6 months and whenever stressing force and elongation measurements cannot be reconciled within 7%.

6.8.6.8

The total loss of prestress due to unreplaced broken wires or strands shall not exceed 2% of the total prestress, unless approved by the owner.

6.8.6.9

Strict safety precautions shall be enforced during tensioning operations. Personnel shall not stand in line with the jack or anchorages during the stressing and anchoring operations.

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6.8.6.10

The person responsible for stressing shall be familiar with the operation of the equipment being used and shall have had previous experience in stressing operations.

6.8.6.11

Stressing records shall be kept. The owner shall determine the extent of stressing records required and shall receive copies of these records signed by the person supervising the stressing.

Note: *See Clause 28 of CSA A23.4 for a list of items that can be considered.*

6.8.6.12

After stressing, the excess length of tendon shall be removed and the stressing pocket filled as specified in Clause 6.8.3.5.

Note: *A portable cutting wheel is preferred but an oxyacetylene cutting torch may be used, provided that the cut is made at least 50 mm from the face of the anchorage, unless tests have established that the specified capacity of the tendon can be maintained with a shorter distance.*

6.8.7 Grouting

6.8.7.1 Protection and flushing prior to grouting

6.8.7.1.1

When the temperature of the ducts can drop below freezing prior to grouting, appropriate measures shall be taken to prevent water from collecting and freezing in the ducts.

Note: *Although drains are sometimes installed at low points, they are not reliable because they can freeze shut. Vents should be spaced at a maximum of 50 to 70 m and at high points. See Clause 3.3.9 of* VSL Grouting of Post-Tensioning Tendons*.*

6.8.7.1.2

Grouting shall be carried out with as little delay as possible after the steel has been tensioned. If grouting is delayed more than one week, measures shall be instituted to reduce the risk of corrosion.

Notes:

1) *Corrosion may be reduced by circulating dry air through the ducts.*
2) *The corrosion risk increases rapidly with increases in temperature and humidity.*

6.8.7.1.3

Cored ducts (ducts with concrete walls) shall be flushed to remove residue and ensure that concrete is thoroughly wetted prior to grout injection. Ducts shall be flushed to clean out foreign materials or oil-free compressed air shall be used to check for blockages. Flushing shall be carried out just prior to grouting.

6.8.7.1.4

Ducts in segmental construction shall be flushed to check that joints are sealed.

6.8.7.2 Grout temperature

Grout shall not be warmer than 30 °C or colder than 5 °C during mixing or pumping.

Note: *Grout will rapidly reach the temperature of the concrete member being grouted. Rapid set might be a problem if the grout temperature approaches 30 °C.*

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6.8.7.3 Grout curing

The temperature of the coldest portion of the grout in a concrete member shall be

a) 4 °C or higher for two weeks; or
b) higher than the chosen curing temperature for the period of time chosen in Table 18, if this period of time is shorter than two weeks.

6.8.7.4 Injection of grout

6.8.7.4.1

Grouting and high-point vent openings shall be open when grouting starts. Grout shall be allowed to flow from the first vent after the inlet pipe until any residual flushing water or entrapped air has been removed. This vent shall then be capped or closed. Remaining vents shall be closed in sequence in a similar manner.

6.8.7.4.2

Grout shall be pumped through the duct and continuously wasted at the outlet pipe until no visible slugs of water or air are ejected and the efflux time of ejected grout is not less than that of the injected grout.

6.8.7.4.3

To ensure that ducts remain filled with grout, the outlet and inlet shall be kept under a 0.52 MPa pressure for 2 min to confirm no leaks in the system.

6.8.7.4.4

The gauge pressure at the tendon inlet shall not exceed 1.5 MPa unless a higher pressure is approved by the owner.

6.8.7.4.5

If the required grouting pressure exceeds the recommended maximum pressure, grout shall be injected in any vent that has been or is ready to be capped, as long as a one-way flow of grout is maintained.

6.8.7.4.6

When a one-way flow of grout cannot be maintained as outlined in Clauses 6.8.7.4.1 to 6.8.7.4.5, corrective action shall be taken.

Note: *An adequate supply of water and a pump capable of developing a pressure of at least 2 MPa should be on site to allow grout to be flushed out if necessary.*

6.8.7.5 Grouting records

The owner shall determine the grouting records required and shall receive copies of these records signed by the owner and the person supervising the grouting.

Note: *A typical field record-keeping procedure is shown in Annex G.*

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7 Placing, finishing, and curing concrete

7.1 Preconstruction quality planning

7.1.1 General

Preconstruction planning is an integral part of successful concrete construction. The owner should facilitate a preconstruction meeting to review the use of specified materials and methods of construction prior to any work commencing on site.

Notes:

1) *Preconstruction meetings should be held at the project site approximately one month prior to the commencement of any concrete activities to ensure adequate time for discussion and planning.*
2) *Meetings should include the attendance of the owners representative, constructor, forming contractor, concrete floor contractor, concrete supplier, major materials suppliers, inspection and testing company, and any other related parties (e.g., granular base contractor).*
3) *The contractor should prepare a proposed joint layout and any specified mock-up samples for review at this meeting.*
4) *A review of applied finishes should be made with consideration for vapour retarding membranes, concrete mix adjustments, curing methodology and surface tolerances.*
5) *The steel or macro-synthetic fibre manufacturer's concrete floor design should be carefully reviewed for the owners loading requirements including the fibre type, configuration, and dosage rate to be used. See Clause 4.2.5 and Annex H.*
6) *The specification should be reviewed fully to ensure that specified materials and methods will be used.*
7) *Sustainability should be considered to minimize waste, increase durability, and minimize the environmental impact of concrete construction.*
8) *The concrete mix should be carefully selected to be compatible with the project specifications, placing and finishing methods, surface treatments, site ambient conditions, and the requirements of this Standard.*
9) *See also ACI 302 for more information.*

7.1.2 Concrete mixes for interior concrete floors

7.1.2.1 General

Interior concrete floors with a steel trowelled finish, other than residential concrete floors (Class R-3 exposure, Table 1), are designated N-CF class of exposure (Table 2) and shall be designed to a maximum 0.55 w/cm and a minimum compressive strength of 25 MPa at 28 d (as specified in Table 2), as well as designed for the methods of placing and finishing, set, and serviceability, as required for intended service.

Concrete mixes for concrete floors shall have a slump of 120 ± 30 mm* at the point of discharge, except where a reduced slump is required for highly sloped floors and ramps. For pump mixes, higher workability or flow shall be achieved and maintained with the addition of chemical admixtures only.

* *This is for reasons including health and safety.*

Notes:

1) *See ACI 302.1 for further information on concrete slabs and concrete mixes.*
2) *The water content of the concrete mix should be minimized to reduce the effects of shrinkage and the slump increased using a normal setting plasticizing admixture.*
3) *SCM use and chemical admixtures in concrete mixes can reduce the amount of bleed water available at the concrete surface unless other changes are made to the mix to address bleed rate. Admixtures used for water reduction, viscosity modification, and air-entrainment commonly reduce the quantity of surface bleed water. The use of plasticizers might also exhibit reduced bleed quantity if the mix water content has been reduced. A reduction in available bleed water at the surface can create difficulties in finishing and in the application of*

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dry shake surface hardeners and can increase the need to protect the slab from rapid evaporation of surface moisture. See Clause 7.6.

4) *Air entrained concrete should not be used for interior ice rink slabs and freezer slabs with a steel trowelled finish. They have been found to perform satisfactorily without entrained air if an adequate period of drying is provided before the initial freezing.*

7.1.2.2 Curing

The owner shall specify the curing type from Table 19.

Note: *Curing type 3 (extended wet curing) will increase the abrasion resistance at the surface.*

7.1.2.3 Drying time for applied finishes

Concrete slabs shall be allowed to dry sufficiently before the application of moisture-sensitive floor coverings. A vapour retarder shall be placed below slabs on grade in accordance with ACI 302.3R to reduce future moisture migration. The areas of the slab on grade requiring vapour retarder shall be specified on the project drawings.

Note: *To reduce the drying time of concrete for applied finishes, the following should be considered:*

a) *decreasing the water content of the concrete mix through the use of a plasticizing admixture;*
b) *decreasing the water-to-cementitious materials ratio;*
c) *using 3 d of continuous wet curing (not using curing membrane);*
d) *protecting the slab surface from environmental re-wetting after the curing period;*
e) *minimizing slab thickness consistent with structural requirements and desired joint spacing; and*
f) *extract moist air to promote drying such as by dehumidifying or exhausting the moisture to the building exterior or drains.*

See also ACI 302.2R for further information on the replacement of vapour retarder membranes.

7.2 Hot and cold weather concreting

7.2.1 Hot weather concreting — Job preparation

When the ambient air temperature is at or above 27 °C, or when there is a probability of the temperature rising above to 27 °C during the placing period (as forecast by the nearest official meteorological office), facilities shall be provided for protection of the concrete in place from the effects of hot and/or drying weather conditions in accordance with Clause 7.6.

7.2.2 Cold weather concreting

7.2.2.1 Job preparation

Protection shall be provided when there is a probability of the air temperature falling below 5 °C within 24 h of placing (as forecast by the nearest official meteorological office). All materials and equipment needed for adequate protection and curing shall be on hand and ready for use prior to concrete placement. All snow and ice shall be removed before concrete is deposited on any surface. Calcium chloride or other de-icing salts shall not be used as a de-icing agent in the forms. Concrete shall not be placed on or against any surface that will lower the temperature of the concrete in place below the minimum value shown in Table 14, except when non-chloride, non-corrosive accelerators are used (see Note 3 of Table 14).

7.2.2.2 Temperature requirements

During cold weather, as defined in Clause 7.2.2.1, adequate protection of the concrete shall be provided that will maintain the concrete temperature at a minimum of 10 °C for the duration of the required curing period as defined by Tables 2 and 19. Protection shall be provided by means of heated

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enclosures, coverings, insulation, or a suitable combination of these methods. In freezing temperatures, all curing water shall be removed from the surface at the end of the curing period.

Note: *For slabs on grade, if there is a large temperature differential between the granular base and the concrete, the surface might exhibit blisters during trowelling. Delaminations might also result if sufficient bleed water is entrapped. Pre-heating the granular base and workspace, and the use of non-chloride concrete accelerators can reduce or eliminate this problem.*

7.2.2.3 Heated enclosures

Enclosures shall be constructed to withstand wind and snow loads and shall be reasonably airtight. The housing shall provide sufficient space between the concrete and the enclosure to permit free circulation of warmed air. Heat shall be supplied to the enclosure by forced hot air, stationary heaters, hydronic heaters, or other heaters of various types. At the time of placing and during curing, concrete surfaces shall be protected from direct exposure to combustion gases by formwork or an impermeable membrane.

Note: *The presence of combustion gases within heated enclosures should be prevented through the use of indirect-fired heaters and adequate fresh air ventilation to avoid harmful carbon monoxide exposure to workers. As well, carbon dioxide emissions from heaters and equipment can react with the fresh cement paste to form a chalky surface.*

7.2.2.4 Protective covers and insulation

The type of protective cover and the amount of insulation required to cure concrete properly in cold weather shall be determined on the basis of the expected air temperature and wind velocity (wind chill factor), the size and shape of the concrete structure, and the amount of cementitious material in the concrete mix.

Notes:

1) *The corners, edges, and thin sections of a concrete member are the most vulnerable locations in cold weather and need more protection than plane surfaces.*
2) *When the concrete reaches a compressive strength of 7 MPa, it will normally have sufficient strength to resist early frost damage.*
3) *Additional information on protective covers and insulation can be found in ACI 306R.*

7.2.2.5 Cooling after protection

To avoid cracking of the concrete due to a sudden temperature change near the end of the curing period, the protection shall not be completely removed until the concrete has cooled to the temperature differential given in Table 20. For high-performance concrete, the maximum temperature differential for all structural components shall be 20 °C.

Notes:

1) *See Clause 7.6.3 for mass concrete.*
2) *In the case of insulated formwork, stripping times are given in Figure D.2.*
3) *For precast concrete, see CSA A23.4.*

7.3 Jointing

7.3.1 Construction joints

7.3.1.1

The locations and details of construction joints shall be shown on the design drawings and formwork drawings. Construction joints in concrete floors shall be smooth from one side to the other such that a tripping hazard is not created.

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7.3.1.2

Construction joints not indicated on the design drawings and formwork drawings shall be subject to the approval of the owner and shall be located and designed so that the strength and appearance of the structure are impaired as little as possible.

7.3.1.3

Where a bonded construction joint is to be made, the surface of the set concrete shall be suitably roughened, thoroughly cleaned of foreign matter and laitance, saturated with water, and left in a damp condition with no free water on the surface immediately before placing new concrete. Where a bonding agent is used, surface treatment shall be as recommended by the manufacturer.

Notes:

1) *Polyvinyl-acetate should not be used in wet environments.*
2) *Joints for slabs on grade should not be bonded to avoid drying shrinkage cracking.*

7.3.1.4

Beams, girders, capitals, brackets, and haunches shall be considered part of the floor system and shall be placed monolithically with the floor, except as otherwise specified by the owner.

7.3.1.5

Where construction joints are specified in watertight construction, all specified layers of reinforcement shall be continuous across the joint unless otherwise detailed on the drawings. The type, size, location, and material of water stops shall be specified by the owner. Joints in water stops shall be made in accordance with the manufacturer's directions. Joints in water stop material shall be as watertight as the continuous material and shall have a permanent strength and flexibility not less than 50% of that of the continuous material.

7.3.1.6

Where dowels are specified for construction joints in slabs on grade, they shall be located at mid-depth of the slab and aligned parallel to the direction of horizontal movement. In order to permit horizontal movement, dowels (including round or square bars, or plates) shall be smooth and 1/2 the length of each dowel shall be coated with a bond breaker or sleeve so that slippage can occur on one side of the construction joint. Dowel plates shall be installed in accordance with the manufacturer's instructions.

Deformed reinforcing bars shall not be used as dowels.

Notes:

1) *Formed keys generally deteriorate quickly under vehicular traffic and should not be used for moving joints.*
2) *Refer to ACI 302.1R for further information on dowel baskets.*
3) *The bond breaker coating should be as thin as possible to avoid creating voids around dowels.*
4) *Dowels cast into fresh concrete should not be moved once the concrete has taken on its initial set.*

7.3.2 Contraction joints

7.3.2.1

Contraction joints shall be installed in slabs on grade and pavements as soon as possible to avoid the development of uncontrolled shrinkage cracks in the concrete. Contraction joints can be formed by diamond sawing, hand tooling, or inserting preformed crack-inducing strips into the surface of the concrete to the specified depth. Contraction joints shall be spaced at approximately 25 times the slab

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thickness and not more than 4.5 m on centre in approximately square patterns unless otherwise specified by the owner.

Notes:

1) *Contraction joints may be installed in slabs on a metal deck above supporting steel members to control shrinkage cracking if specified by the owner. Composite slab construction requires careful consideration and planning of joint locations.*
2) *Further information on contraction joints is available from ACI 302.1R.*
3) *Tooled joints and preformed crack-inducing strips should be installed in the concrete to a minimum depth of 25% of the slab thickness.*
4) *Contraction joints should not be used in slabs with two layers of continuous reinforcing steel bars as they have been shown to not induce cracking.*
5) *Care should be taken to avoid cutting through reinforcement, in-floor heating systems, and other embedded items.*
6) *A contraction joint spacing of greater than 4.5 m on centre generally results in the development of uncontrolled drying shrinkage cracks. The owner may choose to exceed this joint spacing limitation utilizing special concrete mixes and reinforcing solutions to meet their customized needs.*
7) *"T" shaped contraction joint intersections should be avoided because extension cracking can occur.*

7.3.2.2

Wet diamond blade sawing shall commence approximately 8 to 24 h after concrete placement, as soon as the concrete surface has hardened sufficiently to resist ravelling while cutting. Depth of sawcuts shall be between 1/4 and 1/3 of the slab thickness.

Note: *The proper time for cutting will depend upon several factors, including ambient conditions and concrete properties.*

7.3.2.3

Specialized dry-process cutting shall commence immediately following final finishing. Sawcuts shall be made to the depth specified by the equipment manufacturer.

Note: *Specialized dry-process equipment uses unique cutting mechanisms that permit early cutting of the concrete without ravelling and at a reduced depth of cut. The manufacturer's instructions should be followed carefully when employing this contraction joint method.*

7.3.2.4

Contraction joints in concrete walls and curbs shall be formed or saw cut.

Note: *Curb joints should be aligned with slab joints to avoid cracking.*

7.3.2.5

Where dowels are specified for contraction joints, they shall be smooth bars, aligned parallel to the direction of horizontal movement, and shall be fully unbonded.

7.3.2.6

Contraction joints shall not be made in bonded toppings except where they are placed accurately over base slab joints to minimize reflective cracking.

7.3.3 Isolation joints

Isolation joints shall be installed the full slab depth between slabs on grade and abutting walls and columns where horizontal or vertical movement is expected.

Note: *Isolation joints are not required where a slab on grade is tied to the abutting wall or column with reinforcing steel.*

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7.3.4 Expansion joints

Expansion joints which permit thermal expansion and contraction of the concrete shall be located and detailed by the owner.

7.3.5 Joint filling

To avoid de-bonding, filling and sealing of joints in slabs on grade shall commence after sufficient drying shrinkage of the concrete has taken place. Contraction and construction joints subject to solid tire forklift traffic shall be filled with a semi-rigid filler material having a minimum Shore "A" hardness of 80 in accordance with ASTM D2240. Materials shall be installed in accordance with the manufacturer's instructions.

Notes:

1) *Unfilled joints subject to solid tire forklift traffic can deteriorate quickly.*
2) *Joint filling with semi-rigid materials should not commence until after a minimum 120 d air drying period at 20 °C.*
3) *Joint sealing with flexible filler materials should not commence until after a minimum 75 d air drying period at 20 °C.*
4) *Hot rubberized asphalt based sealants possess sufficient elongation to offset drying and thermal shrinkage for exterior applications.*
5) *Joints in freezer floors should be filled after the temperature of the concrete has been reduced to operating temperatures to avoid de-bonding caused by thermal contraction.*

7.4 Storage of materials used for placing, finishing, and curing

7.4.1 General

All materials shall be stored in a manner that will prevent damage, contamination, or deterioration. Access shall be provided to the storage facilities to allow for inspection.

7.4.2 Fabricated and proprietary materials

All fabricated and proprietary materials, such as curing compounds, cardboard forms, and hardware shall be stored in accordance with the manufacturer's instructions.

7.5 Placing of concrete

7.5.1 General

7.5.1.1

Concrete for a placement shall not be ordered until all forms, granular bases, foundations, reinforcement, embedded items, methods, and materials comply with the requirements of the project specification and this Standard.

Notes:

1) *See Clause 7.5.3.11 for ± 10 mm limitation for granular base elevations.*
2) *See Clause 6.4.2.2.1 for slab on grade thickness tolerances and Clause 6.4.2.1 for tolerances for formed sections and suspended slabs.*
3) *See Table 2 and Clause 7.1.2 for concrete mixes for interior floors.*
4) *Annex I provides further guidance on placing methods for high-performance concrete.*

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7.5.1.2

Concrete placing methods and equipment shall be such that the concrete is conveyed and deposited without segregation and without changing or adversely affecting the specified qualities.

Note: *The methods of placing and screeding should be carefully selected when combined with a diamond polished final finish to minimize variations in final appearance.*

7.5.1.3

The temperature of the concrete as placed shall be within the limits shown in Table 14 for the indicated size of concrete section.

7.5.2 Handling

7.5.2.1

Equipment for conveying concrete, such as buckets, trucks, belt conveyors, pumps, etc., shall be of such design, size, and condition to ensure a continuous and adequate supply of concrete of the specified mix and slump, without segregation at the point of deposition and without adversely affecting other properties of the concrete.

7.5.2.2

Handling equipment shall be in good working order, kept free from hardened concrete or foreign material, and cleaned at frequent intervals.

7.5.2.3

Handling equipment, if supported by the falsework or formwork, shall not impart harmful vibration to the freshly placed concrete or cause any deformation or misalignment of the formwork.

7.5.2.4

Placing equipment shall provide for the vertical deposition of the concrete into the form.

7.5.2.5

Belt conveyors shall be so designed and positioned that no spillage will occur at transfer points and the scrapers shall prevent the loss of paste. Concrete shall not be discharged directly off the end of the belt into its final position, but shall be directed vertically by an elephant trunk or hopper.

7.5.2.6

Chutes shall have a slope not exceeding 1 vertical to 2 horizontal and not less than 1 vertical to 3 horizontal, except that chutes having a length that causes segregation or having a slope greater than 1 vertical to 2 horizontal may be used if concrete materials are recombined by a hopper or other means before distribution.

7.5.2.7

A concrete pump shall be proven by demonstration to be able to pump the specified concrete through required line lengths and at the placement rates without impairing or detracting from the specified quality and durability requirements of the concrete.

Notes:

1) *Some makes and models of concrete pumps require special mixes (e.g., higher cement contents, high sand/stone ratios, and/or high slump). Such adjustments should not impair or detract from specified quality and durability properties of the concrete.*

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2) *Pumping of concrete can have an impact on the slump and air void system of plastic concrete. See Clause 7.2.2.1 of CSA A23.2-25C for frequency of testing.*

7.5.2.8

Pipelines made from aluminum alloys shall not be used.

7.5.2.9

Wash water used to clean equipment shall not enter the forms.

7.5.3 Depositing

7.5.3.1

Welded wire mesh shall be installed in the concrete in a manner that prevents it from settling to the granular base by supporting it on appropriately spaced concrete brick or chair supports.

Notes:

1) *Wire mesh should be supplied in flat sheets to promote improved elevation control.*
2) *Welded wire mesh with a gauge less than MW25.8 (4.0) is a flexible fabric material which is impractical to control at a predetermined elevation.*
3) *Wire mesh should be located below the depth of sawcut contraction joints to prevent cutting.*
4) *Two layers of welded wire mesh are not recommended as a practical reinforcing solution.*
5) *See also WRI TF 705-R and TF 702-R for further information on wire mesh reinforcing for slabs on grade.*

7.5.3.2

The vapour retarder shall be protected from damage during construction and casting operations and shall be installed in accordance with ASTM E1643. The vapour retarder seams shall be lapped and sealed with a compatible sealant or tape in accordance with the vapour retarder manufacturer's instructions. All penetrations through the vapour retarder and perimeter joints shall also be taped and sealed.

Note: *When concrete is placed on an impermeable substrate, precautions should be taken through concrete mix adjustments to control the potential for excessive bleeding, drying shrinkage, and curling.*

7.5.3.3

Concrete shall be deposited in the forms in a manner that prevents segregation and in a location as close as practicable to its final position. Lateral movement of concrete, which can cause segregation, shall not be permitted.

Notes:

1) *Alternative methods to prevent segregation include mixture proportion adjustments, the utilization of baffles and trunks, and admixture adjustments.*
2) *With air-entrained concrete, significant free-fall drops can cause reductions in air entrainment.*

7.5.3.4

Concrete walls shall be placed in layers that are approximately horizontal. The rate of placing shall be such that each successive lift can be vibrated into the previous lift for proper bonding but the total depth of plastic concrete shall never exceed that limited by the formwork design (see Clause 6.5.2.1).

Note: *See also ACI 347.*

7.5.3.5

Concrete in place shall not be subjected to injurious vibration or impact.

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7.5.3.6

The depositing of concrete shall be a continuous operation until the placing of the section is completed. However, when placing concrete in a deep beam, wall, or column that is intended to be continuous and monolithic with the slab above, a delay of up to 2 h shall be scheduled before placing the upper slab or soffit concrete to allow for settlement of the lower concrete (see Clause 7.5.3.8).

7.5.3.7

Removable spreaders or separators in walls or deep sections shall not be removed until the concrete has reached their level. Suitable indicators and tools shall be provided for their removal and recovery.

7.5.3.8

Where concrete is to be placed in two or more stages and where a monolithic structure is required, the upper portion shall be placed as soon as the lower portion has stiffened sufficiently. The concrete in the lower portion shall be designed so as to minimize bleeding. Any free water or laitance shall be removed before the next layer of concrete is placed.

7.5.3.9

When concrete is placed by pumping, grout, mortar or chemical lubricant used to lubricate pipelines shall not be discharged into the forms. Washout or wash-down water shall not be discharged into the concrete pump.

7.5.3.10

Slab on grade concrete floors shall be placed such that the average overall slab thickness is no more than 10 mm less than specified, nor more than 20 mm less than the specified thickness in any location.

Notes:

1) *See Clause 6.4.2.2.1 for slab thickness tolerances.*
2) *Granular base and finished floor elevations should be carefully reviewed prior to ordering concrete for a placement.*
3) *The slab thickness may be checked with a thickness probe during concrete placement.*

7.5.3.11

The surface tolerance of a compacted granular base shall have a maximum variation of ±10 mm at the time of concrete placement.

Notes:

1) *Attention should be paid to the selection of a granular base material that will minimize the overall friction coefficient and the variation in the granular base elevation. The use of a finely graded compactable finish course can reduce both the friction coefficient and the variation in the granular base elevation. Sand has proven to be unsatisfactory for this purpose.*
2) *The verification of granular base surface elevations should be done to ensure that variations in granular base and concrete thickness do not affect future performance of the slab.*
3) *Granular bases which are constructed by hand, of clear stone, or are sloped, can produce larger variations in elevation than ±10 mm. Owners should carefully consider that larger variations in granular base elevations will reduce the slab thickness beyond the limits of Clause 6.4.2.2.1 and can necessitate an increase in floor thickness in order to maintain the desired performance.*

7.5.3.12

It shall be the responsibility of the concrete purchaser to verify that the approved concrete mix is delivered and placed.

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7.5.3.13

The top surface of slabs on grade shall be within ± 20 mm of the specified elevation.

7.5.4 Consolidation

7.5.4.1 General

Concrete, when being placed, shall be compacted thoroughly and uniformly by means of hand-tamping tools, vibrators, or finishing machines or through the use of self-consolidating concrete to obtain a dense, homogeneous structure, free of cold joints, voids, and honeycombing. Formed surfaces shall be smooth and free from large air and water pockets. The concrete shall be in full contact with all reinforcement, hardware anchors, waterstops, and other embedded parts to ensure good bond.

7.5.4.2 Vibration

Internal vibrators shall be used wherever practicable for consolidating the concrete, taking into account the size and spacing of reinforcement in the form. Internal vibrators may be supplemented by external form vibrators or vibrating screeds. Vibrators shall be capable of consolidating the concrete with a minimum duration of vibration. A sufficient number of vibrators shall be provided to compact the concrete properly at the rate that it is being placed. Vibrators shall be applied systematically and at such spacing intervals that the zones of influence overlap and the vibrator penetrates the upper part of the previously placed lift of the concrete by its own mass and vibration. The vibrator shall be inserted into the concrete on a plane as nearly vertical as possible and shall be withdrawn slowly in a vertical direction to facilitate the removal of entrapped air bubbles. The vibrator shall be applied, at any one position, until the concrete is consolidated, but not to the extent that segregation of the concrete will occur.

Notes:

1) *See ACI 309R for further guidance.*
2) *Internal vibration can significantly affect entrained air void systems in concrete.*
3) *Superplasticized flowing concrete mixes can have a tendency to segregate easily and take less energy to consolidate.*

7.5.5 Concreting underwater

The following shall apply for concreting underwater:

a) Placing concrete underwater shall be accomplished by the proper use of a tremie pipe or of a concrete pump with its discharge line used as a tremie pipe.
b) Precautions shall be taken to prevent the loss of the cementitious material paste by the washing action of the water. The use of anti-washout admixtures may be used for this purpose, provided that they do not adversely affect the overall quality, durability, workability, placeability, and pumpability of the concrete, mortar, or grout mixture.
c) Concrete shall not be placed in water having a temperature below 5 °C except when the strength gain of the concrete is sufficient, as determined by special test specimens cured under identical conditions as the structure.
d) The water through which the concrete is deposited shall be as still as possible, with the velocity of the current not exceeding 3 m/min. The velocity may be exceeded if it can be shown that an anti-washout admixture will protect against mortar or paste loss.
e) The maximum washout shall not exceed 8% cumulative mass loss, as measured in accordance with the US Army Corps of Engineers Specification CRD-C 61.
f) Efforts should be made to minimize the disturbance of water, or sediment creation, by pumping or

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other operations. To minimize the formation of laitance, care shall be exercised not to unduly disturb the concrete while it is being placed.

Notes:

1) *Concrete should contain sufficient cementitious material to produce a very workable mix, with a water-to-cementitious materials ratio not exceeding 0.45.*
2) *Concrete containing an anti-washout admixture should provide the following benefits, compared to untreated concrete of similar mixture proportions:*
   a) *at least a 50% reduction in cumulative mass loss when tested in accordance with US Army Corps of Engineers Specification CRD-C 61; and*
   b) *an initial setting time within 90 min of the reference mixture.*
3) *Anti-washout admixtures affect the rheological properties of concrete.*
4) *For further reference, see Langley and Leaman (1996).*

7.5.6 Concrete placed by tremie

The following shall apply for concrete placed by tremie:

a) The tremie pipe shall be capable of being raised vertically and shall be positioned on 6 m maximum centres.
b) Concrete shall be deposited in all pipes so that the upper surface of the submerged concrete will rise evenly.
c) The tremie pipe shall have a diameter at least eight times the maximum size of aggregate.
d) The specified concrete slump shall be 190 ± 40 mm as measured by the slump test in CSA A23.2-5C.
e) The tremie pipe shall be watertight and sufficiently large to allow a free flow of concrete. It shall be kept filled with concrete at all times while depositing. If the charge is lost while depositing, the tremie pipe shall be withdrawn and refilled.
f) A watertight tremie pipe shall be maintained by keeping the discharge end buried at least 0.3 m in the previously placed concrete.
g) The tremie pipe shall be raised as the level of the concrete rises.
h) If the tremie operation is interrupted below the water level to the extent that the placed concrete has stiffened to a degree that the resumption of tremie operation is not possible, the surface laitance shall be cut by jetting and removed by pumping or airlifting before tremie placing is restarted.

Note: *It is difficult to remove concrete laitance under water and it is easier to do so when the concrete has sufficiently hardened but has not yet reached a significant strength.*

7.5.7 Concreting tubular piles and drilled shafts

For the concreting of piles and drilled shafts, the methods described in Clause 7.5.5 shall apply when water is present at the bottom. When no water is present at the bottom of a vertical pile or shaft (see Note 2), concrete may be placed with a free-fall placement method, provided that the concrete is directed through the centre of the reinforcing cage or shaft hole, using a centering chute or other suitable device, to prevent concrete from hitting the earth shaft wall or the reinforcing cage. The top section of the pile that contains reinforcing bars shall be vibrated to fully consolidate the concrete around the bars.

A tremie pipe or other suitable device shall be used to place concrete into a battered or inclined drilled pile shaft to prevent damage to, or displacement of, the rebar cage and to prevent concrete from hitting the earth shaft wall to cause sloughing.

Notes:

1) *A test program described in Baker and STS Consultants Ltd. (1994), has demonstrated that the free-fall placement method can be performed to test depths of up to 35 m in a 1 m diameter shaft, without significant loss of strength and without significant segregation of the concrete aggregate.*

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2) *Up to 50 mm of water at the bottom of the excavation is usually considered acceptable for placing concrete using a free-fall placement method. See ACI 336.3 for additional information.*
3) *See ACI 336.1 for additional information.*

7.6 Protection of plastic concrete

7.6.1 General

Freshly placed concrete shall be protected against adverse conditions such as high wind, precipitation, freezing, high and low temperatures, low humidity, and large temperature differentials, until curing can be commenced. All materials and equipment needed for adequate protection shall be on hand and ready for use before each concrete placement is started. One or more of the following measures shall be taken to preserve the surface plasticity of the concrete:

a) delaying a concrete placement until the ambient conditions improve;
b) lowering the concrete temperature;
c) modifying the concrete mix to permit improved surface bleeding;
d) adding an accelerator in cold weather conditions;
e) applying fine mist water fog spray or a liquid evaporation-reducing surface film immediately after placement and between finishing operations;
f) beginning curing immediately after final finishing;
g) placing and finishing at night or early in the morning; and
h) reducing exposure of the fresh concrete to wind.

Notes:

1) *The requirement for plastic protection for any concrete mix depends upon a variety of factors including the bleed rate of the concrete and the ambient conditions. The need for plastic protection should be identified and discussed at the preconstruction meeting and pre-placement meetings.*
2) *Severe drying conditions are known to cause surface drying and plastic shrinkage cracking. Plastic shrinkage cracking is normally caused by loss of moisture from the surface of the concrete due to rapid drying conditions or low bleeding concrete mixes, or both, or at any time when the rate of evaporation from the surface exceeds the rate of bleeding of the concrete.*
3) *Where more detailed information is unavailable, severe drying conditions should be considered to exist when the rate of surface moisture evaporation exceeds 0.50 kg/m²/h. The rate of evaporation of water can be estimated from Figure D.1, using measurements of air temperature, relative humidity, concrete temperature, and wind velocity 0.8 to 1.2 m above the surface of the concrete.*
4) *For structural concretes with slow strength-gain characteristics at early ages, high-performance concrete, or other structural concretes requiring special curing conditions, the owner should specify such conditions in the contract documents.*
5) *Particular care should be exercised to prevent damage and cracking caused by surface drying, from the time of strike-off to the commencement of final curing. Evidence of premature drying can be seen when the surface sheen of water disappears from over the entire surface or in localized areas of the newly placed concrete. Wind and humidity levels can significantly affect the potential for, and magnitude of, shrinkage.*
6) *Spray-on mono-molecular materials can control evaporation. In some cases, these films need to be reapplied when conditions are present in which the film evaporates prior to completion of finishing operations. These films will also evaporate after exposure to drying conditions and should be monitored. Numerous re-applications of these films might be required before final curing conditions can be implemented. These films are not meant as a finishing aid or to be worked into the surface.*
7) *Fog spraying can be a continuous process that requires diligent attention to the balance between drying caused by the environmental conditions and the wetting provided by the spraying process. This is frequently a full-time operation in which one or more spray applicators are required from initial strikeoff until the final curing methods can be applied. A fog spray can be produced with a 15 to 20 MPa pressure washer in combination with an atomizing-type nozzle.*
8) *Rapid or excessive moisture loss from the surface of plastic concrete in excess of the rate of moisture replenishment by bleed water rise to the surface can contribute to surface defects, such as plastic shrinkage*

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cracking, poor finishability, crazing, mortar flaking, and delaminations. Severe drying conditions can be manifested during placing and finishing of concrete flatwork surfaces by characteristics such as rapid loss of surface sheen, crusting, increased tearing of the surface during floating. The rate of bleed water rise and setting time of the concrete mixture will determine the severity of the drying condition. The amount of bleed water available to the surface can be decreased by factors such as fine graded sand, the type and amount of fine cementitious materials and admixtures. The time of set can be increased by factors such as low ambient temperature, increased level of cement replacement by pozzolanic supplementary cementitious materials, and/or retarding admixtures.

9) *Micro synthetic fibres might help concrete surfaces resist plastic shrinkage cracking.*
10) *For further information on shrinkage of concrete, see RILEM Shrinkage 2000.*
11) *See ACI 305R for more information.*

7.6.2 Initial curing for high-strength and high-performance concrete

The exposed surface of high-strength and high-performance concrete shall be provided with water by means of a fog spray or other means immediately after initial finishing to reduce the potential for autogenous and plastic shrinkage cracking.

Note: *See Annex I for further guidance.*

7.6.3 Mass concrete

7.6.3.1 General

Concrete placements having dimensions large enough (typically having a minimum dimension equal or greater than 1 m) to require measures be taken to minimize cracking resulting from the generation of heat from hydration of cement and attendant volume change shall be considered mass concrete unless otherwise specified or approved by the owner.

Notes:

1) *See Annex T on mass concrete for further guidance and considerations to define mass placements.*
2) *Some non-structural concrete applications that meet the typical dimensions of mass concrete might not require thermal control measures to be taken to minimize risk of thermal cracking.*
3) *Some structural concrete applications that do not meet the typical dimensions of mass concrete might require thermal control measures to be taken to minimize the risk of thermal cracking.*

7.6.3.2 Temperature requirements for mass concrete

7.6.3.2.1 General

The temperature requirements for mass concrete placements shall comply with Clauses 7.6.3.2.2 to 7.6.3.2.5 unless otherwise specified or approved by the owner.

7.6.3.2.2 Adiabatic temperature rise

The predicted adiabatic temperature rise of concrete mixes for mass placements shall be reported in the concrete mix design submittal. The method to calculate adiabatic temperature rise shall be identified and reviewed by the concrete producer and contractor.

Notes:

1) *Adiabatic temperature rise of mass concrete can be determined by using tests and analytical methods. Refer to information in Annex T for guidance.*
2) *Refer to Clause 6 of CSA A23.2-24C for further information regarding mix design submittals.*

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7.6.3.2.3 Maximum placing concrete temperature

In the absence of a thermal control plan, the maximum placing concrete temperature for mass concrete placements shall comply with Table 14 for permissible concrete temperatures at placing.

Note: *Lowering the placing concrete temperature is beneficial to reduce temperature rise of mass concrete that can lead to high concrete temperatures and large temperature differentials.*

7.6.3.2.4 Maximum concrete temperature

The maximum concrete temperature in mass placements shall not be greater than

a) 70 °C for non-HVSCM concrete;
b) 75 °C for HVSCM-2 concrete; and
c) 85 °C for HVSCM-1 concrete.

Note: *The maximum concrete temperature is mainly influenced by the temperature rise of concrete and fresh concrete placing temperature at time of placement. Information and references in Annex T are provided for guidance into the considerations to the applicable maximum concrete temperature for different conditions and concrete properties.*

7.6.3.2.5 Maximum concrete temperature difference

7.6.3.2.5.1

The maximum concrete temperature difference in mass placement shall not be greater than 20 °C, specified as a fixed limit, except where higher temperature difference limits are permitted as provided for in Clauses 7.6.3.2.5.2 to 7.6.3.2.5.4.

Note: *The maximum temperature difference in mass concrete can be specified in different ways based on the concrete properties and placement attributes. Refer to Annex T for further information and guidance.*

7.6.3.2.5.2

A maximum concrete temperature difference fixed limit shall be specified not to exceed 25 °C when the coefficient of thermal expansion of the concrete is less than 10 millionths/°C, except as provided for in Clause 7.6.3.2.5.4.

7.6.3.2.5.3

An incremental maximum temperature difference limit shall be specified not to exceed 25 °C, except as provided for in Clause 7.6.3.2.5.4.

Note: *Refer to Clause T.4.3.3 for information on incremental temperature difference limits.*

7.6.3.2.5.4

A performance based approach based on numerical analysis and modeling with a project specific testing program shall be specified when a maximum concrete temperature difference limit higher than 25 °C is permitted.

7.6.3.3 Temperature monitoring

The concrete and ambient temperatures shall be monitored during the thermal control period to determine compliance with temperature requirements in Clause 7.6.3.2. The specific locations for temperature monitoring shall be identified in the thermal control plan. The maximum concrete temperature shall be measured at the interior core of the mass placement where the highest concrete temperature is expected. The temperature differentials between the core and concrete near the surface shall be monitored. The concrete temperature near the surface shall be monitored at a minimum of one

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representative location between 25 and 75 mm of the concrete surface. Any additional monitoring locations shall be identified in the thermal control plan.

Notes:

1) *The maximum temperature at the interior core of the concrete might not be located in the geometrical centre of the mass placement. The concrete temperature near the surface would be typically measured by installing a temperature measuring device tied to a reinforcing bar near the surface.*
2) *Monitoring temperature of concrete at or near the surface of a corner or an edge of a mass placement might be necessary for cold weather protection, but it is not a requirement to meet thermal control of mass concrete.*

7.6.3.4 Thermal control plan

The contractor shall submit to the owner for approval a thermal control plan to demonstrate that the requirements for controlling and monitoring temperature will be achieved during the thermal control period, including the following information unless otherwise specified or approved by the owner:

a) dimensions of mass placements;
b) specified temperature limits;
c) concrete mix design submittal;
d) methodology used for thermal analysis and/or modelling;
e) properties of the concrete;
f) predicted adiabatic temperature rise of the concrete;
g) concrete placing temperature considerations;
h) calculated maximum concrete temperature;
i) calculated maximum concrete temperature difference;
j) ambient temperature and weather considerations;
k) insulation and curing recommendations;
l) temperature monitoring devices and locations;
m) requirements to avoid thermal shock (24 h concrete surface temperature drop);
n) criteria to terminate thermal control;
o) recommendations to meet temperature limits;
p) results from thermal analysis and/or modelling;
q) possible corrective measures;
r) relevant technical guidelines or references; and
s) any other information or details such as pre-cooling or active cooling with embedded pipes that might be required to ensure proper implementation of thermal control measures to meet specifications, construction demands, placement attributes, and technical requirements.

7.7 Finishing of concrete floor surfaces

7.7.1 Surface tolerances

7.7.1.1

Slab or floor finish tolerances shall be measured using the F-Number system and the classifications of Table 21 as specified by the owner.

Notes:

1) *See ACI 117 and ACI 302.1R for further information.*
2) *When the tolerance for a particular use is not specified in Table 21, an existing surface that is satisfactory should be surveyed. The limits determined by this survey may then be used to determine the limit for the proposed surface tolerances after considering the negative effect of curling due to drying shrinkage.*

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3) *The flooring contractor should be provided with copies of the tolerance test results prior to continuing with concrete placements to avoid any compounding of defects.*
4) *Small slab on grade floor areas less than 150 m² may alternatively comply with a 90% compliance to a 12 mm conventional gap under a freestanding 3 m straightedge in accordance with ACI 117.*

7.7.1.2

Slab or floor tolerance measurements shall be made a maximum of 72 h after completion of each floor placement.

Notes:

1) *Tolerance measurements taken after this time period may include significant changes resulting from drying shrinkage curling of the concrete (see Clause 6.4.2.2.2).*
2) *Tolerance measurements taken after this time are not be used for acceptance or rejection, but may be used for information purposes only.*

7.7.1.3

Levelness tolerances shall not apply to cambered, inclined surfaces or suspended slabs.

7.7.1.4

Floor flatness (F_F) and floor levelness (F_L) shall be measured in accordance with ASTM E1155M. Surfaces shall be considered to comply with F-number tolerances if the overall combined values of the entire floor installation are greater than or equal to the overall F-number specified in Table 21, with no area less than 60% of the specified overall value. (Minimum F_F:F_L values shall not be less than F_F 15:F_L10).

7.7.2 Correction of floor flatness deficiencies

Correction shall be made by grinding, unless otherwise specified by the owner. The repaired floor area shall be retested for conformance to the specified tolerance upon completion of grinding.

Note: *The effects of grinding on the appearance and abrasion resistance of an exposed floor surface should be considered prior to proceeding with grinding.*

7.7.3 Initial finishing of horizontal surfaces

7.7.3.1 General

The initial finishing operations of floors shall consist of screeding, immediately followed by bull floating or darbying as necessary to consolidate and level the concrete to the specified levelness tolerance.

Notes:

1) *Other methods of initial finishing may be used for special applications, including concrete deck or pavement finishing machines.*
2) *See ACI* Concrete Flatwork Finisher Certification Program for further information.
3) *See ACI 302.1R for further information.*

7.7.3.2 Screeding

7.7.3.2.1

Screeding shall entail striking off the surface of the concrete to the specified lines and grades, using a properly designed screed or straightedge . This operation is done immediately after the placing and consolidation of the concrete.

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7.7.3.2.2

For sloping floor surfaces where the free drainage of water is desired, a nominal slope of 2% shall be constructed from the high point of the floor to the low point at the drain.

Notes:

1) *Where the granular base is sloped to maintain the specified slab thickness, it is possible that variations in granular base elevations beyond those in Clause 7.5.3.11 might necessitate an increase in the specified slab thickness.*
2) *The coordination of drain elevations and highpoints requires careful planning and inspection. Using conventional wet-screeding methods, a slope of less than 1.5% will generally result in the formation of low points or bird-baths along the drainage slope.*
3) *See CSA S413 for perimeter slope requirements for parking garage floors.*

7.7.3.2.3

If a vibrating screed or straightedge is used, it shall be moved forward in a continuous manner as the proper consolidation of the concrete occurs.

Note: *Prolonged use of a vibrating screed or straightedge can result in a surplus of mortar at the surface.*

7.7.3.3 Bull floating or darbying

The concrete shall be worked with a bull float or darby to remove high spots and ridges, and to fill voids left in the surface after screeding. This operation should only slightly embed the coarse aggregate below the concrete surface.

Note: *If a concrete surface of the required smoothness and texture has been obtained by screeding, then bull floating or darbying might not be necessary.*

7.7.3.4 Completion

Initial finishing shall be completed before any bleeding or free water is present on the surface of the concrete.

Note: *Finishing with bleed water on the surface reduces the surface strength and is a common cause of scaling, delamination, and dusting.*

7.7.4 Final finishing

7.7.4.1 General

7.7.4.1.1

Edging followed by floating and trowelling shall be the final finishing operations.

Note: *Some or all of these finishing operations might not be required depending upon the desired final finish.*

7.7.4.1.2

Final finishing shall commence after the bleed water has disappeared and when the concrete has stiffened sufficiently to prevent the working of excess mortar to the surface. No additional water shall be used to facilitate the finishing. No concrete finishing operations shall be performed where standing water is present.

Note: *After the disappearance of bleed water, a highway straightedge may be used as the concrete sets to increase the surface flatness by cutting high points and filling low spots in the concrete surface. A highway straightedge is a long handled tool attached to a rectangular straightedge that cuts the surface of the plastic concrete to improve surface flatness.*

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7.7.4.1.3

The initial forming of grooves for contraction joints shall be completed prior to the initial set of the concrete.

Note: *See Clause 7.3.2.1, Note 3.*

7.7.4.1.4

Cement shall not be used to dry up excess bleed water on the concrete surface.

Note: *A garden hose may be dragged slowly across the surface of the concrete to remove excess bleed or rain water. To reduce excessive bleeding, the water content may be reduced by using plasticizing admixture or adjusting concrete mixture proportions.*

7.7.4.2 Floating

The purpose of floating is to further consolidate the surface paste, and prepare the surface for trowelling.

Notes:

1) *Under normal conditions, the time lapse between initial and final finishing is 3 to 4 h, but it could be up to 24 h in cold weather conditions.*
2) *Floating operations should commence when a footprint indents the surface approximately 6 mm. The selection of the type and timing of floating operations requires great care as it is not possible to determine whether concrete mix bleed water has fully left the top of a concrete based upon the depth of a footprint.*
3) *Surface moisture evaporation can exceed the rate of bleeding with low bleeding concrete mixes, adverse ambient conditions and high concrete temperatures. This causes the surface to appear to be dry enough for final finishing before bleed water has stopped rising. A sealed surface can trap bleed water and result in delaminations.*
4) *Care should be taken in the development of a concrete mix design for concrete floors to promote normal setting times and continuous surface plasticity without increasing the water content of the concrete. Concrete mixtures for floors placed in cold weather conditions should be designed to reduce the possibility of bleed water entrapment through the use of reduced unit water contents, plasticizing admixtures and accelerators. The timing of initial floating operations should include consideration of delays in set caused by cold weather conditions.*

7.7.4.3 Trowelling

7.7.4.3.1 Interior or non-air-entrained concrete

Multiple passes of a hand or machine trowel shall be made at suitable time intervals to obtain the desired finish.

Notes:

1) *The main purpose of additional trowelling is to increase compaction of fines at the surface, giving it greater density and wear resistance.*
2) *Concrete is generally ready for trowelling when it has hardened to the point that a footprint barely marks the surface.*
3) *After final finishing, curing should commence as soon as practicable, in accordance with Clause 7.8.*
4) *Trowel finishing of concrete having a total air content in excess of 3% may result in blistering and delaminations.*

7.7.4.3.2 Exterior or air-entrained concrete

One or more passes of a hand or machine float or concrete broom shall be made at suitable time intervals to obtain a non-slip finish. A steel trowel finish shall not be applied to air-entrained concrete.

Notes:

1) *After final finishing, curing should commence as soon as practicable, in accordance with Clause 7.8.*

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2) *Special care should be taken when applying dry-shake surface hardeners to air-entrained concrete to avoid surface scaling.*
3) *Surface delaminations can occur if a machine trowel finish is applied to air-entrained concrete.*
4) *Densifying the surface of air entrained concrete by machine trowelling has been shown to significantly reduce the freeze-thaw durability of the surface.*

7.7.5 Abrasion and wear resistance

The owner shall specify the concrete properties, finishing procedures, surface treatments, and a curing method and period appropriate to the intended use of the surface.

Notes:

1) *The most important factors affecting the abrasion resistance of concrete surfaces are the hardness of the surface aggregates, surface compressive strength, water-to-cementitious materials ratio, quality and duration of curing, and the type of final finish. Combinations of these should be carefully considered for the intended usage of each floor surface.*
2) *See Annex F for further information on abrasion resistance.*
3) *Special extra-hard mineral or metallic aggregate significantly increases resistance to abrasion. Refer to the manufacturer's instructions for more information.*
4) *For further details and information, see ACI 302.1R.*

7.7.6 Nonslip surfaces

A nonslip surface finish shall be obtained by one of the following techniques, as specified by the owner:

a) a broom finish;
b) a stamped or imprinted finish;
c) swirl or spin trowel;
d) brooming after trowelling;
e) an exposed aggregate finish obtain through surface retardation and or the controlled removal of the surface paste with water;
f) cutting grooves in the hardened concrete;
g) machine float finish;
h) hand float finish; or
i) any other methods approved by the owner.

Notes:

1) *The owner may specify a mock up sample to determine the final finish when desired.*
2) *Care should be taken in choosing a sealer for nonslip surfaces. When non slip surfaces are intended to receive an application of a film-building sealer, the application should be carefully applied to prevent excessive accumulation that reduces the nonslip characteristics. Nonslip abrasives may be incorporated into the sealer to improve slip resistance of the sealed surface.*

7.7.7 Scratch finish

A scratch finish shall involve texturing the partially set concrete surface with a stiff wire, bristle brush, or a broom following initial finishing. This shall produce closely spaced grooves approximately 3 to 5 mm in depth.

Note: *The scratch finish is generally intended to receive a bonded topping. Other methods of achieving the specified texture in the base course may be used if approved by the owner.*

7.7.8 Grinding

Grinding to achieve an aggregate exposure finish shall proceed only when the concrete has hardened sufficiently to prevent dislodgement of the coarse aggregate particles.

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7.7.9 Moisture condition of concrete floors

Where moisture-sensitive finishes are to be applied to a concrete floor surface, the moisture condition of the concrete shall be verified prior to its application in accordance with the applied finish materials manufacturer's instructions. The moisture condition of the concrete shall be determined in accordance with ASTM F2170. The surface moisture condition shall be determined in accordance with ASTM F2659. The moisture vapour emission rate shall be determined in accordance with ASTM F1869.

Notes:

1) *Test areas should generally be at service temperatures for at least 48 h prior to testing the concrete.*
2) *Using in situ probes, the moisture condition of the concrete can usually be determined in 1 to 4 h.*
3) *Depending on the ambient conditions, the calcium chloride emission rate and plastic sheet test method (ASTM D4263), can produce incorrect results.*
4) *There is no correlation between relative humidity testing and calcium chloride vapour emission test results.*
5) *The moisture condition of slabs on grade can be affected by the water/cement ratio, the lack of a vapour retarder and moisture transmission from the underlying soils (see Clause 6.2.5). This can lead to the delamination of non-breathing floor covering systems (including the potential of entrapped microbial growth).*
6) *The drying time for applied finishes may be reduced by the methods listed in Clause 7.1.2.3.*
7) *See also ASTM F710.*

7.8 Curing

7.8.1 General

Curing requirements for the classes of exposure covered by this Standard are given in Tables 2 and 19. Curing shall begin immediately following the placing and finishing operations and shall provide the temperature and moisture conditions for the period of time necessary for concrete to develop its strength, durability, and other properties. All materials and equipment needed for adequate protection and curing shall be on hand and ready for use before each concrete placement is started. The concrete temperature shall be maintained at no less than 10 °C throughout the curing period in accordance with Table 19.

Notes:

1) *See ACI 308R for further information.*
2) *In-place concrete strength can be assessed by testing field-cured cylinders or by using nondestructive testing methods as covered in Clause 4.4.2.2.4.*
3) *Concrete continues to gain strength under moist conditions and favourable temperature conditions. Following the cessation of moist curing, the development of strength continues for a short time provided that temperature conditions are favourable. Some strength development will also be reactivated if moist curing is resumed after interruption.*
4) *At the end of the curing period for Curing Types 2 and 3, a period of at least one month of air drying should elapse before the application of de-icing chemicals to the concrete surface.*
5) *For guidance on additional curing of high-performance concrete, see Annex I.*
6) *Concrete strength gain is significantly retarded at temperatures below 5 °C. Site cured specimens should be employed for strength testing where early slab loading is anticipated.*
7) *An improvement from Type 1 "basic" to Type 2 "additional" or Type 3 "extended wet" curing will improve the hydration of the cementitious material and the hardened performance of the concrete surface.*

7.8.2 Methods and materials

7.8.2.1 Methods

Curing of concrete surfaces shall commence as soon as the concrete has hardened sufficiently to prevent surface damage. Curing of concrete surfaces shall be achieved using one or more of the following methods in accordance with Table 19 (wet curing methods shall be used for curing Type 3):

a) curing compounds;

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b) ponding or continuous sprinkling with water;
c) applying water and covering with polyethylene sheets (lapped and lying flat on the floor);
d) applying water and covering with absorptive burlap fabric;
e) forms in contact with concrete surface; or
f) other moisture-retaining methods as approved by the owner.

Notes:

1) *See Tables 2 and 19 for required curing regimes.*
2) *Water used for curing should be clean and free of deleterious substances.*
3) *Wet curing should be used on floor areas scheduled to receive applied finishes (see Clause 7.1.2.3) and penetrating liquid treatments.*
4) *Liquid densifying silicate hardeners are not recommended curing regimes as they do not supply or retain moisture for cement hydration.*

7.8.2.2 Materials

Materials for curing concrete shall meet the requirements of one of the following standards:

a) AASHTO M 182;
b) ASTM C171; or
c) ASTM C309.

Water used for curing shall not have a deleterious effect on the concrete.

Notes:

1) *Curing compounds should not be used where a bond is required for additional concrete (e.g., concrete topping) or surface coating (e.g., liquid hardeners), unless*
   a) *the curing compounds are entirely removed at the end of the curing period by sandblasting or by using an approved solvent;*
   b) *conclusive tests show that the residue of the membrane does not reduce bond below design limits; or*
   c) *suitable mechanical means for full bond development are provided.*
2) *For curing of architectural concrete, see Clause 8.3.*
3) *Where penetrating sealers are to be used, a curing compound should not be used as the curing method.*

7.8.3 Curing for special requirements

7.8.3.1 Extended curing for structural safety

The basic curing period defined in Clause 7.8.1 shall be extended until the concrete has achieved sufficient strength for structural safety. The compressive strength level required for structural safety shall be specified by the owner.

7.8.3.2 Curing for accelerated strength development

7.8.3.2.1 Reduced curing period

When it is desired to reduce the curing period by developing the required level of strength within a shorter period, the permission of the owner shall be obtained.

Notes:

1) *Acceleration of strength development may be obtained by the use of accelerating admixtures, CSA Type HE cement, CSA Type HEb cement, higher curing temperatures, or additional cement.*
2) *The detrimental effects of accelerated strength gain, such as higher temperature stresses, increased drying shrinkage, potentially significantly decreased ultimate strength, and potential delayed ettringite formation (DEF), should be taken into consideration by the owner.*

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7.8.3.2.2 Using elevated temperature

For curing at elevated temperatures, application and control of heat shall conform to the requirements for accelerated curing in CSA A23.4.

7.8.3.3 Curing in extreme temperatures

7.8.3.3.1 Hot-weather curing

When the air temperature is at or above 27 °C, curing during the basic curing period shall be accomplished by water spray or by using saturated absorptive fabric unless specified otherwise.

Notes:

1) *Alternatively, curing compounds may be used in some hot-weather applications, when approved by the owner, and where used should be applied in accordance with the manufacturer's recommendations.*
2) *See also ACI 305R for more information.*
3) *Measures should be taken to avoid evaporative cooling since temperature differentials can contribute to thermal cracking (e.g., mass concrete).*

7.8.3.3.2 Cold-weather curing

During freezing weather, water curing of concrete shall be terminated 12 h before the end of the protection period. In freezing temperatures, all curing water shall be removed from the surface at the end of the curing period.

7.9 Bonded toppings

7.9.1 Types

Two types of bonded toppings are covered, as follows:

a) monolithic toppings, constructed by applying a concrete mixture after the base course has lost all slump and bleed water and prior to final set; and
b) deferred toppings, constructed by applying a topping course to a hardened concrete base course to which a bonding agent has been applied.

Notes:

1) *The procedure for bonded toppings may also be applied to repairing surface defects in concrete slabs, provided that concrete patch area shoulders are square cut and that the bonding material is applied to vertical and horizontal surfaces.*
2) *Proprietary pre-packaged topping materials should be installed in accordance with the manufacturer's instructions.*
3) *Bonded toppings have been successfully installed up to 75 mm thick. Owners are cautioned that thicker toppings can delaminate due to drying shrinkage of the concrete.*
4) *Unbonded toppings should be a minimum of 100 mm thick.*
5) *For interface shear transfer, see Clause 11.5 of CSA A23.3.*

7.9.2 Special concrete mixtures for toppings

7.9.2.1 General

Concrete materials and proportions for bonded toppings shall be carefully selected to have reduced drying shrinkage and meet the owner's requirements for tolerance or wear, or both.

Notes:

1) *Special concrete mixtures for toppings may contain plain or coloured nonslip mineral aggregate or metallic aggregates, colorants, and/or proprietary products requiring special techniques to be specified by the owner.*

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2) *Concrete mixes for bonded toppings should be designed for reduced drying shrinkage using a combination of water reduction, plasticizing, and shrinkage reducing admixtures.*

7.9.2.2 Nominal maximum size of coarse aggregate

The nominal size of the coarse aggregates should be as follows:

a) 10 to 14 mm for a topping thickness not exceeding 60 mm; and
b) 20 mm for a topping thickness greater than 60 mm.

Note: *The choice of coarse aggregate size can also be dependent upon the methods of construction and the desired final finish.*

7.9.3 Monolithic toppings

7.9.3.1 Placing monolithic toppings

The topping mixture shall be placed before the base course has completely set. Any free water shall be removed from the base course concrete prior to placing the topping and shall be finished in accordance with Clause 7.7 or as otherwise specified by the owner.

7.9.3.2 Preparation of base course surface

The base course surface condition shall be sound and free of loose particles. The choice of preparation is related to the type of bonding agent to be used. All laitance, dirt, dust, debris, grease, or other substances that would interfere with the bond between the base course concrete and the topping shall be removed using one or an appropriate combination of the following methods:

a) wet or dry grit sandblasting;
b) high-pressure waterblasting;
c) mechanical removal by scarifiers, scabblers, shotblasting, or grinding wheels; or
d) vacuuming.

Notes:

1) *Proper preparation of the surface is one of the most important factors in achieving a good bond.*
2) *Acid etching should not be used to prepare concrete surfaces for bonded toppings due to concerns that acid residue might not be fully neutralized.*
3) *The specific requirements for surface preparation will depend on the selection of the bonding agent to be used.*
4) *If water applied to a cleaned surface beads or does not absorb into the surface, it is an indication that the bonding of a fresh topping will be inhibited.*
5) *Surface profiles may be specified from the ICRI surface profile classifications noted in No. 310.2R.*

7.9.4 Bonding systems

7.9.4.1 Inspection of base course concrete

Before ordering a concrete topping placement, the base slab shall be inspected to ensure that it has been prepared in accordance with the bonding agent manufacturer's instructions.

7.9.4.2 Procedures

The topping concrete shall be bonded to the base course concrete using one of the following procedures, as specified by the owner:

a) Cement slurry: Cement slurry should only be used on rough textured prepared concrete surfaces having a surface texture in accordance with the materials manufacturer's instructions. The surface of the base slab shall be kept wet for approximately 24 h, prior to placement of the topping. Excess standing water shall be removed from the base slab to obtain a surface saturated-damp or dry

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condition. A cement slurry shall be mixed to a thick flowable consistency and scrubbed into the surface of the hardened concrete with stiff brooms immediately prior to the topping placement. The maximum water-to-cement ratio of the slurry shall be 0.5. The topping shall be placed before the cement slurry dries.

b) Latex modified slurry: Cement latex slurry may be used only on roughened concrete surfaces. A latex additive shall be added to the cement slurry in the method specified in Item a). The required surface texture and proportions of cement and latex shall be in accordance with the latex manufacturer's instructions.

Note: *Polyvinyl-acetate should not be used as it can re-emulsify in wet environments.*

c) Epoxy: Epoxy bonding agents may be used on rough or smooth concrete surfaces having a prepared surface in accordance with the materials manufacturer's instructions.
The base slab surface preparation, mixing and application of the epoxy bonding agent and the timing of concrete placement shall be in accordance with the epoxy manufacturer's instructions.

Notes:

1) *Additional information can be found in ACI 503R.*
2) *The success of an epoxy bonding system depends on placing the topping concrete when the epoxy bonding agent has cured to the proper stage; otherwise, adequate bonding might not be achieved.*
3) *Some precast concrete toppings might not require the use of a bonding agent if the precast surface is rake finished and has been prewet for 24 h, and the concrete mix has a water-to-cementitious materials ratio of approximately 0.45.*
4) *Epoxy bonding agents generally provide the best bond to existing interior concrete but they must be prepared and applied in accordance with the bonding agent manufacturer's instructions. Epoxy bonding agents should not be used for exterior use in freeze/thaw environments.*

7.9.5 Bonding fresh concrete to rock

Surfaces shall be thoroughly cleaned of all foreign material prior to depositing fresh concrete. Cleaning may include air or water jets, sandblasting, or stiff brooming. Where roughening of the rock is specified, the surface shall be roughened to a full amplitude of at least 5 mm. The first layer of concrete to be placed on the cleaned surface shall be of the quality specified, and it shall be proportioned to have an excess of mortar, and be well-vibrated to achieve maximum bond. Alternatively, where approved by the owner, a cement grout may be scrubbed onto the cleaned surface immediately before the concreting [see Clause 7.9.4.2 a)].

7.9.6 Tensile bond

The bonding procedure for bonded toppings shall provide a minimum tensile bond strength between topping and base course concrete of 0.9 MPa at 28 d when tested in accordance with CSA A23.2-6B, unless otherwise specified by the owner.

7.9.7 Testing frequency

A tensile load test shall be performed at a frequency of not less than one test per 200 m^2 of floor area.

7.9.8 Finishing bonded toppings

Bonded toppings shall be finished in accordance with Clause 7.7 in accordance with the materials manufacturer's instructions.

Notes:

1) *Pan floating can be problematic for thin bonded toppings.*
2) *Contraction joints should not be used in bonded toppings as these can lead to localized topping delaminations.*
3) *To reduce reflective cracking, contraction joints may be installed over existing base slab joints.*

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7.9.9 Curing

Toppings shall be continuously wet cured, in accordance with Type 3 of Table 19, for a period of 7 d or longer in accordance with the bonding agent manufacturer's instructions.

Notes:

1) *Curing requirements are critical for bonded toppings in order to minimize the likelihood of debonding.*
2) *Great care should be taken to protect bonded toppings from injurious damage caused by vibration, vehicular traffic, or other mechanical impact until the bond has achieved sufficient strength.*

7.10 Finishing of formed surfaces

7.10.1 General

7.10.1.1

For the purpose of this Standard, a formed surface shall mean a concrete surface that has been confined within formwork.

7.10.1.2

Finish requirements for formed concrete surfaces shall be specified by the owner or shall be as specified in Clause 7.10.2.

7.10.1.3

Architectural finishes requiring special materials and procedures, other than those covered by Clause 7.10 shall be in accordance with Clause 8.3.

7.10.1.4

Finishing of formed surfaces shall commence as soon as practicable after stripping the forms.

7.10.1.5

Plastering or parging with a cement paste as a general repair treatment shall not be allowed.

7.10.1.6

Areas that have been repaired shall be cured in accordance with the requirements of Clause 7.8.

7.10.2 Formed surface finishes

7.10.2.1 General

Clause 7.10.2 defines the finishes to be used in concrete construction. See Clause 8.3 for architectural finishes.

Notes:

1) *For further information on finishing of formed surfaces, see ACI 301 and ACI 309.2R.*
2) *For information on consolidation-related defects, see ACI 309.2R.*
3) *The ASCC* Guide for Surface Finish of Formed Concrete *gives a pictorial rating to numerous classes of concrete finish and identifies the finish according to the size and prevalence of voids and imperfections that are visible on the exposed concrete surface. The voids are a function of placing, vibration, form materials and jointing, mix design, and form release agents.*

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7.10.2.2 Reference installation

Prior to tendering, the specifier shall nominate an existing finish or installation that is locally available for inspection to both the specifier and the constructor. This shall be for the purposes of assessing, before awarding the contract, the level of surface blemishes that is acceptable.

7.10.2.3 Reference sample

When specified by the owner, a site reference panel shall be cast. It shall be cast in the same orientation and with the same formwork material and reinforcing that will be used on the project. It shall use the same concrete mix and method of consolidation that will be used for the project. The reference sample shall be viewed from a distance of 3 m. Once a reference sample is accepted, it shall remain on-site for purposes of comparison in assessing compliance with the finish type for the project.

Note: *To most effectively demonstrate the panel jointing systems for the project, the size of the samples should be at least 1.5 lifts in height and 2 formwork panels in width.*

7.10.2.4 Surface defects

Surface defects in formed concrete can be described as honeycombing, sand streaking, lift lines, variations in colour, soft areas, and large surface voids. Surface voids less than 12 mm in diameter, commonly described as bug holes or blowholes, shall not to be considered as surface defects. Surface voids and colour variations shall not be patched unless they are beyond the level of the reference sample or unless there is a special requirement in the specification that all surface voids be filled or patched.

Notes:

1) *For further information, see Reading (1972) and ACI 309.2R.*
2) *For classes C-XL, A-XL, C-1, A-1, and A-2, bug holes should be filled to avoid reducing the effective depth of cover.*

7.10.2.5 Rough-form finish

No specific form facing materials shall be required for rough-form finish surfaces. Tie holes and defects beyond the acceptable level, as identified in the reference sample, shall be patched as specified in Clause 7.10.3. Fins exceeding 5 mm in height shall be chipped off or rubbed off. Otherwise, surfaces shall be left with the texture imparted by the forms. Unless otherwise specified in contract documents, rough-form finish shall be used for all concrete surfaces not exposed to public view.

7.10.2.6 Smooth-form finish

The form facing material shall produce a smooth, hard, uniform texture on the concrete. This material shall be plywood, tempered concrete-form-grade hardboard, metal, plastic, paper, or other material capable of producing a smooth finish. It shall be supported by studs or other backing capable of preventing excessive deflection. Material with raised grain, torn surfaces, worn edges, patches, dents, or other defects that will impair the texture of the concrete surface shall not be used. Tie holes and defects beyond the acceptable level, as identified in the reference sample, shall be patched. All fins shall be completely removed. Unless otherwise specified in the contract documents, smooth-form finish shall be used for all surfaces exposed to public view.

7.10.3 Patching

7.10.3.1

All form ties and other metal items shall be removed or cut back to a depth of at least 15 mm from the surface of the concrete (see Clause 6.6.7.6.1).

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7.10.3.2

Tie holes, cutout areas, and cavities shall have their edges as nearly perpendicular to the surface as possible and shall be sufficiently deep to hold the patching mortar.

7.10.3.3

All cutout areas and cavities shall be saturated with water and repaired after scrubbing the surfaces to be patched with neat cement paste and filling with a mortar using the same sand and cement as that used in the concrete.

Note: *On exposed formed surfaces, it might be necessary to blend white cement with the job cement in order to obtain a finish colour that matches the surrounding concrete surfaces. Trial batches of mortar should be made prior to application on the job surfaces to determine the correct mix proportions to be used. A mix of 1 part cement to 1-1/2 parts sand is normally satisfactory.*

7.10.3.4

The mortar shall be well pressed or packed into the depressions so as to fill the cavities completely and then finished to match the texture of the adjacent surface.

7.10.3.5

Honeycomb areas discovered after removal of the forms shall not be repaired until inspected by the owner. Where honeycombing has occurred in nonstructural elements, the affected area shall be cut out and filled with mortar in accordance with Clauses 7.10.3.1 to 7.10.3.4. Where honeycombing has occurred in structural elements, the corrective method of treatment shall be carried out as directed by the owner.

7.10.4 Rubbed finishes

7.10.4.1 General

The type of rubbed finish and those surfaces requiring a rubbed finish shall be designated in the contract documents. A rubbed finish is obtained by using an abrasive to remove surface irregularities from concrete. Where a rubbed finish is required, forms shall be removed and any necessary patching completed as soon after placement as possible without damage to the structure.

7.10.4.2 Smooth-rubbed finish

Smooth-rubbed finishes shall be produced on newly hardened concrete surfaces. Surfaces shall be thoroughly wetted and rubbed with carborundum brick or another abrasive until uniform colour and texture are produced. No finishing mortar shall be used other than that produced from the concrete by the rubbing process.

7.10.4.3 Sand-rubbed finish

Sand-rubbed finishes shall be produced on newly hardened concrete surfaces. Surfaces shall be thoroughly wetted and rubbed with a wood float in a circular motion, with fine sand rubbed into the surface until the resulting finish is even and uniform in colour and texture.

7.10.4.4 Sack-rubbed finish

The following shall apply for sack-rubbed finish:

a) The sack-rubbed finish shall be undertaken as soon as the surfaces are accessible.
b) The concrete surfaces shall be thoroughly saturated with water and maintained wet for at least 1 h before finishing operations are begun.

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c) All free water on the surface shall be removed prior to the application of the finishing mortar.
d) The mortar shall consist of one part (by volume) of cement to two parts (by volume) of clean sand passing a 630 µm sieve and enough water so that the mixed mortar shall have a consistency of thick paint.
e) The mortar shall be preshrunk by mixing at least 1 h before it is used and then remixing without the addition of water prior to its use.
f) The sand and cement shall be the same materials as those used in the concrete.
g) The mortar shall be rubbed thoroughly over sections of the prepared concrete surfaces with clean burlap pads or other suitable materials so that all surface voids are filled.
h) While the application mortar is still plastic, the surfaces shall be rubbed with the sack pads, using a mixture of mortar of the same proportions as previously specified, except that no mixing water shall be used.
i) The final rubbing shall be performed in such a manner that the filled voids are left flush with the surface of the surrounding concrete.
j) The finished surface shall be cured continuously in accordance with Clause 7.8.
k) The manufacturer's instructions shall be followed for all prepackaged sack-rubbing materials. Other sack-rubbing procedures may be used if approved by the owner.

Note: *See Note to Clause 7.10.3.3.*

8 Concrete with special performance or material requirements

8.1 General

8.1.1 Application

Clause 8 covers the production and use of concrete with special performance characteristics or material requirements.

Note: *Proposals for new technology will be considered for inclusion in future editions of this Standard, provided that they specifically cover the performance criteria superseding conventional concrete technology and include the following:*

a) *identification of acceptable test methods for evaluation; and*
b) *substantive data in support of the proposal.*

8.1.2 Purpose

The purpose of Clause 8 is to assemble past practices of this Standard that meet the criteria for concrete with special performance and to allow advancements in concrete technology to be standardized for use in Canada.

8.1.3 Criteria

When specified, special performance or material requirements shall supersede other relevant clauses of this Standard. Selection of mix materials, proportions, concrete quality, production of concrete, placing, and/or curing shall be addressed in each relevant clause, where appropriate.

8.1.4 Relevant clauses

Relevant clauses shall identify the pertinent requirements that require attention by all parties involved in the construction or rehabilitation of the structure. Each clause shall stipulate the methods used to evaluate the performance of the concrete or concrete materials.

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8.1.5 Performance evaluation

The owner shall be responsible for stipulating the methods to be used to evaluate the performance of the concrete and the acceptance criteria.

Note: *See Table 5.*

8.1.6 Materials

Materials for use in each concrete shall be selected on the basis of the performance criteria stipulated. Minimum requirements shall be in accordance with this Standard and the reference standards listed in Clause 2.

8.1.7 Mix proportions

Unless adequate data on prior use are available from the concrete supplier, the determination of mix proportions for concrete defined in Clause 8 should be based on laboratory and field trials with the project materials and should be undertaken by the owner prior to construction.

8.1.8 Placing and curing

Methods used to place and cure concrete shall be identified by the contractor and shall be subject to the approval of the owner.

8.2 High-performance concrete and ultra-high performance concrete

For guidance on high-performance concrete, see Annex I. For guidance on ultra-high-performance concrete, see Annex U.

8.3 Architectural concrete

8.3.1 General

8.3.1.1

Contract documents shall identify the standards and details required for architectural concrete. Procedures for cast-in-place architectural concrete shall be developed prior to actual construction. The procedures shall be based upon sample projects and a realistic assessment of form construction, placement of reinforcement, the concrete mix and its placing, and the possible subsequent treatment of the surface.

Note: *Information and recommendations, including assessment of weathering for the construction of cast-in-place architectural concrete, can be found in ACI 303R. See also ACI 309.2R and the ASCC* Guide for Surface Finish of Formed Concrete.

8.3.1.2

Material requirements for architectural cast-in-place concrete shall conform to the material requirements for architectural concrete in CSA A23.4.

8.3.1.3

Selection of mix proportions, concrete quality, production of concrete, and placement methods shall conform to the requirements for these items in CSA A23.4.

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8.3.1.4

Where self-consolidating concrete (SCC) is used for architectural concrete, the concrete shall meet the requirements of Clause 8.6.

Note: *The use of SCC can ease placement and can improve the surface appearance of the concrete.*

8.3.2 Reference samples

The owner shall provide a reference sample for bidding purposes. The sample shall be at least 1 m² and cast in an orientation similar to that of the proposed concrete on the project. The surface texture, quality and type of finish, and other features of the sample shall be similar to those proposed for the actual project.

Note: *The sample should not establish a "one-of-a-kind excellence" standard but should be representative of what is achievable.*

8.3.3 Mock-up field samples

8.3.3.1

A preconstruction mock-up field sample shall be made for each finish or shall incorporate all finishes by the contractor, using equipment, materials, and procedures planned for the actual construction. The owner shall examine the mock-up field samples and compare them with the reference samples prepared in accordance with Clause 8.3.2 for approval prior to ordering formwork. The panels should be full-size to match the actual work as closely as possible. Additional samples shall be cast by the contractor to the satisfaction of the owner to achieve the required matching.

The sample(s) shall serve as the standard for acceptance of the finished construction.

8.3.3.2

Physical irregularities, such as bug holes, shall be characterized by size and frequency with respect to a referenced standard mock-up.

Note: *See ACI 309.2R and the ASCC* Guide for Surface Finish of Formed Concrete*.*

8.3.3.3

Any changes in the source of materials, mix proportions, or construction procedures shall require new mock-up samples and approval review, as specified in Clause 8.3.3.1.

8.3.3.4

The field sample shall include a repaired area, with the repair mixes and procedures developed to ensure matching of colours and textures to the base concrete of the mock-up sample. Examples of repairs to surface voids, bleed lines, honeycombing, and form tie holes shall be included.

8.3.4 Formwork for special architectural finishes

8.3.4.1

Formwork shall meet the requirements of moulds for precast architectural concrete (see CSA A23.4). The design procedures for the formwork shall follow the requirements of CSA S269.1. Specific attention shall be paid to the requirements for deflection, freedom from defects in the form-facing material that will reflect into the finished surface, sealing of the vertical joints, and methods of tightening formwork at horizontal joints to prevent leakage.

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Deflection of facing materials between studs, as well as deflection of studs and wales, shall be limited to 0.0025 times the span or as otherwise specified by the owner.

Notes:

1) *Some formwork plywoods are affected by the high alkalinity of concrete. Special formwork finishes that resist these high pH levels are required in some cases to reduce or eliminate the effects of the alkalis diffusing into the base wood plies and reacting with the wood resins.*
2) *Since the appearance of architectural concrete mirrors the shape, details, and conditions of the forms, the materials and construction of these forms should be of the appropriate quality.*

8.3.4.2

Location of joints in formwork for architectural concrete surfaces shall be clearly designated by the owner. The owner may request a submission of the formwork design and detailed drawings for review.

8.3.4.3

Form ties for architectural cast-in-place concrete shall be specified by the owner with respect to the type of ties, their location, and their final treatment, including possible treatment of recesses. Form ties shall be of a non-corroding material. The use and type of spacers shall also be specified. Spacers shall be of non-corroding materials that will not mar the finished surface.

8.3.4.4

Forms shall be designed to permit easy removal. Workers shall not pry against the finished surface or otherwise mark the surface.

8.3.4.5

Forms shall not be reused if there is any evidence of surface wear and tear or defects that would impair the quality of the surface. Forms shall be thoroughly cleaned and properly coated before reuse.

8.3.5 Placing of architectural cast-in-place concrete

8.3.5.1

Architectural concrete mixes shall not be contaminated with other mixes during mixing and conveying.

8.3.5.2

Uniform mixing and placing schedules shall be maintained to facilitate uniformity of appearance and to avoid cold joints.

8.3.5.3

Architectural concrete shall be placed in a way similar to the placement of the approved mock-up field sample, and placing methods shall not be changed without constructing a new field sample for approval.

8.3.5.4

Architectural concrete shall be deposited in approximately horizontal layers to avoid any lateral movement from vibration, which might cause segregation. The thickness of the layers will depend on the configuration of the form and the amount of reinforcement, but shall normally not exceed 300 mm. When insertion vibrators are used, the insertion pattern shall be organized to provide uniform

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consolidation and a controlled time of insertion. Vibrators shall not touch the formwork surface. These restrictions shall not apply to self-consolidating concrete.

Note: *Disruption of a fluid and laminar hose stream into a turbulent flow in most cases increases the likelihood of surface imperfections or bug holes. In some cases, it is necessary to consider using elephant trunks or self-consolidating concretes to obtain the desired as-cast finish characteristics.*

8.3.5.5

When an architectural concrete mix is placed as a face mix with a standard backup mix, care shall be taken to ensure proper vibration without any penetration of the backup mix into the face mix. The thickness of the face mix shall be not less than 50 mm or twice the maximum size of the coarse aggregate in the face mix, whichever is larger. If the face mix is contained by a close wire mesh or movable dividing plates, the backup mix shall be placed prior to the initial set of the face mix.

8.3.5.6

Form vibration shall not be used unless the forms have been designed to withstand the additional stresses (see Clause 6.5).

8.3.6 Special finishes

8.3.6.1

Where finishes are obtained directly from the form without any further treatment, attention shall be paid to the choice and application of release agents and efforts shall be made to control variations in the concrete mix, placing, and curing in order to minimize colour and texture variations.

Note: *See CSA A23.4.*

8.3.6.2

Where finishes are obtained by special processes following removal of formwork, such finishing shall be performed with due respect to safety hazards to workers and the general public.

Notes:

1) *If a sandblasted finish is required in populated areas, it will in some cases have to be done by wet sandblasting.*
2) *Specific finishes and recommended practices are described in ACI 303R.*
3) *Some finishing processes might lead to an increased risk of scaling if the finished surface is exposed to freezing and thawing in the presence of deicing salts in a saturated condition. See Hover (2006) and Suprenant (1999).*

8.4 Pervious concrete

Pervious concrete is typically an open-graded, no-slump, concrete consisting essentially of coarse aggregate particles bound together by a binder consisting of a paste of cementitious material, water, and admixtures (sand may be used in small quantities). Pervious concrete is designed specifically to be free draining, typically having a void content ranging from 15 to 30%. Pervious concrete pavement is intended to be used in lightly-trafficked roads or parking areas. See Annex N for additional requirements for pervious concrete.

Notes:

1) *Pervious concrete is predominantly used in pavement or flatwork applications.*
2) *For more information on pervious concrete, see ACI 522R and ACI 522.1.*

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8.5 High-strength concrete

8.5.1 General

High-strength concrete is defined as concrete having a specified compressive strength of at least 70 MPa at a specified age not exceeding 91 d. The requirements of Clause 8.5 for high-strength concrete shall supersede those in relevant clauses elsewhere in this Standard.

8.5.2 Aggregate

The concrete supplier shall demonstrate, by appropriate tests and test results, that the aggregates chosen have the potential to meet the design strength requirements.

8.5.3 Mixing

The efficiency of the mixer and the uniformity of mixing shall be demonstrated to the satisfaction of the owner.

Note: *High-efficiency central mix plants are preferred. If truck mixing is used, mixing trials should be made to determine the batching sequence and load that produces a uniform mixture.*

8.5.4 Trial mixes

Laboratory trial mixes, followed by full-size trial batches, shall be made to demonstrate that the materials, mix formula, and production techniques chosen will produce concrete meeting the requirements for strength and other properties. If recent and adequate test data exist, the owner may waive the requirement of this Clause.

8.5.5 Temperature

The maximum concrete temperature at delivery shall be specified when the owner requires a delivery temperature lower than the values given in Table 14. The maximum temperature reached during hydration shall be limited to 70 °C for non-HVSCM concrete, 75 °C for HVSCM-2 concrete, and 85 °C for HVSCM-1 concrete.

Notes:

1) *Delivery temperatures of 20 °C or less can be obtained through the use of ice as mixing water or by cooling the concrete with liquid nitrogen.*
2) *The lower delivery temperature may be required by the owner where the structure contains concrete sections that would be classified as mass concrete.*
3) *The quality and strength, and hence the durability and service life, of high-strength concrete is highly dependent on the quality of the matrix. High temperatures and large temperature gradients tend to degrade the quality because of rapid hydration and microcracking.*
4) *If maximum temperatures and temperature gradients exceed certain limits, macro- and microcracking can occur, with deleterious effects on durability and strength. Based on recent experience on projects in Canada, an absolute maximum of 25 °C at the time of delivery is permissible, with 20 °C preferred.*

8.5.6 Consolidation

The concrete shall be vibrated to achieve full consolidation. Excessive vibration shall not be applied.

Note: *The strength of high-strength concrete can be reduced significantly if the voids content increases by only a few percentage points.*

8.5.7 Curing and protection

Curing and protection shall be specified by the owner, taking into account the configuration and

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accessibility of the structural components. Where used in slabs or floors, the concrete shall be fog cured as soon as the surface has been struck off.

Note: *Some structural elements, such as columns, can be difficult to water cure. Horizontal surfaces need fog curing to avoid plastic shrinkage cracking.*

8.5.8 Strength testing

8.5.8.1 General

High strength concrete shall be tested in accordance with Clause 4.3.5 and the additional requirements specified in Clauses 8.5.8.2 to 8.5.8.4.

8.5.8.2 Test moulds

Test moulds shall be of heavy-duty steel or plastic. Plastic moulds shall have a wall thickness of at least 6 mm.

Note: *Care should be taken to ensure that the test specimens are kept round and that loss of moisture is prevented.*

8.5.8.3 Initial site curing of test specimens

Test specimens shall be cured in water or in a fog room at 15 °C to 25 °C from the time casting and finishing are completed to the time that they are transported to the laboratory in accordance with Clause 9 of CSA A23.2-3C.

8.5.8.4 Testing machines

8.5.8.4.1 Capacity

The testing machine shall not be loaded to more than 80% of its rated maximum capacity.

8.5.8.4.2 Stability

The testing machine shall have a frame rigidity that meets the following requirements when compressive loads applied to the specimens are in excess of 750 kN:

a) a lateral frame stiffness of 18×10^6 N/m; and
b) a longitudinal frame stiffness of 18×10^8 N/m.

Note: *A procedure for checking testing machines is given in BSI BS EN 12390.*

8.6 Self-consolidating concrete

8.6.1 General

Self-consolidating concrete (SCC) is a highly flowable yet stable concrete that can readily spread into place, fill the formwork, and encapsulate the reinforcement, if present, without any mechanical consolidation and without undergoing any significant separation of material constituents. In many countries, it is also called self-compacting concrete. SCC can facilitate placement of concrete, especially in heavily reinforced structures, in architectural concrete, and in structures where proper consolidation by vibration is difficult.

Note: *For more information on SCC, see ACI 237R, RILEM Report 23, EFNARC 2005, and Norsk Betongforenig Publication No. 29.*

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8.6.2 Materials

The constituent materials used for the production of SCC shall comply with the requirements of Clause 4.2, except that the gradation requirements of Clause 4.2.3 in some cases do not apply.

Notes:

1) *The maximum nominal size of the aggregates depends on the particular application and is usually limited to 20 mm.*
2) *High-range water reducers (superplasticizers) are an essential component of SCC to provide the necessary fluidity.*
3) *Viscosity-modifying admixtures (VMAs) are often used to increase the segregation resistance of SCC mixes.*
4) *Finely ground mineral fillers may be used, as specified in Annex L, to enhance flowability and stability of fresh SCC mixtures. Mineral fillers containing calcium or magnesium carbonate should not be used in the production of concrete exposed to S1, S2, or S3 exposure classes.*

8.6.3 Performance requirements for SCC

8.6.3.1 Workability requirements

8.6.3.1.1

The workability of SCC is very different from that of normal concrete and can be characterized by the following properties:

a) filling ability (flowability);
b) passing ability; and
c) segregation resistance (stability).

8.6.3.1.2

Table 22 lists the various test methods for evaluating the workability characteristics of SCC. For the purposes of qualification of the mix design, the passing ability, filling ability, and segregation resistance shall be evaluated using the appropriate tests from Table 22. Site quality control shall utilize a slump flow test (see CSA A23.2-19C) to measure flowability, viscosity, and visual stability, in addition to any other tests specified by the owner.

Note: *The following test methods may also be considered:*

a) *PCI TR-6;*
b) *EFNARC (2005 and 2002); and*
c) *JSCE* Recommendation for Construction of Self-Compacting Concrete.

8.6.3.2 Other performance requirements

SCC shall be designed to fulfill the following requirements, as required by the owner:

a) Clause 4.1.1, for durability;
b) Clause 4.3.3 for air-void system;
c) Clause 4.3.4, for density; and
d) Clause 4.3.5 for strength.

8.6.4 Mixture proportions

8.6.4.1

The mixture proportions of SCC shall be established to achieve the performance described in Clause 8.6.3.

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Material characteristics, placement conditions, the arrangement and density of the reinforcement, and the intricacy of the formwork, as well as required engineering properties, shall be taken into consideration in the mix design process.

8.6.4.2

For the initial mix design of SCC, all three workability parameters (filling ability, passing ability, and segregation resistance) shall be assessed to ensure that all aspects are fulfilled. At the request of the owner, a full-scale test shall be used to verify the self-consolidating characteristics of the chosen design for a particular application.

Note: *This requirement may be waived if there is sufficient experience and documentation for a particular mix.*

8.6.5 Delivery and placing

Delivery and placing shall be completed while workability characteristics of the SCC still meet the criteria specified in Table 22 or specified by the owner.

Immersion vibrators shall not be used to consolidate SCC.

Notes:

1) *Unexpected interruption in concrete delivery and placement can lead to variations in surface appearance and adversely affect the properties of hardened concrete.*
2) *Contractors might wish to consider possible advantages of pumping from the bottom of formwork. If concrete is placed by bucket skip, attention should be paid to the tightness of the gate to prevent leakage.*
3) *The vertical free fall distance should be less than 1.5 m and the distance of horizontal flow from point of discharge should be less than 10 m in order to minimize the risk of segregation. These limits can be increased when concrete performance is confirmed by field trial.*

8.6.6 Finishing

The finishing operations shall be in accordance with Clauses 7.7.3 and 7.7.4.

Notes:

1) *In some cases, repeated steel-trowelling can cause difficulties during the final finishing of horizontal areas of concrete. Alternative procedures or different tools may be used.*
2) *Special designs of SCC can be used as self-levelling concrete with zero or minimum screeding, bull floating, and finishing. This type of finish will not be suitable when the surface is subjected to heavy abrasion.*
3) *For walls over 5 m high, there should be a 20 min delay prior to final finishing.*

8.6.7 Formwork

The formwork shall be in accordance with Clause 6.5.3.1.

Note: *The formwork should be designed and constructed to withstand full hydrostatic pressure unless it is demonstrated that lower pressures are acceptable.*

8.6.8 Curing

Curing shall be in accordance with Clause 7.8.

8.7 Concrete made with high-volume supplementary cementitious materials

8.7.1 Proportion of SCM

High-volume supplementary cementitious materials (HVSCM) concrete contains a level of SCM above that typically used for normal construction. Annex K contains additional information on HVSCM concretes. For the purposes of this Standard, two categories of HVSCM, 1 and 2, are defined, as follows:

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HVSCM-1:
$FA/40 + S/50 \geq 1.00$

HVSCM-2:
$FA/30 + S/40 \geq 1.00$
where
FA = fly ash (Types F, CI, or CH) content of the concrete (% mass of total cementitious materials)
S = slag content of the concrete (% mass of total cementitious materials)

A concrete that meets the definitions for HVSCM-1 and HVSCM-2 shall be deemed to be HVSCM-1 concrete.

Note: *For the naming practice for supplementary cementitious materials and blended supplementary cementitious materials, see CSA A3001.*

8.7.2 Materials

Supplementary cementitious materials used in HVSCM shall meet the requirements of CSA A3001.

8.7.3 Trial mixes

Laboratory trial mixes, followed by full-size batch tests, shall be made to demonstrate that the materials, mix formula, and production techniques chosen will produce concrete meeting the requirements for the job. The following properties, as applicable to the work, shall be evaluated in the trial:

a) workability;
b) air content;
c) finishability;
d) setting time;
e) temperature development;
f) hardened air-void parameters;
g) strength; and
h) durability.

If recent and adequate test data exist, the owner may waive the requirement of this Clause.

Note: *If materials or placing conditions change significantly, further trials might be necessary.*

8.7.4 Curing requirements

8.7.4.1 General

The curing and protection requirements of Table 2 shall be implemented for HVSCM-1 and HVSCM-2 concrete. Measures shall be taken to protect the freshly placed concrete from surface moisture evaporation until the commencement of curing.

Note: *Methods of protecting concrete from evaporation of surface moisture are covered in Clause 7.6. The use of fog spraying or evaporation retardants is particularly effective.*

8.7.4.2 Curing plan

The contractor shall submit to the owner for approval a plan for protection and curing of the HVSCM concrete, including

a) the method for protecting the concrete from evaporation of surface moisture from the fresh concrete;
b) the type of curing material to be used;

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c) the manner in which the surface will be kept moist and the quality control requirements for keeping the surface moist;
d) the time of initiation and duration of curing;
e) provisions to address potential problems, such as high winds and hot and cold weather; and
f) the limitations of access, if any, to the surfaces being cured.

8.8 Low-shrinkage concrete

8.8.1 General

Low-shrinkage concrete is a type in which the use of special mixture proportions, materials, and/or shrinkage-reducing admixtures results in drying shrinkage less than that of normal concrete.

8.8.2 Qualification testing

Concrete shall be qualified by testing in accordance with CSA A23.2-21C, except that drying in air at 50% relative humidity shall commence after a total of 7 d of wet curing, and the initial comparator reading (zero-day reading) shall be taken at the end of the wet curing period immediately before the commencement of drying. Unless otherwise specified by the owner, the shrinkage after 28 d of drying (at the concrete age of 35 d) shall be not greater than 0.040% if prisms with a cross-section of 75 × 75 mm are used, or 0.035% if prisms with a cross section of 100 × 100 mm are used.

Notes:

1) *Typical shrinkage values for conventional concrete range from 0.035 to 0.070%.*
2) *Shrinkage reducing admixtures can affect the stability of the air void system of the concrete. Some adjustments might be required to compensate.*

8.8.3 Qualification of the mixture proportions

The concrete supplier shall, based on tests of trial mixtures, provide the owner with certification that the proposed mixture will meet the specified shrinkage limits. The certification shall be based on tests conducted within the previous 24 months.

The certification shall specify the maximum water-to-cementitious materials ratio for which the trial mixture is representative.

Any significant change in source of materials or specified mixture proportions shall necessitate a new certification.

Notes:

1) *Increases in the mixing water content by more than 5 kg/m³ or in the w/cm by more than 0.03 are likely to lead to significant increases in shrinkage.*
2) *Where shrinkage testing conducted on field-cast samples is used as a basis of acceptance, concrete should be considered acceptable if the average value of tests conducted is equal to or less than 0.040% with no individual value greater than 0.057% (for 100-mm cross-section concrete prism tests) and equal to or less than 0.050% with no individual value greater than 0.061% (for 75-mm cross-section concrete prism tests).*

8.9 No-slump concrete

8.9.1 General

No-slump concrete is similar to conventional concrete, except that it is proportioned for consolidation by heavy vibration or mechanical compaction, or both. The successful production and use of no-slump concrete requires appropriately proportioned concrete mixture, the presence of appropriate water content and adequate compaction of the in-place concrete. Appropriate mix proportions and the

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presence of appropriate water content significantly affect the compactibility of the concrete mixture and the quality of the in-place product.

8.9.2 Trial mixtures

Laboratory trial mixtures shall be made by the concrete supplier to demonstrate that the materials, mix formula, and production techniques chosen will produce concrete meeting the requirements for strength and other properties necessary for obtaining a good-quality final product (e.g., placeability and compactibility). Additionally, the trial mixes should also be carried out to enable the concrete supplier to determine the water content range in which the concrete will be compactible to within 2% of the design concrete density. If recent and adequate test data exist, the owner may waive the requirement of this Clause.

8.9.3 Concrete mix design

Based on the trial mixes, the concrete supplier shall propose an appropriate concrete mix design that will satisfy the project specification requirements and the requirements of the concrete placing contractor.

Additionally, the concrete supplier shall specify the design plastic concrete density (*Dd,* kg/m^3) and the design plastic concrete water content (*Md,* %). The concrete supplier and the concrete placing contractor shall agree together on the desirable range for field concrete water content in which the concrete will be compactible to within 2% of the design concrete density.

Note: *The plastic concrete water content, Md, should represent all water in concrete, including the water absorbed by aggregates.*

8.9.4 Field testing of no-slump concrete

Field testing of concrete shall consist of sampling concrete, determining water content, casting cylinders for compression testing, and determining the plastic density of concrete in accordance with CSA A23.2-12C.

8.9.5 Consolidation

The concrete placing contractor shall compact the concrete to achieve sufficient consolidation such that the density of the in-place concrete will be within 2% of the mix design density.

Note: *The owner may obtain samples of the in-place concrete to verify that the concrete density is within the prescribed range.*

8.9.6 Slump and air content tests

The slump and air content tests are not applicable to no-slump concrete.

8.9.7 Contractor co-operation

To facilitate concrete testing, the general contractor shall provide and maintain, for the sole use of the testing agency, adequately shaded and sheltered facilities for conducting water content tests on concrete and for casting concrete cylinders on a firm base. The facilities should also include a protected area for safe storage and proper curing of concrete test specimens for the initial curing period at the project site in accordance with the requirements of CSA A23.2-3C.

Note: *This can include provision of a continuous power supply.*

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8.9.8 Pre-construction meeting

A pre-construction meeting of all concerned should be held to discuss the requirements of all relevant CSA specifications and guidelines associated with the use of no-slump concrete.

8.10 Roller-compacted concrete

Roller-compacted concrete (RCC) is a zero-slump mixture of aggregate, cementitious materials, water, and admixtures that is compacted in place by vibratory rollers or plate compaction equipment. The mixture is placed and roller compacted with the same commonly available equipment used for asphalt pavement construction.

Notes:

1) *New high-density pavers are now capable of performing the placing and compaction operations, thereby eliminating the need for rolling, as well as providing a surface suitable for high speed traffic.*
2) *There are two types of RCC: one for dams and one for paved slabs on ground (grade). RCC for dams comprises of a multiple layered mass. The mix is formulated for low strengths attained at periods well in excess of the conventional 28 d. The nominal size of the large aggregates are normally much greater than 20 mm. This coarse mix is spread and placed with grading equipment, then rolled. RCC for paved slab on ground (grade) is higher strength with flexural strengths typically 6 MPa or more at 28 d. The material is finer grained and placed with conventional paving equipment.*
3) *The Cement Association of Canada has developed design and quality control manuals on RCC and can be consulted for additional information on RCC. Information on RCC can also be found in ACI 207.5R, ACI 327R, and ACI 309.5R.*

8.11 Controlled low-strength materials (CLSM)

8.11.1 General

CLSM is a construction material that consolidates under its own weight and is used in a variety of applications including backfill in lieu of compacted soil. When used as backfill, low strength is required to enable excavation in the future, if a need arises. CLSM is usually mixed at a concrete batching plant, transported to the site in a ready mix truck, or made on site in a mobile mixer. Clause 8.11.2 covers "unshrinkable fill", a type of CLSM used as backfill in Canada which has some properties that can distinguish it from other types of CLSM.

Note: *For a complete list of CLSM applications, see ACI 229R.*

8.11.2 Unshrinkable fill

8.11.2.1 General

Unshrinkable fill is a specialized flowable, non-settling material. The material shall be capable of flowing into the excavation so that it fills the entire space without voids being created beneath horizontal projections or in other locations within the excavation or utility, and without long-term subsidence or deformation (settlement). Compressive strength of the unshrinkable fill should be such that it can be easily removed later by normal excavation tools and equipment.

Notes:

1) *Unshrinkable fill should be treated from an engineering point of view as a soil in accordance with the* Canadian Foundation Engineering Manual*.*
2) *Unshrinkable fill is generally used in backfilling applications (e.g., utility trenches, road repair trenches, over excavation, bridge abutment).*

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8.11.2.2 Materials

8.11.2.2.1 Cementitious materials

All cementitious materials shall conform to CSA A3000. This includes Portland cement, Portland-limestone cement, blended hydraulic cement and supplementary cementitious materials.

Notes:

1) *Portland cement at a dosage of 25 kg/m³ has been used with success for unshrinkable fill.*
2) *Research with recycled concrete aggregate (RCA) has shown that some Type S granulated blast furnace slags can also be used without hydraulic cement.*

8.11.2.2.2 Aggregate

8.11.2.2.2.1 General

Coarse aggregate shall be crushed stone, crushed gravel, natural gravel, recycled concrete aggregates (RCA), or a combination thereof. The typical maximum nominal size is 20 mm; however, other sizes may be used. Fine aggregates shall be natural sand, crushed sand, recycled concrete aggregates, or a combination thereof. Coarse and fine aggregate shall meet the requirements in Table 24 or 25.

8.11.2.2.2.2 Use of recycled concrete aggregate

The producer shall ensure that the level of RCA used in the fill does not compromise the performance of the fill. Recycled aggregates shall satisfy environmental regulations.

Notes:

1) *The use of high levels of some types of recycled concrete aggregates was found to produce high contents of fines during mixing and transporting. This reduces the ability of the fill to consolidate and drain the mixing water during placement. The consequence of this is a delay in achieving the load carrying capacity of the fill during its early age.*
2) *Hydration of residual unhydrated cement particles in recycled concrete aggregate can increase compressive strength of unshrinkable fill at later ages.*

8.11.2.2.2.3 Grading

The grading of the combined aggregate shall be selected to produce unshrinkable fill that meets the performance requirements of the intended application and the requirements of this Standard.

Note: *Grading of combined aggregate (fine and coarse) using the maximum density curve (Fuller power equation) is one optimization method, see Annex Q.*

8.11.2.3 Performance requirements

8.11.2.3.1 Compressive strength

Maximum compressive strength shall be specified by the owner to ensure that the material can be excavated with standard excavation equipment without the use of concrete breakers. Typical values of maximum strength range from 0.3 to less than 1.0 MPa at an age of 28 d. Compressive strength shall be determined in accordance with CSA A23.2-3C on 150 mm diameter cylinders, except that the material shall be placed in one layer with no consolidation. Cardboard moulds may be used to facilitate demoulding. Initial and final curing shall be conducted in accordance with CSA A23.2-3C, except that initial curing shall be on a draining support and final curing shall be conducted without removing specimens from the mould. Test specimens shall be removed from the moulds just before the determination of compressive strength. Compressive strength shall be determined in accordance with

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CSA A23.2-9C, but the load shall be increased at a constant rate such that the cylinder will be failed between 20 and 80 s.

Note: *Where moisture can be rapidly lost to subgrade soils, perforated cylinders should be used.*

8.11.2.3.2 Consistency

Unshrinkable fill shall be of adequate flowability to allow it to flow under its own weight and be placed without vibration or other means of consolidation.

8.11.2.4 Transportation and discharge

When unshrinkable fill mixtures are transported to the jobsite in truck mixers, agitation is required during the transportation and waiting times to ensure the constituent materials remain in suspension. After a minimum of 3 min mixing at the truck's mixing speed, discharge shall be started. Agitation is not required when mobile mixers are used to place the unshrinkable fill since the material is immediately placed as it is mixed.

8.11.2.5 Placing

Unshrinkable fill shall be placed directly by chute from the delivery equipment. Since the material consolidates under its own weight, internal, or surface compaction is not required.

Note: *The ball-drop apparatus described in ASTM D6024/D6024M may be used to evaluate consolidation time; ball penetration should be less than 25 mm or the diameter of indentation less than 76 mm.*

8.12 Concrete made with alternative supplementary cementitious materials

8.12.1 General

Alternative supplementary cementitious materials (ASCM) are defined as inorganic constituents that show pozzolanic or hydraulic properties, or both, and contribute to the strength or other characteristics of concrete, but do not meet the definitions of supplementary cementitious materials in CSA A3001.

CSA A3004-E1 provides evaluation of ASCMs for use in concrete.

Note: *ASCMs may be natural, manufactured, or reprocessed materials. Such materials can include non-ferrous slags from pyro-metallurgical processes, steel slag, incinerator or co-combustion ashes, by-products from ferro-silicon alloy processes, finely-ground glass cullet, silica fume with SiO_2 content less than 75%, and other industrial by-products containing amorphous silica.*

8.12.2 Materials

ASCMs shall meet the requirements of CSA A3004-E1.

8.12.3 Use in concrete

ASCMs shall not be used in concrete without the consent of the owner.

8.13 Shotcrete

8.13.1 General

Shotcreting is the process of applying concrete at a high velocity onto a surface. Proper placement is the most important element in achieving good shotcreting results. Most defects that occur in shotcreting are due to poor placement techniques or inappropriate mixture design. Shotcreting success depends largely on the skill of the nozzleman. The nozzleman's goal is to achieve adequate compaction and good encasement of the reinforcement (if present) with no entrapped rebound or overspray. Dry-mix process

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shotcrete is a process in which most of the mixing water is added through a water ring at or close to the nozzle. Compressed air, added at the shotcrete delivery equipment (gun), is used to pneumatically convey the shotcrete mix through the hose to the nozzle where it is projected. Wet-mix process materials including water, any additives and fibers, if used, are already added at a batch plant. The shotcrete is delivered by ready mix truck. Compressed air is added at the nozzle at the end of the pump hose, to pneumatically project the shotcrete.

Note: *See ACI 506R for more information on shotcrete.*

8.13.2 Materials

The constituent materials used for the production of shotcrete shall comply with the requirements of Clause 4.2, except that the gradation requirements of Clause 4.2.3 in some cases do not apply.

Notes:

1) *The maximum nominal size of the aggregates depends on the particular application but should be limited to 14 mm.*
2) *High-range water reducers (super plasticizers) may be used in wet-mix shotcrete mixes to provide the necessary workability for pumping and shooting.*
3) *In ground support applications, or with some overhead work, shotcrete accelerators are often used to achieve very quick initial set to allow build thickness in a single pass, with both wet and dry process mixes.*
4) *Silica fume is often used to increase adhesion and cohesiveness of the mix. Silica fume should not be more than a 10% replacement of cement in a shotcrete mix.*
5) *Fibers may be used in shotcrete mixes. See ACI 506.1R for additional information.*
6) *Corrosion inhibitor, if used, should be added in the wet-mix shotcrete mixes or in the nozzle water in the dry-mix process.*

8.13.3 Performance requirements for shotcrete

8.13.3.1 General

Shotcrete shall meet the requirements of Clause 4.1.1 as modified in Clauses 8.13.3.2 to 8.13.3.5.

Notes:

1) *The freezing-and-thawing resistance of shotcrete, as it is for normal concrete, is strongly dependent on the w/cm and on the quality of the air voids system, especially the entrained-air-void content and spacing factor.*
2) *The workability of shotcrete is very different from that of normal concrete and can be characterized as follows:*
   a) *Wet-mix shotcrete: Slump killing is a process that uses a high initial air content mix to produce a higher slump for workability purposes. The air content and slump is reduced during the shotcreting process. Air content should be between 10 and 15% before introduction into the pump. The "temporary high initial air content" is an approach by which workability is achieved by the mean of high air content in a concrete prior to its introduction into the pump. Because larger bubbles are lost through the pumping process and upon impact onto the receiving surface, the resulting shotcrete has lower air content and a reduced slump, improving adhesion and build up thickness.*
   b) *Dry-mix shotcrete: The mix quality is highly dependent on water addition by the nozzleman, who is able to instantly change the water content of the mix. Too much water can cause the shotcrete to sag or fall out, as well as affecting the long term strength due to the excessive water. Too little water can cause dry sand lenses in the finished product, making the material weak and porous.*

8.13.3.2 Water content

Water content in wet-mix shotcrete should be determined in accordance with CSA A23.2-18C.

Note: *Water content of dry-mix shotcrete should be averaged for a specified period of time according to the amount of water used relative to the powder used.*

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8.13.3.3 Air entrainment and air-void parameters

When required for freeze-thaw resistance, the air content of hardened shotcrete shall be within a range of 3.0 to 7.0% (Dufour, *et al*., 2006). Air content and air-void parameter shall be determined on cores from test panels and pre-construction test panels. The air-void system for shotcrete subjected to freezing and thawing in moist or wet conditions shall meet the following requirements:

a) For wet-mix shotcrete the air voids system shall meet the requirements of Clause 4.3.3.3.
b) For dry-mix shotcrete the average of all tests shall have a spacing factor not exceeding 300 µm with no single test greater than 320 µm; and the air content shall be greater than or equal to 3.0%.

8.13.3.4 Density and absorption

Testing shall be done on cores from test panels in accordance with CSA A23.2-11C. The absorption after immersion shall be less than 8% after 28 d.

Note: *In fresh shotcrete compaction is normally checked by pressing on the applied material to feel for adequate compaction, but this takes experience to properly determine. A more measurable method of measuring compaction is by using a proctor penetrometer with a large diameter needle or a modified pocket soil penetrometer.*

8.13.3.5 Chloride ion penetrability

Where specified, chloride ion penetrability shall be determined by CSA A23.2-23C on cores cut from test panels or from the in-place shotcrete.

8.13.4 Mixture proportions

8.13.4.1 General

Mix design should be developed to

a) minimize rebound;
b) satisfy class of exposure;
c) develop a good air-void distribution;
d) develop a good compaction and adhesion to the support; and
e) minimize drying shrinkage.

Note: *See ACI 506R and ACI 506.1R for more information.*

8.13.4.2 Rebound

Rebound should be less than 12% for wet-mix and less than 20% for dry-mix.

Note: *Rebound is dependent on mix design, air pressure, but more importantly, the nozzleman's skill level. Rebound can be measured by placing a tarpaulin at the base of the wall or ceiling to be shot to collect the rebound, which is then weighed and divided by the weight of the product that was shot.*

8.13.4.3 Air content

In order to obtain the required air void system in the hardened shotcrete, trials should be conducted with the equipment, the nozzleman and the mix to be used on the job to determine the appropriate dosage of air entraining agent.

The air content of wet-mix shotcrete may be achieved by adding air-entraining agent in the ready mix truck. Ready mix air contents in combination with the "slump killing" shotcrete technique have been used to achieve good plastic air content and hardened air void parameters.

The air content of dry-mix shotcrete is controlled by the dosage of air entraining admixture in the dry

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mix. Air entraining agent may be added in a powder format to a dry-mix, or a liquid air entraining agent may be added to the nozzle water.

Notes:

1) *When shotcreting, the impact of the shotcrete on the substrate will significantly reduce the in-situ air content of the wet mix. A good starting point for determining the required air content of the fresh shotcrete is to ensure that at least two times the required air is in the mix as it exits the mixer, then re-test air content after impact with the substrate.*
2) *Plastic air content may be used as a first evaluation in accordance with CSA A23.2-4C.*
3) *For wet-mix shotcrete, it is common practice to sample and test the concrete coming out of the chute.*
4) *For dry-mix shotcrete, the presence of air-entraining admixture may be determined by shooting directly into the pot. Air contents above 4% have been found to provide a satisfactory air void system in the hardened shotcrete.*

8.13.4.4 Bond strength

Bond strength of the shotcrete to the receiving surface and between two layers of shotcrete should be determined in accordance with CSA A23.2-6B and should satisfy the requirement of Clause 7.9.6.

8.13.5 Delivery

8.13.5.1 Delivery of wet-mix shotcrete

Delivery of wet-mix shotcrete shall meet the requirements of Clause 5.

8.13.5.2 Delivery of dry-mix shotcrete

Delivery of dry shotcrete shall meet the requirements of Clause 5.2.2, with the exceptions of Clauses 5.2.2.2 and 5.2.2.6.

Note: *Dry shotcrete may be delivered by mobile trucks or bags that meet the requirements of CAN/CSA-ISO 9001.*

8.13.6 Placing

8.13.6.1 General

The success of a shotcrete application is a direct result of the combined skill and knowledge of the shotcrete crew. See ACI 506R for more in-depth information.

8.13.6.2 Nozzleman certification

The nozzleman shall comply with ACI C660 Shotcrete Nozzleman certification program (wet process or dry process) depending on the specific application.

8.13.6.3 Pre-construction test panels

Pre-construction test panels shall be shot to determine permeability, density, absorption and hardened air void parameters with the same equipment, mix and nozzleman as proposed for the actual work.

8.13.7 Consolidation considerations

For structural shotcrete applications, there shall be full encapsulation of the reinforcing steel. Full encapsulation of the reinforcing steel is dependent on the nozzleman, therefore visual examination of cores that are removed from the pre-construction test panels and production panels, and of the saw-cut beams, shall be used to determine adequate encapsulation of reinforcing steel in the work.

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8.13.8 Hardened shotcrete testing

8.13.8.1 General

Hardened shotcrete testing shall be conducted from cores or beams obtained from the test panels.

8.13.8.2 Test panels

The shape and size of a test panel should be 350 mm × 350 mm at the base with the sides tapering outward at 135°. Panel thickness should be a minimum of 125 mm. Shotcrete should be projected into the panel at an angle perpendicular to the base of the panel with the nozzle held at a distance of 1 to 2 m from the base of the panel. The test panel should be immediately covered with an absorptive mat and a plastic sheet to prevent evaporation of water. Any type of finishing of a shotcreted panel, other than RDP (round determinate panels), should not be used. At the worksite, test panels should be maintained at a temperature between 15 °C and 25 °C during the first 20 to 28 h. Test panels should be stored in moist conditions in accordance with CSA A23.2-3C until it is time to core the panels.

Note: *A test panel may be produced each work day or every 40 m³, whichever is more frequent.*

8.13.8.3 Compressive strength

Compressive strength testing shall be done on cores taken from test panels, obtained at an age between 3 to 5 d from the time of shooting, and shall be stored in a moist room in accordance with CSA A23.2-3C. Cores shall be between 75 and 100 mm nominal diameter with a ratio of length to diameter (L/D) ranging between 1.0 and 1.1 (because of the reduced L/D ratio, a correction factor should be applied to the test value in accordance with CSA A23.2-14C). For compressive strength determination a minimum of two cores shall be tested for each curing period. The compressive strength shall be the average of two cores at the same age and measured in accordance with CSA A23.2-9C.

8.13.8.4 Flexural strength

Specimens for flexural strength shall be prepared from beams sawn from test panels at between 3 d to 5 d from the time of shooting, and maintained in a moist room in accordance with CSA A23.2-3C. Flexural strength shall be measured in accordance with CSA A23.2-8C.

8.13.8.5 Air-void testing

The hardened air void system shall be evaluated in accordance with ASTM C457 from cores obtained from the substrate or from a test panel.

9 Concrete for housing and small buildings (R class concrete)

9.1 General

Clause 9 applies to unreinforced concrete construction for housing and small buildings, in accordance with Part 9 of the *NBCC*.

Notes:

1) *In preparation of this Standard, the committee is keenly aware of the performance requirements of concrete in housing and small buildings constructed under Part 9 of the NBCC. For the most part the performance has been satisfactory; however, exposure conditions vary widely throughout Canada, and there have been numerous cases of poor durability and some notable failures of concrete in Part 9 buildings where the requirements of this Standard have not been followed. Users are advised to consider carefully the exposure conditions affecting Part 9 buildings and to invoke the requirements of this Standard where appropriate.*

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Authorities having jurisdiction are also advised to consider carefully the exposure conditions in their localities, and to invoke, as a minimum, the requirements of this Standard for Part 9 buildings where appropriate.

2) *Clause 9 is applicable to construction that contains nominal reinforcement provided solely for crack control purposes.*
3) *Clause 9 also includes requirements for formwork and formed sections extracted from CAN/CSA-A438.*

9.2 Formwork and formed sections

Forms shall be so constructed that the finished concrete will conform to the shape, dimensions, and tolerance shown on the construction drawings.

Notes:

1) *For R class concrete used in the construction of buildings conforming to Part 9 of the NBCC:*
   a) *The variation from a straight line in plan view should not exceed ±12 mm in 6 m (1:500) and ±25 mm over the total length.*
   b) *The variation from level for flatwork other than floors and the specified grade for walls should not exceed ±12 mm in 6 m.*
   c) *The variation in wall thickness should not exceed –6 mm or +12 mm.*
   d) *The variation in length of walls or diagonal measurements should not exceed ±25 mm.*
2) *For concrete floor tolerances, see Table 21, Note 8).*
3) *For R classes, the variation from plumb should not exceed 15 mm in 3 m (1:200).*
4) *For R classes:*
   a) *Additional loads that might be imposed on the formwork by the construction practice used (e.g., pumping concrete or wheeling concrete in buggies on walkways or by internal vibration) should be taken into account when constructing the formwork and bracing.*
   b) *Formwork should be tied and arranged so that slack or spring in the form framing will be eliminated when the ties are tightened.*
   c) *Form ties should be so arranged that when forms are removed, no part of a permanently embedded tie will be less than 15 mm from the face of the concrete.*
   d) *Forms should be constructed such that loss of mortar between joints is minimized. Any fins, holes, patches, or other surface imperfections should not project more than 5 mm from a plane surface.*

9.3 Requirements for concrete

R classes of concrete shall meet the requirements of this Standard (see Tables 1 and 2 for exposure classes).

9.4 Chloride exposure of R class concretes

R classes of concrete exposed to chlorides shall comply with the minimum requirements of the appropriate C class in Table 2.

9.5 Sulphate exposure of R class concretes

R classes of concrete exposed to sulphates shall comply with the minimum requirements of the appropriate S class in Table 2.

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Table 1
Definitions of C, F, N, A, S and R classes of exposure
(See Clauses 3, 4.1.1.1.1, 4.1.1.1.3, 4.1.1.5, 4.1.1.8.1, 4.1.2.3, 6.1.4, 6.6.7.6.1, 7.1.2.1, 9.1, L.3, and R.1, Tables 2, 3, and 17, and Annex L.)

C-XL	Structurally reinforced concrete exposed to chlorides or other severe environments with or without freezing and thawing conditions, with higher durability performance expectations than the C-1 classes.
C-1	Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions. Examples: bridge decks, parking decks and ramps, portions of structures exposed to seawater located within the tidal and splash zones, concrete exposed to seawater spray, and salt water pools. For seawater or seawater-spray exposures the requirements for S-3 exposure also have to be met.
C-2	Non-structurally reinforced (i.e., plain) concrete exposed to chlorides and freezing and thawing. Examples: garage floors, porches, steps, pavements, sidewalks, curbs, and gutters.
C-3	Continuously submerged concrete exposed to chlorides, but not to freezing and thawing. Examples: underwater portions of structures exposed to seawater. For seawater or seawater-spray exposures the requirements for S-3 exposure also have to be met.
C-4	Non-structurally reinforced concrete exposed to chlorides, but not to freezing and thawing. Examples: underground parking slabs on grade.
F-1	Concrete exposed to freezing and thawing in a saturated condition, but not to chlorides. Examples: pool decks, patios, tennis courts, freshwater pools, and freshwater control structures.
F-2	Concrete in an unsaturated condition exposed to freezing and thawing, but not to chlorides. Examples: exterior walls and columns.
N	Concrete that when in service is neither exposed to chlorides nor to freezing and thawing nor to sulphates, either in a wet or dry environment. Examples: footings, walls, and columns.
N-CF	Interior concrete floors with a steel-trowel finish that are not exposed to chlorides, nor to sulphates either in a wet or dry environment. Examples: interior floors, surface covered applications (carpet, vinyl tile) and surface exposed applications (with or without floor hardener), ice-hockey rinks, freezer warehouse floors.
A-XL	Structurally reinforced concrete exposed to severe manure and/or silage gases, with or without freeze-thaw exposure. Concrete exposed to the vapour above municipal sewage or industrial effluent, where hydrogen sulphide gas might be generated, with higher durability performance expectations than A-1 class.
A-1	Structurally reinforced concrete exposed to severe manure and/or silage gases, with or without freeze-thaw exposure. Concrete exposed to the vapour above municipal sewage or industrial effluent, where hydrogen sulphide gas might be generated. Examples: reinforced beams, slabs, and columns over manure pits and silos, canals, and pig slats; and access holes, enclosed chambers, and pipes that are partially filled with effluents.
A-2	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure. Examples: reinforced walls in exterior manure tanks, silos and feed bunkers, and exterior slabs.
A-3	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure in a continuously submerged condition. Concrete continuously submerged in municipal or industrial effluents. Examples: interior gutter walls, beams, slabs, and columns; sewage pipes that are continuously full (e.g., forcemains); and submerged portions of sewage treatment structures.
A-4	Non-structurally reinforced concrete exposed to moderate manure and/or silage gases and liquids, without freeze-thaw exposure. Examples: interior slabs on grade.
S-1	Concrete subjected to very severe sulphate exposures (Tables 2 and 3).

(Continued)

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Table 1 (Concluded)

S-2	Concrete subjected to severe sulphate exposure (Tables 2 and 3).
S-3	Concrete subjected to moderate sulphate exposure and to seawater or seawater spray (Tables 2 and 3).
R-1	Residential concrete for footings for walls, columns, fireplaces and chimneys.
R-2	Residential concrete for foundation walls, grade beams, piers, etc.
R-3	Residential concrete for interior slabs on ground not exposed to freezing and thawing or deicing salts.

Notes:

1) *"C" classes pertain to chloride exposure.*
2) *"F" classes pertain to freezing and thawing exposure without chlorides.*
3) *"N" class is exposed to neither chlorides nor freezing and thawing.*
4) *All classes of concrete exposed to sulphates shall comply with the minimum requirements of S class noted in Tables 2 and 3. In particular, Classes A-1 to A-4 and A-XL in municipal sewage elements could be subjected to sulphate exposure.*
5) *No hydraulic cement concrete will be entirely resistant in severe acid exposures. The resistance of hydraulic cement concrete in such exposures is largely dependent on its resistance to penetration of fluids.*
6) *Decision of exposure class should be based upon the service conditions of the structure or structural element, and not upon the conditions during construction.*

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Table 2
Requirements for C, F, N, A, and S classes of exposure

(See Clauses 4.1.1.1.1, 4.1.1.1.3, 4.1.1.3, 4.1.1.4, 4.1.1.5, 4.1.1.6.2, 4.1.1.8.1, 4.1.1.11, 4.1.2.1, 4.3.1, 4.3.7.1, 4.3.7.2, , 7.1.2.1, 7.5.1.1, 8.7.4.1, 9.4, 9.5, L.1, L.3, and R.3 and Table 1.)

			Air content category as per Table 4[d]		Curing type (see Table 19)			
Class of exposure[a]	**Maximum water-to-cementitious materials ratio[b]**	**Minimum specified compressive strength (MPa) and age (d) at test[b, i]**	**Exposed to cycles of freeze/thaw**	**Not exposed to cycles of freeze/thaw**	**Normal concrete**	**HVSCM-1**	**HVSCM-2**	**Chloride ion penetrability requirements and age at test[c]**
C-XL or A-XL	0.40	50 within 56 d	1	[e]	3	3	3	< 1000 coulombs within 91 d
C-1 or A-1	0.40	35 within 56 d	1	[e]	2	3	2	< 1500 coulombs within 91 d
C-2	0.45[h]	32 at 28 d	1	n/a	2	2	2	—
C-3	0.50	30 at 28 d	n/a	[e]	1	2	2	—
C-4[e]	0.55	25 at 28 d	n/a	[e]	1	2	2	—
A-2	0.45	32 at 28 d	1	[e]	2	2	2	—
A-3	0.50	30 at 28 d	2	[e]	1	2	2	—
A-4	0.55	25 at 28 d	2	[e]	1	2	2	—
F-1	0.50[j]	30 at 28 d	1	n/a	2	3	2	—
F-2 or R-1 or R-2	0.55[j]	25 at 28 d	2[f]	n/a	1	2	2	—
N	As per the mix design for the strength required	For structural design	n/a	[e]	1	2	2	—
N-CF[g] or R-3	0.55	25 at 28 d	n/a	[e]	1	2	2	—
S-1	0.40	35 within 56 d	1	[e]	2	3	2	—

(Continued)

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Table 2 (Concluded)

Class of exposure[a]	Maximum water-to-cementitious materials ratio[b]	Minimum specified compressive strength (MPa) and age (d) at test[b, i]	Air content category as per Table 4[d]		Curing type (see Table 19)			Chloride ion penetrability requirements and age at test[c]
			Exposed to cycles of freeze/thaw	Not exposed to cycles of freeze/thaw	Normal concrete	HVSCM-1	HVSCM-2	
S-2	0.45[j]	32 within 56 d	1	[e]	2	3	2	—
S-3	0.50[j]	30 within 56 d	1	[e]	1	2	2	—

[a] *See Table 1 for a description of classes of exposure.*

[b] *The minimum specified compressive strength may be adjusted to reflect proven relationships between strength and the water-to-cementitious materials ratio provided that freezing and thawing and de-icer scaling resistance have been demonstrated to be satisfactory. The water-to-cementitious materials ratio shall not be exceeded for a given class of exposure.*

[c] *In accordance with CSA A23.2-23C, an age different from that indicated may be specified by the owner. Accelerated moist curing in accordance with CSA A23.2-23C may be specified by the owner; in such cases, the age at test shall be 28 d. Where calcium nitrite corrosion inhibitor is to be used, the same concrete mixture, without calcium nitrite, shall be qualified to meet the requirements for the permeability index in this Table. For field testing, the owner shall specify the type of specimen and location from which it is taken. If cores are required, the concrete cores shall be taken in accordance with CSA A23.2-23C.*

[d] *Air entrained concrete shall not receive a steel trowelled finish. See Note 4) to Clauses 7.7.4.3.1 and 7.7.4.3.2.*

[e] *Class N-CF concrete shall not contain an air entraining admixture. Other classes of concrete falling in this air content category have no requirement to provide entrained air however the producer may choose to add entrained air in order to modify plastic concrete properties such as bleeding, workability, cohesiveness, etc. No air entrainment shall be added to concrete which is to receive a steel trowel finish.*

[f] *Air entrainment shall be waived for F-2 class exposures frozen in an air dry condition and receiving very limited cycles of freeze/thaw. Interior ice rink slabs brought to sub-zero levels before the introduction of water and dry freezer slabs have been found to perform satisfactorily without entrained air when steel trowelled.*

[g] *See Clause 7.1.2 for concrete mixes for concrete floors.*

[h] *The maximum water-to-cementitious material ratio for HVSCM-1 concrete in a C-2 exposure shall not exceed 0.40.*

[i] *A different age at test may be specified by the owner to meet structural or other requirements.*

[j] *For reinforced concrete surfaces exposed to air and not directly exposed to precipitation, with depths of cover less than 50 mm, the water-to-cementitious materials ratio shall be not greater than 0.40 for HVSCM-1 concrete and not greater than 0.45 for HVSCM-2 concrete. This requirement is intended to minimize the risk of corrosion of embedded steel due to carbonation of the concrete cover. The exposure conditions that present the greatest risk are the soffits of suspended slabs and balconies and exposed vertical surfaces that receive little direct precipitation. For concrete that is continuously moist, the process of carbonation will be very slow.*

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Table 3
Additional requirements for concrete subjected to sulphate attack[1]
(See Clauses 4.1.1.1.1, 4.1.1.6.2, 4.1.1.6.3, and L.3 and Tables 1, 7, 24, and 25.)

Class of exposure	Degree of exposure	Water-soluble sulphate (SO_4) in soil sample,[2] %	Sulphate (SO_4) in groundwater samples,[3] mg/L	Water soluble sulphate (SO_4) in recycled aggregate sample, %	Cementitious materials to be used[4]	Performance requirements[4, 6]	
						Maximum expansion when tested using CSA A3004-C8, %	
						At 6 months	At 12 months[7]
S-1	Very severe	> 2.0	> 10 000	> 2.0	HS[5], HSb, HSLb, or HSe	0.05	0.10
S-2	Severe	0.20–2.0	1500–10 000	0.60–2.0	HS[5], HSb, HSLb, or HSe	0.05	0.10
S-3	Moderate (including seawater exposure[1])	0.10–0.20	150–1500	0.20–0.60	MS, MSb, MSe, MSLb, LH, LHb, HS[5], HSb, HSLb, or HSe	0.10	

[1] *For sea water exposure, also see Clause 4.1.1.5.*

[2] *In accordance with CSA A23.2-3B.*

[3] *In accordance with CSA A23.2-2B.*

[4] *Where combinations of supplementary cementitious materials and Portland, Portland-limestone, or blended hydraulic cements are to be used in the concrete mix design instead of the cementitious materials listed, and provided they meet the performance requirements demonstrating equivalent performance against sulphate exposure, they shall be designated as MS equivalent (MSe) or HS equivalent (HSe) in the relevant sulphate exposures (see Clauses 4.1.1.6.2, 4.2.1.1, and 4.2.1.3, and 4.2.1.4).*

[5] *Type HS cement shall not be used in reinforced concrete exposed to both chlorides and sulphates, including seawater. See Clause 4.1.1.6.3.*

[6] *For demonstrating equivalent performance, use the testing frequency in Table 1 of CSA A3004-A1 and see the applicable notes to Table A3 in CSA A3001 with regard to re-establishing compliance if the composition of the cementitious materials used to establish compliance changes.*

[7] *If the expansion is greater than 0.05% at 6 months but less than 0.10% at 1 year, the cementitious materials combination under test shall be considered to have passed.*

Note: *Limestone fillers shall not be used in concrete for any S class exposure listed in Tables 1 to 3. Portland-limestone cement shall not be used as the sole cementitious material in concrete for any S class exposure listed in Tables 1 to 3. However, blended hydraulic cements, or combinations of Portland-limestone cement and the minimum levels of supplementary cementitious materials listed in Table 9 of CSA A3001 and also meeting the test requirements of Table 5 in CSA A3001, may be used in any S class exposure listed in Tables 1 to 3.*

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Table 4
Requirements for air content categories
(See Clauses 4.1.1.1.1, 4.1.1.3, 4.1.1.4, 4.1.1.5, 4.3.1, 4.3.3.1, and 4.3.3.2, and Table 2.)

Air content category	Range in air content* for concretes with indicated nominal maximum sizes of coarse aggregate, %		
	10 mm	14–20 mm	28–40 mm
1†	6–9	5–8	4–7
2	5–8	4–7	3–6

* *At the point of discharge from the delivery equipment, unless otherwise specified.*

† *For hardened concrete, see Clause 4.3.3.2.*

Notes:

1) *The above difference in air contents has been established based upon the difference in mortar fraction volume required for specific coarse aggregate sizes.*
2) *Air contents measured after pumping or slip forming can be significantly lower than those measured at the end of the chute.*

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Table 5
Alternative methods for specifying concrete
(See Clauses 4.1.2.1, 4.1.2.3, 4.4.1.1, 4.4.1.2, 4.4.1.5, and 8.1.5 and Annex J.)

Alternative	The owner shall specify	The contractor shall	The supplier shall
1) Performance: When the owner requires the concrete supplier to assume responsibility for performance of the concrete as delivered and the contractor to assume responsibility for the concrete as placed, finished, and cured.	a) required structural criteria, including strength at age; b) required durability criteria, including class of exposure; c) additional criteria for durability, volume stability, architectural requirements, sustainability, and any additional owner performance, pre-qualification or verification criteria; d) quality management requirements (see Annex J); e) whether the concrete supplier shall meet certification requirements of concrete industry certification programs; and f) any other properties that might be required to meet the owner's performance criteria.	a) work with the supplier to establish the concrete mix properties to meet performance criteria for plastic and hardened concrete, considering the contractor's criteria for construction and placement and the owner's performance criteria; b) submit documentation in accordance with CSA A23.2-24C demonstrating the owner's pre-qualification performance requirements have been met; and c) prepare and implement a quality control plan to ensure that the owner's performance criteria will be met and submit documentation in accordance with CSA A23.2-24C demonstrating the owner's performance requirements have been met.	a) certify that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard; b) certify that the mix design satisfies the requirements of this Standard; c) certify that production and delivery of concrete will meet the requirements of this Standard; d) certify that the concrete complies with the performance criteria specified; e) prepare and implement a quality control plan to ensure that the owner's and contractor's performance requirements will be met, if required; f) provide documentation verifying that the concrete supplier meets industry certification requirements, if specified; and g) submit qualification documentation in accordance with CSA A23.2-24C demonstrating that the proposed mix design will achieve the required strength, durability, and performance requirements.
2) Prescription: When the owner assumes responsibility for the concrete.	a) mix proportions, including the quantities of any or all materials (i.e., admixtures, aggregates, cementitious materials, and water) by mass per m^3 of concrete; b) the range of air content; c) the slump range;	a) plan the construction methods based on the owner's mix proportions and parameters; b) obtain approval from the owner for any deviation from the specified mix design or parameters; and	a) provide verification that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard; b) demonstrate that the concrete complies with the prescriptive criteria as supplied by the owner; and

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Table 5 (Concluded)

Alternative	The owner shall specify	The contractor shall	The supplier shall
	d) use of a concrete quality plan, if required; and e) other requirements.	c) identify to the owner any anticipated problems or deficiencies with the mix parameters related to construction.	c) identify to the contractor any anticipated problems or deficiencies with the mix parameters related to construction.

Notes:

1) *The owner may accept an industry-recognized concrete facility certification program that is operated by members of the Canadian Ready Mixed Concrete Association.*
2) *Some of these specification performance requirements necessitate that performance be measured (pre-qualified) by test submissions that demonstrate conformance. If the requested performance characteristics cannot be demonstrated from a pre-existing concrete mix design, timing for developing the mix, testing, and reporting shall be accommodated in the job schedule and planning process.*
3) *See Annex J for background information and guidance on the use of this Table.*
4) *See Annexes M and S for background information and guidance on sustainability and their use in specifications.*

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Table 6
Types of hydraulic cement
(See Clauses 4.2.1.1.2 and 4.2.1.4.1.)

Name	Portland cement	Portland-limestone cement (PLC)	Application
General use hydraulic cement	GU	GUL	For use in general concrete construction when the special properties of the other types are not required.
High-early-strength hydraulic cement	HE	HEL	For use when high-early-strength is required.
Moderate sulphate-resistant hydraulic cement	MS	—	For use in general concrete construction exposed to moderate sulphate action.
High sulphate-resistant hydraulic cement	HS	—	For use when high sulphate resistance is required.
Moderate heat of hydration hydraulic cement	MH	MHL	For use in general concrete construction when moderate heat of hydration is required.
Low heat of hydration hydraulic cement	LH	LHL	For use when low heat of hydration is required.

Notes:

1) *A detailed guideline to the naming practice is provided in Annex C of CSA A3001.*
2) *There is no type of sulphate resisting Portland-limestone cement (see Clause 4.1.1.6.2).*
3) *HS cement shall not be used in reinforced concrete exposed to both chlorides and sulphates. See Clauses 4.1.1.5 and 4.1.1.6.3.*

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Table 7
Types of blended hydraulic cement
(See Clauses 4.1.1.6.2, 4.2.1.2, and 4.2.1.4.1.)

Name	Type*	Application
Blended general use hydraulic cement	GUb GULb	For use in general concrete construction when the special properties of the other types are not required.
Blended high-early-strength hydraulic cement	HEb HELb	For use when high-early-strength is required.
Blended moderate-sulphate-resistant hydraulic cement	MSb MSLb	For use in general concrete construction exposed to moderate sulphate action.
Blended high-sulphate-resistant hydraulic cement	HSb HSLb	For use when high sulphate resistance is required.
Blended moderate heat of hydration hydraulic cement	MHb MHLb	For use in general concrete construction when moderate heat of hydration is required.
Blended low heat of hydration hydraulic cement	LHb LHLb	For use when low heat of hydration is required.

* *A detailed guideline to the naming practice for cements is provided in Annex C of CSA A3001.*

Table 8
Types of supplementary cementitious materials
(See Clause 4.2.1.3.)

Type	Identification
N	Natural pozzolan
F, CI, CH	Fly ash [F: low calcium content* (≤ 15%), Cl: intermediate calcium content* (> 15% and ≤ 20%), and CH: high calcium content* (> 20%)]
S	Ground granulated blast-furnace slag
SF	Silica fume

* *Calcium content expressed as CaO.*

Notes:

1) *CSA A3001 allows blending of up to three individual supplementary cementitious materials to produce a blended supplementary cementitious material.*
2) *For additional information, see Clause 5 of CSA A3001.*

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Table 9
Water used for making concrete — Optional limits
(See Clause 4.2.2.4.)

Parameter	Maximum concentration in mixing water (mg/L)	Test method*	Comparable methods
Chlorides	500 (for prestressed concrete)† 1000 (for other reinforced concrete)†	ASTM D512	APHA 4110B or MA. 300§-ions 1.3 or MA. 303-anions 1.0
Sulphates (as SO_4)	3000	ASTM D516	APHA 4110B or MA. 300 1.3 Ions/MA.303-anions 1.0
Alkalis (Na_2O + 0.658 K_2O)	600‡	ASTM D4192	APHA 3125B or MA.200-Met. 1.2
Total solids	50 000	AASHTO T 26	APHA 2310B and 2320B or MA. 100-S.T. 1.1

* *Other test methods that have been demonstrated to yield comparable results may be specified.*
† *The contribution of the mixing water to the total chloride ion content in the concrete should not exceed the limits specified in Clause 4.1.1.2.*
‡ *The contribution of the mixing water to the total alkali content in the concrete should follow the guidelines in of CSA A23.2-27A.*
§ *MA = Methode d'analyse du Centre d'expertise en analyse environmental du Québec.*

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Table 10
Grading limits for fine aggregate (FA)
(See Clauses 4.2.3.2.3, 4.2.3.3.2.1, 4.2.3.7, and U.4.3.3.)

	Total passing sieve, percentage by mass	
Sieve size	**FA1***	**FA2***
10 mm	100	100
5 mm	95–100	80–90
2.5 mm	80–100	60–75
1.25 mm	50–90	35–50
630 µm	25–65	15–30
315 µm	10–35	5–15
160 µm	2–10	0–8
80 µm	0–3†	0–3†

* *The fineness modulus of fine aggregate shall be not less than 2.3 nor more than 3.1 for FA1, and not less than 3.3 nor more than 4.0 for FA2.*

† *This limit shall be 5% if the clay size material (finer than 2 µm) does not exceed 1% of the total fine aggregate sample. The amount of material of clay size shall be determined by performing a hydrometer analysis as per ASTM D422 on a sample washed through an 80 µm sieve.*

Notes:

1) *The minimum percentages for material passing the 315 µm and 160 µm sieves may be reduced to 5 and 0, respectively, if the aggregate is to be used in air-entrained concrete containing more than 250 kg/m³ of cementitious material or in non-air-entrained concrete containing more than 300 kg/m³ of cementitious material.*
2) *For high-strength concrete, the amount of material passing the 160 µm sieve should be limited to a maximum of 2%.*
3) *Workability problems have been experienced when the percentage passing the 315 µm sieve is less than 10.*
4) *Individual sands combined to meet the requirements of this Table may have any grading, provided that the final blend meets the specified requirements of this Table.*

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Table 11
Grading requirements for coarse aggregate
(See Clauses 4.2.3.2.3, 4.2.3.4.2, 4.2.3.5.2, 4.2.3.7, and U.4.3.3.)

	Nominal size of aggregate, mm	Total passing each sieve*, percentage by mass										
		112 mm	80 mm	56 mm	40 mm	28 mm	20 mm	14 mm	10 mm	5 mm	2.5 mm	1.25 mm
Group I	40–5†	—	—	100	95–100	—	35–70	—	10–30	0–5	—	—
	28–5†	—	—	—	100	95–100	—	30–65	—	0–10	0–5	—
	20–5	—	—	—	—	100	85–100	50–90	25–60	0–10	0–5	—
	14–5	—	—	—	—	—	100	90–100	45–75	0–15	0–5	—
	10–2.5	—	—	—	—	—	—	100	85–100	10–30	0–10	0–5
Group II	80–40	100	90–100	25–60	0–15	—	0–5	—	—	—	—	—
	56–28	—	100	90–100	30–65	0–15	—	0–5	—	—	—	—
	40–20	—	—	100	90–100	25–60	0–15	—	0–5	—	—	—
	28–14	—	—	—	100	90–100	30–65	0–15	—	0–5	—	—
	20–10	—	—	—	—	100	85–100	—	0–20	0–5	—	—
	14–10	—	—	—	—	—	100	85–100	0–45	0–10	—	—
	10–5	—	—	—	—	—	—	100	85–100	0–20	0–5	—
	5–2.5	—	—	—	—	—	—	—	100	70–100	10–40	0–10

* *Sieves shall meet the requirements for woven wire cloth testing sieves given in ISO 3310-1 made with the preferred wire diameter.*
† *To prevent segregation, aggregates that make up either of these gradings shall be stockpiled and batched in two or more separate sizes selected from Groups I and II.*

Note: *Group I comprises combined aggregate gradings most commonly used in concrete production. Group II provides for special requirements, (e.g., gap grading, pumping, etc.), or for blending two or more sizes to produce Group I gradings.*

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Table 12
Limits for deleterious substances[a] and physical properties of aggregates
(See Clauses 4.2.3.4.3, 4.2.3.5.1, 4.2.3.5.3.2, and 4.2.3.7.)

		Maximum percentage by mass of total sample		
			Coarse aggregate	
CSA Test method	Property	Fine aggregate	Concrete exposed to freezing and thawing	Other exposure conditions
	Standard requirements			
A23.2-3A	Clay lumps[b, j]	1.0	0.3	0.5
A23.2-4A	Low-density granular materials[c, j]	0.5	0.5	1
A23.2-5A	Material finer than 80 µm	3.0[d]	1.0[e]	1.0[e]
A23.2-13A	Flat and elongated particles			
	Procedure A, ratio 4:1; or	—	20	20
	Procedure B			
	Flat particles	—	25	25
	Elongated particles	—	45	45
	Elongated particles (for pavements and high-performance concrete)	—	40	40
A23.2-23A A23.2-29A	Micro-Deval test[f]	20	17	21
A23.2-24A	Unconfined freeze-thaw test[g]	—	6	10
A23.2-16A A23.2-17A	Impact and abrasion loss[h]	—	50	50
	Alternative requirements[i]			
A23.2-9A	$MgSO_4$ soundness loss	16	12	18

[a] *Limits for deleterious substances not listed in this Table, such as coal, ochre (ironstone), shalestone, siltstone, or argillaceous limestone, shall be specified by the owner to encompass deleterious materials known to be present in a particular region. In the absence of such information, aggregate shall be accepted or rejected in accordance with Clause 4.2.3.10.*

[b] *Clay lumps are defined as fine-grained, consolidated, sedimentary materials of a hydrous aluminosilicate nature.*

[c] *A liquid with a relative density of 2.0 is generally used to separate particles classified as coal or lignite. Liquids with relative densities higher or lower than 2.0 might be required to identify other deleterious low-density materials.*

[d] *This limit shall be 5% if the clay size material (finer than 2 µm) does not exceed 1% of the total fine aggregate*

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Table 12 (Concluded)

sample. The amount of material of clay size shall be determined by performing a hydrometer analysis in accordance with ASTM D422 on a sample washed through an 80 µm sieve.

[e]*In the case of crushed aggregate, if material finer than the 80 µm sieve consists of the dust of fracture, essentially free from clay or shale, the maximum shall be 2.0%.*

[f]*CSA A23.2-23A, a test for fine aggregate, is rapid, has excellent precision, and has a significant correlation with the $MgSO_4$ soundness test. For more information, see Rogers et al. (1991).*

[g]*CSA A23.2-24A, a test for coarse aggregate, has good precision and shows fair correlation with the $MgSO_4$ soundness test. For further information, see Rogers et al. (1989).*

[h]*The abrasion loss shall not be greater than 35% when the aggregate is used in concrete paving or for other concrete surfaces subjected to significant wear. This does not refer to air-cooled iron blast-furnace slag coarse aggregate. The abrasion loss requirements for coarse aggregate shall be waived provided that the material meets the alternative requirements for Micro-Deval detailed in this Table.*

[i]*The Micro-Deval test requirements for fine aggregate or the freeze-thaw requirements for coarse aggregate shall be waived provided that the material meets the alternative requirements for $MgSO_4$ soundness loss detailed in this Table.*

[j]*If the coarse aggregate when tested in accordance with CSA A23.2-15A does not show the presence of either clay lumps or low-density granular materials, the requirements for testing in accordance with 3A and 4A may be waived.*

Notes:

1) *See CSA A23.2-30A, Clause 10.2 for D-cracking.*
2) *For certain aggregates, such as limestone and dolomites from the St. Lawrence Lowlands in the province of Québec, the freeze-thaw limit of 9 instead of 6 has been found to be satisfactory for exposure classifications F-1, C-XL, A-XL C-1, and C-2 and the limit of 13 instead of 10 for other exposure conditions (see Clause 10.3 of CSA A23.2-30A).*
3) *For aggregates, such as limestone and dolomites from the St. Lawrence Lowlands in the province of Québec, the Micro-Deval limit of 19 instead of 17 has been found satisfactory for exposure classifications F-1, C-XL, A-XL, C-1, and C-2 (see Clause 10.3 of CSA A23.2-30A). These higher limits will be accepted only if the aggregate producers can demonstrate that the annual production shows less than 2.0% of poor and deleterious material, as determined by CSA A23.2-15A.*
4) *For Notes 2 and 3, see report by Blanchette, Alain (2004) and (2006) by RPPG (Québec Aggregate Producers Association) for information on the St. Lawrence Lowlands limestones and dolomites.*
5) *The owner shall specify Procedure A or Procedure B for determination of particle shape of coarse aggregate.*
6) *If the Micro-Deval limits in this Table for fine aggregate are met, then the tests for clay lumps and low-density granular materials may be waived.*

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Table 13
Determination of within-batch uniformity
(See Clauses 5.2.2.1, 5.2.4.1.2, and 5.2.4.5.2.1.)

	Range between highest and lowest values of three test samples	
Uniformity test	**Accept if equal to or less than**	**Reject if more than**
Density of concrete, kg/m³	30	50
Air content, %	0.8	1.0
Slump, mm	30	50
Slump flow, mm	50	70

Note: *For uniformity of fibre content, see CSA A23.2-16C for information and the expected variations in steel fibre content.*

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Table 14
Permissible concrete temperatures at placing
(See Clauses 5.2.5.4.1, 7.2.2.1, 7.5.1.3, 7.6.3.2.3, and 8.5.5.)

	Temperatures, °C	
Thickness of section, m	**Minimum**	**Maximum**
< 0.3	10	32
≥ 0.3 – < 1	10	30
≥ 1 – < 2	5	25
≥ 2	5	20

Notes:

1) *In no case shall the placing temperature for high-performance concrete exceed 25 °C.*
2) *The placing temperature should be kept as close as possible to the suggested minimum temperatures shown in this Table. Higher temperatures result in an increase of mixing water, increased slump loss, and an increase in thermal shrinkage.*
3) *Some non-chloride, noncorrosive accelerators conforming to ASTM C494/C494M, Type C and E, have been found to accelerate setting and strength gain at ambient temperatures of 5 °C and below. When adequate information pertaining to past performance records is available, concrete containing non-chloride, noncorrosive accelerators may be placed at ambient temperatures as low as –5 °C. Test panels/placements and compressive strength cylinders should be made to verify that the setting time and early strength gain characteristics of the proposed mix design are satisfactory to the contractor. Cement characteristics and initial concrete temperature will have a significant impact on setting and early strength gain.*
4) *Additional information on cold weather admixtures and concreting can be found in ACI 306R.*
5) *When the temperature of concrete as placed is consistently above 25 °C, consideration should be given to the use of a suitable set-retarding admixture.*
6) *Higher concrete temperatures result in a faster set times, increased rate of slump loss, a reduction in surface plasticity, a higher water demand, lower ultimate strengths, and an increase in drying shrinkage.*
7) *Additional information on hot weather can be found in ACI 305R.*

Table 15
General dimensional tolerances
(See Clauses 6.4.6.1 and 6.4.6.3 and Figure 1.)

Dimensions, m	**Allowable variation, mm**
0–2.4	±5
2.4– 4.8	±8
4.8–9.6	±12
9.6–14.4	±20
14.4–19.2	±30
19.2–57.6	±50
57.6 – as specified by the designer	

Notes:

1) *The tolerance on the top surface elevation of suspended slabs shall be ±20 mm before removal of formwork.*
2) *This Standard shall not be used for determining the deflection of slabs on structural steel or precast concrete.*

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Table 16
Bend diameter for standard hooks
(See Clause 6.6.2.3.)

	Minimum bend diameter,* mm		
	Steel grade		
Bar size, mm	300R‡	400R or 500R	400W or 500W§
10	60	70	60
15	90	100	90
20	—	120	100
25	—	150	150
30	—	250	200
35	—	300	250
45	—	450†	400
55	—	600†	550

* *Bend diameters shall not be reduced by more than 10% from those listed unless otherwise permitted by the owner.*
† *Special fabrication is required for bends exceeding 90° for bars of these sizes and grades.*
‡ *R refers to "Regular" grade.*
§ *W refers to "Weldable" grade.*

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Table 17
Concrete cover
(See Clauses 4.3.2.2.1, 6.6.6.2.3, and 6.6.8.)

	Exposure class (see Tables 1 and 2)		
Exposure condition	**N, N-CF, R-3**	**F-1, F-2, S-1, S-2, S-3, R-1, R-2**	**C-XL, A-XL, C-1, C-3, A-1, A-2, A-3**
Cast against and permanently exposed to earth, including footings and piles	75 mm	75 mm	75 mm
Beams, girders, and columns	30 mm*	40 mm	60 mm
Slabs, walls, joists, shells, and folded plates	20 mm*	40 mm	60 mm
Ratio of cover to nominal bar diameter†	1.0*	1.5	2.0
Ratio of cover to nominal maximum aggregate size	1.0*‡	1.5	2.0

** This refers only to concrete that will be continually dry within the conditioned space (i.e., members entirely within the building envelope).*
† The cover for a bundle of bars shall be the same as that for a single bar with an equivalent area.
‡ The specified cover from screeded surfaces shall be at least 1.5 times the nominal maximum aggregate size to reduce interference between aggregate and reinforcement where variations in bar placement result in a cover smaller than specified.

Notes:

1) *Greater cover or protective coatings might be required for exposure to industrial chemicals, food processing, and other corrosive materials. See PCA IS001.*
2) *For information on the additional protective measures and requirements for parking structures, see CSA S413.*
3) *For information on the additional protective measures and requirements for bridges, see CSA S6.*

Table 18
Air content requirements for grout
(See Clauses 6.8.4.3.1 and 6.8.7.3.)

		Air content, %	
Curing time, h	**Temperature, °C**	**w/c = 0.45**	**w/c = 0.40**
24	5	5.5	4.5
	15	4.5	3.5
48	5	4.0	3.0
	15	3.0	2.0
96	5	2.5	1.5
	15	1.5	0.5
192	5	1.0	0.0
	15	0.0	0.0
336	4	0.0	0.0

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Table 19
Allowable curing regimes
(See Clauses 4.1.1.1.1, 7.1.2.2, 7.8.1, 7.8.2.1, 7.9.9, and Table 2.)

Curing type	Name	Description
1	Basic curing	3 d at ≥ 10 °C or for the time necessary to attain 40% of the specified strength.
2	Additional curing*	7 d total at ≥ 10 °C and for the time necessary to attain 70% of the specified strength.
3	Extended wet curing	A wet-curing period of 7 d at ≥ 10 °C and for the time necessary to attain 70% of the specified strength. The curing types allowed are ponding, continuous sprinkling, absorptive mat, or fabric kept continuously wet.

* *When using silica fume concrete, additional curing procedures shall be used. See Clause I.3.13.*

Notes:

1) *Curing of plant production of precast concrete shall be as set out in CSA A23.4.*
2) *Concrete should be allowed to air-dry for a period of at least one month after the end of the curing period, before exposure to de-icing chemicals.*
3) *The rate of compressive strength gain in concrete is significantly reduced below 10 °C.*

Table 20
Maximum permissible temperature differential between concrete surface and ambient to minimize cracking — Wind up to 25 km/h
(See Clauses 7.2.2.5 and 7.6.3 and Figure D.2.)

	Maximum permissible temperature differential, °C				
	Length-to-height ratio of structural elements*				
Thickness of concrete, m	0†	3	5	7	20 or more
< 0.3	29	22	19	17	12
0.6	22	18	16	15	12
0.9	18	16	15	14	12
1.2	17	15	14	13	12
> 1.5	16	14	13	13	12

* *Length shall be the longer restrained dimension and the height shall be considered the unrestrained dimension.*
† *Very high, narrow structural elements such as columns.*

Notes:

1) *See also Figure D.2.*
2) *This Table was originally developed from studies performed to address thermal shock concerns for cold weather concreting in Canada (see Ghosh and Mustard, 1983). This Table may be used for guidance in reducing the risk of thermal shock for concrete when removing thermal protection.*

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Table 21
Slab and floor finish classifications
(See Clauses 7.7.1.1, 7.7.1.4, and 9.2.)

Class	Examples	Recommended procedures	Overall F-number	
			F_F	F_L
A	"Conventional" slab on grade and elevated floors	Hand screeded and steel trowel finished	20	15*
B	"Flat" slab on grade and elevated floors or surfaces with thin applied finishes.	Advanced hand or mechanical screeding, pan floating, and steel trowel finished	25	20*
C	"Very Flat" slab on grade floors	Specialized materials, advanced hand or mechanical screeding, pan floating, and steel trowel finished	35	25
D	"Extremely Flat" slab on grade floors	Specialized: materials, advanced mechanical screeding, large pan float, highway straightedged, and steel trowel finished	45	30
E	Specialized surfaces including automatic guided vehicles and air pallet systems	Specialized materials and methods of concrete construction	†	†

* *Class A and B levelness tolerances are not applicable to elevated slabs.*
† *Refer to the equipment manufacturers instructions.*

Notes:

1) *Many items can affect the achievement of specified tolerances, including placement methods, concrete consistency, concrete thickness, the application of surface hardeners, environmental conditions, and physical restrictions of the placement area. These should be reviewed carefully at the concrete floor pre-construction meeting.*
2) *It is not possible to obtain Class B tolerances on elevated slabs where double pan float machines cannot be employed for reasons of safety or accessibility.*
3) *Tolerance losses of up to 50% can occur in a jointed slab on grade through drying shrinkage curling in the first year. Owners are cautioned to consider these losses carefully when designing floor slabs including the use of shrinkage reducing admixtures and restraining reinforcing steel to meet their needs. See ACI 360R for further information.*
4) *Owners may specify tolerances other than those listed in this Table after carefully considering their actual usage requirements. Owners are cautioned that higher tolerance specifications generally require more expensive methods of construction including modifications to concrete mixes, reinforcing, and surface treatments.*
5) *Specialized Class E floors involve customized floor tolerances, materials, and methods of construction that are beyond the scope of this Standard. Specialists should be consulted for this type of traffic surface. Further information is available from the Concrete Floor Contractors Association of Canada.*
6) *Improved levelness tolerances on suspended slabs generally require the use of a deferred bonded topping. Tolerance Class A through E may be applied to bonded toppings.*
7) *Compliance with the ASTM F710 requirement for F_F30 is generally achievable using the methodology in Class B.*
8) *"Small slab on grade floor areas less than 150 m² may alternatively comply with a 90% compliance to a 12 mm "conventional" gap under a freestanding 3 m straightedge in accordance with ACI 117.*
9) *Measurements shall be taken within 72 h of each slab placement.*

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Table 22
List of test methods for workability properties of SCC
(See Clauses 8.6.3.1.2 and 8.6.5.)

Method	Acceptance criteria		Governing property
	Minimum	Maximum	
Slump flow test CSA A23.2-19C			
Flow†	500 mm	800 mm	Filling ability
T-50 cm time	2 s	7 s	
VSI value	0	1	Segregation resistance
J-ring CSA A23.2-20C		Difference between slump flow and J-ring slump flow ≤ 25 mm	Passing ability
L-box MTO LS-440	h2/h1 = 0.8	h2/h1 = 1.0	Filling ability and passing ability
Screen stability test*	0	15%	Segregation resistance
Column Segregation ASTM C1610/C1610M		Static segregation ≤ 10%	Segregation resistance
Static segregation resistance ASTM C1712		Pd ≤ 10 mm	Segregation resistance

* *See Association Française de Genie Civil "Screen Stability Test, Annex 3", Betons Auto-Placants (Self-consoliding Concrete), Bagneux, France, July 2000 and Khayat, et. al. (2004).*
† *The target value of slump flow plus the specified tolerance of ± 70 mm shall be between 500 and 800 mm.*

Note: *Either ASTM C1712 or the visual stability index (VSI) value in accordance with CSA A23.2-19C may be used for field evaluation of the segregation resistance of SCC. ASTM 1610 Clause 5.1 acknowledges that ASTM C1712 "provides a rapid method for assessing static segregation resistance of self-consolidating concrete". Panesar and Shindman (2011) recommends the ASTM C1610/C1610M column segregation test method for qualification and/or laboratory study only.*

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Table 23
Batching tolerances
(See Clauses 5.2.2.1, 5.2.2.3, 5.2.2.4.2, 5.2.2.8, and 5.2.3.1.)

Ingredients	Batch weights greater than 30% of scale capacity	Batch weights less than 30% of scale capacity
Cement and other cementitious materials	± 1% (by mass)	Not less than the required mass and not more than 4% in excess
Water	± 1% (by volume or mass) ± 3% (by volume or mass) for water from all sources	± 1.5% (by volume or mass) ± 3% (by volume or mass) for water from all sources
Aggregates	± 2% (by mass)	For separate batching: ± 2% For cumulative batching: ± 0.3% of scale capacity or ± 3% of required cumulative mass, whichever is less
Admixtures	± 3% (by volume or mass) or 30 mL, whichever is greater	

Note: *To ensure the batching system meets the tolerances, the analysis of any 15 consecutive samples should demonstrate that 80% of the readings meet the above tolerances, with no individual result exceeding twice the tolerance.*

Table 24
Requirements for fine and coarse aggregates for use in controlled low-strength materials other than unshrinkable fill, and concrete of strength < 10 MPa
(see Clauses 4.1.1.1.6 and 8.11.2.2.2.)

Maximum limit	Coarse	Fine
Micro-Deval abrasion % (CSA A23.2-23A)	25% — max	30% – max
Organic impurities	N/A	As per Clause 4.2.3.3.3.2
Water soluble chloride (ASTM D1411)*	0.10% — max	0.10% – max

* *This requirement is specified if the CLSM or concrete strength < 10 MPa will be in contact with concrete or steel pipe. For controlled low-strength materials (CLSM) or other product in contact with permanent concrete elements, the limit of SO_4 in aggregates including of RCA shall be a maximum of 0.20%, unless the permanent concrete element meets the requirements of S1, S2, or S3 of Table 3. The CLSM shall have field performance to demonstrate it does not cause excessive expansion due to sulphate.*

Note: *For unshrinkable fill, see Table 25.*

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Table 25
Requirements for fine and coarse aggregates for use in unshrinkable fill
(See Clause 8.11.2.2.2 and Table 24.)

Maximum limit	Coarse	Fine
Micro-Deval abrasion % (CSA A23.2-23A)	25% – max	30% – max
% crushed particle (ASTM D5821 – one face)	50% – min	N/A
% passing 80 µm* (CSA A23.2-5A)	3% – max	5% – max
Organic impurities	N/A	As per Clause 4.2.3.3.3.2
Sulphate content (SO_4)‡ (CSA A23.2-3B or 8B).	1.5% – max	1.5% – max
Water soluble chloride (ASTM D1411)†	0.10% – max	0.10% – max

* *This requirement may be waived provided that the % passing the 80 µ sieve for the combined aggregate does not exceed 5% of the total.*
† *This requirement is specified if fill will be in contact with concrete or steel pipe.*
‡ *For unshrinkable fill in contact with permanent concrete elements, the limit of SO_4 in aggregates RCA shall be a maximum of 0.20%, unless the permanent concrete element meets the requirements of S1, S2, or S3 of Table 3 as appropriate. RCA used in unshrinkable fill to be placed in contact with sulphate-bearing soil or ground water with sulphate shall be produced from sulphate resistant concrete.*

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Figure 1
Construction tolerances for cast-in-place concrete
(See Clauses 6.4.2.3, 6.4.3, and 6.4.5.)

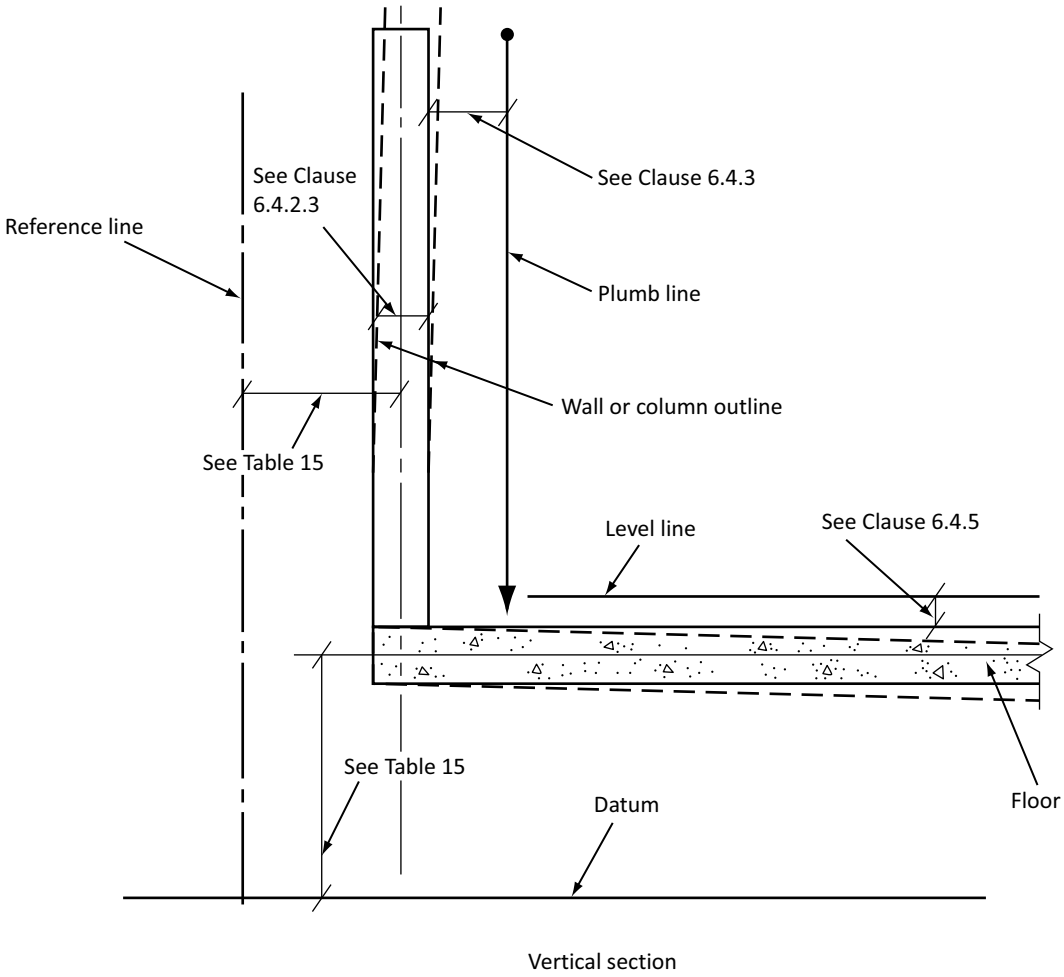
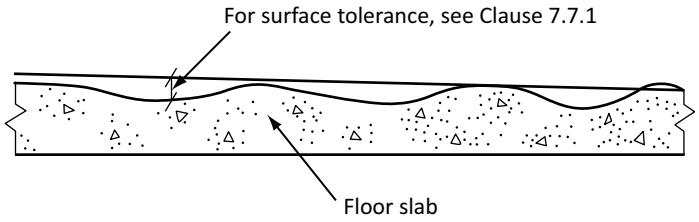


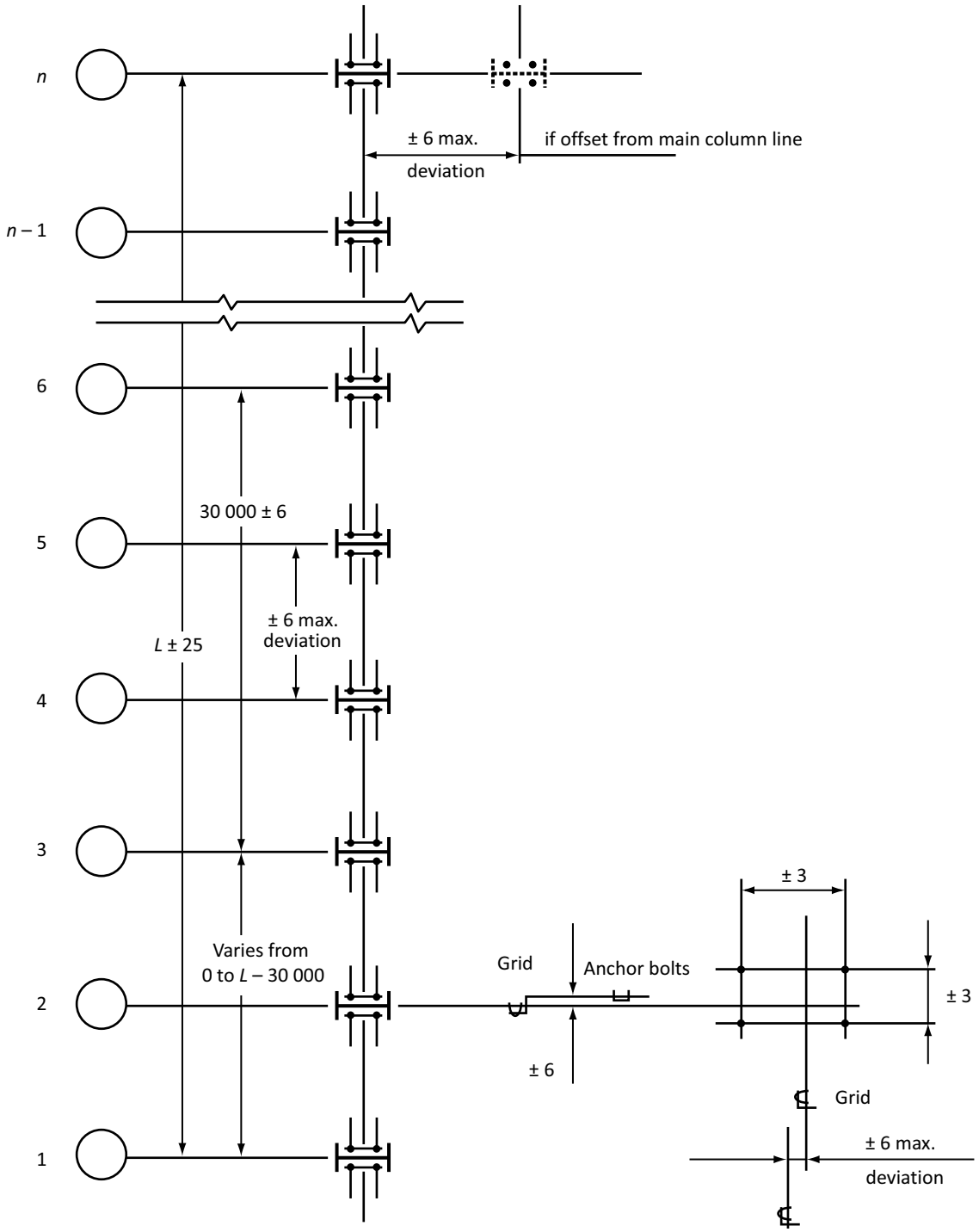
Figure 2
Surface tolerances of floor slabs
(See Clause 6.4.1.3.)



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Figure 3
Tolerances on anchor bolt placement
(See Clauses 6.7.3.1 and 6.6.8.)

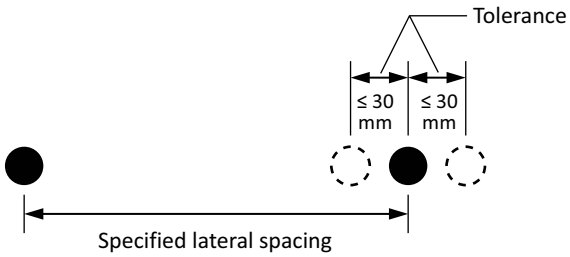


Note: *All measurements are in millimetres.*

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Figure 4
Lateral spacing of bars
(See Clause 6.6.8.)



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Annex A (informative)
Special cements

Note: *This Annex is not a mandatory part of this Standard.*

A.1 General

Some special cements, not included in the types of cements covered by CSA A3000, could be used to produce types of concrete covered by this Standard. This Annex provides some guidance for using such special cements properly in specifying and making concrete.

A.2 Calcium aluminate cement

A.2.1 General

This type of cement is used in Canada for refractory and other special applications. To assess the quality of such cement, see BSI BS 915-2 or AFNOR P15-315.

A.2.2 Characteristics

Calcium aluminate cement hardens very rapidly and high strengths can develop within one day. However, the hydrates responsible for this behaviour change over time, subsequently resulting in a loss of strength. This process, called conversion, always occurs. The design of durable concrete using this type of cement must therefore be based on long-term performance, not on the high but transient strengths that can occur initially.

A.2.3 Limitations

Long-term compressive strengths of 40 MPa are typical for well-made calcium aluminate cement concrete using aggregate of average quality. Higher values can be obtained with limestone coarse aggregate. However, some other aggregates do not perform as well. For this reason, an unrestricted recommendation of this type of cement for some types of concrete construction (e.g., prestressed concrete) would not be appropriate.

Note: *In choosing an aggregate for high temperature purposes, the following properties should be considered:*

a) *chemical bond between the cement and the aggregate;*
b) *modulus of elasticity; and*
c) *porosity.*

A.2.4 Proportioning

On the basis of the information provided in Clauses A.2.2 and A.2.3, and to avoid the possibility of misusing calcium aluminate cement, concrete should be proportioned with a ratio of total water-to-cement not exceeding 0.40 and a minimum cement content of 400 kg/m^3 of concrete.

Note: *The ratio of total water-to-cement includes water absorbed by the aggregate.*

A.2.5 Reference

The user should consult with the manufacturers of this type of cement before using it. Information can be found in Mangabhai (1994) and Concrete Society (1997).

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A.3 Shrinkage-compensating cement

This type of cement is not at present manufactured in Canada, but has been used occasionally in this country. Particular care must be exercised in its use to ensure desired performance. See the manufacturer's specifications and ACI 223R.

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Annex B (informative)
Alkali-aggregate reaction

Note: *This Annex is not a mandatory part of this Standard.*

B.1 General

In several regions of Canada, concrete deterioration occurs due to a reaction between some minerals in certain rock types used as concrete aggregate and the soluble alkaline components in the concrete that are present mainly in the hydraulic cement. This phenomenon is known as alkali-aggregate reaction.

For alkali-aggregate reactivity to occur, there must be reactive materials in the aggregates, sufficient alkali in the concrete, and sufficient moisture in the concrete to support the reaction process.

Alkali-aggregate reactivity can result in detrimental expansion of the concrete characterized by a well-defined crack pattern. The crack pattern is commonly identified as “map-cracking” or “pattern-cracking” (see Figure B.1). Other deterioration mechanisms can also cause pattern-cracking. Cracking in the concrete and the resultant deterioration is generally slow, although some extremely reactive aggregates can produce cracks within a few years. With time, alkali-aggregate reactivity can cause significant expansion, severe cracking, and differential movements in concrete components.

The risk of sudden structural failure in concrete components is almost nonexistent (Haavik and Mielenz, 1991) and, in Canada, much concrete made with reactive aggregate remains in service. Nevertheless, concrete affected by alkali-aggregate reactivity can pose serviceability problems, in some cases severe ones, which might result in high maintenance/rehabilitation costs or replacement of a component before the end of the anticipated service life. Cracking, regardless of origin, can allow rapid ingress of moisture or salts, or both, which might result in acceleration of deterioration due to other mechanisms.

Alkali-aggregate reaction problems in concrete should be avoided. This Annex provides general advice on strategies, test methods, and selection criteria for this objective. A useful general reference on alkali-aggregate reaction can be found in Fournier and Bérubé (2000). CSA A864 provides guidelines for the management of existing concrete structures already affected by alkali-aggregate reaction.

B.2 Types of alkali-aggregate reaction

B.2.1 General

Two types of alkali-aggregate reaction are encountered in Canada:

a) alkali-silica reaction (ASR); and
b) alkali-carbonate reaction (ACR).

Note: *The mechanisms of these expansive reactions are not clearly understood. The alkali-silica reaction is associated with the formation of expansive alkali-silica gel in concrete (Diamond, 1989). Alkali-carbonate reaction is caused by the expansion of coarse aggregate particles. Katayama and Grattan-Bellew (2012) have recently proposed that expansion due to ACR was related to the formation of alkali-silica gel in a special case of alkali-silica reaction.*

B.2.2 Alkali-silica reaction

Aggregates exhibiting this type of reactivity contain various forms of reactive silica. For convenience, the

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alkali-silica reaction is divided into two categories according to the type of reactive silica involved (see Table B.1):

a) the alkali-silica reaction that occurs with poorly crystalline or metastable silica minerals and volcanic or artificial glasses (see Category A in Table B.1):
   i) opal, tridymite, cristobalite, and beekite;
   ii) acid, intermediate, and basic volcanic glasses; and
   iii) artificial glasses.

   Aggregates containing such materials might cause deterioration of concrete when the reactive component is present in amounts as little as 1%. Cracking of concrete structures containing these aggregates and high alkali content is usually observed within 10 years of construction; and

   Note: *Volcanic and artificial glasses are included in the alkali-silica reactive materials, although they should strictly be termed alkali-silicate reactive.*

b) the alkali-silica reaction that occurs with varieties of quartz (see Category B in Table B.1):
   i) chalcedony;
   ii) cryptocrystalline to microcrystalline and macrogranular quartz with deformed crystal lattice, rich in inclusions, intensively fractured, or granulated;
   iii) poorly crystalline quartz at grain boundaries; and
   iv) quartz cement overgrowths.

   Some aggregates containing such materials can cause deterioration of concrete when the reactive component is present in amounts as little as 5% by mass of aggregate. Cracking of concrete structures containing these aggregates and having a high alkali content might be observed within 10 years of construction (e.g., with some cherts and flints, siliceous limestones, volcanic rocks, and sandstones). This category includes several slowly expanding aggregates in which microcrystalline quartz (often associated with optically strained quartz) is thought to be the principal reactive component. A wide variety of quartz-bearing rocks fall into this group: greywacke, argillite, quartz wacke, quartz arenite, hornfels, granite and granitic gneiss, phyllite, quartzite, sandstone, and arkose. This list is not exhaustive; other quartz-bearing rock types can also be reactive. In some instances, field concretes containing these types of aggregates do not show cracking and deterioration for up to 20 years, but in other instances, particularly when exposed to de-icing salts, cracking can occur in 5 years or less.

B.2.3 Alkali-carbonate reaction

Alkali-carbonate reaction occurs between certain argillaceous dolomitic limestones that contain small quantities of chert, and the alkaline pore solutions in the concrete. The gel formed by reaction of the chert causes expansion and extensive cracking of concrete. The reaction under laboratory conditions is usually characterized by the rapid expansion of concrete (Lu *et al*., 2004); however, such alkali-carbonate reactive rocks generally induce limited expansion of 0.10% or less in the accelerated mortar bar test (Lu *et al*., 2008), unless there is an alkali-silica reaction component to it.

Alkali-carbonate reactive dolomitic limestones are characterized by a matrix of fine calcite and clay minerals with scattered dolomite rhombohedra (see Figure B.1). The characteristic texture can be observed in thin sections with a petrographic microscope or in a scanning electron microscope. Structures affected by this reaction usually show cracking within 5 years of construction. At present, deleteriously reactive alkali-carbonate reactive aggregates have only been found in quarries. Crushed stone from gravels has not been found to be deleteriously reactive.

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B.3 Methods of evaluating potential reactivity of aggregates

B.3.1 General

B.3.1.1 General procedures

The procedures to be followed in assessing the suitability of concrete aggregate are given in CSA A23.2-27A.

B.3.1.2 Field performance

A history of satisfactory field performance in concrete is possibly the best method of evaluating the potential for an aggregate to cause premature deterioration of concrete due to alkali-aggregate reaction. A useful document describing the process of investigating of field performance is CSA A864. When field performance is to be assessed,

a) it is essential that the cement content and the alkali content of the cement are the same or higher in the field concrete as those proposed in the new structure;
b) the concrete examined should be at least 10 years old;
c) the exposure conditions of the field concrete should be at least as severe as those in the proposed structure;
d) a petrographic study should be conducted to demonstrate that the aggregate in the structure is identical to that under investigation in the absence of conclusive documentation; and
e) the possibility of supplementary cementitious materials having been used should be considered because the water-to-cementitious materials ratio of the concrete might affect performance.

Such a field performance review is conducted by a professional who is experienced in the assessment of alkali-aggregate reaction in structures.

Note: *Field performance criteria are specified in Clause 6.1 of CSA A23.2-27A.*

B.3.1.3 Laboratory investigations

In many instances, a field investigation is not possible, either because the aggregate has not previously been used in concrete or because the aggregate is derived from a different location in the pit or quarry than was used previously. Under these circumstances, or when the alkali content of the new concrete or the exposure conditions are more severe than those of the existing concrete structure, a laboratory investigation is undertaken to determine the potential reactivity of the aggregate.

There are two types of test methods:

a) petrographic examination and/or chemical analysis and tests in which the mineralogical and/or chemical composition and texture of an aggregate are compared with those of known reactive and innocuous aggregates; and
b) length change measurements of mortar or concrete specimens, stored at elevated temperatures to accelerate the reaction.

Petrographic examination is rapid, convenient, and powerful but is handicapped by the uncertainty in the correlation between the mineralogical composition and texture of an aggregate and its potential alkali-reactivity.

Caution is necessary when interpreting the results of laboratory experiments because with many types of aggregate, a correlation between the results of laboratory tests and field performance has not yet been adequately documented. The problem of interpretation of test results is most acute with marginally reactive aggregates, but in all cases engineering judgment, based on experience, is necessary

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in predicting field performance from the laboratory test results. If both coarse and fine aggregates proposed for a project are marginally reactive, they should be tested together in accordance with CSA A23.2-14A.

B.3.1.4 Pessimum proportion

When certain minerals (e.g., opal, chalcedony, cristobalite, tridymite, cryptocrystalline and microcrystalline quartz, and possibly volcanic glass) are present in small quantities (as little as 1% in some instances) in an aggregate, maximum expansion of concrete can be observed. That percentage causing maximum expansion is known as the ”pessimum proportion”.

Rocks, such as chert, may also exhibit a pessimum proportion. With cherts, the pessimum proportion can vary from as little as 5% of an aggregate to as much as 50%. The pessimum proportion appears to be related to the reactivity of the aggregate: the more reactive, the lower the pessimum proportion.

Lower expansions are observed when amounts of rocks or minerals smaller or larger than the pessimum proportion are present in aggregates (Hobbs, 1984). The pessimum proportion can also be influenced by the alkalinity of the concrete, the particle size of the reactive component, and the water-to-cementitious materials ratio. In pits or quarries, where the composition of the aggregate can vary from one location to another, consideration should be given to evaluating minerals or rocks suspected of exhibiting the pessimum proportion at various proportions of the aggregate. The pessimum proportion can be observed in mortar bar and concrete expansion tests.

B.3.2 CSA A23.2-15A, *Petrographic examination of aggregates*

Petrographic examination is an essential first step in evaluating the potential reactivity of an aggregate. It is carried out to determine the type or types of rock comprising an aggregate. This information is required when judging the need for further testing and is essential for interpreting the test results.

Petrographic examination plays a critical role in the process of evaluating the potential alkali-reactivity of aggregates, as described in Figure 1 of CSA A23.2-27A. Petrographic examination is used to identify quarried carbonate rocks that should be subjected to a screening process for identifying a potential alkali-carbonate reactivity using CSA A23.2-26A.

In certain instances, where specific rocks or minerals are known to cause deterioration of concrete, identification of these constituents in an aggregate, by petrographic examination, might be sufficient evidence to reject the aggregate. Care is needed, for instance, when making petrographic examinations of siliceous limestones, in which less than 5% finely divided quartz particles, invisible in the petrographic microscope, can cause deleterious expansion in concrete (Bérard and Roux, 1986, and Fournier and Bérubé, 1991b). Petrographic examination can also be used to determine the potential reactivity of quartz-bearing rocks by determining the presence and amount of microcrystalline quartz. Petrographic examination is also helpful in determining the potential alkali-carbonate reactivity of limestone and dolostone aggregates.

B.3.3 CSA A23.2-25A, *Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars*

This Test Method can be used to identify nearly all varieties of alkali-silica reactive aggregates (Grattan-Bellew, 1990; Fournier and Bérubé, 1991a and 1991b; Hooton, 1991; Bérubé and Fournier, 1992a; and Lu *et al.*, 2006). This Test Method is not suitable for evaluating the expansivity of aggregates exhibiting alkali-carbonate reactivity, as alkali-carbonate reactive aggregates typically induce limited expansion in this test (Lu *et al.*, 2008). This Test Method is suitable for the acceptance of many aggregates for use in concrete, but the results should not be used as the basis for rejection of an aggregate without first

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determining its expansivity in the concrete prism test (CSA A23.2-14A). This Test Method is not suitable for evaluating the effectiveness of low-alkali cement in preventing or minimizing expansion due to alkali aggregate reaction.

A number of quarried siliceous limestone aggregates in the Montréal area that expand less than 0.15% after 14 d when tested in accordance with CSA A23.2-25A have caused deleterious expansion in field structures and shown more than 0.040% expansion in concrete prism tests (CSA A23.2-14A). Therefore, a lower limit of 0.10% is recommended for this type of aggregate (Fournier and Bérubé, 1991b). Investigations have also shown that dolostone aggregates from the Montréal area that expand less than 0.15% after 14 d when tested in accordance with CSA A23.2-25A gave expansions greater than 0.040% in the concrete prism test (CSA A23.2-14A); however, there are no indications that these aggregates have caused deleterious expansion and cracking of concrete in the field. There are reports of deterioration of field concretes made with aggregates containing granites, gneisses, and granodiorites of Grenville age (Rogers, 1983) and also some horizons of the Potsdam sandstone (Lu *et al.*, 2006) that exhibit less than 0.10% expansion at 14 d when tested in accordance with CSA A23.2-25A.

Research has shown that the degree of reactivity of reactive aggregates is not similarly assessed by the accelerated mortar bar and the concrete prism tests (Lu *et al.*, 2006; Fournier *et al.*, 2006). In the process of selecting preventive measures for concrete incorporating reactive aggregates, the reactivity of concrete aggregates should be assessed. CSA A23.2-27A indicates that when concrete prism expansion test data are not available, the expansion of mortar in the accelerated mortar bar test may be used. For accelerated mortar bar expansions between 0.15% and 0.40%, the aggregate is to be considered as highly-reactive while an aggregate inducing an accelerated mortar bar expansion of greater than 0.40% is considered as extremely reactive when based on that test only.

The method is commonly used for assessing the effectiveness of supplementary cementitious materials (SCMs) in preventing or minimizing expansion due to alkali-silica reaction (CSA A23.2-28A). It has also been developed into a specific test method by ASTM (ASTM C1567). Data using Canadian reactive aggregates indicate that the use of a 14 d expansion limit of 0.10% generally provides a good indication of the effectiveness of SCMs in preventing deleterious expansion based on correlations with long-term testing of concrete prisms (Durand *et al.*, 1990; Duchesne and Bérubé, 1992; Fournier *et al.*, 1996; and Thomas *et al.*, 2006, 2007). The accelerated mortar bar test is part of the optional test requirements of CSA A3001 for evaluating the effectiveness of SCMs to control expansion due to alkali-silica reaction. Because of the nature and severity of the test, conclusions based on data obtained with this test on the effectiveness of SCMs should be confirmed using CSA A23.2-28A or long-term field performance.

B.3.4 CSA A23.2-14A, *Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)*

This is the recommended test method for the determination of the potential reactivity (alkali-carbonate and alkali-silica reactivity) of all types of aggregates. In this test, concrete prisms are stored at 38 °C and 100% humidity to accelerate expansion. Aggregates inducing concrete prism expansions at 0.040% or greater at one year are considered as reactive; however, CSA A23.2-27A recognizes that, in the case of critical structures such as those used for nuclear containment or large dams, a lower expansion limit might be required. It is the only test that allows the evaluation of combinations of fine and coarse aggregates proposed for specific projects.

In the process of selecting preventive measures against alkali-silica reaction in accordance with CSA A23.2-27A, the degree of reactivity of the aggregate is best determined using the concrete prism test and is obtained as follows:

a) 0.040% ≤ one year expansion < 0.120%: moderately reactive;

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b) 0.120% ≤ one year expansion < 0.260%: highly reactive; and
c) one year expansion ≥ 0.260%: extremely reactive.

The test has been adapted to evaluate the effectiveness of supplementary cementitious materials and lithium-based admixtures on expansion of concrete-containing reactive aggregates, as described in CSA A23.2-28A. When the test is used for this purpose, care should be taken to prevent alkali leaching (Rogers and Hooton, 1991) and expansion should be measured for at least two years.

Variation in the amount of expansion of concrete prisms in this test can be quite high and for this reason it is good practice to periodically include in each test series, as a check, prisms made with reactive and non-reactive aggregates with known expansion characteristics.

Note: *Known alkali-silica and alkali-carbonate reactive aggregates are available from the Materials Research and Engineering Office, Ontario Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8.*

B.3.5 CSA A23.2-26A, *Determination of potential alkali-carbonate reactivity of quarried carbonate rocks by chemical composition*

This test involves the analysis of quarried carbonate aggregate for CaO, MgO, and Al_2O_3. The results are plotted on a graph showing zones that correspond to aggregates potentially expansive or not due to alkali-carbonate reaction. Relatively pure limestones and dolomites can be readily identified and do not require further testing for alkali-carbonate reactivity. Dolomitic limestones plot in the potentially expansive area of the graph and require further testing in accordance with CSA A23.2-14A before they are considered for use in concrete. This chemical test is quick and inexpensive, and can reduce some of the difficulties or subjectivity inherent in using petrographic examination to identify potentially alkali-carbonate reactive dolomitic limestones.

B.3.6 Other test methods

B.3.6.1 General

A number of other test methods have frequently been used in the past to evaluate the potential alkali-reactivity of aggregates but, owing to deficiencies in these methods, they are not generally recommended. The most commonly used of these test methods are discussed in Clauses B.3.6.2 to B.3.6.5. Comments are also provided on two test methods that have been proposed in recent years (i.e., the accelerated concrete prism test (60 °C) (see Clause B.3.6.6) and the concrete microbar test (see Clause B.3.6.7)). These tests have shown promise but, due to the lack of technical data, they are not recommended at this stage.

B.3.6.2 ASTM C289, *Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)*

In this test method, a representative sample of the aggregate is crushed and 25 g of 300 µm to 160 µm material is placed in a container with 25 mL of 1 N NaOH. The container and sample are then stored at 80 °C for 24 h. The amount of silica dissolved and the reduction in alkalinity are determined. The results are plotted on a graph showing the following regions:

a) aggregates considered innocuous;
b) aggregates considered potentially deleterious; and
c) aggregates considered deleterious. ASTM C33/C33M indicates that the potential for expansion in concrete of aggregates identified as deleterious or potentially deleterious in the ASTM C289 should be verified using ASTM C227 or ASTM C1293 (equivalent to CSA A23.2-14A).

The chemical method has been widely used, but in its present form correlation between the amount of dissolved silica obtained in this test and either field experience or the results of the concrete prism

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expansion test is in some instances poor (Grattan-Bellew, 1989; Hooton, 1990). In the crushing of the aggregate necessary to prepare test samples, the reactive phase might be lost if it passes through the retaining sieve, resulting in misleading results. Satisfactory aggregates can give poor results due to the higher surface area exposed in the crushing process (Bérubé and Fournier, 1992b). There is also a problem created by interference of carbonates and some other minerals in the results of the chemical test. To overcome this, a modified version of the test has been proposed for use with carbonate aggregates (Bérard and Roux, 1986; Fournier and Bérubé, 1990).

B.3.6.3 ASTM C227, *Potential alkali reactivity of cement-aggregate combinations (mortar-bar method)*

In this test method, an aggregate is prepared to a specific fine aggregate grading (identical to that specified in the accelerated mortar bar test ASTM C1260). Coarse aggregate is first crushed. The aggregate is mixed with hydraulic cement in the ratio 2.25:1 and water is added to meet a specified flow. The mortar is cast in 25 mm × 25 mm × 285 mm bars and cured for 24 h. The bars are demoulded and their length measured. The bars are then stored at 38 °C over water in a sealed container for the duration of the test. Length measurements are made at regular intervals, normally for up to one year. Excessive expansion indicates a potential for deleterious expansion in concrete. ASTM C33/C33M indicates that despite the fact that there is no precise line of demarcation between innocuous and potentially deleterious combinations, mortar bar expansions are generally considered “excessive” when they exceed 0.05% at three months or 0.10% at six months. Also, expansions greater than 0.05% at three months should not be considered excessive when the six m expansion is less than 0.10%.

The mortar-bar method, withdrawn in 2018, was the earliest test method developed for the evaluation of the potential reactivity of aggregates; however, it has been found that in many instances it underestimates the potential expansivity of certain aggregates, especially slowly reactive aggregates (Grattan-Bellew, 1989). The low expansions obtained in this test can be caused by the lack of sufficient alkalis in the cement and leaching of alkalis from the mortar bars in the storage containers (Rogers and Hooton, 1991). It has been found that a cement alkali content of 1.25% Na_2O equivalent (achieved by adding sodium hydroxide in solution to the mortar) and testing for at least one year is necessary to successfully identify the majority of alkali-silica reactive aggregates.

B.3.6.4 ASTM C586, *Potential alkali reactivity of carbonate rocks for concrete aggregates (rock cylinder method)*

Cylinders 35 mm long and 9 mm in diameter are cored from a rock specimen. Conical or plane ends are machined on the ends to facilitate length measurements. The cylinders are immersed in 1 N NaOH at 23 °C. Length measurements are made periodically, normally for up to one year. Excessive expansion indicates a potential for deleterious expansion in concrete.

This test method is only suitable for evaluating rock susceptible to the alkali-carbonate reaction. It is most useful for identifying specific potentially reactive beds or ledges in quarries. A large number of specimens are needed for proper evaluation of a source, at least three specimens for each metre of stratified rock in a quarry. This test method is not suitable for identifying alkali-silica reactive rock. When used on alkali-silica reactive rock, the specimens sometimes do and sometimes do not show expansion, disaggregation, apparent contraction, or reaction gels (Bérubé and Fournier, 1992b). Non-alkali-reactive aggregate might expand in this test due to swelling clays found in some carbonates (Dolar-Mantuani and Laakso, 1974). Results obtained using this test method should always be confirmed by the concrete prism expansion test in CSA A23.2-14A.

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B.3.6.5 ASTM C342, *Potential volume change of cement-aggregate combinations (also known as the conrow test)*

This test method is not suitable for determining the potential alkali-reactivity of Canadian aggregates (Hooton, 1990). It has been found useful with certain aggregates found in parts of the Midwestern US.

B.3.6.6 Accelerated concrete prism test

The accelerated concrete prism test (ACPT) was proposed by Ranc and Debray (1992) for evaluating, in a timely manner (i.e., less than two months), the performance of job mix designs regarding their potential alkali-silica reaction. The authors proposed to accelerate the process of reaction/expansion by increasing the testing temperature from 38 to 60 °C. Since then, a number of studies have confirmed the potential for the ACPT to quickly evaluate the potential alkali-silica and carbonate reactivity of concrete aggregates (Murdock and Blanchette, 1994; DeGrosbois and Fontaine 2000; Touma *et al.*, 2001, Fournier *et al*. 2006). Using a 13 week 0.04% expansion limit at 60 °C, the ACPT has been found to generally provide a similar assessment of the potential alkali-reactivity of aggregates as the conventional CPT (0.04% expansion at one year).

Reasonably low multi-laboratory variability was observed when test prisms were made in one location but tested at 60°C for expansion in different laboratories (Fournier *et al.*, 2004a). However, recent research has shown that the type of non-reactive sand used in the concrete (i.e., when evaluating the potential alkali-reactivity of coarse aggregates) can have a significant impact on the expansions measured in the ACPT (Ideker *et al.*, 2010, Fournier *et al.*, 2006).

The test was also used for evaluating the efficacy of SCMs and lithium-based admixtures to control expansion due to alkali-silica reaction. Using a 0.04% expansion limit at either 6 m (SCMs) or 9 m (lithium), the accelerated CPT was found to generally provide a similar assessment of the various systems evaluated as for the CPT performed at 38 °C (0.04% expansion at two years) (Tremblay *et al.*, 2007; Fournier *et al.*, 2008).

B.3.6.7 Concrete microbar test

The concrete microbar test (CMBT) was proposed by Xu *et al.* (2000) for evaluating the potential alkali-carbonate reactivity of limestone/dolostone aggregates. This test is essentially similar to CSA A23.2-25A except that the bar size is 40 mm × 40 mm × 160 mm and the aggregate is graded to pass a 8 mm or 10 mm sieve and be retained on 4 mm or 5 mm sieve. The mixture proportions include one part Portland cement to one part aggregate, while the water-to-cement ratio is 0.30. The testing period in the 1N NaOH solution at 80 °C is 30 d. A tentative limit of 0.10% at four weeks had been proposed in the original work performed by Xu *et al.* (2000).

The method has been adopted by RILEM (Method AAR-5) to assess the potential contribution of alkali-carbonate reaction in the process of deleterious expansion of concrete incorporating reactive carbonate aggregates (Sommer *et al.*, 2004). In order to better differentiate alkali-carbonate reactive limestone/dolostone aggregates from alkali-silica reactive ones, it was proposed to run the CMBT using 30% Type F (low alkali) fly ash, knowing that such a proportion of fly ash would likely control expansion due to alkali-silica reaction, but would have limited effect at controlling alkali-carbonate reaction (Lu *et al.,* 2004).

Grattan-Bellew *et al.* (2003, 2004) evaluated the use of the CMBT (however, using –12.5 to +4.75 mm particle sized aggregate) on a wide selection of carbonate and siliceous aggregates. The results showed good correlation between expansion of concrete microbars containing alkali-silica reactive limestone aggregates and in the CPT, with a proposed expansion limit of 0.09% at 30 d. The correlation was not so good for the assortment of alkali-silica reaction aggregates tested, which included greywackes,

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sandstones, volcanic rocks, gravels, mylonite, and cataclastite; however, the aggregates, which exhibited concrete microbar expansions of less than 0.04% at 30 d, were found not to expand significantly in the CPT as well.

B.4 Distribution of potentially reactive aggregates

B.4.1 Introduction

Potentially reactive aggregates occur in all regions of Canada. In this compilation of the occurrence of potentially reactive aggregates, the published and unpublished experiences of a number of agencies have been drawn upon. However, this catalogue of known potentially reactive aggregate occurrences is not all-inclusive and it should be expected that new occurrences of such aggregates will be found.

B.4.2 Newfoundland and Labrador

A detailed description of the occurrence of alkali-aggregate reaction is found in Bragg (2000).

Some Ordovician limestones of the Pigeon Head Formation in western Newfoundland that contain chert nodules and quartz ”eyes” are alkali-silica reactive in laboratory testing. Siliceous ”cherty” siltstone and sandstones have caused cracking in concrete structures in eastern Newfoundland. These rocks were also identified as reactive in laboratory tests.

Argillites, greywackes, arkose, phyllites, gneisses, schists, granites, felsic volcanics, psammites, and pelites have caused various degrees of damage, from slight in 10- to 20-year-old concrete, to moderate in 20- to 30-year-old concrete, to severe in more than 30-year-old concrete. Aggregates found in Labrador contain gneiss, metavolcanics, metasediments, greywacke, and felsic volcanics that are potentially alkali-silica reactive. Only limited testing has been conducted, but it has confirmed that the greywackes, metasediments, and gneisses are potentially deleteriously reactive.

B.4.3 Atlantic Canada

B.4.3.1 Nova Scotia

A detailed description of the occurrence of alkali-aggregate reaction is found in Langley (2000).

An extensive investigation was initiated in 1965 by the Nova Scotia Power Commission to determine the cause of concrete expansion and cracking in the province. Alignment problems with generators and turbines on the Mersey River hydroelectric plants were attributed to slow concrete expansion due to an alkali-aggregate reaction.

A series of field surveys carried out from the 1960s to the 1980s confirmed that alkali-aggregate reaction was widespread in Nova Scotia, with the exception of Cape Breton, and that many structures were at an advanced state of deterioration. While many non-reactive aggregate sources can be verified for conformance to the limits established in CSA A23.2-27A using CSA A23.2-25A, the Cape Breton aggregate sources generally need to be tested to the requirements of CSA A23.2-14A to show conformance to the specified limits. The main alkali-reactive rock types are derived from the Meguma Group and consist of metamorphosed greywackes, argillites, and phyllites, and some quartzites, schists, and rhyolites. The intrusion of igneous rocks into the sediments has resulted in changes in the crystal structure of the minerals so that the reactivity of the metasediment is reduced in the area of contact with the igneous rocks. The further the metasediments are from the igneous rocks, the greater the reactivity. The plutonic igneous rocks are generally non-reactive.

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Moderately- to highly-reactive metasediments from several quarries in the Halifax-Dartmouth area are used as concrete aggregates. These aggregates have been used with Type F fly ash at an appropriate rate of cement replacement to make durable concrete in this area. This approach generally applies to all reactive aggregate sources exploited for use in concrete in the province.

B.4.3.2 New Brunswick

A detailed description of the occurrence of alkali-aggregate reaction is found in DeMerchant *et al*. (2000).

Alkali-aggregate reactivity has been suspected to be a factor in the deterioration of concrete structures in New Brunswick since the early 1960s. Investigations in the 1980s and 1990s showed that concrete structures affected by alkali-aggregate reactivity with gravel or bedrock aggregates can be found in every region of the province. Alkali-aggregate reaction was generally found in a higher proportion of structures in the southern and western portions of the province. The primary reactive material in the reactive rock types is believed to be microcrystalline quartz.

Deposits of sand and gravel are exploited for concrete aggregates in the western and northwestern portions of New Brunswick. These deposits are derived from underlying Silurian-Devonian and Ordovician-Silurian sedimentary rocks that are folded and metamorphosed to Greenschist grade. Reactive rock types are argillites, greywackes, and argillaceous limestones.

From the northeast to the southwest of New Brunswick, passing through the central area of the province, is a deposit of Cambrian-Ordovician sediments and volcanics with large Devonian granite intrusions. Some sedimentary and fine-grained volcanic rocks, such as greywackes and basalts, are reactive. Coarse aggregates obtained from greywacke from the intake channel excavation have caused concrete distress in the Mactaquac Dam, built between 1965 and 1968, near Fredericton. Reactive greywackes and argillites are also found in the southwestern portion of the province, which is characterized by a complex of Devonian to Cambrian metamorphosed sediments and volcanics. Along the south shore is a complex of deformed Precambrian rocks with some reactive schists, gneisses, and granites.

Non-reactive rock types in New Brunswick generally consist of limestones and marbles free of quartz and phyllosilicates, and undeformed basalts, diabase, gabbros, granitoids, and rhyolites.

B.4.4 Québec

B.4.4.1 General

A detailed description of the occurrence of alkali-aggregate reaction is found in Bérubé *et al.* (2000).

B.4.4.2 St. Lawrence Lowlands

Some siliceous limestones of the Trenton and Black River age (Middle Ordovician) outcropping from Hull through Montréal, Trois-Rivières, and Québec City to La Malbaie have been found to be alkali-silica reactive in numerous highway structures and in a number of dams in the St. Lawrence Lowlands. Some varieties of Potsdam sandstone of the Cambrian and Early Ordovician age found near Montréal are deleteriously reactive. The Beauharnois Dam and a number of bridge and seaway (lock) structures have been affected. Secondary quartz overgrowths around the detrital quartz sand grains in the sandstone are thought to be the reactive phase. The Hemmings Dam, located on the Saint-François River, is made with greywacke and is also affected by alkali-silica reactivity.

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B.4.4.3 Appalachian region

Rhyolitic tuffs of the Beauceville Formation (Magog Group) in the southeast of Québec City have been found to be deleteriously reactive in the Sartigan Dam. Some reactive volcanic rocks and chloritic schists and phyllites in the Eastern Townships have been identified as marginally alkali-silica reactive. Gravels containing various quantities of greywackes, quartzites, volcanics, and metavolcanic rock fragments have been found to be alkali-silica reactive in dams in the Eastern Townships (Allard Dam), in "Bas St-Laurent" (Témiscouata Dam), and in the Gaspé Peninsula (Lac Mitis Dam).

B.4.4.4 Laurentian Shield

In the Abitibi-Témiscamingue area and along the Ottawa River, some granitic gneisses, metagreywackes, and biotite schists are known to be expansive in a number of dams (Rapide-des-Îles, Rapide-des-Quinze, Première-Chute and Angliers Dams). Some granites and granitic gneisses, quartz diorites, and quartz-biotite hornblende gneisses of Grenville age (Precambrian) are thought to be marginally alkali-silica reactive in dams in the Gatineau region (Chelsea and Paugan Dams) and deleteriously alkali-silica reactive in dams north of Trois-Rivières (La Tuque, Rapide-Blanc, La Gabelle, Gouin, and Grand-Mère Dams).

Several dams of hydro-electric complexes from the Manicouagan-Outardes and James Bay regions made with Precambrien granitic aggregates (granite, granitic gneiss granitique, and quartz-biotite-hornblende gneiss) show some signs of alkali-silica reactivity (i.e., silica gel, dark rims, and polygonal crack pattern). Strains measured at these dams are generally in the order of magnitude of 5-10 µm/m/year. Some sources of concrete aggregates of the dams from these regions have been submitted to CSA A23.2-14A concrete expansion tests and to long term outdoor exposure expansion tests, and they were classified as non-reactive to weakly or marginally reactive (or just above the 0.040% limit).

B.4.5 Ontario

B.4.5.1 General

A detailed description of the occurrence of alkali-aggregate reaction is found in Rogers *et al*. (2000).

B.4.5.2 Northern and central Ontario

Potentially reactive Paleozoic cherts from the James Bay Lowlands appear in gravels over much of northern Ontario and have caused distress in concrete structures, from Ear Falls in the west to the Smooth Rock Falls area in the east. Precambrian chert from iron mines known as "Taconite" has also been shown to be deleteriously reactive in concrete. Rhyolitic porphyry quarried northeast of Timmins has caused expansion of concrete in the Frederick House River Dam. Quartz/mica schist from the Lake Nipigon area has been found to be reactive in laboratory studies. Silicified volcanic rocks in gravels near Wawa have been found to be potentially reactive in laboratory tests.

Precambrian sandstones, argillites, quartz arenites, quartzites, and greywackes of the Huronian Supergroup found in the north shore of Lake Huron, Sudbury, and New Liskeard regions have been found to be slowly alkali-silica reactive. Damage to concrete containing these aggregates generally does not appear for at least 10 years. However, some bridges in the Sudbury area were found to be cracked after only four years. Gravel coarse aggregates found to be deleteriously reactive are those which contain more than 15% of these rock types.

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B.4.5.3 Southern Ontario

Quarried granite of the Grenville age (Precambrian) has been found to be slowly alkali-silica reactive and causes deterioration of concrete. Potentially reactive granites of the Grenville age occur mainly in the region to the southeast of the line joining Bracebridge and Pembroke.

Some quarried limestones of the Black River and Trenton age (Middle Ordovician) in the Pembroke, Ottawa, Cornwall, and Peterborough regions that contain a small percentage of chert and finely disseminated silica have been shown to be deleteriously expansive in concrete in the field and in the laboratory. The gravels in Durham, Northumberland, and Peterborough counties contain these slightly siliceous limestones and have caused cracking in many structures due to alkali-silica reaction. Results using the chemical test method in ASTM C 289 have indicated that some Paleozoic cherts from southwestern Ontario are potentially reactive, but this was not confirmed by subsequent laboratory studies and damage was usually not observed in concrete structures when the chert content of the aggregate was less than 5%. Recent laboratory and field studies, however, have shown that some aggregates containing chert are reactive. Sands imported from southeastern Michigan have also been found to be alkali-silica reactive.

Rock exhibiting alkali-carbonate reactivity is found in the Gull River Formation of Middle Ordovician age that outcrops along the southern margin of the Canadian Shield from Midland to Kingston. The same reactive rock also outcrops in the Ottawa-St. Lawrence Lowlands near Cornwall and in the Ottawa area. Nepean sandstone found in gravels and bedrock in the Frontenac Arch in the Brockville to Lanark area has been found to be alkali-silica reactive.

B.4.6 Hudson Bay and James Bay Lowlands of northern Ontario and Manitoba

Potentially alkali-carbonate reactive rocks of the Ordovician age can also be found in the Hudson Bay lowlands of northern Manitoba and northern Ontario. Dolomitic limestone of the Bad Cache Rapids Group near the Nelson River shows potential for expansion in concrete. Cylinders of this rock immersed in NaOH also expand excessively. Surficial sands and gravels in this area can contain potentially alkali-silica reactive chert, argillite, and greywacke.

B.4.7 Prairie region

B.4.7.1 General

A detailed description of the occurrence of alkali-aggregate reaction is found in Roy and Morrison (2000).

B.4.7.2 Manitoba and Saskatchewan

In eastern Manitoba, aggregates derived from Canadian Shield granitic rocks have been found to have potential for deleterious alkali-aggregate reactivity, based on reports of alkali-aggregate reactivity at the Pointe du Bois generating station on the Winnipeg River.

Instances of alkali-aggregate reactivity in concrete in southern Saskatchewan and southwestern Manitoba have not been clearly documented. The use of locally-produced cements with relatively low alkali contents (0.5% to 0.8% Na_2O equivalent) combined with the low humidity of the region have resulted in limited occurrence of and potential for alkali-aggregate reactivity (AAR). External sources of alkali have been linked to some suspected cases of AAR. Cements currently used in Manitoba are increasingly supplied by plants in central Canada, where higher-alkali cements are produced. Several sand and gravel deposits in the Winnipeg region and throughout southern Manitoba have been tested, with expansion classified as ”non-reactive” when measured in accordance with CSA A23.2-25A.

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Quarried carbonate rocks used as aggregates in the Winnipeg (Stonewall) area have shown low reaction potential when evaluated in accordance with CSA A23.2-26A.

Granular deposits in southwestern and south-central Manitoba and in much of the grain belt of Saskatchewan contain varying amounts of a siliceous (opaline) shale. This material was first identified during the construction of the Gardiner Dam in Saskatchewan. Although the siliceous shale is very reactive, it is generally found only in small amounts in the surficial sands and gravels and does not usually produce harmful expansion in concrete made with the locally available cements. These aggregates have caused cracking of concrete in cases where the concrete has been exposed to external sources of alkali, such as alkali-laden groundwater. These aggregates also cause problems relating to popouts on flat work and other exposed concrete surfaces. Surficial granular deposits in the region also contain a significant proportion of quartzite with potentially reactive microcrystalline quartz. Approximately 80% of the aggregates tested from the southern grain belt have given more than 0.15% expansion when tested in accordance with CSA A23.2-25A. In some cases this potential for deleterious reaction has been confirmed by expansion greater than 0.040%, when tested in accordance with CSA A23.2-14A.

B.4.7.3 Alberta

Some bridges, dams, and water management structures in Alberta exhibit evidence of alkali-silica reaction. Currently, well-documented cases of structures affected by AAR are confined to southern Alberta. These are structures that are more than 50 years old and include dams and spillways. Other instances of AAR have been reported in central Alberta and the Edmonton region. Concrete prism tests of fine and coarse aggregates indicate that potentially reactive aggregates occur throughout the province. Many sand and gravel deposits in central and northwest Alberta and the Edmonton region have expansion levels that are classified as “moderately to highly reactive”, when tested in accordance with CSA A23.2-14A. Accelerated mortar bar tests have given similar indications of reaction potential. The indicated reactive aggregates include chert, arenite, sandstone, greywacke, cherty sandstone, and quartzite. These rock types are found throughout Alberta.

Reaction levels of aggregates from the Calgary-area and southern Alberta range from “low” to “high”, depending upon the geology of the aggregates. Reactive aggregate components in this area include chert, quartzite, sandstone, as well as volcanic rocks from the Blairmore area.

Fort McMurray-area aggregate supplies tend to have low reaction potentials when tested in accordance with both CSA A23.2-25A and CSA A23.2-14A. However, geological composition of area sand and gravel deposits varies widely, necessitating individual assessment of aggregate supplies.

The levels of alkalis in cements supplied to the Alberta market since 1990 are typically 0.45% to 0.65%. These low levels of cement alkalis are likely the main reason that Alberta has experienced a low overall incidence of problems related to alkali-aggregate reaction.

B.4.8 British Columbia

A detailed description of the occurrence of alkali-aggregate reaction in British Columbia is found in Shrimer (2000) and Shrimer *et al.* (2008).

Although alkali-aggregate reactivity has not been a major problem in British Columbia, the number of documented cases of alkali-aggregate reactivity in concrete structures have increased. Historically, locally produced cements have had low alkali contents (0.3 to 0.55% Na_2O equivalent). This has resulted in a very low incidence of alkali-aggregate reactivity in most concrete in BC. However, testing of BC aggregates indicates that the potential for alkali-aggregate reactivity is significant. It has been found

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that 90% of BC aggregates exceed the recommended limit (0.15%) when tested in accordance with CSA A23.2-25A. When tested in accordance with CSA A23.2-14A, the proportion of BC aggregates that exceed the recommended limit of 0.040% at one year is approximately 45%. Most of the reactive concrete aggregates are derived from sand and gravel deposits, which contain variable amounts of sandstone, quartzite, chert, volcanic rock, granitic, and metamorphic rocks. Quarried sources of concrete aggregate are less common in British Columbia, although their use is increasing.

ASR-affected structures, such as dams and bridges, have been identified in the North Coast and central parts of the province, in the Prince Rupert-Terrace-Kitimat area, Smithers-Hazleton-Burns Lake areas, Prince George-North Cariboo area, and Dawson Creek-Chetwynd area. In the central interior, AAR-affected structures have been identified at Williams Lake, 100 Mile House, Spences Bridge, Lillooet, Kamloops, Chase, Sicamous, Yoho, and Merritt. In the southern interior of the province, alkali-aggregate reaction has been reported throughout the Crowsnest Highway (#3) corridor (primarily in bridges) in the Cranbrook, Okanagan, Princeton, and Grand Forks-Rock Creek areas. Alkali-silica reaction has been identified in a number of dams in the Okanagan Valley. The aggregates comprise volcanic rocks of mixed composition and texture, quartzite, chert, and various metamorphic rocks.

In the South Coast area, structures reported to be affected by alkali-aggregate reactivity include dams, bridges, harbour facilities, and retaining walls throughout the Fraser Canyon and lower Fraser Valley areas, and in the Greater Vancouver Region. Central and upper Fraser Valley sand and gravel aggregates have a moderate-to-high potential for alkali-reactivity. Gravel aggregates derived from granitic rocks of the coast ranges tend to have a low potential for alkali-aggregate reactivity. Recent volcanic rocks from the Garibaldi area (at the north end of the Cascade Volcanic Range) have been found to be very expansive in laboratory testing (0.8 to 1.3% expansion in accordance with CSA A23.2-25A). The presence of opal has been confirmed in volcanic rock of alkali-reactive concrete in Vancouver harbour. On Vancouver Island, the aggregates range in potential for alkali-aggregate reactivity from innocuous to moderately reactive. Confirmed sites of alkali-aggregate reactivity have been reported in the Victoria area.

B.4.9 Arctic Canada

Because of the low volume of construction, little is known about the quality of northern aggregates. As the demand for concrete aggregate increases due to pipeline construction or other large-scale projects, there will be a need to evaluate potential sources of aggregate. Reactive greywacke and chert have been identified at Alert on Ellesmere Island (Gillott and Swenson, 1973). Potentially reactive cherty carbonate gravels and cherty and shaley dolomitic limestones are found in the Inuvik area. Accelerated mortar bar tests have identified potentially reactive sand and gravel deposits along the Mackenzie River and volcanics in Nunavut. Fly ash has been used. Non-reactive sands and quarried granitic and basaltic aggregates have been identified in the Yellowknife region. Expansion due to alkali-aggregate reactivity is slowed by low temperatures, but low temperatures should not be relied upon to protect the concrete if highly reactive aggregates are used. Aggregates taken from raised beach deposits in the Arctic can contain unusually high amounts of sodium chloride. If used in concrete, these aggregates can contribute extra alkalis to the mixture as sodium.

B.5 Preventive measures to mitigate alkali-aggregate reactions in concrete

B.5.1 Alkali-carbonate reaction

The best and most practical preventive measure has been to avoid the use of these aggregates. In some cases, low alkali-cement (i.e., less than 0.6 Na_2O equivalent) does not prevent deleterious expansion

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(Swenson and Gillott, 1964, Shehata *et al*., 2009). Blast-furnace slag cement has not been found to be effective (Rogers and Hooton, 1992) even with replacement levels up to 65% (Thomas and Innis, 1998). Shehata *et al.* (2009) found that replacement levels up to 25% Type F, 30% Type CI, and 50% Type CH fly ash, 10% silica fume, 15% metakaolin, and ternary blends containing 5% silica fume and up to 25% Type F or CI fly ash or 30% slag were ineffective in mitigating expansion in concrete containing highly reactive carbonate aggregate from Kingston, Ontario. Many of these blends reduce the 2 year expansions of concrete prisms but did not meet the 0.040% expansion limit. Combination of Portland cement of 0.8% Na_2O_e and 20% Type CI fly ash was not effective in mitigating the expansion (Shehata *et al*., 2009). Lithium hydroxide and lithium carbonate have been found to increase expansion of alkali-carbonate reactive rock (Wang *et al.,* 1994). In the horizontally bedded carbonate bedrock quarries, where these aggregates have been found, the use of a specific level or bench of non-reactive rock for concrete aggregate supply is a recommended practice (Ryell *et al.*, 1974).

B.5.2 Alkali-silica reaction

B.5.2.1 General

The risk for deleterious expansion and cracking of concrete due to alkali-silica reaction can be minimized through preventive measures. Selective extraction or beneficiation of the aggregate to reduce or eliminate the reactive material is the safest method (see Clause B.5.2.2). Reduction in the alkali content of the concrete by reducing the cement content or using a cement with lower alkali content, or both, may be used (see Clause B.5.2.3). Supplementary cementitious materials (e.g., fly ash, ground granulated blast-furnace slag, silica fume, or metakaolin) and lithium-based admixtures, when used in appropriate amounts, can be effective in preventing or reducing expansion due to alkali-silica reactions (see Clauses B.5.2.4 to B.5.2.6).

Clause B.5.2.7 provides guidance on the occurrence of unusual sources of alkalis that can be encountered, and the migration of alkalis. The recommended strategy for identifying appropriate measures for prevention of alkali-aggregate reactivity is in CSA A23.2-27A.

B.5.2.2 Aggregate beneficiation

The most commonly used measure to avoid alkali-aggregate reaction is the beneficiation or selective quarrying of aggregate. In areas that contain significant amounts of chert in gravel, it is possible to selectively crush oversize gravel, which normally contains less chert (Ingham and Koniuszy, 1966). Heavy media separation and jigs have been used to remove shale and chert from gravels (Price, 1961). In horizontally bedded carbonate bedrock quarries, the use of a specific level or bench for concrete aggregate supply is a recommended practice. Other benches or levels might have deleterious aggregate. However, careful, conscientious extraction and stockpiling can often ensure an adequate supply of suitable aggregate (Ryell *et al.*, 1974).

B.5.2.3 Reduced alkali content

Reducing the alkali content of concrete can be effective in reducing expansion due to alkali-silica reaction. Such a reduction can be achieved by reducing the cement content of the concrete or the cement alkali content, or both. The specific maximum alkali level for any situation should be selected in accordance with CSA A23.2-27A. Allowance should be made for likely variations that will occur in the alkali content of the cement and for variations that will occur in the cement content of the concrete.

In some cases, a limit of 3.0 kg/m^3 is not effective with massive concrete structures where slight expansion can be deleterious. For example, in dams, problems have been experienced when the concrete alkali content has been as low as 2.0 kg/m^3. A limit of 3.0 kg/m^3 is also not effective in some

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cases when the concrete is exposed to external sources of alkali and/or when the aggregate is severely reactive or might itself contribute alkalis (Bérubé *et al.*, 1996). Rogers *et al.* (2000) reported expansion and cracking of concrete blocks (0.6 m × 0.6 m × 2.0 m) containing Spratt aggregate and just 1.9 kg/m^3 Na_2O after eight years storage on an outdoor exposure site in Kingston, Ontario.

CSA A23.2-27A specifies the levels of concrete alkali necessary to provide satisfactory prevention depending on the reactivity of the aggregate, the environment, and the expected service life. Also, limiting the alkali content to less than 3.0 kg/m^3 has been found ineffective with concrete containing recycled concrete aggregates (RCA) produced from demolished concrete that has been affected by alkali-silica reaction (Shehata *et al.*, 2010). Details on the reactivity of RCA are described in Clause B.6.

B.5.2.4 Fly ash and ground granulated blast-furnace slag

Fly ash and ground granulated blast-furnace slag have been used with alkali-silica reactive aggregates in other countries (Thomas *et al.*, 1992). To date, there have been no reported incidents of damaging alkali-silica reaction in concrete structures containing sufficient levels of these materials. In Canada, there are a limited number of examples of such reactions. The first use of fly ash as a preventive measure, with a high-alkali cement, was in the Lower Notch Dam in 1970. Ontario Hydro specified the use of 20% and 25% Type F fly ash in combination with a high-alkali hydraulic cement (0.94% Na_2O equivalent) in this structure to prevent alkali-silica reaction with a known reactive argillite (Sturrup *et al.*, 1983). After 40 years, deleterious expansion had not occurred (Thomas *et al*., 2012). The fly ash used was a low-calcium fly ash derived from a bituminous coal, which would probably have met the requirements of Type F fly ash in CSA A3001. Ground granulated blast-furnace slag cement at a 50% replacement level was used on a recent hydroelectric development in northern Ontario in which a marginally reactive metavolcanic aggregate was used with a hydraulic cement having an alkali content of 0.70% Na_2O equivalent and cement contents of 290 kg/m^3 and 340 kg/m^3 (Hooton *et al.*, 2000). In the Halifax area, recently built structures have been constructed with known reactive aggregates with 15 to 25% fly ash and a high-alkali cement (Langley, 2000). To date, these structures have not cracked due to alkali-aggregate reactivity. In the construction of the Oldman River Dam Spillway in Alberta, 25% fly ash was used with a slightly reactive aggregate. The total alkali content of the concrete was also limited to a maximum of 3.0 kg/m^3 Na_2O equivalent. In the early 1990s, a number of Canadian outdoor exposure sites were established to provide demonstration of the efficacy of various supplementary cementitious and other materials in the prevention of deleterious alkali-aggregate reaction. Although the sites are not sufficiently old to provide unequivocal demonstration of effectiveness, the results, at present, confirm the advice given in CSA A23.2-27A.

Laboratory testing using the concrete prism test has clearly demonstrated that the efficacy of fly ash in controlling expansion of concrete due to alkali-silica reaction is a function of the calcium content of the fly ash (Shehata and Thomas, 2000). Fly ashes with low-to-moderate calcium contents that meet the requirements for Type F and Type CI fly ash in CSA A3001 are generally effective in controlling expansion of concrete when used at moderate levels of replacement of 15 to 30%. This was also confirmed through comparative field and laboratory investigations performed on a variety of reactive aggregates (Fournier *et al.*, 2004b; Hooton *et al.*, 2006). Fly ashes with higher calcium contents that would be classed as Type CH fly ash by CSA A3001 are generally not effective unless they are used at replacement levels in excess of 30% and in many cases up to 50% (Shehata and Thomas, 2000; Fournier *et al.*, 2008).

B.5.2.5 Silica fume

The use of silica fume to control alkali-silica reaction was first noted by Asgeirsson and Gudmundsson (1979) in Iceland. Since then, a large amount of research on this means of controlling alkali-silica reaction has been conducted. A synthesis of this data indicates that the efficiency of the silica fume in

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controlling pore solution alkalinity and expansion due to alkali-silica reaction is strongly dependent on the amount of alkali contributed by the hydraulic cement (Thomas, 1996b). Consequently, it is considered appropriate to specify the minimum level of silica fume on the basis of the availability of cement alkalis. The requirements in CSA A23.2-27A are based on the following:

$SF = 2.5 \times AL$

where

SF = silica fume content, % replacement by mass for cement

AL = total alkali content of concrete from hydraulic cement, kg/m^3 Na_2O equivalent

In cases where silica fume is the only supplementary cementitious material to be used, the silica fume content should not be less than 7% by mass.

This relationship is generally consistent with laboratory expansion data for Canadian aggregates (Thomas, 1996b). The use of increased amounts of silica fume with increasing alkali levels is also consistent with the field exposure tests in South Africa reported by Oberholster (1989). A replacement level of 7% silica fume was effective in preventing cracking for at least 7.5 years in concrete containing approximately 4 kg/m^3 Na_2O equivalent, but was not effective when the alkali content was raised to 5 kg/m^3 Na_2O equivalent.

There are relatively few well-documented field cases of using silica fume with reactive aggregates. In Iceland, silica fume has been blended with high-alkali cement (approximately 1.5% Na_2O equivalent) and used with reactive aggregates for housing concrete since 1979. To date there are no reported incidences of alkali-silica reaction in such concrete (Gudmundsson and Olafsson, 1996). In Québec, many structures have been recently built with potentially reactive aggregates and blended silica fume cements containing seven to nine percent silica fume and high-alkali cement. Long-term performance studies need to be conducted to determine if this initial premise is confirmed in field exposure (Bérubé and Duchesne, 1992).

Laboratory testing of concrete has shown that ternary blends containing combinations of silica fume with either fly ash (Shehata and Thomas, 2002; Fournier *et al.*, 2008) or slag (Bleszynski *et al.*, 2002) are effective in controlling expansion due to alkali-silica reaction. In the field, after 20 years, a combination of silica fume and slag was found to control expansion due to alkali-silica reaction (Hooton *et al.*, 2013).

B.5.2.6 Lithium

The ability of lithium compounds (LiF, LiCl, and Li_2CO_3) to control expansion due to alkali-silica reaction was first reported in the early 1950s. It was not until recently, however, that the use of lithium was given serious consideration as a practical remedy for controlling alkali-silica reaction, including as part of a major research project (with field trials) performed in the US under the auspices of the Strategic Highway Research Program (Stark, 1992; Stark *et al.*, 1993). A summary of research and field applications regarding the use of lithium-based admixtures for preventing alkali-silica reaction in new concrete and for mitigating alkali-silica reaction in existing concrete structures affected by alkali-silica reaction was recently published by the US Department of Transportation Federal Highway Administration, Folliard *et al.* (2006).

The level of lithium required to control deleterious expansion due to alkali-silica reaction varies depending on the alkali content of the concrete and the nature and reactivity of the aggregate. Research has demonstrated that Li/(Na + K) molar ratios in the range 0.60 to 1.00 are sufficient to suppress expansion with a significant number of aggregates (Blackwell *et al.*, 1997, and Lumley, 1997) but could reach higher values in the case of some moderately- to highly-reactive aggregates in which

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the reactive component corresponds to micro/cryptocrystalline quartz disseminated in the matrix of the rock, such as greywackes/sandstones, siliceous limestones, and quartzites (Tremblay *et al.* 2007).

It should be noted that lithium hydroxide and lithium carbonate have been found to increase expansion of alkali-carbonate reactive rock (Wang *et al.*, 1994).

Research has shown that insufficient quantities of certain lithium compounds can actually increase expansion. This is related to the increased hydroxyl ion concentration in the pore solution as many lithium compounds combine with calcium hydroxide producing insoluble calcium salt and lithium hydroxide. Lithium nitrate ($LiNO_3$) does not cause this effect due to the high solubility of calcium nitrate. The addition of $LiNO_3$ to cement paste has been found to increase the lithium and nitrate ion concentrations of the pore solution with no significant augmentation of the hydroxyl ion concentration (Stokes *et al.*, 1997). For this reason, lithium nitrate does not exhibit a pessimum effect (i.e., low dosages do not lead to higher expansions).

The evaluation of the efficacy of lithium-based admixtures to control alkali-silica reaction in new concrete is best carried out using the concrete prism test specified in CSA A23.2-28A. Recent research suggests that a modified version of the accelerated mortar bar test could also be used where lithium-based admixtures are added both in the mortar bar and in the soak solution (Tremblay *et al.*, 2008).

B.5.2.7 Alkalis from aggregates and other sources

Some aggregates, such as feldspar-rich rocks, argillaceous limestones, acid volcanic rocks, and aggregates containing alkali-carbonate minerals and alkali-zeolite minerals can contribute significant amounts of alkali to the concrete (Gillott and Rogers, 1994 and 2003; Bérubé *et al.*, 1996). The effect of such alkalis on the promotion of alkali-aggregate reaction and their accelerating effect on the rate of expansion should be considered.

In some cases, where the concrete is exposed to an external source of alkali (e.g., alkali hydroxides in industrial processes) and when a small expansion of the concrete is unacceptable, some preventive measures do not provide adequate protection against long-term deleterious expansion.

Specific service exposures can concentrate alkalis in certain areas of a structure, which can aggravate alkali-aggregate reactions. Examples of such exposures include cycles of wetting and drying, cycles of freezing and thawing, humidity gradients, and electrical currents (Xu and Hooton, 1993).

Sodium chloride has not been found to contribute alkalis to alkali-silica reaction in the laboratory or to increase expansion of Canadian aggregates (Duchesne and Bérubé, 1996). Field experience shows that alkali-silica reactive concrete exposed to sea water and de-icing salts often shows more pattern-cracking than similar concrete not exposed to sea water and de-icing salts. Limited laboratory studies have shown that sodium chloride can increase expansion with certain aggregates.

B.6 Reactivity of reclaimed concrete for use as recycled aggregate

Petrographic examination of the recycled concrete aggregate (RCA), or the concrete to be demolished, should be carried out prior to testing to identify any signs of deleterious reaction. Concrete or RCA identified as being affected by alkali-carbonate reactivity or containing potentially alkali-carbonate reactive aggregates should be rejected for use as RCA in new concrete.

Recent laboratory investigations have shown that recycled concrete aggregates (RCA) produced from demolished concrete affected by alkali-silica reaction can cause deleterious expansion when used as an aggregate in new concrete (Shehata *et al.*, 2010). Consequently, all RCA should be assessed for potential

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alkali-reactivity prior to its use as an aggregate in new concrete. This is best performed by conducting the concrete prism test in CSA A23.2-14A.

Recent research has shown that the accelerated mortar bar test (CSA A23.2-25A) can be effective in detecting the alkali-silica reactivity of RCA when meticulous sample preparation is employed, as identified in the Note from Clause 9.2 of CSA A23.2-25A (Shehata *et al.*, 2010). Fine aggregate (less than 5 mm) obtained from the production crushing processes in plants should not be considered as representative of the coarse RCA product as they are likely to be mainly composed of residual mortar.

Testing using an RCA produced from ASR-affected concrete blocks has shown that the levels of supplementary cementitious materials required to mitigate expansion are higher in RCA concrete than those required with the original virgin aggregate or those recommended in Table 7 of CSA A23.2-27A (Shehata *et al*., 2010). However, the use of ternary blends of 5% silica fume and 25% low- or intermediate-calcium fly ash was effective in mitigating the expansion (Shehata *et al*., 2011). Another approach to mitigate disruptive expansion was blending the reactive RCA with natural non-reactive aggregate. At a blending ratio of 30% non-reactive to 70% reactive RCA, expressed as a percentage of the total coarse aggregate content, the use of 25% low- or intermediate calcium fly ash or 50% slag was effective in mitigating the expansion in concrete prisms (Shehata *et al*., 2011). Also, the use of low-alkali cement might not be sufficient to mitigate the potential for disruptive expansion, as alkalis from the mortar fraction in the RCA can contribute to the reaction. Consequently, the selection of the correct dose or type of SCM should be evaluated using the concrete prism test, in accordance with CSA A23.2-28A. At this stage, because of the lack of technical data, the accelerated mortar bar test is not recommended for evaluating the efficacy of SCM for controlling expansion due to alkali-silica reaction with RCA.

Note: *For use as RCA in new concrete see Figure B.2.*

B.7 Summary

B.7.1 General

The currently available options to avoid the deleterious expansion and cracking of concrete due to alkali-silica reaction in an exposure condition with sufficient available moisture to support the reaction mechanism are as follows:

a) Use proven non-reactive aggregates.
b) Use a reduced alkali content in the concrete, typically by the use of a low-alkali hydraulic cement.
c) Use supplementary cementitious materials or other admixtures in adequate quantities in the concrete when such materials are proven effective in mitigating the detrimental effects of the reaction.

For alkali-carbonate reaction, the best and most practical preventive measure is to avoid the use of the aggregate.

While the mechanisms of the various types of alkali-aggregate reaction are not completely understood, sufficient Canadian studies have been completed over the last 40 years to provide a foundation for the assessment and testing of concrete aggregates so that the requirements of this standard, when used properly, are not likely to lead to the rejection of acceptable aggregates or acceptance of aggregates with subsequent poor field performance.

A history of satisfactory long-term field performance in concrete (i.e., a proven service record) is generally the best way of ensuring that the aggregate is non-reactive. The investigation of field performance will often require the use of laboratory investigation to demonstrate the source of the

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aggregate. In most cases, it will be necessary to carry out a laboratory investigation either to determine the potential reactivity of the aggregates or to determine the effectiveness of mitigation measures.

The correct assessment and testing for alkali-aggregate reactivity characteristics of aggregate is a formidable task due to the subjective nature of some of the work, the impact of relatively small deviations from the standard test procedures, and the inherent difficulty of measuring very small movements in concrete or mortar specimens. In addition, the long period of time required (sometimes in excess of one year) to undertake some of the laboratory tests make the evaluation procedure onerous and difficult to apply for many commercial construction needs.

B.7.2 Considerations

The owner or the contractual party having the responsibility of assessing whether an aggregate is acceptable or not should carefully consider the following guidelines:

a) The assessment and testing for alkali-aggregate reactivity characteristics of aggregates should be carried out under the direction of an individual with considerable experience in this type of work.
b) A petrographic examination of the aggregate source is an essential step in the evaluation of the potential reactivity of an aggregate.
c) The testing laboratory responsible for the testing of the aggregates is able to demonstrate considerable experience and precision in this type of work. Such requirements might be considerably in excess of the normal capability of some concrete testing laboratories meeting the requirements of CSA A283.
d) Where possible, a field investigation of concrete structures containing the aggregate under investigation should be carried out. Petrographic examination (see ASTM C856) and determination of the alkali content of the existing concrete should be carried out. Particular attention should be given to identifying the source and the alkali content of the hydraulic cement, the concrete mix proportions, and the age of the concrete.
e) When determining the potential expansivity of an aggregate using concrete prisms or mortar bar specimens, the test program should include an aggregate of known satisfactory performance in concrete and an aggregate with known deleterious expansion. It is advantageous if the known deleterious aggregate is of the same or a similar rock type as the aggregate under test.
f) The testing of aggregate for alkali-aggregate reactivity properties is seldom practical on a project-by-project basis. Aggregates should be evaluated in advance of specific projects to assist in a timely decision-making process.
g) To ensure that the non-reactive nature of an aggregate has not changed, periodic testing of the source is required. The frequency of testing will vary depending on the nature of the source of the aggregate and the type of construction. In some cases, inspection or testing (petrographic examination) on a daily basis might be necessary. In other cases, testing once a year may be sufficient provided that there has been no obvious change in the aggregate deposit.
h) For alkali-silica reactive aggregates, where economic, engineering, and contractual considerations permit, the options of using the aggregate with supplementary cementitious materials, other admixtures, or a low-alkali hydraulic cement should be investigated.

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Table B.1
Mineral phases and corresponding rocks susceptible to deleterious alkali-silica reactions in concrete
(See Clause B.2.2.)

A. Alkali-reactive poorly crystalline or metastable silica minerals and volcanic or artificial glasses (classical alkali-silica reaction)	
Reactants:	Opal, tridymite, and cristobalite; acid, intermediate, and basic volcanic glasses; artificial glasses; beekite
Rocks:	Rock types containing opal, such as shales, sandstones, silicified carbonate rocks, some cherts, flints, and diatomite
	Vitrophyric volcanic rocks: acid, intermediate, and basic, such as rhyolites, dacites, latites, andesites and their tuffs; perlites and obsidians; all varieties with a glassy groundmass; some basalts
B. Alkali-reactive quartz-bearing rocks	
Reactants:	Chalcedony; cryptocrystalline to microcrystalline quartz; quartz with deformed crystal lattice, rich in inclusions, intensively fractured or granulated; poorly crystalline quartz at grain boundaries; quartz cement overgrowths (in sandstones)
Rocks:	Cherts, flints, quartz veins, quartzites, quartz arenites, quartzitic sandstones that contain microcrystalline to cryptocrystalline quartz or chalcedony, or both
	Volcanic rocks such as those listed in (a) but with devitrified, cryptocrystalline to microcrystalline groundmass
	Microgranular to macrogranular silicate rocks of various origins that contain microcrystalline to cryptocrystalline quartz: a) metamorphic rocks: gneisses, quartz-mica schists, quartzites, hornfelses, phyllites, argillites, and slates; b) igneous rocks: granites, granodiorites, charnockites; and c) sedimentary rocks: sandstones, greywackes, siltstones, shales, siliceous limestones, arenites, and arkoses
	Sedimentary rocks (sandstones) with epitaxic quartz cement overgrowths

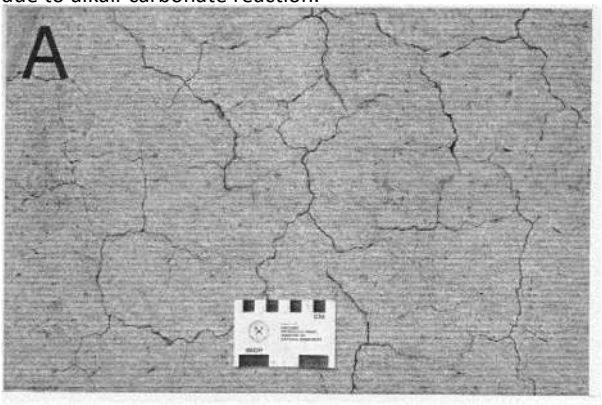
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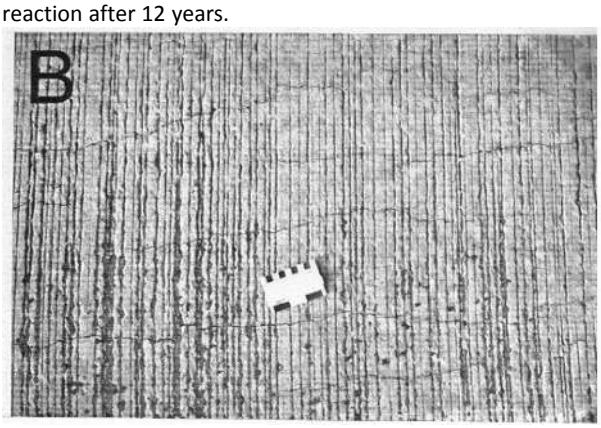
Figure B.1
Examples of cracking caused by alkali-aggregate reaction and microphotographs of typical texture of alkali-carbonate reactive dolomitic limestone

(See Clauses B.1 and B.2.3.)

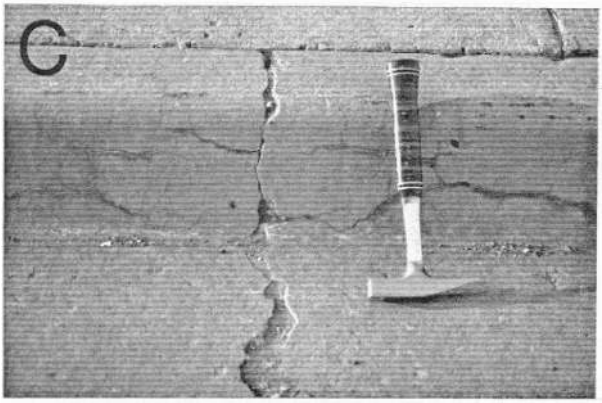
a) Pattern-cracking of concrete sidewalk slab after five years due to alkali-carbonate reaction.



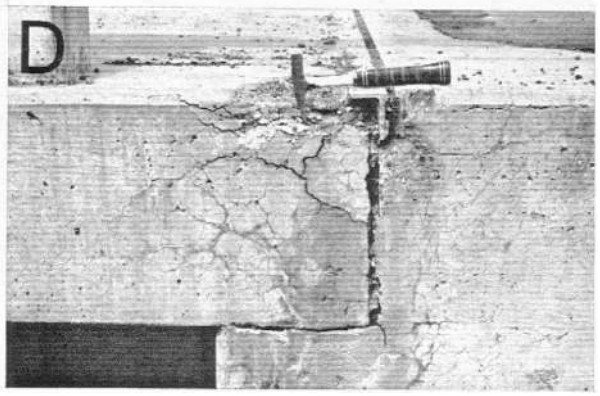
b) Linear-cracking of concrete pavement due to alkali-silica reaction after 12 years.



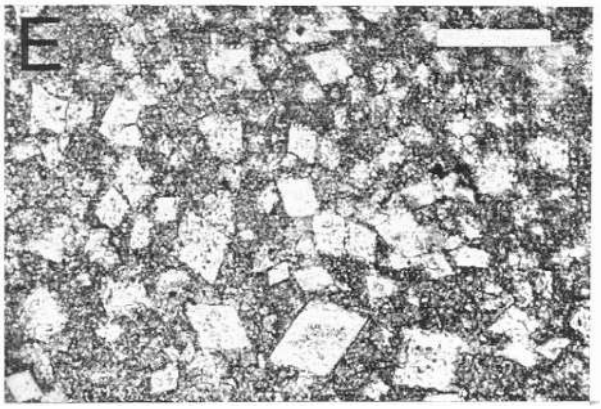
c) Cracking of curb due to alkali-silica reaction after nine years.



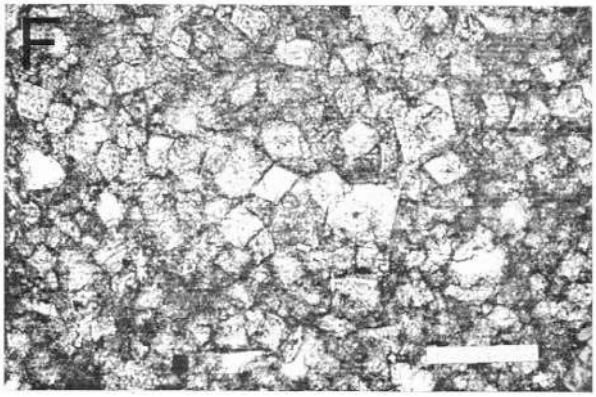
d) Cracking of bridge deck and abutment due to alkali-carbonate reaction and associated closing of expansion joint after five years.



e) Microphotograph of thin section of alkali- carbonate reactive dolomite limestone from Kingston, Ontario; length of scale bar = 0.1 mm.



f) Same as e), but from a quarry in Cornwall, Ontario; length of scale bar = 0.1 mm.



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Figure B.2
Photograph of reclaimed concrete aggregates produced from old concrete affected by alkali-silica reaction
(See Clause B.6.)



B.8 Publications

The following is a list of additional publication references applicable to this Annex:

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Xu, Z., Lan, X., Deng, M., and Tang, M. 2000. A New Accelerated Method for Determining the Potential Alkali-Carbonate Reactivity. *Proceedings of the 11th International Conference on Alkali-Aggregate Reactions in Concrete, June 2000, Quebec City (Canada)*, CRIB, Laval University, Québec (Canada): 129–138.

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Annex C (informative)
Tolerances: Principles, preferred sizes, and usage

Note: *This Annex is not a mandatory part of this Standard.*

C.1 Tolerance principles

C.1.1 Definitions

The following definitions apply in this Annex:

Basic size, *B* — the size to which the limits of size are fixed.

Note: *This will normally be the size specified or shown on the drawings.*

Curvature or alignment of edges — the distance from a straight line through the end points, which would apply to both horizontal or vertical edges.

Deviation, *v* — the difference between an actual size, *x*, obtained by measuring a dimension and the corresponding basic size, *B*; thus, $v = x - B$.

Note: *Deviations can be, therefore, either negative or positive dimensions.*

Skew — the angular variation from the basic rectangular shape.

Note: *This is normally checked by measuring and comparing diagonals, provided that both parallel sides are within tolerances.*

Tolerance, *T* — the difference between the permissible limits of size.

Note: *The tolerance is thus an absolute value without sign. Building tolerances are normally specified as the maximum allowable variations, ±T/2, from the basic (or specified) dimension. By specifying tolerances as ±T/2, it is easy to identify the basic dimension to which everyone has to work. It is also a clear method to instruct workers with little danger of misunderstanding. Finally, the probability of producing smaller or larger elements is equal in most cases.*

C.1.2 Statistical analysis

For construction of a series of identical members in the field or identical elements for attaching to a structure, a statistical analysis of deviations can be useful to limit the number of control measurements and to obtain a percentage of probability for compliance with the specified requirements.

Deviations may be treated as statistical variables when caused by independent incidents outside reasonable control. Such incidents might be the result of normal uncertainties in the adjustment and use of production tools and variations in the quality of materials. Under these circumstances, the distribution of the measurements will often follow a normal distribution curve illustrated by the Gaussian curve shown in Figure C.1.

The average (mean) dimension is as follows:

$$\bar{x} = \frac{1}{n}\Sigma x$$

where

$\bar{x}$ = the average (mean) dimension

n = the number of measurements

Σ = the sum of individual readings

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x = the individual readings

The standard deviation by definition is

$$s = \sqrt{\frac{1}{n-1}\Sigma(x-\bar{x})^2}$$

where

s = standard deviation

In Figure C.1, the area under the curve represents 100% of probabilities. The hatched areas represent the percentage probability for unacceptable or defective results. Normally, 90% of the construction should fall within the tolerance limits. The remaining 10% is only conditionally acceptable, but may be used in the final structure if the defects are remedied to the degree that the completed job will comply with the tolerance for the finished project. When the work of one contractor falls outside tolerances for interfacing by a second contractor, the defects should be corrected by the first contractor to the extent that tolerances are re-established or that the second contractor can install to the specified tolerances for the subsequent work without modifications.

C.1.3 Controls

The tolerances may be controlled by the designer or the contractor, but may also be enforced by a third party. The owner should specify who is responsible for enforcement and what reports are required to this effect.

C.1.4 Measuring instruments and measuring conditions

The controls should be carried out in a way that makes the contribution of inaccurate measuring instruments insignificant. Generally, it can be assumed that the maximum error of the measuring instrument should not exceed 1/10 to 1/5 of the allowable variations. The inaccuracies caused by insufficient tension of measuring tapes, accidental temperature differences, calibration of optical instruments, and reading of the dimensions should all be reduced to a similar level.

A tolerance specification should state the age of construction for control measurements and certain specified physical conditions, such as temperatures, moisture content, and support conditions for prefabricated elements. For precast concrete elements, it is sometimes desirable to measure deviations at the time of erection, but it is more practical to control dimensions at an earlier age.

All elements should be controlled at approximately the same age or strength level. The reference temperature for measurements is normally 20 °C, unless otherwise specified. The reference moisture content is rarely important and is therefore specified only under special conditions. Support conditions for precast floor and wall elements should be similar to the support conditions of such elements in service, unless otherwise specified. Deformation caused by temperature, creep, and shrinkage of prestressed concrete and some precast elements can be substantial in relation to tolerances and should be considered by the contractor in selecting initial construction sizes.

C.1.5 Measuring points

The surface finish, local damage, or particular edge details can cause uncertainties in measuring deviations. Such uncertainties can normally be minimized by establishing special measuring points by means of planes, angles, straightedges, or special corner protection pieces with reference points for measuring.

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C.2 Preferred sizes

C.2.1

The following series of numbers should be used for determination of tolerances whenever possible: ±5 mm, ±8 mm, ±12 mm, ±20 mm, and ±30 mm. Where necessary, the series may be continued by multiplying by a whole, negative, or positive power of 10. The next lower size would then be ±3 mm and the next higher size would be ±50 mm.

For the development and common usage of these sizes, see Holbek and Andersen (1977).

C.2.2

Tolerances should be designated in such a way that common tolerances are specified for components constructed by similar technology or for similar applications.

C.3 Concept of tolerances for usage

C.3.1

This Standard provides tolerances in the form of allowable variations for all major dimensions, placing of reinforcement and hardware, and finishes for plastic concrete. CSA A23.4 has similar provisions for precast concrete. The owner can then specify tolerances for normal concrete construction simply by referencing these standards.

C.3.2

Where certain types of construction or special conditions warrant it, closer tolerances may be specified by the owner. Where closer tolerances are required, a size should be used that is one step lower in the series given in Clause C.2.1.

Generally, compliance with closer tolerances can prove difficult and can result in substantially increased construction costs. Closer tolerances should therefore be specified only where structural or performance requirements justify these costs, or where the advantages of more accurate construction outweigh the increased costs. The latter case should be at the discretion of the contractor.

C.3.3

Similarly, tolerances may be relaxed for certain types of construction by using a size one step higher in the series given in Clause C.2.1.

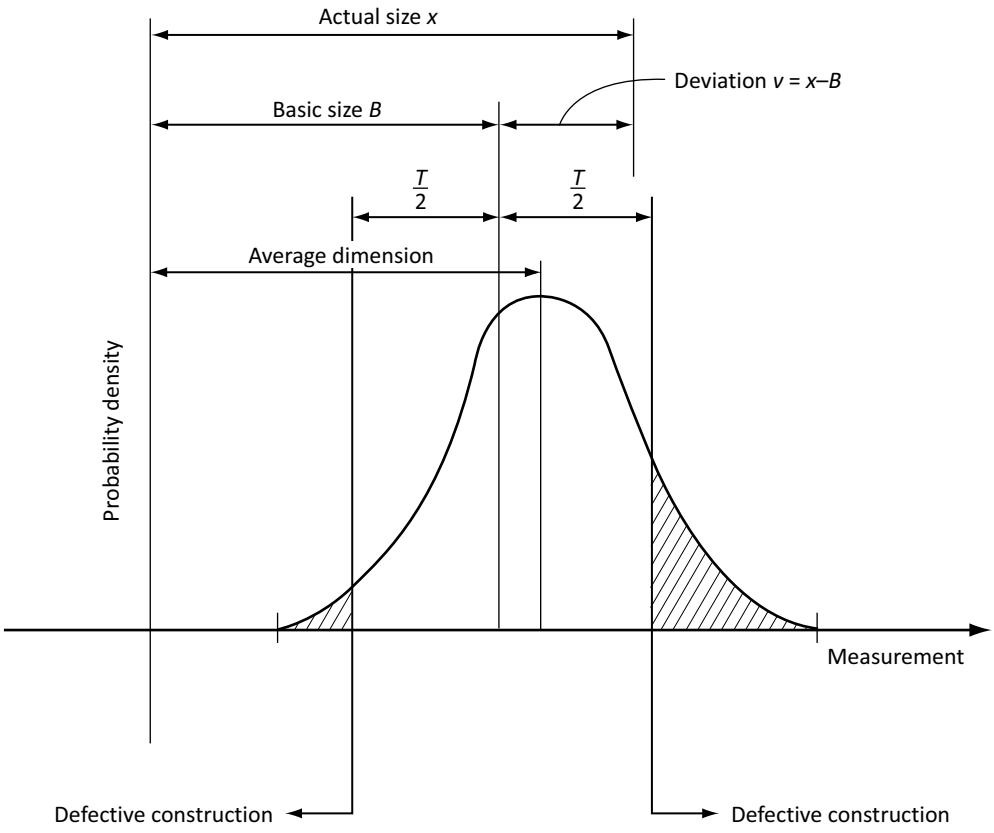
C.3.4

The owner should clearly identify on the drawings or in the contract documents all tolerance requirements differing from those provided in this Standard and in CSA A23.4.

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Figure C.1
Tolerance concepts and distribution of deviations
(See Clause C.1.2.)

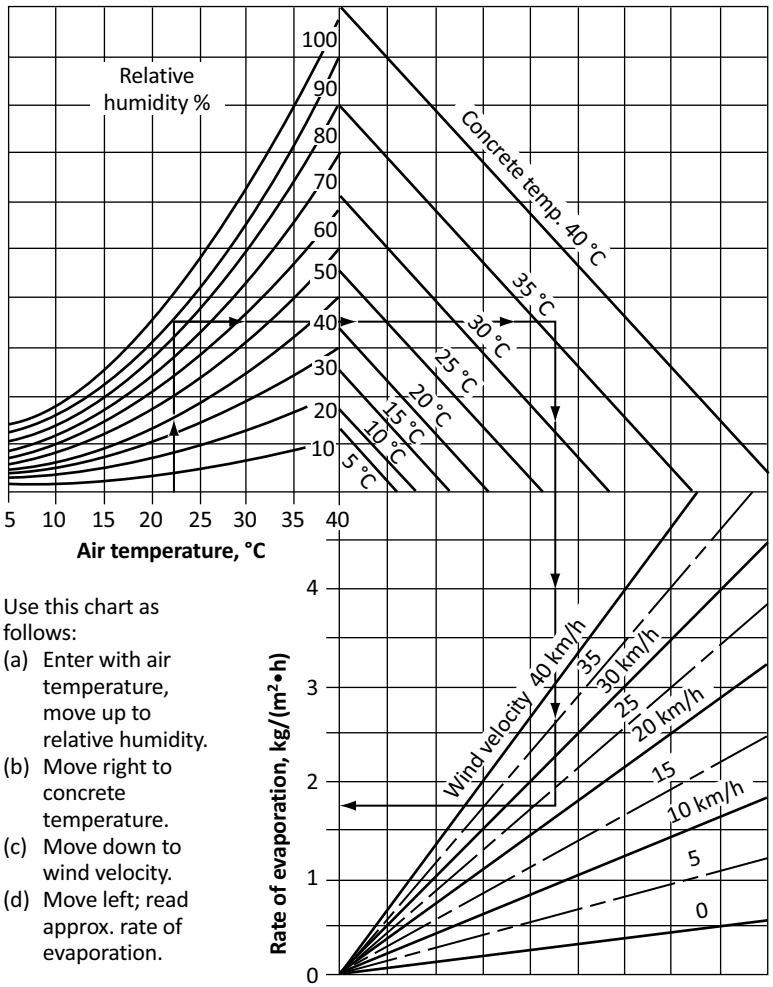


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Annex D (informative)
Guidelines for curing and protection

Note: *This Annex is not a mandatory part of this Standard.*

Figure D.1
Estimation of rate of evaporation of moisture from concrete covered with water
(See Clause 7.6.1.)



Notes:

1) *This Figure is adapted (with metric values) from CAC EB101 with permission. Additional information can be obtained from Berhane (1984) and discussions of this article in ACI Materials Journal, Vol. 82, Nov./Dec. 1985. Further information and background can be obtained from Uno (1998).*

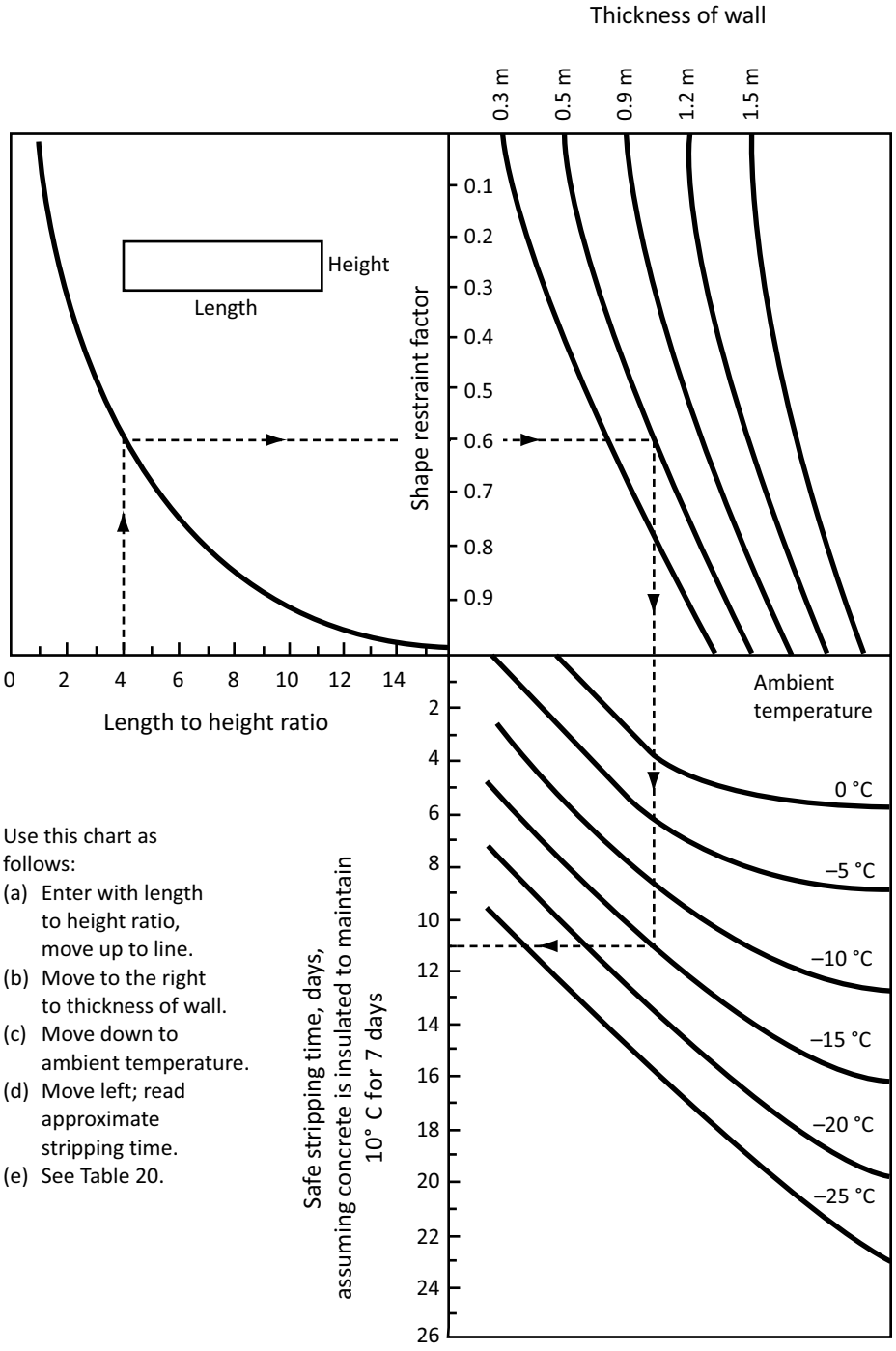
2) *Evaporation rate can also be estimated through the use of the following formula:*
$E = 5([T_c + 18]^{2.5} - r\,[T_a + 18]^{2.5})(V + 4) \times 10^{-6}$ *(SI units)*
where
E = evaporation rate, kg/m²/h
T_c = concrete temperature, °C
T_a = air temperature, °C
r = relative humidity, %

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V = wind velocity, km/h

Figure D.2
Graphical determination of the safe stripping time for insulated formwork to avoid cracking due to thermal stresses
(See Clause 7.2.2.5 and Table 20.)



Note: *This Figure is adapted from Ghosh and Mustard, 1983. © Canadian Science Publishing or its licensors.*

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Annex E (informative) "Reserved"
Concrete surface tolerances: Elevation, slope, and waviness

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Annex F (informative)
Abrasion resistance of concrete surfaces

Note: *This Annex is not a mandatory part of this Standard.*

F.1
This Annex provides information about improving the resistance of concrete surfaces to abrasion.

F.2
Improvements in abrasion resistance result from the use of
a) lower water-to-cement ratio concrete;
b) increased surface aggregate hardness;
c) increased compressive strength;
d) increased duration and quality of curing; and
e) improved density of the final finish of the concrete.

F.3
It is common practice in most parts of North America to employ surface-applied dry shake-on hardeners to economically increase surface wear resistance from 150% to 400% over plain concrete. These shake-on aggregate hardeners incorporate proportions of cement binder and special hard aggregates that are applied to the surface of fresh concrete in order to form a monolithic hardened surface. The application rate (see Table F.1) and aggregate selection (see Table F.2) vary depending upon the desired degree of protection required for an intended usage.

F.4
The application of dry shake-on surface hardeners reduces the attainable floor tolerance. Floors with specified tolerances of Class D and higher commonly do not employ dry shake-on hardeners but use lower water-to-cement ratio concrete mixes (0.45), liquid hardeners, and/or abrasion-resistant toppings, depending upon the desired degree of abrasion resistance desired.

F.5
Urethane and epoxy floor coatings have traditionally been used to seal concrete surfaces and can also provide specialized chemical resistance. Penetrating liquid silicate hardeners are also commonly used to seal concrete surfaces through chemical densification.

F.6
Heavy-duty toppings incorporating emery and iron aggregates are commonly used in high-wear areas to significantly improve wear resistance for an extended period of time. Heavy-duty toppings are used in areas where high-quality conventional concrete can wear very rapidly.

F.7
A base concrete mix is not required to have abrasion-resistant qualities when surface-applied dry shake-on hardeners or abrasion-resistant toppings are employed.

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F.8

In areas utilizing steel tracked vehicles, steel plates or protective mats should be used to isolate the concrete surface from direct contact with the steel tracks.

F.9

A combination of different concrete mixes, shake-on hardeners, and finishing and curing methods may be specified by the owner for each particular type of floor usage within a single facility in order to optimize abrasion resistance and economy where required.

Table F.1
Hardener application rates
(See Clause F.3.)

Type of floor usage	Recommended application rate
Foot traffic	0 kg/m^2
Light commercial or industrial use	3.0 kg/m^2
Moderate commercial or industrial use	5.0 kg/m^2
Heavy industrial use	7.0 kg/m^2
Heavy-duty	25–50 mm thick toppings incorporating special wear-resistant aggregates

Note: *Application rates in excess of 5.0 kg/m^2 are in some cases impossible to incorporate fully into concrete with a low water content and in hot or windy application conditions. Specialized application methods and concrete mixes might be necessary to facilitate the complete installation of high rates of shake-on surface hardeners.*

Table F.2
Aggregate hardeners
(See Clause F.3.)

Material	Relative hardness
Plain concrete	4
Liquid hardened concrete	5
Traprock aggregates	6
Silica aggregates	7
Emery aggregates	8
Iron aggregates	–

Notes:

1) *Metallic aggregates deform with impact and abrasion, and while they impart one of the highest levels of abrasion resistance, they do not have a relative aggregate hardness comparable to that of mineral aggregates.*
2) *Further information is available from ACI 302.1R and ASTM STP 169D.*

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Table F.3
Abrasion resistance of concrete surfaces
(See Figures F.1 and F.2.)

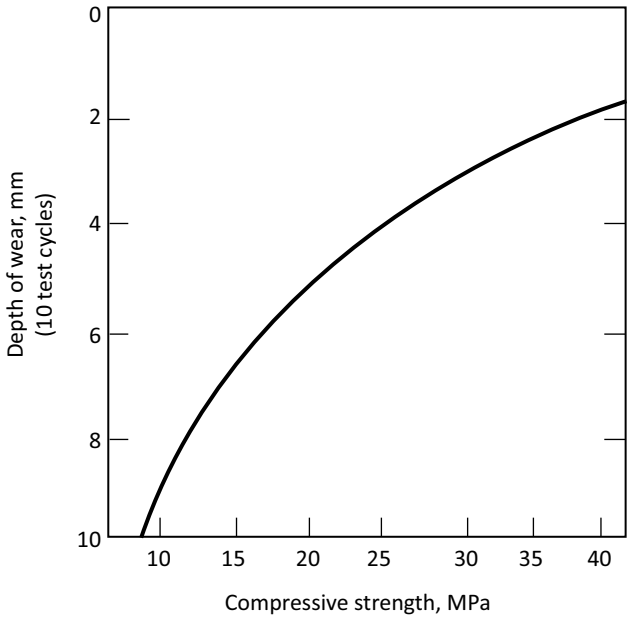
Finishing procedure	Depth of wear, mm (10 test cycles)
A — Steel trowel – 1 pass*	5.0
B — Steel trowel – 3 passes*	4.4
C — Float finish*	5.7
D — Procedure A plus cement/sand (1:1-1/2) shake at 6 kg/m^2	4.4
E — Procedure B, plus cement/iron (1:2) shake at 7.2 kg/m^2	1.7
F — Procedure A, curing delayed 24 h	8.3

* *When subjected to immediate curing (curing compound or wet burlap for 3 d).*

Notes:

1) *The depths of wear shown in this Table and Figures F.1 and F.2 have been established using an Ebener machine in conformance with the method for abrasion test described in the Deutsches Institut für Normung standards (see Abrasion Resistance, ASTM C627).*
2) *For further details and information, see ACI 302.1R, Fentress (1973), and Sawyer (1957).*

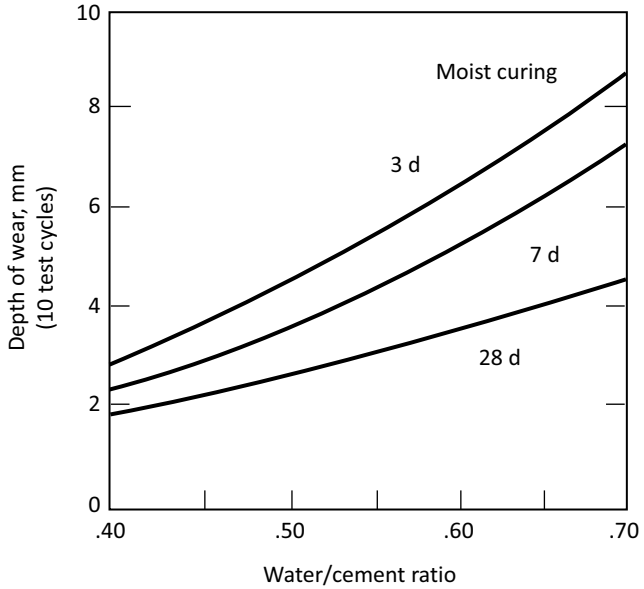
Figure F.1
Relation of depth of wear to compressive strength
(See Table F.3.)



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Figure F.2
Effect of water-to-cement ratio and length of moist curing on depth of wear
(See Table F.3.)



Notes:

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2) *These concretes were made with hydraulic cement only; the results can be different when supplementary cementitious materials are used.*

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Annex G (informative)
Sample grouting record

Note: *This Annex is not a mandatory part of this Standard.*

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Sample grouting record

Grouting Record											
Project: _____											
			Grout temperature								
Location	**Date Y/M/D**	**Air temp.**	**Tank**	**Duct**	**w/c***	**Efflux time, s**	**Grout pressure, kPa**	**Air, %**	**Expansion, %**	**Bleeding, %**	**Strength (7 d), MPa**
Notes:											
Recorded by:											

* *Water-to-cementitious materials ratio.*

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Annex H (informative)
Fibre-reinforced concrete

Note: *This Annex is not a mandatory part of this Standard.*

H.1 Introduction

Steel and macro-synthetic fibres are added to provide crack control and stress redistribution in concrete. Micro-synthetic fibres are added to provide improved plastic shrinkage. The reasons for use, volume fraction, fibre types and configurations, and desired properties should be determined by the owner after consulting the available technical publications and manufacturer's data. References include: CSA A23.2-16C; ACI 544.2R; ACI 544.3R; ACI 544.4R; ACI 544.5R; ACI 544.6R; ACI 544.7R; ACI 544.8R; ACI 544.9R; ASTM A820/A820M; ASTM C1116/C1116M; and ASTM C1609.

H.2 Background

H.2.1 Reasons for using fibres

Fibres are used primarily to provide

a) early plastic shrinkage control;
b) long-term crack control;
c) economical design;
d) improvements to residual strength; and
e) a practical means of reinforcing concrete.

H.2.2 Fibre types

H.2.2.1 Micro synthetic fibres

Micro fibres are typically found in the form of very fine (i.e., low denier) monofilament or fibrillated synthetic material and are commonly added in relatively low volumes (0.3 kg/m^3 to 0.9 kg/m^3) for the control of plastic shrinkage cracking. The relatively high surface area of micro fibres makes their use difficult at higher volumes without causing a severe impact on the workability of the concrete mixture. As a result, the benefits associated with the use of micro synthetic fibres are mostly limited to reducing plastic shrinkage cracking of concrete surfaces.

H.2.2.2 Macro synthetic fibres

Macro synthetic fibres are coarse monofilaments. Due to their relatively low surface area, macro fibres can be used at higher volume addition rates than micro fibres and will have a positive impact on the hardened characteristics of concrete. The benefits associated with the use of macro synthetic fibres include improved fatigue and impact resistance, improved crack control, and also improvements to residual strength (the ability to carry tensile stresses after cracking). In addition, some types of macro synthetic fibres have been demonstrated to be very effective in the control of plastic shrinkage cracking (Trottier *et al.,* 2002).

H.2.2.3 Steel fibres

Steel fibres are commercially available in various lengths and diameters (i.e., aspect ratio), cross-sections, anchorage styles, and tensile strengths. Steel fibres can significantly improve the residual strength of concrete. Steel fibres provide no plastic shrinkage cracking control but are used to improve

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fatigue and impact resistance, improve crack control, and redistribute stresses in the hardened concrete created by dynamic and static loading conditions.

H.2.2.4 Applications

Both steel and synthetic fibres have been used as crack-control reinforcement in commercial, industrial, and residential applications such as floor slabs, machine pads, overlays, and exterior pavements. Steel and synthetic macro fibres have also been used to replace welded wire mesh and light gauge steel rebar temperature reinforcing in slabs. Steel fibres have been extensively used for the past 30 years (Bentur and Mindess, 1998) to provide post-crack residual strength with improved impact and fatigue resistance. Macro synthetic fibres have been shown to provide similar performance in laboratory studies and in field applications for the past 10 years (Ramakrishnan, 1995).

Owners should pay careful attention to the fibre manufacturer's design data and the volume fraction of each particular fibre type to achieve the desired result for each intended use.

H.2.3 Fibre volume fraction

H.2.3.1

Improvements in the performance of concrete by the addition of fibres is generally proportional to

a) the volume of fibre added;
b) the quality of the anchorage of the fibre; and
c) the tensile strength of the fibre.

H.2.3.2

Typical fibre dosages are

a) for steel: 15 to 45 kg/m^3;
b) for micro synthetic for plastic shrinkage control: 0.3 to 0.9 kg/m^3; and
c) for macro synthetic for improved mechanical properties: 1.8 to 9 kg/m^3.

Notes:

1) *78 kg/m^3 of steel fibre is equivalent to approximately 1% by volume; 1 kg/m^3 of synthetic fibre is equivalent to approximately 0.1% by volume.*
2) *Higher fibre volumes reduce workability and have a propensity to ball during mixing.*
3) *CSA A23.2-16C may be used to determine the mass of fibres, steel or synthetic, in a given volume of concrete.*

H.2.3.3

Performance testing data should be developed in accordance with ASTM C1609/C1609M and supplied by the manufacturer to determine the volume fraction of fibre needed for a particular application. In some cases, tests are necessary to verify that concrete with the desired fibre dosage can be properly mixed and placed.

H.3 Commentary and guidance on CSA A23.2-16C

H.3.1 Test method and results

This Test Method specifies the procedure to determine the concentration of steel or macro synthetic fibres in the plastic concrete. Determining the concentration of fibre in hardened concrete is both extremely difficult and subject to more variability than fibre washout testing of plastic concrete.

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Fibre must be added at the specified dosage rate per volume of concrete, or higher, in accordance with Clause 5.2.2.9. Under no circumstances should the fibre addition rate be purposely reduced below the specified dosage rate.

Recent field test data indicates that there may be large variations in fibre dosage within a load of concrete as compared to the specified dosage rate (see Table 1 from CSA A23.2-16C). Washout testing should be used for all steel and macro synthetic fibre concrete placements on a daily basis.

Table H.1
Measured variation in steel fibre content
(See Clause H.3.)

Design requirement, kg/m³	Overall average, kg/m³	Number of loads tested	Maximum range between loads, kg/m³	Average within load variation, kg/m³*
25	24.2	15	7.9	3.9
25	21.8	8	3.6	3.2
25	27.3	16	14.6	3.4
30	29.3	5	2.9	4.8
30	29.2	6	3.2	4.2
40	40.1	21	5.0	3.3

** Within load variation is difference between highest and lowest of three samples obtained at approximately 25, 50, and 75% of the discharge.*

General observations about field measurements are as follows:

a) The average result of three test samples obtained from quarter points of discharge more accurately reflects the dosage rate of fibres in a truckload of concrete than a single washout test.
b) Single washout test samples may vary significantly from the average and specified dosage rate. No measured test data is available for macro synthetic fibres.

H.3.2 Fibre inspection

All fibres shall conform to the project specification and the requirements of CSA A23.2-24C.

Each type of steel or macro synthetic fibre has unique performance characteristics and must never be substituted by an alternative fibre material without undergoing a design review and acceptance by the owner. There are no equivalent substitution rates for steel and macro synthetic fibres.

The owner may visually confirm the fibre addition either at the batch plant or in the field (when site added). The owner's inspection company must note the type of fibre being used in addition to its dosage rate. A verification of the mass of the manufacturer's bag or box is also recommended.

The location of the load in the concrete placement from which the sample for the washout test was obtained should be accurately noted for future reference.

H.3.3 Testing frequency

While there is generally no concern in relation to the addition of more fibre than specified, there is a concern that a reduction in the fibre concentration below the specified dosage rate may produce unacceptable performance. Washout testing should therefore be performed for each concrete placement to verify the fibre dosage. Initial washout testing should occur on the first load of concrete,

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in concert with other plastic concrete tests. If the initial load of concrete is rejected, washout testing should continue for every load of concrete until the dosage rate is within the acceptance limit. Washout testing should be performed randomly thereafter for each 100 m^3 to 500 m^3 of concrete placed each day (in accordance with the manufacturer's recommendations).

H.3.4 Reporting

CSA A23.2-16C can be used in the field or the laboratory to determine fibre dosage rates. Tests on samples should be obtained from transit mixers be determined and reported in the field. The reporting of washout test results after the completion of a concrete placement is problematic as the lack of timely reporting does not provide any opportunity to identify any deficiencies, to increase the frequency of testing (if necessary), to accurately determine the extent of any out of compliance work, and/or take any other meaningful corrective action.

The average of the three individual tests, taken from a single truckload of concrete at discharge quarter points, should be immediately reported on site upon completion of the test.

The results of individual test samples should also be reviewed to improve within truckload uniformity.

H.3.5 Fibre concentration uniformity

Fibre concentration uniformity can vary within a load of concrete depending upon a variety of factors including the slump of the concrete, the speed of fibre addition, the composition of the concrete mixture, mixing time, and the quality of mixing action in the concrete truck.

The washout tests should be considered acceptable if the average of three test samples from a load of concrete is no more than 10% less than specified dosage rate with no individual test sample being more than 20% less than the specified dosage rate.

H.3.6 Corrective action

If the average test results exceed the recommended limits noted in Clause H.3.5, then the concrete placement should be paused while both the materials and mixing procedures are reviewed and any suggested corrections implemented.

Should a single washout test produce deviations in excess of the allowable variations noted above, the load of concrete should be further mixed and retested. If the concrete load has finished discharging, the location in the placement of the load represented by the single washout test should be accurately noted for further consideration.

The failure of a load of concrete to be within the allowable concentration uniformity, based upon an averaging of three test samples, should result in its rejection.

A review of the fibre addition rate, bag/box mass, automatic dispenser (if used) calibration should occur to ensure that the fibre is being added at the specified dosage rate as per Clause 5.2.2.9.

If the measured fibre concentration is greater than the tolerance limits noted in Clause H.3.5, the fibre manufacturer should be consulted to perform a design review to determine the acceptability of the hardened concrete prior to any corrective action.

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Annex I (informative)
High-performance concrete

Note: *This Annex is not a mandatory part of this Standard.*

I.1 Introduction

The increasing use of high-performance concrete (HPC) in Canada for the construction and rehabilitation of structures has led to the need for guidance in writing specifications. This Annex attempts to address this need.

HPC is user-friendly. Its high workability and exceptional cohesiveness make it easy to place and compact. Most of the principles discussed below are those of good practice and should be applied to all concretes, not just HPC.

I.2 General

Clause I.3 discusses high-performance concrete in relation to specified clauses of this Standard.

High-quality materials meeting or exceeding the requirements of this Standard are used in making HPC. In addition, it is important that a high degree of quality control be achieved at all stages in making HPC. The consistency of the properties of materials used is therefore an issue, as well as their quality.

I.3 Explanation of relevant clauses

I.3.1 Clause 4.2.1 — Cements and supplementary cementitious materials

Any hydraulic cement, blended hydraulic cement, or supplementary cementitious material (e.g., silica fume, slag, or fly ash) combined with a hydraulic cement can be used to make HPC.

The cement or blend of cementitious materials used will depend on the properties of fresh and hardened concrete required for the project. For most projects, a hydraulic silica fume cement or a ternary blended cement should be used.

A blended hydraulic cement is the most convenient way to incorporate silica fume into a mix. It should be specified in preference to the separate addition of silica fume. The number of cementitious materials to be handled and batched is reduced and problems related to batching silica fume separately are eliminated. On the other hand, the use of hydraulic silica fume cement fixes the silica fume content available. In practice this has not been a disadvantage. CSA A3001 facilitates the marketing of a range of blended cements with varying contents of supplementary cementitious materials (SCMs).

Where concrete is specified on a performance basis, there should be no need to specify a cement content. Most authorities prefer to specify a minimum cement or cementitious materials content. Bidders tend to bid on the basis of the minimum content of cementitious material. If a minimum cementitious materials content is specified, it should be compatible with the properties required of the hardened concrete. It would also be desirable to make it clear that a higher content of cementitious material should be used if necessary to meet all specification requirements.

Limits to the amount of SCMs should be based on prior research and experience, and confirmed by appropriate pre-construction testing. This Standard suggests a limit to silica fume of 10% of the total cementitious content.

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The use of SCMs can reduce
a) the maximum temperature rise in the concrete during hydration;
b) permeability to water and chemical ions; and
c) finishing problems.

Properly used, SCMs can improve the strength and the durability of concrete.

I.3.2 Clause 4.2.2 — Water

The requirements specified in this Standard are adequate. They are similar to ACI requirements.

I.3.3 Clause 4.2.3 — Aggregates

High-quality, clean aggregates complying with this Standard are suitable for use in HPC. As with all aspects of the quality control of HPC, consistency in grading, cleanliness, and other properties is important.

Where high strength is required, it is important to establish by test that the aggregates can achieve the average strength required to meet the specified strength, allowing for the variations that occur in production.

There is no fixed relationship between the compressive strength and modulus of elasticity that a particular coarse aggregate will produce (Baalbaki *et al.,* 1990). If a high modulus of elasticity is required, as in some tall buildings, pre-contract testing is essential.

Where specifications contain unusually strict requirements for other properties, such as impermeability and resistance to freeze-thaw, sulphate attack, or abrasion, pre-contract tests should be conducted to confirm the suitability of available aggregates.

Both standard and nonstandard grading limits might produce optimum mixture proportions and pre-contract testing can confirm this. What is essential is that whatever aggregate source is chosen, the grading and quality be consistent.

I.3.4 Clause 4.2.4 — Admixtures

Where no previous history has been established, pre-construction laboratory or field trials should be performed to demonstrate the compatibility of admixtures with the cementitious materials.

I.3.5 Clause 6.1 — Reinforcement

HPC, properly placed, consolidated, cured, and free of cracks exceeding 0.15 mm in width, provides much better corrosion protection to the reinforcing steel than conventional concrete. Recent field evidence suggests that coated steel might not need to be specified where HPC is used as the exposed surface.

I.3.6 Clause 6.5 — Formwork

All formwork should be grout-tight. Leakage of grout creates planes of poorly compacted cover concrete, which reduce the effective cover and hence the durability of the concrete.

I.3.7 Clause 6.6 — Fabrication and placement of reinforcement

Since the durability, and hence the service life and maintenance costs, of a structure depend on the amount of cover for the steel, it is vital that the specified cover be achieved. The placing tolerances specified in this Standard are somewhat optimistic. In bridge decks, for instance, it has been shown that

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a conscientious contractor can in some cases only achieve a standard deviation of 10 mm in cover. This means that 95% of bars will have cover between ±20 mm of the specified cover (Ryell and Manning, 1982). On a carefully controlled HPC bridge deck, a standard deviation less than 10 mm is achievable.

Minimum cover for bridge deck durability is usually considered to be 50 mm. Specified cover should therefore be 50 mm + 2 standard deviations of the expected cover variation.

As adequate cover is essential to a long service life, contract management provisions should ensure that correct and consistent cover is achieved in the structure. Pre-concreting inspections and post-concreting cover checks are part of this process. Performance requirements for cover provide an incentive for accurate placement.

Properly cured HPC provides excellent corrosion protection to uncoated reinforcement. Acceptable curing involves adequate moist curing to ensure hydration plus thermal curing to avoid cracking that will allow the ingress of ions that cause corrosion. The usually accepted crack width limit is 0.15 mm (Mehta, 1997).

In view of the cost of repairing corrosion-damaged concrete structures, all exposed structures should be instrumented at the time of construction so that corrosion activity can be monitored. A corrosion probe, developed by Hansson, facilitates the monitoring of corrosion (Seabrook and Hansson, 1996).

I.3.8 Clause 4.3.1 — Mix proportions

The requirements of this Standard are generally applicable. Unless adequate data on prior use are available from the concrete supplier, the determination of mix proportions for HPC should be based on laboratory and field trials with the materials proposed for the project. Field trials of the proposed mix should precede construction. HPC mixes are nearly always made highly workable by the inclusion of superplasticizers.

Compaction is necessary for these highly workable mixes, but over-vibration should be avoided.

Control of slump is important in ensuring compliance with the specified quality plan. The administration of this Clause should be discussed at a pre-construction meeting.

Correct general practice with regard to air-entrainment is to follow the requirements of this Standard. With high slump mixes, the site transportation and placing systems used, particularly pumping, might result in a degradation of the quality of the air-void system of the concrete as delivered by the supplier. Research to date has not identified systematic ways of mitigating this problem by modifying site transportation and placing systems. One solution is to have the air-void system of the concrete at the point of delivery to the site significantly better than required.

This Standard generally requires an average spacing factor of 230 µm, with no single test result greater than 260 µm (see Clause 4.3.3.3). This Standard warns that, because of the variability of the ASTM C457 test procedure, a spacing factor of 170 µm be targeted. For highly workable HPC mixes, the target spacing factor should be less than 170 µm. Some research (Aïtcin *et al.,* 1996) has shown that HPC does not need an air-void system as restrictive as the requirements of this Standard in order to provide excellent resistance to freeze-thaw attack. This Standard has been amended to allow a larger spacing factor for concrete with a water-to-cementitious materials ratio of 0.36 or less.

Tests are made on cylinders cast at the point of discharge of the concrete truck or cores taken from the structure. Since the owner’s concern and right is to obtain a durable structure, tests on the hardened

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concrete in the structure would be the preferred approach, provided that this is made clear in the contract specifications.

The concrete supply industry's concern is that the site transportation and placing methods used by the contractor, particularly pumping, can significantly degrade the air-void system provided at the point of discharge. In some cases, this concern can be mitigated by including a note in the specifications similar to the following:

> Contractors should note that the site transportation and placing of high-workability mixes, particularly when pumps are used, can degrade the air-void system of the concrete. Contractors should ensure that they and their contractors take into account the potential effects of the site transportation and placing system proposed by the contractors when designing mixes for this project. Field testing might be required.

The concrete supply industry is also concerned about the inherent variability of ASTM C457 and the level of competence of some technicians who carry out this test method. To address these concerns, an independent agency should pre-qualify the laboratory chosen to carry out the air-void system determinations, including designating the operator who will carry out the tests. The testing should be restricted to that operator. The contractor should be informed that this will be done. A pre-qualification protocol will be needed if this approach is taken.

The US Department of Transportation Federal Highway Administration (FHWA) procedure for HPC is to base acceptance of laboratory freezing and thawing tests on ASTM C666/C666M, Procedure A (Goodspeed and Vannikar, 1996). This is an alternative way of proving resistance to freezing and thawing. The acceptance limit used by the FHWA is a minimum durability factor of 80%. This is generally considered to be too low for high-performance concrete mixes. A minimum value of 90% is suggested where this test is used to qualify an HPC mix.

This test method is expensive and takes about three months to compete if a new mixture design needs to be qualified. Delays could be avoided, and this test method could be used for acceptance, if freeze-thaw data were available for typical HPC mixes using local materials.

I.3.9 Clause 4.1.1 — Durability requirements

High strength is generally easy to attain. There are special requirements in producing and testing high-strength concrete, which are covered in Clause 8.5 and in ACI 363.2R.

The prime concern in writing and enforcing specifications for HPC is durability. Thus, some additional points related to durability to be considered are as follows:

a) HPC will have higher strengths and a lower water-to-cementitious materials ratio than normal concrete.
b) Where there is a potential for sulphate attack and supplementary cementitious materials are to be used in an HPC mix, prior evidence of the performance of the proposed mix might be required.
c) HPC will provide better resistance to sulphate attack than normal mixes.
d) HPC is significantly less permeable to water and chemical ions than normal concrete. Rapid chloride permeability test results below 1000 coulombs at 28 d are typically achieved.

Note: *See CSA A23.2-23C for further information on the rapid chloride permeability test.*

I.3.10 Clause 4.4 — Quality control

Three test cylinders per test are preferable to two. If one result is significantly different from the other two, it can be easily determined which result is the erroneous one.

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Field-cured cylinders should not be used to determine in-place strength.

I.3.11 Clause 5 — Production and delivery

High-efficiency mixers at pre-mix plants are preferable. Mixing times for these mixers can be different from the requirements of this Standard, and the owner should take this into account. Currently, most concrete is truck-mixed. Only a small segment of the concrete supply industry has central-mix plants. It is premature to limit contract specifications to pre-mix plants.

Where truck mixing is used with ternary mixes in which undensified silica fume is added separately, some experimentation in the sequence of batching all materials might be necessary to ensure thorough mixing (Ryell and Bickley, 1987).

It is desirable that all concrete, including HPC, be delivered at the lowest practical temperature. A maximum placing temperature for HPC of 25 °C is specified in Note 1 of Table 14. Note 4 of Clause 8.5.5 notes that a delivery temperature of 20 °C is preferred to 25 °C for high strength concrete. The lower the initial temperature of the concrete, the higher its final quality. The maximum temperature rise and cracking will be reduced. If it is necessary to reduce the temperature of concrete at the time of delivery, concreting at night should be considered.

I.3.12 Clause 7.5 — Placing of concrete

No special provisions are required. Vibration is required. This cannot be quantified and, therefore, it should be determined during pre-concreting site trials.

I.3.13 Clause 7.8 — Curing

Adequate moist curing is the most effective and cost-effective way to ensure the durability of all concrete. With HPC, the enforcement of proper curing is essential.

Adequate curing is not simply the avoidance of moisture loss during the setting and initial hardening of high performance concrete. A supply of water is needed to avoid autogenous shrinkage due to self-desiccation. Provided that moisture is available during the initial setting and hardening, total shrinkage and the incidence of cracking will be reduced.

The curing regime for HPC adopted by the Ontario Ministry of Transportation (MTO) is a good model to follow (MTO, 1998). This applies to structure decks, approach slabs, curbs, and sidewalks:

> Fog mist must be applied continuously from the time of screeding until concrete is covered with burlap, in such a way as to maintain high relative humidity above the concrete and prevent drying of the concrete surface. Water must not be allowed to drip, flow, or puddle on the concrete surface during fog misting, when placing the burlap, or at any time before the concrete has achieved final set.
>
> **Curing with burlap and water**
>
> Burlap must be presoaked by immersing it in water for a period of at least 24 h immediately prior to placing. Two layers of burlap must be applied to the surface of the concrete. Strips must overlap 150 mm and must be held in place without marring the surface of the concrete.
>
> The burlap must be applied immediately after finishing of the concrete surface within 2 m to 4 m of the finishing operation, and for bridge decks within 2 to 4 m of the pan or screed of the finishing machine.

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Curing with burlap and water must be maintained for a minimum period of 7 d. The burlap must be maintained in a continuously wet condition throughout the curing period, by means of a soaker hose. The burlap must be covered with a layer of moisture vapour barrier [i.e., impervious plastic sheeting], within 12 h of placing of the concrete, in a manner which will prevent deformation of the surface of the concrete.

Air flow in the space between the moisture vapour barrier [i.e., impervious plastic sheeting] and the burlap must be prevented.

Regardless of ambient temperature, moist curing with burlap and water must be provided at all times. During cold weather, burlap must be prevented from freezing.

For exposed concrete riding surfaces, the following regime may also be considered:

Curing with membrane compound

After 7 d of curing with burlap and water, a curing compound must be applied to exposed concrete riding surfaces. The method of application must be as follows:

The membrane curing compound must be applied to the concrete surface by means of motorized spraying equipment approved by the manufacturer of the compound. The compound must be agitated by mechanical means to provide a homogenous mixture at the time of application. The membrane curing compound must be available on-site for sampling 7 d prior to application. The compound must be applied within 2 m to 4 m of the burlap removal operation, completely covering the surface of the concrete. A second application of curing compound must be applied within 1 h to 2 h after the first application. Each application must be such that the membrane formed is uniform in thickness and colour and free from breaks and pinholes. The surface must be maintained in this condition for a minimum period of 7 d. The rate of each application must not be less than the rates specified by the manufacturer of the compound.

The efficiency of curing compounds diminishes significantly as coverage is reduced and it is necessary to use the recommended coverage to achieve effective curing.

To ensure the proper coverage of the curing compound, a simple trial should be made in which a known amount of curing compound is applied to a trial area of known dimensions. The amount of curing compound used should be that which will result in the correct coverage. Since the curing compound used on highway structures is white, it results in a visual standard that can be readily recognized by applicators and inspectors. If the concrete paving surface is tined, more compound can be required.

Thermal curing is as important as wet curing. Temperature rise should be limited by mixture design and by delivering the concrete at the lowest practical temperatures. The temperature of the concrete should be monitored until it is close enough to the ambient temperature that thermally induced cracking is not a problem. Generally, temperature gradients of 20 °C or less within the deck are considered acceptable in bridges. If excessive gradients are likely to occur, the structural elements will need to be insulated to control the rate of cooling. Excessive thermal gradients can occur even in hot weather conditions. It is necessary to provide for the supply and installation of insulation in the contract documents.

Concrete placed in severe drying conditions is prone to plastic shrinkage cracking. The provisions of this Standard should be followed to avoid plastic shrinkage cracking. This requires pre-planning on the part of the contractor.

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Annex J (informative)
Guide for selecting alternatives when ordering concrete using Table 5

Note: *This Annex is not a mandatory part of this Standard.*

J.1 Introduction

The purpose of this Annex is to provide background information and guidance to users of this Standard on selecting either the performance or prescriptive option for specifying and ordering concrete found in Table 5. In particular, the focus is on the materials selection and the design of concrete mixtures for the performance option and the enhancement of this approach in accordance with this Standard.

The advantage of the performance approach is that the contractors and materials suppliers are free to use their expertise, innovative talent, and other resources at their disposal to design and deliver the product in the most efficient and economical manner. This is consistent with the owner's interest, which is generally to own a structure that will fulfill his or her needs at reasonable cost. In most circumstances, the owner has no vested interest in the nature of the constituent materials or the methods used, provided that the performance requirements are met.

The incorporation of performance language within this Standard began in the 1994 edition. In the 2004 edition, Table 5 was modified significantly, reducing the number of alternatives for specifying concrete to two through the elimination of the "common" alternative. Enhancements were also made in other areas of the Standard to facilitate the adoption of the performance approach for concrete construction and to remove the barriers to doing so. The performance and prescriptive alternatives now described in Table 5 are intended to provide a clear definition of the roles and responsibilities of the various parties when specifying concrete, and to emphasize the importance of the need for the concrete to perform as intended in both the plastic and hardened states.

Many challenges accompany such a significant change in the concrete materials and construction industry. These include the importance of ensuring clear understanding of the roles and responsibilities of all interested parties; the need for formal quality control, quality assurance, and verification processes; and the importance of writing project specifications that capture the intent of the performance option and clearly articulate the expected performance criteria in measurable or verifiable terms. This Annex contains information and direction on all of these issues.

J.2 Background

The early development of this Standard was based largely on empirical relationships between prescribed materials, mix designs, and construction methods and the corresponding overall performance of the concrete in service. The construction industry has since moved away from the prescriptive approach toward a performance approach. Furthermore, the "common" alternative has become a much less viable option due to the lack of clarity in defining the roles and responsibilities for specifying the various mix design parameters and for assuming responsibility for the concrete mix proportions. In concert with this general direction, this Standard has, over several editions, acquired a combination of prescriptive and performance language.

The essence of an effective performance specification is that the performance requirements are stated in measurable terms and the ability of the finished product to meet those requirements can be verified at the time the construction is complete. In many instances however, the state of the art has not yet

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developed to the point where performance can be conveniently verified at the necessary time. For this reason, there are significant portions of this Standard, beyond the selection of materials and mix designs, that are likely to remain prescriptive in nature for the foreseeable future. However, for purposes of specifying and ordering ready-mixed concrete, it is believed that the adoption of a performance approach and the elimination of the "common" alternative are timely. Accordingly, the 2004 edition provided the owner with the option of following either the prescriptive or performance approach.

The purpose of this Annex is, therefore, to provide guidance and background information to the user when specifying and ordering concrete, with a view towards enhancing and facilitating a performance approach.

J.3 Definitions

In addition to the definitions in Clause 3, the following definitions apply in this Annex:

Contractor's quality plan — the planning of the activities performed by the contractor to ensure the project meets the owner's specifications.

Owner's quality plan — the planning of activities performed by the owner to assure the shareholders (private company) or the public (public organization) of the control of the concrete construction quality.

Pre-construction and pre-placement meetings — meetings involving construction team members to review major items of concrete construction (pre-construction) and address specific issues related to concrete placement of an individual concrete element or placement period (pre-placement).

Qualification testing — the testing of concrete prior to the beginning of the construction phase to assess whether the concrete has the potential to meet the specified performance criteria.

Quality control plan — the planning of the quality control activities of the contractor by defining items, such as sampling and testing frequency, and alerting or rejecting criteria for non-conformance.

J.4 What is performance?

J.4.1 General

During the course of a construction project, a number of parties will be involved in the production and construction of concrete. The custody of the concrete and its constituent materials will change hands several times, with each custodian having the ability and opportunity to affect the final performance of the concrete. As a result, each of the parties will have different and sometimes conflicting performance requirements. A definition of performance is therefore paramount. Clauses J.4.2 to J.4.4 set out key terms and the criteria that should be taken into consideration when specifying concrete on a performance basis.

J.4.2 Performance concrete specification

A performance concrete specification is a method of specifying a construction product in which the final outcome is given in mandatory language, in a manner that the performance requirements can be measured by accepted industry standards and methods. The processes, materials, or activities used by the contractors, subcontractors, manufacturers, and materials suppliers are then left to their discretion. In some cases, performance requirements can be referenced to this Standard or other commonly used standards and specifications, such as those covering cementitious materials, admixtures, aggregates, or construction practices.

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J.4.3 Prescriptive concrete specification

A prescriptive concrete specification is a method of specifying a construction product in which all processes, activities, materials, proportions, and methods used to achieve the intended final outcome are specified in mandatory language contained in the project specifications. The contractors, subcontractors, materials suppliers, and manufacturers should then follow a prescribed process and use prescribed materials and proportions to deliver the product.

J.4.4 Performance criteria

J.4.4.1 General

In order to accommodate the interests of the various parties, the measurement and verification of the performance of concrete should be defined as set out in Clauses J.4.4.2 to J.4.4.4.

J.4.4.2 Plastic state

The essential performance characteristics are

a) uniformity;
b) placeability;
c) workability (i.e., the ability to be placed and consolidated to completely fill the forms without unacceptable surface blemishes, loss of mortar, colour variations, segregation, etc.);
d) finishability (including limitations on the acceptable amount of bleeding); and
e) set time.

For the most part, these performance characteristics will be of interest to the contractors, concrete suppliers, and subcontractors involved in placing and finishing the concrete.

J.4.4.3 Hardened state

The essential performance characteristics are

a) physical properties of compressive, flexural, or tensile strength and modulus, as applicable;
b) rate of strength development;
c) durability in the expected service environment, including resistance to corrosion, scaling, deleterious expansion, chemical degradation, freeze-thaw attack, abrasion, and other deterioration processes to which the concrete might be exposed;
d) volume stability (limitations on acceptable volume changes due to shrinkage, creep, and thermal differentials caused by heat of hydration);
e) appearance and architectural characteristics (i.e., limitations on acceptable levels of shrinkage cracking);
f) surface texture (e.g., non-skid finish, steel trowel finish); and
g) geometrical requirements (e.g., flatness and levelness, slope for drainage).

For the most part, the properties of the hardened concrete will be of interest to the designer and owner, but in some cases, these properties will also be of interest to the contractor and concrete supplier.

J.4.4.4 Specifying performance criteria

The challenge when preparing a performance specification for concrete is to state performance requirements that can be satisfied and that can be measured by accepted industry standards and methods. Specifications are normally written by and for the owner, whose interest is usually, but not always, long-term. The required performance criteria should therefore be stated in terms that can be measured early in the life cycle of the concrete and can be used to verify at that time that the long-term

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performance criteria will be met. Hence, the verification process becomes an essential and critical part of the success of the performance approach. Without a comprehensive and reliable verification process, the owner's performance requirements cannot be verified at the appropriate time and the process is not workable.

J.5 Roles and responsibilities

J.5.1 Performance specifications

J.5.1.1 Owner

Prior to endorsing the use of a performance specification, the owner should have confidence that this approach will meet his or her objectives. This requires reliance on the design team to prepare an effective performance specification and on the implementation of a reliable quality assurance process that will verify that the performance criteria will be met.

The owner is therefore responsible for appointing a competent design authority and implementing an appropriate quality assurance process. Often responsibility for quality assurance will be delegated to the design authority.

J.5.1.2 Design authority

The designer is responsible for

a) establishing the performance criteria, usually in consultation with the owner;
b) preparing the technical specification that states the performance criteria in appropriate terms; and
c) under the direction of the owner, conducting quality assurance and reviewing quality assurance reports, or both, to ascertain on the owner's behalf that the performance criteria have been met.

J.5.1.3 Contractor

The construction team is responsible for procuring concrete and related materials and incorporating them into the structure in a manner that meets the performance requirements.

The contractor is also responsible for conducting appropriate and sufficient quality control to demonstrate and document that the performance requirements have been met. The quality control documents should be communicated to the design authority and owner in a manner, and according to a schedule, that will accommodate the quality assurance process.

J.5.1.4 Concrete supplier

The concrete supplier is responsible for procuring materials and producing concrete that will, in its plastic and hardened states, meet the performance requirements. This includes responsibility for implementing a quality control program to demonstrate and document that the product as delivered is of appropriate quality and will meet the performance requirements.

Since in a typical construction project the custody of the concrete transfers from the supplier to the contractor while in its plastic state, a high degree of coordination is required between supplier and contractor to ensure that the final product meets the performance criteria and that the quality control processes are compatible and demonstrate compliance.

J.5.1.5 Responsibilities of the testing agency

The testing agency is responsible for complying with the applicable standard concrete test methods of CSA A23.2 and the relevant portions of the project specifications. The concrete testing laboratory is

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responsible for ensuring that personnel and equipment meet the requirements of CSA A283 (or equivalent) for the appropriate category.

J.5.2 Prescriptive specifications

J.5.2.1 Owner

The owner is responsible for appointing a competent design authority and implementing an appropriate quality assurance process. Responsibility for quality assurance is often delegated to the design authority.

The use of the prescriptive approach transfers responsibility for the prescribed materials and processes from the contractor and supplier to the owner and design authority. The owner is therefore responsible for ensuring that the prescribed materials and processes will meet the performance requirements.

J.5.2.2 Contractor

The construction team is responsible for supplying materials and conducting the work in accordance with the prescribed requirements.

The contractor is also responsible for conducting appropriate and sufficient quality control to demonstrate and document that the prescribed requirements have been met.

J.5.2.3 Concrete supplier

The concrete supplier is responsible for supplying concrete in accordance with the prescribed requirements and for conducting appropriate and sufficient quality control to demonstrate and document compliance.

J.5.2.4 Testing agency

The testing agency is responsible for complying with the applicable standard concrete test methods of CSA A23.2 and the relevant portions of the project specifications. The concrete testing laboratory is responsible for ensuring that personnel and equipment meet the requirements of CSA A283 (or equivalent) for the appropriate category.

J.6 Selecting an alternative

J.6.1 General

In selecting an alternative for specifying concrete in accordance with Table 5, it is up to the owner to determine the relative merits, costs, and other implications (including intellectual property rights) associated with the prescriptive and performance approaches. To some extent, this will involve a risk management approach.

J.6.2 Prescriptive environment

In a prescriptive environment, the owner should make decisions about the balance between capital investment and long-term maintenance costs. From a purely concrete materials perspective, this risk-based approach makes the owner responsible for matching long-term performance expectations with material selection and mix design parameters and the owner should make conscious decisions about his or her front-end and life-cycle costs. The owner empowers the consultant/architect to design a concrete structure that will meet certain performance criteria, considering primarily the medium- and long-term performance characteristics. The consultant then prescribes the materials, quantities, mix design

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parameters, and methods to achieve the intended performance. The contractor, on the other hand, is most concerned with the short-term performance characteristics (e.g., plastic concrete and strength gain properties) that will most cost-effectively enable construction. These properties need to be established to ensure the required medium- and long-term requirements are met. Key assumptions, therefore, include the following:

a) The consultant is knowledgeable enough about the most cost-effective way to correlate the prescriptive directions/measures with medium- and long-term performance.
b) The general contractor will follow the prescriptive directions and plan construction methods and sequence without compromising medium- and long-term performance.

In the prescriptive environment, the owner, through the consultant, takes the lead role in monitoring the materials and methods to determine that the prescription has been followed.

J.6.3 Performance environment

J.6.3.1 General

In a performance environment, the owner stipulates the required performance of the concrete and then relies on the contractor and his or her suppliers and subtrades to provide materials and methods to achieve the performance required. Superimposed on the owner's performance requirements, which normally focus on the medium- and long-term performance requirements, are the contractor's short-term performance requirements.

J.6.3.2 Quality management

Verification of concrete quality to ensure performance that meets the requirements of this Standard and the project specifications is the responsibility of the owner.

Quality plans should take into account any quality management elements, both internal and external, to the owner's concrete acceptance requirements and that these elements should be tailored to each specific project and concrete performance that is being sought. This includes ensuring that the contractor has in place an industry-recognized quality control (QC) plan (e.g., an ISO 9000 type of process) that prevents or corrects defects and nonconformities in the concrete, and that is commensurate with the size and complexity of the project. Care should be taken during the contractor selection and award stages of a project, to ensure that contractors and suppliers are provided with the necessary incentives for the added effort and cost of maintaining such a QC process.

The external QC effort (e.g., inspection and testing for verification and acceptance) made by the owner should complement and balance the internal QC effort made by the contractor, ensuring that the contractor's QC systems are in place, operating effectively, and preventing or correcting nonconformance.

In a performance environment, a higher level of responsibility is placed on the contractor and all of the contractor's suppliers (e.g., ready-mix, hardware, reinforcing steel, etc.) and subcontractors (e.g., formwork, reinforcing steel, pumping, placing finishing, etc.) for the internal QC effort. The owner, in turn, balances this effort by reviewing the QC plans and records of primary contractors, subcontractors, suppliers, and secondary suppliers, and by conducting independent quality assurance, testing, and verification of concrete and other material properties to validate the results of the contractor's processes. The owner should also undertake an independent audit of the quality management system.

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J.6.3.3 Components of specifications

Project or contract specifications should include pre-qualifiers and post-qualifiers. Pre-qualifiers include the experience, proprietary mix design performance record, testimonials, proposal evaluation, integrated quality control plan evaluation, contractor-to-subtrades communication plan evaluation, and other criteria necessary to allow the owner to place reliance on the contractor, suppliers, and subtrades. Post-qualifiers include the qualitative or subjective evaluation, quantitative or objective evaluation, quality control results, quality assurance results, rationalization of discrepancies between quality control and quality assurance, and other criteria necessary for the owner to be satisfied that the performance criteria have been met.

Performance-based contract documents (i.e., owner-contractor) will typically include plans and specifications complete with

a) clearly articulated and understood roles and responsibilities of all parties, including owner, consultant, contractor, supplier, subcontractors, testing agency, etc.;
b) terms and conditions for interaction among owner, contractor, and supplier;
c) clearly understood definitions of performance and point of delivery;
d) pre-qualifiers (i.e., past performance and quality plan) and post-qualifiers (i.e., quality control and quality assurance);
e) performance criteria (i.e., durability, architectural requirements, volume stability, strength, and structural requirements), test methods, and acceptance criteria;
f) reference to (contractor-supplier) quality plan;
g) penalties for non-compliance; and
h) procedures for dispute resolution.

J.6.3.4 Verification process

An effective performance specification will require a comprehensive verification process in which quality control and assurance processes verify and ensure that the performance criteria are being met. There are two components of the quality control program. Some of the performance criteria are, of necessity, subjective in nature (e.g., appearance and freedom from surface blemishes). It will be necessary to define in some measurable way how the performance will be evaluated. Also, some parameters overlap into responsibility for design and serviceability (e.g., freedom from cracking). Again, it will be necessary to define these types of parameters in a way that can be effectively evaluated.

J.7 Contents of quality plans

J.7.1 Owner's quality control plan

J.7.1.1 Qualification

The project specification or quality control plan may define some qualification requirements, including

a) certification required from the contractor, subcontractors, testing agency, and suppliers;
b) test results required as part of the qualification of concrete;
c) duration of the historic data required; and
d) type of samples for qualification tests and type of samples samples prepared in laboratory or field conditions.

For some tests that may be included in a quality plan and their approximate durations (i.e., lead time), see Table J.1.

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J.7.1.2 Contractor's quality control plan

The specification or owner's quality control plan should define the requirements for the contractor's quality plan, including

a) a list of required elements to be included in the contractor's quality plan;
b) the organization responsible for the review of the contractor's quality plan; and
c) qualifications of the personnel reviewing the contractor's quality plan.

J.7.1.3 Audits

The specification or owner's quality control plan should define an audit plan of the general contractor's quality plan. Audits are required to verify that the general contractor's quality management system is implemented and effective. Owner's audit plan should include

a) the organization responsible for the audits;
b) independence and confidentiality measures required from the auditors;
c) qualifications of the personnel performing the audits; and
d) frequency of the audits.

J.7.1.4 Acceptance testing

Owner's specifications should identify

a) the party responsible for acceptance testing with a reference to the tests required for acceptance;
b) the qualifications of the organization responsible for the test or inspection;
c) the qualifications of the personnel performing the test or inspection;
d) frequency of the test or inspection;
e) timing and distribution of reports; and
f) appeal procedure.

For some acceptance tests that might be specified and their approximate durations see Table J.1. Lead time is important for qualification. Duration is more applicable to acceptance testing.

J.7.1.5 Pre-construction and pre-placement meetings

The owner's quality plan should specify pre-construction and pre-placement meetings, defining the

a) meetings schedule;
b) attendance list; and
c) agenda (checklist).

Note: *A typical checklist is found in* Best Practices guidelines for concrete construction*, OGCA-RMCAO; Revision 1.0; 2005.*

J.7.1.6 Submittals

As required under the project specifications and by the specifying alternative selected from Table 5, documents are to be submitted to the owner in accordance with the owner's and contractor's quality plans. Typical information required for the submittals include

a) identification of the concrete mix tested for qualification;
b) intended use of the concrete mix (i.e., part of the concrete structure it will be used);
c) complete test report following the requirements of the standard used; and
d) historic data on the same or similar concrete mix for the same test for the specified duration. When this data is not available qualification tests can be conducted.

For a typical concrete mix submittal form see Figure J.1.

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J.7.2 General contractor's quality control plan

A general contractors quality plan should define the contractor's responsibilities and actions required to meet the specifications. The management of the plan, including compliance with the quality plan and any modifications, remain the responsibility of the general contractor. A plan may be implemented wholly or partially by a contractor, subcontractor, supplier, or an independent organization. Responsibilities are presented in Table 5.

Changes to the plan should be in writing and accepted in kind by the owner. Acceptance of the contractor's quality plan does not exclude that changes can be requested by the owner at any time, following observations from audits. A quality plan should include

a) organization charts, roles and responsibilities, and identification of the person in charge of quality management for the project (this can include personnel for the supplier and subcontractor as well as the contractor);
b) document management and retention process;
c) concrete construction processes, including placing, protection, finishing, and curing;
d) verification of concrete mixes and submittal process;
e) non-conformance management process including identification, reporting, and procedure to correct and prevent re-occurrence of the non-conformance;
f) quality control testing and inspection plan complete with test results reporting; and
g) change management process.

Note: *It is important that the change management process include a procedure for informing all parties of changes to the construction process or concrete mix design affecting performance and, if required, indicate how the quality control will be adjusted in order to assess how performance criteria will still be met.*

J.7.3 Testing agency's quality control plan

The testing agency's quality plan should evaluate resources and access provided to project site prior to the start of work to ensure that these are adequate for conduct of acceptance testing and for storage and care of test specimens. The general contractor and the owner's representative need to be notified in writing if these are inadequate.

The testing agency needs to participate in concrete pre-construction conference(s) to establish or confirm

a) site safety requirements;
b) responsibilities for scheduling of agency performing plant or project site inspection and testing;
c) project site access and requirements;
d) requirements and responsibilities for project site sampling;
e) requirements and responsibilities for sample storage and security;
f) communication protocol for inspection and testing non-conformances; and
g) report distribution and transmission method(s).

J.8 Summary

The adoption of a performance approach to supplying concrete and building a structure is an obvious departure from the traditional approach. Recent experience has demonstrated that success is achieved when the owner has confidence in the ability of the contractors and suppliers to meet the performance criteria, and the contractors and suppliers embrace the concept of quality control to the point where the quality control process not only identifies and corrects deficiencies, but provides persuasive evidence to the owner that the required performance will be met.

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Table J.1
Potential tests for concrete and approximate test duration (required lead time)
(See Clauses J.7.1.1 and J.7.1.4.)

Property	Test method or procedure*	Time required to complete testing
Materials requirements (beyond physical tests)		
Alkali-aggregate reactivity of aggregates	CSA A23.2-14A and A23.2-25A	12 months (concrete) and 16 days (mortar)
Fresh concrete properties		
Slump or slump flow	CSA A23.2-5C or A23.2-19C	Same day
Air content on fresh concrete	CSA A23.2-4C or A23.2-7C	Same day
Passability	CSA A23.2-20C	Same day
Set time	ASTM C403	Same day
Plastic shrinkage	ASTM C1579	Same day
Water content of fresh concrete	CSA A23.2-18C	Same day
Density of fresh concrete	CSA A23.2-6C	Same day
Temperature	CSA A23.2-17C	Same day
Structural properties		
Compressive strength on cylinders	CSA A23.2-9C	1 to 91 days
Compressive strength on cores	CSA A23.2-14C	2 days
Flexural strength	CSA A23.2-8C	7 to 91 days
Splitting tensile strength	CSA A23.2-13C	7 to 91 days
Pull out strength	CSA A23.2-15C	1 to 91 days
Modulus of elasticity and Poisson's ratio	ASTM C 469	7 to 91 days
Direct tensile strength	CSA A23.2-6B or CRD-C 164	7 to 90 days
Durability properties		
Hardened air voids	ASTM C457	14 days
Freeze-thaw resistance	ASTM C666/C666M	4 months
Salt scaling resistance	CSA A23.2-22C or BNQ 2621-905	4 months
Rapid chloride permeability	CSA A23.2-23C	3 months (for 91-day test)
Resistivity (Wenner probe)	AASHTO T 358	1 day
Mitigation of alkali-aggregate reactivity	CSA A23.2-28A	24 months (concrete) and 16 days (mortar)
Sorptivity	ASTM C1585	30–60 days
Chloride bulk diffusion	ASTM C1556	75 days
Abrasion resistance	ASTM C944/C944M	2 months

(Continued)

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Table J.1 (Concluded)

Property	Test method or procedure*	Time required to complete testing
Water soluble chloride content	CSA A23.2-4B	7 days
Sulphate resistance	CSA A3004-8C	6 to 18 months depending on cement type
Carbonation resistance	Phenolphthalein indicator	28 to 365 days (1 day on in-place cores)
Volume stability properties		
Shrinkage	CSA A23.2-21C	35 days
Restrained shrinkage	ASTM C1581	14 to 56 days
Creep	ASTM C512/C512M	1 year
Thermal coefficient of expansion	CRD-C 39	14 days
Architectural properties		
Colour	Mock-up	1 month
Texture	Mock-up	1 month

* *This list is not meant to be exhaustive, nor is it intended that all of the tests listed are required. Tests selected for qualification or acceptance will vary based on the requirements of each specific project.*

Note: *Time required to complete is for testing alone, and allowance should be made for the time from receipt of samples to start of test. Many durability and volume stability tests require an extra 7 d allowance for sample preparation and reporting. The duration of some tests also depends on the test ages provided in the project specification.*

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Figure J.1
Sample concrete mix submittal form
(See Clause J.7.1.6.)

Project: _____ Date: _____

Location: _____ Submitted By: _____

Contractor: _____ Contact: _____

SPECIFICATION	**CONCRETE MIX CODE**				
	Application of Mix				
	Structural Requirements				
	• CSA Exposure Class				
	• Maximum W/CM Ratio				
	• Specified Strength — Age				
	• Plastic Air Range (%)				
	• Nominal Maximum Aggregate Size				
	• Maximum % SCM Replacement				
	• HVSCM Type 1 or 2				
	Durability Requirements				
	• Exposure to Sulphate Attack				
	• Alkali Aggregate Reactivity				
	• Aggressive Chemical/Waste				
	Architectural Requirements				
	• Colour/Texture				
	• Other				
CONTRACTOR REQUIREMENTS	Quantity m^3				
	Rate (m^3/h)				
	Slump Range (mm)				
	Method of Placement				
	Strength/Age (MPa/Days)				
	Specialty Information				
	• Concrete Set (Delay, Normal, Accelerated)				
	• Floor or Slab Type — (Exposed/Covered)				
	• Other				
MATERIALS SECTION	**Source & Type**				
	• Hydraulic cement(s)				
	• SCM 1 – Slag, Fly Ash				
	• SCM 2 – Silica Fume, other				
	• Fine aggregate				
	• Coarse aggregate				
	• Air-entraining admixture				
	• Water-reducing admixture				
	• Other (admixtures, fibres, etc.)				

Notes:

1) *The "concrete supplier" provides to the contractor, a valid provincial concrete association "Certificate of Concrete Production Facilities".*
2) *All concrete and materials should be supplied in accordance with CSA A23.1.*
3) *Concrete test reports should be provided to the owner, contractor, and concrete supplier within 5 d.*
4) *Concrete tests not done in accordance with CSA standards should not be accepted for any basis of measurement.*
5) *The owner should be responsible for all concrete performance when specifying any material proportion(s).*

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Annex K (informative)
Concrete made with high-volume supplementary cementitious materials

Note: *This Annex is not a mandatory part of this Standard.*

K.1 Explanation of Clause 8.7 — Concrete made with high-volume supplementary cementitious materials

Supplementary cementitious materials (SCMs), covered in CSA A3001, include pozzolanic materials, such as fly ash, silica fume, and natural pozzolans and ground granulated blast furnace slag (GGBFS), a latent hydraulic material (hereafter referred to as slag). Most of these materials have been used in concrete in North America and Europe for more than 50 years (silica fume for 25 years) and the technology behind their use is reasonably well understood. In Canada, much of the research was developed by CANMET, starting in the early 1980s (Malhotra and Mehta, 2002). However, there have recently been increased economic and environmental incentives (e.g., LEED) to use higher levels of these materials, especially fly ash and to a lesser extent slag, to replace larger proportions of hydraulic cement in concrete mixtures. The environmental advantages are linked to the desire to use more recycled materials in "green buildings" and to reduce greenhouse gas emissions by lowering the use of hydraulic cement, the production of which consumes large quantities of energy and releases substantial quantities of carbon dioxide, a greenhouse gas. Some developers and designers are also interested from the perspective of producing sustainable concrete (Mehta, 2001 and 1999). While the use of concrete with high levels of SCM offers many advantages, both technical and otherwise, such concrete displays different characteristics (in both plastic and hardened concrete) from plain hydraulic cement concrete and requires special consideration in the design and production stages (e.g., increased quality control).

The requirements of this Standard have been used effectively for traditional SCM replacement levels. Clause 8.7 is intended to define the additional requirements that need to be considered when using high-volume supplementary cementitious material (HVSCM) concrete. The purpose of this Annex is to give guidance on the use of HVSCM concrete and to provide a rationale for Clause 8.7. At this time, only fly ash and slag are covered by this Annex and Clause 8.7, as there is little information available on the use of high levels of silica fume and natural pozzolans, and few field applications of such use. Furthermore, the term "natural pozzolan" covers a broad range of materials that can be used at very different replacement levels. At the time of writing, little or no natural pozzolan is used in concrete in Canada.

K.2 Explanation of Clause 8.7.1 — Proportion of SCM

Typical replacement levels for SCM vary depending on the nature of the material, the type of construction, and the placement conditions and traditionally fall in the range of 15% to 35% for fly ash and 25% to 40% for slag (Kostamatka *et al.*, 2002). Concrete with these SCMs has a record of good performance and durability. There is precedent for using concrete with up to 60% fly ash replacement and 75% slag. Such mixtures have been used successfully in industrial and heavy civil construction (Malhotra and Mehta, 2002). Currently, interest in using HVSCM concrete has expanded to commercial, institutional, and residential construction. For the purpose of this Standard, two types of HVSCM concrete are defined as any concrete in which the combined quantity of fly ash (*FA*) and slag (*S*), expressed as percentages by mass of the total cementitious material, meets the following condition:

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HVSCM-1:

$$\frac{FA}{40}+\frac{S}{50}\geq 1.00$$

HVSCM-2:

$$\frac{FA}{30}+\frac{S}{40}\geq 1.00$$

It should be noted that these quantities include fly ash and slag that is added as a separate ingredient at the mixer or as a component of blended cement.

Concrete that meets the definitions of both HVSCM-1 and HVSCM-2 is deemed to be HVSCM-1 concrete.

K.3 Explanation of Clause 8.7.2 — Materials

Concrete that contains supplementary cementitious materials and blended cements that do not meet the requirements of CSA A3001 are outside of the scope of this Standard.

K.4 Explanation of Table 2 — Requirements for C, F, N, A, and S classes of exposure

Numerous laboratory studies have examined the effect of fly ash and slag on the resistance of concrete to cyclic freezing and thawing and de-icing salt scaling. A review of the published results from accelerated laboratory studies on fly ash indicates that the scaling resistance of fly ash concrete generally decreases as the fly ash content increases above about 30% and the water-to-cementitious-material ratio increases above 0.45 (Thomas, 1997). However, it has been demonstrated that concretes containing relatively high levels of fly ash can provide satisfactory performance when used in structures exposed to de-icing salts, provided that proper consideration is given to the proportioning, placing, finishing, and curing of the concrete (Thomas, 1997; Malhotra and Mehta, 2002). Because of the increased susceptibility of HVSCM concrete to de-icing salt scaling, it is prudent to ensure a higher quality concrete (i.e., with a lower water-to-cementitious-materials ratio) is used when the structure is prone to being saturated and exposed to freezing and thawing.

Although ultimately the strength of HVSCM concrete will be higher than that of concrete containing no or small amounts of SCM, the rate of strength gain at early ages tends to be lower. Consequently, a longer curing period might be required for HVSCM concrete to attain the required strength and durability. For this reason, the strength acceptance age for HVSCM concrete should be increased from the typical 28 d to 56 d or possibly 90 d. This can be necessary in order to accommodate the slower strength gain of these mixtures. The suitability of such an age increase for a particular project should be evaluated by the project's design engineer.

The general principle that durability is proportional to the water-to-cementitious materials ratio applies both to HVSCM concrete and to plain hydraulic cement concrete. Permeability and porosity increase with an increasing water-to-cementitious materials ratio.

K.5 Explanation of Note j) to Table 2 — Requirements for reinforced concrete

Concrete containing high levels of SCM will generally carbonate at a faster rate than concrete of the same water-to-cementitious materials ratio, but without SCM. Laboratory research has indicated that

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concrete with a high volume of fly ash (e.g., 50%) will carbonate very rapidly unless the concrete is adequately cured and has a low water-to-cementitious materials ratio (e.g., less than 0.40) (Thomas and Matthews, 2000). Carbonation poses a risk of corrosion to embedded steel with low-to-moderate depths of cover. Corrosion will occur if there is sufficient moisture available. The exposure conditions that present the greatest risk are the soffits of suspended slabs and balconies and exposed vertical surfaces that receive little direct precipitation. For concrete that is continuously moist, the process of carbonation will be very slow. For steel-reinforced concrete exposed to moisture and air, with low to moderate depths of cover, HVSCM concrete will require a low water-to-cementitious materials ratio and adequate curing (discussed in Clause 8.7.4) to ensure sufficient protection of the embedded steel.

K.6 Explanation of Clause 8.7.3 — Trial mixes

Unless there is experience with the production of HVSCM from a particular supplier, it is necessary to perform trial mixes to ensure that the required concrete properties are achieved. SCM should not simply be substituted for cement, mass for mass; the mixture should be specifically proportioned for its intended use.

HVSCM fly ash mixtures, if optimized, will usually have

a) a lower unit mixing water content (e.g., if conventional mixtures in a particular region use 150 L/m^3 to 160 L/m^3, the HVSCM mixtures should have approximately 130 L/m^3). If the proportioning does not result in a significant water reduction, the the mixture should not be used;
b) a reduced fine aggregate content (and possibly increased coarse aggregate content); and
c) a higher total mass of cementitious materials than the comparable plain hydraulic cement mixture for a particular strength, if a particular strength is required at ages up to 28 d. If the strength is specified at later ages, HVSCM concrete in some cases will not require an increased cementitious material content.

Similar trends can be observed for high-volume slag mixtures.

HVSCM concrete mixtures have a tendency to be sticky. This results from the higher paste content of HVSCM concrete compared to plain hydraulic cement concrete. However, HVSCM concrete responds well to vibration. As such, the slump test sometimes does not give a proper measure of consistency.

HVSCM concrete generally does not bleed. Therefore, in the case of finishing flatwork, the finishers must become accustomed to judging timing without the benefit of the disappearance of the bleed water. In addition, there is an increased risk of plastic shrinkage cracking (while the concrete is still plastic) and premature shrinkage cracking during the first 24 h after the concrete has set. Measures should be in place (e.g., fog curing) to ensure that the concrete does not dry out before full curing is applied.

HVSCM concrete will normally contain common air-entraining admixtures and water-reducing admixtures (WRA). It is also common, but not necessarily critical, to use high-range water-reducing admixtures (HRWRA). With HRWRA, it is possible to achieve an extremely low water-to-cementitious materials ratio, such as is required to meet the requirements of Clause 8.7.4, and improved dispersion of the fine SCM particles.

Admixture dosages are typically based on the total cementitious materials content. In the case of the WRA, this gives an increased effectiveness because WRA acts preferentially with the cement particles, of which there are fewer in HVSCM concrete than in comparable plain hydraulic cement concrete of a comparable strength. WRA dosages can sometimes be reduced without loss of strength and reduction

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typically results in quicker setting times. Air-entraining agent dosages are typically higher for a given air content when using SCMs.

Admixtures that are optimum for normal concrete are sometimes not optimum for HVSCM. Industry sources indicate that some WRAs that retard setting in normal concrete will produce significantly higher retardation in HVSCM. Type C fly ash is particularly susceptible to this potential problem.

Accelerating admixtures can be used with HVSCMs to partially offset the delayed setting time and slower early-age strength development, but it is necessary for their effectiveness to be evaluated for each combination of admixture and SCM. In general, mixes should be proportional to achieve the original setting times and early strengths required. For mixes where an early strength is required, HVSCM is sometimes not appropriate.

K.7 Explanation of Clause 8.7.4 — Curing requirements

It is well established that concrete containing fly ash and slag develops its properties at a slower rate than comparable plain hydraulic cement concrete for a particular design strength; thus, longer periods of moist curing are required to achieve equivalent maturity and durability. The need for extended curing becomes more acute with higher levels of replacement. Malhotra and Mehta (2002) recommend a minimum moist curing period of 7 d at a minimum temperature of 10 °C for high-volume fly ash concrete. Longer periods might be required for concrete in a severe exposure condition.

HVSCM should not be used in concrete for which the extended curing in Clause 8.7.4 is not feasible.

K.8 Explanation of Clause 8.7.4.2 — Curing plan

Given the critical nature of this curing, the requirements of a curing plan prepared by the contractor and reviewed by the owner have been added in Clause 8.7.4.2. This plan would be normally expected to contain, at minimum

a) the type of curing material;
b) the manner in which the surface is to be kept moist and the quality control requirements for keeping the surface moist;
c) the duration of curing;
d) provisions to address potential problems (e.g., high winds and hot weather); and
e) the limitations of access, if any, to the surfaces being cured or the protection of the accessible surfaces.

K.9 Quality control requirements

Given that the development of HVSCM concrete is ongoing, it is prudent to increase the quality control in its production. This includes the quality control for the materials themselves and for the concrete.

One major aspect of quality control can be the monitoring of early strength. The normal early strength expected by construction crews is sometimes not achieved, particularly with high volumes of Type F fly ash, particularly in cooler weather. Designers should ensure that the contractor has in place adequate methods of monitoring the *in situ* strength where form stripping or support of suspended members is required.

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Annex L (informative)
Mineral filler as an aggregate for concrete

Note: *This informative (nonmandatory) Annex has been written in normative (mandatory) language to facilitate adoption where users of the Standard or regulatory authorities wish to adopt it formally as additional requirements to the Standard.*

L.1 General characteristics

Mineral fillers are fine powders manufactured or produced from crushing coarse aggregate and is considered a very fine aggregate, not a supplementary cementitious material. Mineral fillers should to be added as a separate ingredient in the concrete mix. For air-entrained concrete, the specified maximum w/c ratios of Table 2 apply. The particle size distribution is determined and monitored regularly, as with other aggregates.

L.2 Organic impurities

The clay size material (i.e., finer than 2 µm) shall not exceed 1% of the mineral filler. The amount of material of clay size shall be determined by performing

a) a hydrometer analysis, as per ASTM D422, on a sample washed through an 80 µm sieve; or
b) the methylene blue test, in accordance with CSA A3004 D-1, shall not exceed 1.20 g/100 g. For this test, the limestone shall be ground to a fineness of approximately 5000 cm^2/g determined as specific surface in accordance with ASTM C294.

The total organic carbon (TOC) content, when tested in accordance with CSA A3004, D2, shall not exceed 0.5% by mass

L.3 Deleterious reactions

When mineral filler is proposed for use by the concrete supplier, the supplier shall provide the owner with all test data necessary to demonstrate that the material will produce concrete of acceptable quality that meets requirements of Clause 4.2.3.6 and all other relevant requirements of this Standard.

In particular, the potential alkali-aggregate reactivity (AAR) of mineral filler shall be assessed using either the accelerated mortar bar test with a non-reactive aggregate or, preferably, using the concrete prism test with non-reactive fine and coarse aggregates, even if the coarse aggregate of the same source is proven non-reactive. In the case of alkali-rich mineral filler, the potential alkali contribution of the filler to the concrete can be assessed by running the concrete prism test with the coarse and fine aggregates proposed for use in the project. Assessment of performance shall include, but not be limited to, the following tests:

a) compressive strength;
b) splitting tensile strength; and
c) drying shrinkage.

Limestone fillers should not be used in sulphate environments for any S class listed in Tables 1 to 3.

Note: *Until sufficient research is conducted, mineral fillers containing carbonates (e.g., limestone and dolomite) should not be used in concrete exposed to sulphate environment.*

L.4 Application

Mineral fillers should be used to optimize the aggregate gradation to achieve an improved concrete performance. Mineral fillers are not cementitious materials and should not be used to replace

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cementitious material in concrete. Mineral fillers shall not be included in the calculation of the water-to-cementitious materials ratio (w/cm). The water/cement shall not vary significantly with or without the use of mineral fillers.

L.5 Quantities

Documentation should be provided by the concrete supplier verifying successful concrete performance containing mineral filler at the percentage proposed for use. If Portland limestone cement is used, the documentation of concrete performance should be done based on a combination of limestone cement and mineral filler to be used in the concrete.

L.6 Additional publications

The following is a list of additional publications applicable to this Annex.

American Concrete Institute. 2017. *Guide for Proportioning Concrete Mixtures with Ground Limestone and Other Mineral Fillers*. ACI 211.7R.

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Annex M (informative)
Sustainable development, construction, and concrete

Notes:
1) *This Annex is not a mandatory part of this Standard.*
2) *Also see Annex D in CSA A3000 and Annex D in CSA A23.4.*

M.1 Introduction

The *Report of the World Commission on Environment and Development: Our Common Future* (Brundtland Report, 1987), defines Sustainability as:

> "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Often termed the "Triple-Bottom-Line" considering economic, environmental (climate change, greenhouse gas emissions, carbon footprint, embodied energy, land use changes, etc.), and social (aesthetics, education, employment, community engagement, etc.) aspects, it is clear that sustainable development covers a wide range of very broad issues. There are specific issues such as governments wanting to construct public buildings that meet a form of sustainable accreditation, and builders and homeowners wanting green construction to address concerns about energy generation, consumption, and the environment.

Sustainability needs to consider the creation and long-term performance of buildings and infrastructure in a holistic manner. To best succeed, practical sustainability thinking needs to be considered as an inherent influence and in a continual manner and not as an optional extra; success requires a broad emotional commitment from all.

Sustainable development is about balancing human needs with the earth's capacity to meet them. Concrete offers a wide range of capabilities to help achieve this balance. There are a variety of green building movements in existence and the consideration of some of these systems offers a useful presentation of possible sustainable targets for projects.

Owners, designers, material suppliers, and contractors must continue to address the influencing factors in order to identify and offer sustainable solutions through products and services. A wide variety of construction methods and products offer techniques to create both aesthetical and functional benefits that reduce the impact of buildings on the environment and even ultimately have a positive impact on the environment. Concrete as a construction material provides many sustainable benefits such as architectural appearance, durability, mould-ability, structural rigidity, thermal mass, long service life, appearance, reflectivity and economy.

Although sustainability as a term is becoming reasonably widely understood and often referenced back to the Bruntland Commission definition, resiliency is a term that is used to describe both the long term durability and life of a product or material, as well as the ability of a product or material to offer protection from adverse events such as seismic disasters and the extremes of wind, fire, water, and explosion. Clause M.4, on resiliency, explores these concepts in more detail.

M.2 Background

Society now recognizes the importance of addressing sustainable development issues, as well as identifying and further developing solutions.

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Many sectors of the construction industry are developing products and practices to support sustainable development in their manufacturing and supply processes, as well as on job sites. For example, general contractors look at reducing environmental project impact by reducing job site noise, completion time, or waste materials. Green building is a predominant theme in some markets and market segments as owners and investors become increasingly concerned with issues such as long life, energy and water conservation, reducing consumption of virgin materials, and how these affect future resource demands. Marketing demands are moving towards increased environmental support.

At the same time, the concrete industry looks to concrete as being able to offer many solutions in response to the demand for green products and will act as a responsible partner to address local and global concerns. The concrete industry can also look to an *Environmental Concrete Facility Certification* designation offered by some provincial associations that identifies and addresses suppliers' facility operations, production and manufacturing processes and practices relative to the reduction of carbon footprint, conservation of electricity and water, reuse and recycling of materials, and the use of by-products to offer sustainable solutions. It is also important that the concrete industry properly communicates its own processes and achievements.

Like other building materials, concrete has embodied energy: it takes energy to manufacture and construct a concrete building or structure. However, concrete's lower embodied energy from cradle-to-grave or cradle-to-cradle can be leveraged more efficiently. Concrete can be used as an integrated design to optimize sustainable development and construction, and can also assist the owner or architect in obtaining points within green rating systems.

Concrete plays a vital role in reducing the operational energy requirements of buildings due to its thermal mass. This potential cost reduction is especially important when considering that over the typical lifespan of a building the operational impact (i.e., energy requirements) is far greater than their embodied impact to produce.

The concrete industry uses the latest conservation and recycling practices and technologies for the manufacturing, production, and operational processes to assist in making concrete a sustainable building product. These practices and technologies continue to improve.

The intent of this Annex is to begin the process of bridging standards with specifiers' intentions (i.e., a "green building" that fits appropriately within existing standards and vice versa). Moving forward, building green should not be an informative piece, but the reality of all construction. This is the first step in that process.

M.3 Green building movement

M.3.1

To address the green building movement, a number of green rating systems and guides have been developed. Some of these rating systems include:

a) BRE Environment Assessment Method (BREEAM) (www.breeam.com);
b) Green Globes (www.greenglobes.com);
c) Green Guide for Healthcare (www.gghc.org);
d) ASHRAE Green Guide (www.ashrae.org); and
e) Leadership in Energy and Environmental Design (LEED) (www.usgbc.org).

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M.3.2

The ratings systems tend to focus on buildings, but can often impact broader elements. However, the systems are evolving and some systems contain arbitrary or artificially created elements that might not always be totally valid. Nevertheless, they encourage lateral thinking and offer a broad perspective for items to be considered. This is not an exhaustive list and the rating systems in Clause M.3.1 are examples that are currently prevalent in the market. The current mainstay in green building in Canada continues to be the LEED rating system, which is arranged into 22 different rating systems grouped by type of project. Project types include building design and construction, interior design and construction, operations and maintenance, neighborhood development, and homes. Each of these project types is further broken down into the specific rating systems, of which the most commonly used in Canada is building design and construction: new construction (BD+C: NC). The LEED references and discussions in the remainder of this Annex are specific to the BD+C: NC rating system. The LEED system gives owners, designers, and consumers insight into the major features and benefits of using concrete in an integrated solutions design to address sustainable development and construction. LEED v4 which was published November 2013 and fully adopted by November 2016 has seven credit categories for the BD+C: NC system:

a) location and transportation (7 credits with 16 potential points);
b) sustainable sites (6 credits with 10 potential points);
c) water efficiency (4 credits with 11 potential points);
d) energy and atmosphere (7 credits with 33 potential points);
e) materials and resources (5 credits with 13 potential points);
f) indoor environmental quality (9 credits with 16 potential points); and
g) innovation and design process (6 credits with 10 potential points).

Each category is divided into credits, each of which has a potential number of points. A unique and challenging feature of the LEED rating system is the approach to “greening” the building, which is a holistic approach. Projects are LEED certified (i.e., products can contribute to LEED credits through their footprint reduction, recyclability, life cycle, and other attributes that the LEED system values). The points are added, compared to ranges of achievement from certified to platinum, and certificates are provided for meeting the predetermined levels.

M.4 Resiliency

There are a wide number of definitions of resiliency commonly referenced including that of the US Department of Homeland Security: “…the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies”. As with sustainability, consideration of resiliency extends well beyond most building codes where the focus is on minimum standards for immediate life safety. When considering the multitude of resiliency definitions together however, they can often be summarized into two key concepts:

a) resistance to an unusual external event; and
b) the ability to recover from those events.

Those unusual external events can be naturally occurring, such as rising sea levels due to climate change, earthquakes, extreme winds and wildfires, or un-natural events such as terrorist attacks and explosions. Although further discussion here is focused on building resiliency, it is also important to consider that the concepts of resilient construction do not only apply to buildings, but they also equally apply to infrastructure.

Naturally occurring unusual or extreme events can be specific to a geographical location, such as coastal communities with respect to sea level rise, or location of fault lines, but un-natural event assessment might need to consider the type of building, e.g., a military building might be considered a target for a

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terrorist attack. Any resiliency assessment must consider risk of event occurrence, i.e., type and extent of hazard and probability of occurrence. The ability of a structure to resist these events can be considered a function or attribute of the building materials themselves and each construction material offers certain inherent benefits with respect to resistance to different types of extreme events.

When the recovery of a building after an extreme event is being considered, the recovery can be defined as anticipated or required performance in response to those events, i.e., performance rather than prescriptive specifications. Anticipated or required performance after an event can be further detailed such as in the Federal Emergency Management Agency (FEMA)/American Society of Civil Engineers (ASCE) building performance levels (see FEMA 356): collapse prevention, life safety, immediate occupancy, and the highest performance level, operational. Required post-event performance is often a functional consideration in that buildings such as hospitals and emergency shelters require significantly higher performance levels than other buildings and to achieve these goals, they can incorporate redundant systems. Post-event performance is effectively a function of the building materials, the structural design elements, and redundancy.

Each building can be assessed for both risk of an event and the required post-event performance. Such assessments can direct a designer at the concept development stage or during consideration of rehabilitation or upgrade of existing buildings. Concrete has a number of beneficial attributes when considering resistance to extreme events and offers a multitude of structural design options to improve post-event recovery and performance.

Although concepts of resilience are more recent that those of sustainability, some programs and rating systems are starting to emerge such as the Insurance Institute for Business and Home Safety (IBHS) FORTIFIED program.

M.5 Concrete as a sustainable material

M.5.1 Overview

The sustainable use of concrete in buildings and infrastructure involves not only the design and specification of performance requirements, but also the sourcing of raw materials, production, delivery, placing, finishing, curing, testing, acceptance, and finally the overall performance during the life cycle of use, potential re-use, and disposal. At each phase in the process there are opportunities to support sustainability and achieve appropriate performance standards. The capabilities of concrete to enhance environmental aspects are considered under the following categories:

a) innovation, sustainability, and design;
b) materials, resources, and concrete properties;
c) production and delivery — energy and atmosphere;
d) formwork, reinforcement, and prestressing;
e) placing, finishing, and curing;
f) testing;
g) use and life cycle; and
h) decommission/recommission and end-of-life.

The location of any suggested aspect within a category is somewhat arbitrary and examples could be readily considered in several categories. The categories are more related to concrete rather than the available green systems but many are readily transferable. For example, reduction in fuel consumption because of mechanically efficient, large volume mixer trucks delivering to a site close to the production plant could be considered under sustainable sites, energy and atmosphere, or materials and resources,

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but is listed once to minimize duplication. The suggestions listed are intended as prompts to thinking and not in any way as an exhaustive checklist.

M.5.2 Innovation, sustainability, and design

M.5.2.1

Site selection, building orientation, building envelope, surface treatments, surrounding area hardscaping, and community connectivity are integral parts of sustainable design. In *LEED*, there are a total of 16 points available in the location and transportation category and 10 points available in the sustainable sites category. The use of concrete and cement can help in securing a number of these points, for example:

a) For reduced site disturbance, protection or restoration of open spaces and reduction of development footprint, concrete parking garages on the lower floors of a building can be used to limit overall building impacts. Parking garages within buildings help maintain existing natural areas that would be consumed by paved surface parking.
b) For a positive heat island effect on a site there can be use of light-coloured or open grid pavement, or both, for a site's finished surfaces. This requirement can be met by using concrete paving rather than asphalt for all sidewalks, parking lots, drives, and other impervious surfaces. Using building materials with higher albedo (reflectance of at least 0.3) will reduce the heat island effect, consequently saving energy by reducing the demand for air conditioning, and improve air quality. This fact drastically decreases the temperature and energy costs in and around buildings, towns and cities and subsequent energy demands.
c) In redevelopment of contaminated sites, cement, SCMs, and cement kiln dust (CKD) can be used to solidify and stabilize contaminated soils and reduce leaching concentrations to well below regulatory levels.
d) Pervious concrete pavements and permeable paving systems can offer advantages in storm water management in terms of runoff rate and quality because they increase infiltration of storm water. This appropriately replenishes ground source water and water tables.

M.5.2.2

Designing buildings and infrastructure in concrete offers many benefits, such as the following:

a) Anticipation of longer life expectancy for buildings and infrastructure can be beneficial to building use.
b) Built homes and high rise buildings that can offer greater durability in terms of standing up to ever increasing natural disasters, fire, and security issues and save both lives and property. Concrete structural framing offers good fire resistance capability. Avoiding loss of property due to fire negates the need to rebuild.
c) High-rise buildings use less land footprint than low rise. Concrete framing is a valid choice.
d) Performance characteristics minimize the environmental impacts of building construction by allowing earlier completion times, minimizing other construction products and materials, and reducing trades, services, and energy related requirements.
e) Concrete can be a moisture resistant material and improve overall building durability.
f) High or ultra-high performance concrete addresses forward thinking designs for thinner, post-tensioned slabs, or smaller building columns to reduce material consumption and impact.
g) Structural elements using both reinforcing steel and concrete create a highly efficient structural system and provide protection against possible corrosion. Reinforcing steel is also typically produced from 100% recycled scrap feedstock.

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h) The high thermal mass characteristics of concrete can lower the operational energy consumption (e.g., electric, natural gas, or oil) for homes and businesses. Building applications, such as insulated concrete forming systems, can further increase the savings.
i) Innovative applications, such as green roofs for usable space positively affects our green spaces, water consumption and collection, and energy use.
j) Concrete offers a number of architectural finishes that release no volatile organic compounds and are healthy for indoor air quality environments.
k) Thermal mass characteristics of concrete coupled with solar/radiant floor heating can assist in the reduction of energy required for air movement for healthier air quality.
l) Pavements for highways, streets, and parking areas that have high light reflectance (albedo) require lower lighting requirements.

M.5.2.3

Designers have choices, such as the following:

a) Life cycle assessment (LCA) is being used by designers and owners as they better understand the benefits to society. As part of an LCA, environmental product declarations (EPD) are being developed which are intended to provide the designer with specific material/product information on environmental impacts. This allows them to make more informed choices based on developed models.
b) A continued move toward performance- and objective-based specifications rather than prescriptive allows variety in supply and flexibility in providing good concrete.
c) Life cycle costing assessment (LCCA) should be considered that includes all issues from extraction and processing, to production, delivery and construction, use, decommissioning, and end of life.
d) Use of high performance concretes can utilize higher cement contents but may also allow a reduction in the cross section of structural elements and longer spans providing an overall reduction in material use.
e) Recycled materials in the mix reduces use of virgin materials and can also reduce concrete's carbon footprint. For example:
    i) recycled concrete aggregate (see Annex O) can be used to have a positive impact on both material use and carbon footprint; and
    ii) fly ash, silica fume, and slag, also known as supplementary cementitious materials (SCMs), are preconsumer recycled materials and can be used in concrete to reduce permeability and increase lifespan. These products can also enhance concrete's resistance to deleterious reactions such as sulphate attack or alkali-silica reactivity (ASR) susceptible aggregates. This beneficial use of these materials also reduces landfill wastes.
f) Where not required to have an early strength gain, for construction scheduling, rather than the typical 28 d strength specification, designers could specify strength on a 56 d basis, or longer to allow for increased use of SCMs and an overall reduction in total cementitious material use provided exposure class requirements are maintained. Designers could also consider specifying lower design strengths, provided durability and other requirements are met.
g) Data collection on key aspects of concrete allows for informed and practical decisions on concrete. For example, sharing information on joint spacing, fibre reinforcement, placement practices, curling, and joint spacing with respect to performance of slab on grade for warehouses might highlight the impact of certain design decisions.
h) Minimizing the variety of concrete classes on site can minimize mistakes and wastage.

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M.5.2.4

As always there needs to be design wisdom and any potential negatives need to be mitigated, such as the following:

a) Pervious pavement to address stormwater control requires maintenance to prevent build up of fine material and loss of permeability. Structural loading and freeze/thaw are also considerations.
b) Use of a green roofs requires application of building science skills and adequate concrete impermeability to be acceptable.
c) Designers could consider details to avoid thermal bridging resulting in heat loss from concrete balconies withdrawing heat from flooring.

M.5.3 Materials, resources, and concrete properties

Partners in providing concrete materials are responsible community-based businesses, employers, and taxpayers who drive an environmental and sustainable culture through their own organizations and those of their associated suppliers. There are good standards in place such as responsible materials procurement that might be addressed by environmental assessments and certifications offered by some industry associations. The capability of being able to use suitable locally availably raw materials provides opportunity to minimize adverse environmental impacts. In LEED, there are a total of 13 points available in the Materials and Resources category. There are a variety of beneficial opportunities in material selection and combinations of use that should be followed, such as the following:

a) Raw materials with lower embodied primary energy used in their production can be considered.
b) Concrete's carbon footprint can be reduced by specifying Portland-limestone cement (PLC) or use of supplementary cementitious materials (SCMs) such as fly ash, silica fume, or slag.
c) Concrete recycles by-products or waste materials from other processes such as fly ash, slag (ground granulated blast furnace slag), and silica fume or kiln dust as part of its standard manufacturing process, and this reduces the carbon footprint of cement by up to 50%. These products do not need to be land-filled. Concrete can utilize high volumes of these supplementary cementitious materials to meet the requirements of LEED or similar green building accreditation systems.

   Note: *High-volume supplementary cementitious material categories (i.e., HVSCM 1 and HVSCM 2) are described in Clause 8 of this Standard.*
d) Specifiers should focus on performance criteria for concrete and where overall performance standards can be met; allow the use of flexible aggregate grading rather than maintain grading specifications which might not be realistic for local aggregates or might be out of date or possibly copied from other not relevant projects within an organization's documentation. Optimally graded aggregate should be utilized where possible. Gap-graded aggregate can be suitable, or even necessary, for some concrete applications, provided placement and performance criteria can be achieved.
e) Local aggregate supplies for use in concrete have significant economic, social, and environmental benefits over transporting aggregate long distances.
f) Aggregate stockpiles need to be located and managed in a manner that reduces contamination and dispersal of materials as a nuisance.
g) Care needs to be taken for possible re-use of concrete aggregate in concrete because of a possible adverse cumulative level of salts, alkali reaction or other impurities.
h) Recycled concrete, with removal of reinforcement generally provides excellent material for floor and road sub-bases.
i) Proper concrete production conserves potable water use. Admixtures are used for part of the operations and production processes to reduce the potable water requirement of the mix and non-potable (grey) water (i.e., recycling water that has been used before, thereby reducing and conserving the use of potable water).

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j) Process water and storm water can be continuously captured and reused for truck washing/cleaning and slurry is used as an ingredient back into the concrete production process for zero discharge from the facility. This reduces the energy consumption footprint and maximizes the use of previously produced products and resources.
k) Admixtures reduce water demand and content.
l) Concrete pavements for highways often reduce total aggregate consumption by 50% compared with a traditional flexible pavement, which results in reduced use of non-renewable resources, reduced truck traffic, lower emissions, and fewer road hazards.
m) Concrete is a 100% reusable resource.
n) Corrosion inhibitors can be used to improve product life.

M.5.4 Production and delivery — Energy and atmosphere

Driven by the need to place concrete in a timely manner after initial mixing, concrete is a locally produced product by nature, utilizing locally sourced materials and minimizing transportation distances. This aspect complies well with green ranking criteria such as LEED and does much to aid the environment. There are other positives available, such as the following:

a) High-efficiency concrete production facilities and sustainable development designations reduce all environmental impacts.
b) Local materials, including all binder materials and aggregates minimizes transportation emissions.
c) Local ready mixed concrete suppliers, as well as site-cast and precast fabrication close to construction sites minimizes delivery fuel consumption and vehicle emissions.
d) Truck fuel consumption (i.e., fossil fuels) and emissions are reduced by routing trucks on concrete pavements because of less rolling tire resistance.
e) Bio-fuels or hybrid vehicles minimize transportation emissions.
f) User costs are reduced because of fewer delays on concrete pavements for road repair and maintenance, detours, goods delivered late, and fewer emissions from truck and car idling.
g) Pre-construction meetings tend to provide efficiencies, minimize misunderstandings, and result in less time/idling wastage.
h) Delivery trucks should have good mileage and volume ratios and be well maintained.
i) GPS tracking and dispatch systems minimize travel times, road congestion, time on project and overall vehicle emissions.
j) Smart ordering and scheduling of concrete minimize time, travel, truck emissions, and waste.
k) The incorporation of residential concrete into this Standard allows an opportunity to share expertise, improve placement practices of placing concrete upon soft, unsound subgrade or rebar placed upon subgrade instead of spacers, thereby working towards a reduction of failed concrete.

M.5.5 Formwork, reinforcement, and prestressing

Formwork, reinforcing and prestressing are processes where taking care of details offers benefits, such as the following:

a) Timely inspections and making sure formwork is ready to receive concrete, in associating with placing orders, allows the appropriate transfer of concrete and minimizes idling time for trucks and minimizes erratic set times for multiple batches of concrete with varied delay times in truck mixers.
b) Use of polyethylene and steel fibre can reduce undue cracking in warehouse floor slabs and extend functional life.
c) Environmentally friendly form release materials should be considered.
d) Care should be exercised in specifying such protective measures as epoxy coated and galvanized rebar and make sure of a balance between innovation and long term performance.
e) Standardization of formwork allows re-use on a site or even between sites.

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M.5.6 Placing, finishing, and curing

Site management and construction practices are a major influence on the quality of the finished concrete product and the following should be considered:

a) Ensuring concrete pumps are of correct output capability, fully working, and unobstructed access to the delivery points minimizes truck idle times.
b) Ensuring proper plans for equipment idle-times, clean out and disposal, and emission and fluids monitoring.
c) Careful site planning can minimize wastage of concrete by utilizing load surpluses by use in other elements within the site. It can be helpful to have areas where formwork is in place and capable of receiving small volumes of concrete without risking cold joints.
d) Proper tolerances for floor flatness and levelness can avoid unnecessary rejection of placed floors and yet provide functional floors.
e) Use of foundation mud slabs can reduce aborting of deliveries or undue wait times to provide clean receiving surfaces less dependent upon weather.
f) Heating and hoarding does use energy. It is vital concrete is placed and cured in acceptable temperatures. In adverse weather heating and hoarding should not be compromised, but if choice is available, curing and placement could be scheduled for more appropriate weather conditions.
g) Environmental plans should include controlled disposal of concrete surpluses and washouts. Wet concrete has a high pH and can cause serious chemical burns to exposed skin and other body parts such as eyes. Personnel training and provision of adequate PPE can help miminize the chances of serious injury. Water from truck chute and drum washing can also have a high pH which harms fish habitat in rivers.
h) Health and safety on-site plans need to be discussed along with pre-construction meetings with all stakeholders as worker welfare is of prime concern on any project. Such meetings also offer opportunity to discuss environmental factors.

M.5.7 Testing

It is vital to appropriately test concrete, but it is important to optimize test methods and not to over-specify or over-test and waste concrete. The following should be considered:

a) Take care in specifying the overall volume to be tested in a project to minimize waste.
b) Use non-destructive testing rather than destructive methods.
c) Ensure all testing equipment matches performance requirements.
d) Ensure test methods and calibration of results are unambiguous.
e) Conduct internet distribution of test results and trend analysis to reduce paper and time.
f) Review test results as soon as available to identify and deal with any inappropriate, evolving performance issues.

M.5.8 Use and life cycle

Concrete can be used to provide a benefit back to society in many forms, such as

a) lower first cost to purchase and construct;
b) lower life cost to own, maintain and use;
c) lower environmental inventory cost through sustainable benefits such as
    i) maintenance reductions;
    ii) high durability results in lower maintenance and repair;
    iii) energy conservation through
        1) lower energy use in structures through thermal mass abilities; and
        2) lower energy use through higher pavement reflectivity (albedo);

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iv) fuel conservation — fuel savings through reduced fuel consumption with trucks on rigid pavements;
v) CO_2 emissions reductions — reduced CO_2 and GHG emissions from reduced energy and fuel use; and
vi) natural resources conservation — reduces up to 50% use of virgin aggregates with concrete pavements saving non-renewable resources.

M.5.9 Decommission/recommission and end-of-life

Concrete's advantages during decommissioning/recommisioning include the following:

a) Concrete can be 100% recycled and reused (crushed) which saves resources, keeps materials out of landfills, and reduces emissions attached to vehicle delivery and transport, etc.
b) Concrete structures might be able to be recommissioned depending on intended use and condition of the structure.

M.6 Roles and responsibilities

Looking toward sustainable development and the world's future, owners' and designers' specifications are embracing todays and tomorrow's technology and innovation with the obvious intent of having a positive and sustainable impact on construction.

The issues of sustainable construction should be considered for products from cradle to end of life to reuse. It is important to consider the total affect of a product on society from a social, environmental, and economic perspective. Careful consideration and fact-based data begins with the extraction and manufacturing of raw materials, such as aggregates, admixtures, and cements, through the manufacturing, production, and delivery processes and finally at end of service.

The concrete industry has an Environmental Concrete Facility Certification designation offered by some provincial associations which might in some cases address responsible material sourcing.

More detailed documents regarding sustainability and environmental performance and stewardship have been developed by industry partners such as members of the Canadian Ready Mixed Concrete Association (www.crmca.ca), Cement Association of Canada (www.cement.ca), and Canadian Precast/ Prestressed Concrete Institute (www.sustainableprecast.ca).

Roles and responsibilities of the project team are described in Clause 4.4 of this Standard.

M.7 Summary

All parties working together as suggested and increasing the beneficial use of concrete can positively influence sound sustainable practices. However, roadblocks to sustainable construction do exist. Decisions that deter sustainable construction use or advancement can be made based on false or incomplete information. It is confusing for designers, contractors, and suppliers to hear that an owner has a desire to use sustainable construction practices only to see that, in actuality, as-prescribed or outdated methods or products are specified that can neither achieve the goals nor offer the best product. A great deal of education is necessary for the concrete and construction industry. Through these educational efforts, more owners, designers, and contractors are now realizing that concrete can be enhanced to provide performance (e.g., desired strength gain, set, and stripping times with high volumes of SCM).

Owners are becoming aware that true technologies and their actual benefits are readily available in the marketplace and how to take advantage of them. Any failure of a concrete element to fully perform should be determined, understood, resolved, and communicated. Any potential benefit of concrete

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should also be considered, understood, and increasingly utilized. The concrete industry is continually working with stakeholders and partners to provide an environment of information and education.

Innovation also lies in the minds of all users as new applications, technologies, and designs are developed to meet future sustainable requirements. The internet is allowing this information to be shared instantly and globally, which greatly reduces the time from which an idea is born until it is brought to market.

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Annex N (informative)
Requirements for pervious concrete

Note: *This informative (non-mandatory) Annex has been written in normative (mandatory) language to facilitate adoption where users of the Standard or regulatory authorities wish to adopt it formally as additional requirements to the Standard.*

N.1

Pervious concrete pavement shall be designed for the intended traffic loads, the soil conditions, and the anticipated drainage requirements. Pervious concrete shall not be used

a) where concrete is required to be impermeable;
b) where it will be exposed to loads greater than designed; and
c) for reinforced concrete.

N.2

Pervious concrete pavement shall be placed on a layer of granular material. The granular material shall be at least the minimum thickness required to act as a reservoir to allow water to drain from the concrete and prevent the pervious concrete from becoming saturated under freezing conditions. The depth of free draining material beneath the pervious concrete shall be based on the soil conditions (permeability) of the site and, as a minimum, be able to act as a reservoir for the average rainfall over a two-year period.

Note: *Pervious concrete can provide sufficient durability when exposed to freezing and thawing, provided that the paste fraction is adequately air entrained and the design incorporates a free draining granular material beneath the concrete. Information on the design of pervious concrete pavements is given in Tennis et al (2004).*

N.3 Materials

N.3.1 General

All materials shall conform to the pertinent clauses of this Standard.

N.3.2 Proportioning and testing

N.3.2.1 Mix proportions

N.3.2.1.1 General

Mix proportions shall be governed by the strength, density and void content requirements, and workability required for placement. The minimum design void content of pervious concrete shall be 15 percent.

N.3.2.1.2 Cementitious material

The cementitious material paste consistency shall be adjusted by trial and inspection during the mixing operation to ensure that all the particles are completely coated with a film that is sufficiently thick for the intended application. Excess fluidity of the paste shall be prevented to avoid the paste draining down from the coarse aggregate and clogging the voids of the mixture.

Notes:

1) *Because there is relatively small tolerances in the allowable water-to-cementitious materials ratio for pervious concrete, the attainable compressive strength for a given type of cementitious material and aggregate is*

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mainly governed by the ratio of cementitious materials to aggregate. However, a strong paste fraction does not always lead to an increased compressive strength. A higher cementitious materials content is associated with higher compressive strength and lower void ratio. It will be apparent that a higher cementitious materials content provides the aggregate particles with a more generous coating of cement and with a greater volume of filler in the contact area, but the consistency of the paste is maintained by control of the water-to-cementitious materials ratio and admixture selection to preclude paste drain-down during placing.

2) *Aggregate-to-cementitious materials ratios ranging from 4.0 to 4.5 have been found to give satisfactory results in the proportioning of pervious concrete for various applications, the proportions being by mass for use with normal-density aggregate (i.e., having a relative density in the range of 2.60 to 2.70).*
3) *The term "consistency" is not applicable to pervious concrete, as such, but is used to refer to the consistency of the cement paste that has been found to produce the desired coating of the aggregate, without being too dry to form the necessary filler or too wet to produce paste drain-down.*
4) *Mid-range and high-range water reducers have been shown to be effective to provide increased workability to the paste fraction. Viscosity modifiers reduce the paste drain-down effect. Retarding admixtures, especially hydration stabilizers, have been found to be effective to protect the concrete from rapid setting prior to application of curing. The use of air entrainment can improve the freeze thaw resistance of the paste fraction. The use of fibres can improve discharge from the truck.*
5) *The water-to-cementitious materials ratio necessary to obtain satisfactory consistency will vary with each particular source or type of cementitious material and each mixing temperature, and it will usually fall within the range of 0.26 to 0.45 with normal hydraulic cement at ordinary temperatures. Mixtures having water-to-cementitious material ratios of 0.26 to 0.30 generally benefit from the use of admixtures as noted above (see also ACI 522R).*

N.3.2.1.3 Trial batches and trial sections

N.3.2.1.3.1 Trial batches

Trial batches shall be made to establish the mix proportions with the proposed materials. A uniform coating of paste on the aggregates shall be attained with no visual evidence of cementitious material paste draining down through the aggregate particles. The trial mix shall be tested for plastic density and the void content calculated in accordance with Clause N.3.2.3.1. The cementitious materials-to-aggregate ratio and water-to-cementitious materials ratio that will meet the job requirements shall then be established on the basis of these results.

N.3.2.1.3.2 Trial section

In concert with the owner, the contractor shall construct a satisfactory trial section to demonstrate the ability to successfully produce, place, and finish pervious concrete pavement to the contract requirements and to meet the testing requirements prior to placement of concrete.

The trial section shall be constructed in accordance with the project specifications and the requirements of this Clause. The contractor shall place a representative test panel at a minimum area of 20 m^2 with the required project thickness. The test panel shall be consolidated, jointed, and cured using the materials, placing equipment, and personnel proposed for the project to demonstrate to the owner that a satisfactory pervious concrete pavement can be produced.

The trial section shall have acceptable surface finish, joint details, thickness, void content, and curing procedures and shall comply with the testing and acceptance requirements of Clause 8.4. The freshly mixed pervious concrete shall be tested for density and the void content shall be calculated in accordance with Clause N.3.2.3.1. Three cores from the trial section shall be tested for thickness in accordance with ASTM C174/C174M and for void content and density in accordance with Clause N.3.2.3.2. Satisfactory performance of the trial section shall be determined by the following:

a) plastic density shall be within ±80 kg/m^3 of the design density;

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b) compacted thickness shall not vary from the specified thickness by less than 6 mm or more than 25 mm;
c) void content of hardened pervious concrete shall be not less than 15 ± 5% and not more than 30 ± 5% of the design void content; and
d) density of hardened pervious concrete shall be within ±80 kg/m^3 of the design density.

If the trial section does not meet these requirements, it shall be determined to be unacceptable and another trial section shall be constructed. If the trial section is found to be satisfactory, the contractor may proceed with construction of the pervious pavement construction at the site.

N.3.2.2 Strength requirements

The required strength of the concrete shall be determined based on the pavement design and the site characteristics. The pervious concrete pavement shall not be opened to vehicular traffic until the concrete has cured for at least 7 uninterrupted days at 10 °C and until the pavement is accepted by the owner for opening to traffic.

Notes:

1) *Compressive strength depends on the compaction achieved with the equipment used for placing. Higher compaction will increase strength but will decrease void content. Compressive strengths in range of 10 to 20 MPa are achievable with previous concrete.*
2) *To establish the compressive strength of the pervious concrete pavement in place, cores should be cut from the pavement at the desired test age and tested in compression. Standard test methods for producing moulded cylindrical specimens have yet to be established. Flexural strength specimens can be cast from the trial batches and compacted using similar techniques to those that will be employed to compact the pervious concrete at the site. The flexural strength determined from tests at the specified age can confirm that the pervious pavement design parameters have been satisfied. Coring of pervious pavements has been found to require copious amounts of water to cool the drill bit.*

N.3.2.3 Determination of density and void content

N.3.2.3.1 Determination of density and void content of freshly mixed pervious concrete

The density of freshly mixed pervious concrete shall be measured in accordance with ASTM C1688/C1688M. The void content, V_c, shall be calculated in accordance with ASTM C1688/C1688M. Density tests shall be performed on each load of concrete until satisfactory control is established, and then on every fifth load. Satisfactory control is established when three trucks in a row meet the specified requirements.

Note: *ASTM C1688/C1688M is only intended to be used for general evaluation of the pervious concrete mixture for general conformance to the mix design. It should not be used to evaluate the in-situ concrete of the pervious concrete pavement.*

N.3.2.3.2 Determination of density and void content of hardened pervious concrete pavement

For determination of density and void content, three cores shall be taken from randomly selected locations for every 500 m^2 of pervious concrete pavement. Cores shall be drilled through the complete depth of the pervious concrete pavement perpendicular to the surface of the slab. The unit weight and void content of hardened pervious concrete shall be determined in accordance with MTO LS-443 or the Haselbach Porosity Test Method (Montes, Valavala and Haselbach, 2005).

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N.3.3 Placing

N.3.3.1 General

Pervious concrete placement shall be conducted under the direct supervision of a contractor certified by an industry-recognized program.

Pervious concrete shall be placed, screeded, and compacted as quickly as possible to prevent drying of the mixture. Placing shall be in accordance with Clause 7.5, except as specified in Clauses N.3.3.2 to N.3.3.6. To prevent closing of the voids in the previous concrete mixture, construction personnel shall minimize walking on or through the concrete during the placing or finishing operations.

Notes:

1) *Pervious concrete is not prone to segregation; thus it is not necessary to control the height of discharge and the use of a vertical drop pipe is not mandatory.*
2) *Pervious concrete applications require specific knowledge and training for the contractor, the concrete producer, and the consultant and these parties should all be certified by an industry-recognized program. Such industry-recognized programs include Pervious Concrete Contractor Certification by the National Ready Mixed Concrete Association (NRMCA).*
3) *Pervious concrete pavement may be placed by a conventional asphalt paving machine.*

N.3.3.2 Screeding

Pervious concrete placed in pavements shall be screeded using hand or vibratory screeds to establish the desired grade.

Note: *Slightly overfilling the formwork during screeding of pavements by approximately 15 to 20 mm has been shown to be effective to accommodate consolidation after screeding. Removable strips of uniform thickness temporarily attached to the top of the forms provide a suitable means to screed the pervious concrete to the desired overfilled height. The strips are then removed prior to compaction.*

N.3.3.3 Compaction

Immediately after screeding, temporary screeding strips (if used) shall be removed and the concrete shall be compacted to the required elevation with a weighted roller or a hydraulically actuated rotating tube screed (e.g., a roller screed or Bunyan roller) operated on top of the forms or a plate compactor operated on pieces of plywood to prevent indentations. Hand tampers can be used to provide compaction along form edges. The minimum number of passes shall be provided with the compaction equipment to uniformly compact the pervious concrete to the top of the forms.

N.3.3.4 Contraction joints

Contraction joints shall be installed as specified by the owner. Joints can be installed by tooling the fresh concrete or saw cutting the hardened concrete. Tooled joints shall be formed to a minimum depth of 1/4 the thickness of the pervious concrete with a steel roller to which a bevelled metal fin has been welded to the circumference of the roller.

N.3.3.5 Construction joints

Construction joints in pervious concrete shall be further compacted with a hand tamper and edged with a suitable hand tool.

N.3.3.6 Isolation joints

Isolation joints shall be used at all abutting vertical surfaces. Isolation joints shall be further compacted with a hand tamper and edged with a suitable hand tool to minimize ravelling when exposed to traffic.

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N.3.4 Finishing

Pervious concrete shall be finished by screeding and compaction only. Surface finishing shall be kept to a minimum to prevent closing the void structure at the surface.

N.3.5 Formwork

Design and construction of formwork for pervious concrete shall be governed by the same principles as those for conventional concrete. The formwork shall be sufficiently rigid to withstand the compaction effort during placing.

Note: *Watertightness is not a requirement for pervious concrete formwork.*

N.3.6 Curing

Curing shall be implemented immediately after compaction to prevent surface drying and to ensure surface durability. The concrete should be covered by plastic sheets of at least 0.15 mm (6 mil) thick immediately after the final pass of the roller screed. The screeding, compaction, and curing steps of pervious concrete construction shall be kept as close as possible to each other to prevent drying of the mixture. Surface curing shall be applied within 2 to 4 m of the finishing operation. At no time shall concrete be left unprotected for more than 20 min after compaction.

Notes:

1) *Curing compounds are considered ineffective for curing of pervious concrete. Curing pervious concrete with polyethylene sheeting maintained in direct contact with the concrete for a minimum of 7 d is the preferred technique.*
2) *Insulated curing blankets should be used during cold weather placing operations (when the air temperature is at or can fall below 5 °C in the next 96 h).*

N.3.7 Maintenance

The permeability of pervious concrete shall be maintained. Pervious concrete pavements should be cleaned as required and at least once a year.

Note: *Failure to perform regularly scheduled maintenance of the surface could result in a clogged pervious concrete and can impair the service life of the pavement. Regular scheduled cleaning comprised of power washing, commercial vacuuming, sweeping, or a combination of these methods should be carried out in order to remove potentially clogging debris from the voids of the concrete at the surface.*

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Annex O (informative)
Aggregate made from recycled concrete for use in hydraulic cement concrete

Note: *This Annex is not a mandatory part of this Standard.*

O.1 Introduction

O.1.1

In Canada, no concrete need become a waste or be land-filled. In most cases, and almost always in populated areas, concrete recovered from roadways, sidewalks, buildings, and bridges is stockpiled and, when sufficient material is present, a portable crusher brought to the site and the material is crushed and graded to produce reclaimed (or recycled) concrete aggregate (RCA). At present, the majority of this material is used in place of virgin aggregate for unbound road base applications. There has been little use of RCA in concrete.

It is likely that in the future RCA will continue to be used in road base applications in place of virgin aggregates. However, RCA may also be used as a partial or total replacement of coarse aggregate for non-structural applications such as sidewalks, curb and gutter and some pavements or concrete base and unshrinkable fill (also known as controlled low strength material or CLSM) and other low risk applications. Virgin aggregates will probably continue to be used in more demanding structural applications. This Annex deals specifically with the use of RCA as a concrete aggregate and does not address any other current or future use of RCA.

O.1.2

To encourage the use of RCA in concrete, specifications need to be developed that classify and control the properties of the RCA. The purpose of this Annex is to highlight some of the properties that need to be considered and suggest best practices in this developing field. Introducing RCA into concrete will require the use of quality control procedures to ensure that deleterious materials and other properties of RCA do not adversely impact the quality of the new concrete product.

O.1.3

There are three main categories of RCA. They are as follows:

a) **Construction and demolition waste (CDW):** CDW consists of building materials arising from activities such as the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning, and maintenance. CDW can be mainly composed of concrete, but might also be contaminated with other demolition materials.
   Note: *Other examples of CDW can include metals, glass, solvents, gypsum, brick, and wood.*

b) **Reclaimed concrete material (RCM):** RCM is a generic term for after-use, hardened, hydraulic cement concrete that has been obtained from variable sources such as sidewalks, concrete roads, and construction and demolition waste (CDW) for use as a construction material. If one source of demolished concrete (e.g., a pavement), is made into RCA then the quality of the "single source RCM" will be more uniform and consistent than "mixed source RCM" made from several sources of demolished concrete.

c) **Returned hardened concrete (RHC):** RHC is unused concrete material obtained from plastic concrete that has been returned directly to the concrete plant, or from in plant waste streams, which is allowed to harden and processed by crushing. RHC also includes unused precast concrete

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products that have been returned to the plant and crushed. It can be used for the same applications as CDW and RCM. If the RCA is manufactured from returned-to-plant concrete, then even though the paste/mortar fraction might vary with the original concrete quality, the aggregates in the RHC will be essentially the same as the virgin aggregates; thus RHC can be better suited for use in concrete. The mortar fraction of RHC can be compromised during the wash-out procedures of concrete trucks returning unused concrete. If the drum of the truck is washed out into the same pile as the unused concrete then the water-to-cementitious materials ratio of the mortar fraction can be significantly increased. High quality RHC depends on proper material handling/storage procedures.

O.1.4

The appropriateness of RCA for use in concrete as an aggregate will be a function of the amount of contamination, care taken in the preparation of the material, and the amount of virgin aggregates intended to be replaced within the mix. The order of decreasing usefulness and increasing effort would be RHC, followed by RCM, then CDW.

Much of the research that has been done has examined the use of the coarse RCA fraction. The finer fraction of RCA generally is of lower relative density and more porous and absorptive than the coarse fraction which can limit its use in concrete.

O.2 Physical properties of RCA

RCA is generally of lower density and higher water absorption than that of virgin aggregates (di Niro *et al.,* 1996). This is due to the presence of the more porous mortar fraction. The amount and quality of the mortar also affects the response to other physical tests such as the Micro-Deval abrasion test (Table O.1). Andal et al. (2016) tested two different coarse RHCs and found the amount of residual mortar to be about 20% by mass for RHCs between 4.75 mm and 9.5 mm and 26% by mass for RHCs between 9.5 mm and 19.0 mm. Although both RHCs had similar level of residual mortar, the Micro-Deval abrasion was lower for the RHC produced using strict quality control protocol (18.8%) compared to that of the other RHC (23.2%). The same physical property limits as used for virgin aggregates should be used to qualify RCA for use in structural concrete; however, as additional research becomes available and dependent on the final application the concrete being produced, these limits might need to be revisited. RCA that does not meet the physical requirements for concrete aggregate might be indicative of a weak or poorly bonded mortar and the material should not be used for structural concrete or other applications where durability issues are a concern, but it may be suitable for use in CLSM and other low-risk applications.

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Table O.1
Typical physical properties of various sources of RCA
(See Clause O.2.)

Type of material	Water absorption, %	Bulk relative density — dry	Micro-Deval abrasion A23.2-29A/23A, loss in %	Freeze-thaw A23.2-24A, loss in %
RCA, MTO data 1998	2.53	2.460	Coarse agg = 14.6 fine agg = 15.7	12
RCA, MTO data 1998	3.54	2.387	Coarse agg = 17.8 fine agg = 14.0	20
RCA, MTO data 1999	4.01	2.391	Coarse agg = 17.7 fine agg = 12.7	—
RCA, MTO data 2000	—	—	Coarse agg = 19.4 fine agg = 15.3	—
RCA, MTO data 2005	—	—	Coarse agg = 23.9 fine agg = 16.4	—
RCA, Smith et al. 2008, concrete from curb and gutters	4.41	2.38	Coarse agg = 14.6	—
RCA -1, Butler *et al* 2012 — concrete from sidewalk and curb	4.66	2.36	Coarse agg = 15.1	—
RCA -2, Butler *et al* 2012, concrete from runway, apron and structures at Toronto airport	6.15	2.28	Coarse agg = 22.1	—
RCA -3, Butler *et al.* 2012, concrete returned to ready-mix plant	7.81	2.22	Coarse agg = 25.0	—
RCA, Pickel *et al.* 2013, concrete left-over from precast production	4.65	2.40	Coarse agg = 17.3	—
Coarse RCA, Andal and Shehata, 2014, concrete returned to ready-mix plant	4.88	2.32	Coarse agg = 18.8	—
RCM, Hui et al. 2015, stockpiled material	2.8	2.38	—	11

Note: *MTO = Ontario Ministry of Transportation, data from specific contracts.*

The sulphate soundness test (see CSA A23.2-9A) is probably not a useful test for evaluating RCA, since old mortar can be attacked by sulphate solutions, particularly sodium sulphate, resulting in higher than expected losses in these tests. It is likely that the unconfined freeze-thaw test (CSA A23.2-24A) might be a more suitable test but further investigation is required to set a suitable specification limit.

In the case of concrete pavements that have shown signs of D-cracking it is probably unwise to recycle such concrete in new pavement. The Ontario Ministry of Transportation in the Chatham area of southwest Ontario has either recycled such pavement as unbound granular base or sub-base or alternatively broken the old pavement in-situ and used it as a sub-base.

RCA typically shows high absorptivity and may have low and variable bulk relative density values. Such RCA, if not homogeneous, could adversely affect the consistency of weigh batching during concrete production. Pre-saturation of the RCA prior to use in concrete generally resolves this issue and avoids any impact on the fresh concrete properties. Research has shown that pre-saturated RCA can improve

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concrete strength and extend the period of concrete strength gain (Pickel *et al.*, 2014). Care should be taken to ensure that the stockpile is well drained and blended.

RCA used as a concrete aggregate should be expected to meet the conventional requirements for flat and elongated particles, fines content and grading.

In the case of CDW /RCM, the chemical and physical properties vary more when compared to virgin aggregate depending on the amount of attached mortar, or exposure of the concrete to foreign materials and chemicals during its lifecycle, processing, and storage. This is not generally an issue with RHC.

O.3 Deleterious or foreign materials

O.3.1

In addition to physical property issues, CDW/RCM might contain deleterious and foreign materials not normally encountered in virgin aggregates. These are usually the results of contamination during the demolition and recycling process. These materials might affect the setting time as well as the physical and durability properties of concrete. Again this is not generally an issue with RHC.

O.3.2

The CDW that are likely to be found include adherent fines and soil, vegetable matter, plastics, paper products, plaster and gypsum board, metals and reinforcing steel, fabrics, wood, clay brick, ceramic tile, glass, bituminous materials, and very rarely asbestos fibres or asbestos cement products. The percentages of these materials need to be determined in accordance with CSA A23.2-15A. The maximum amount of all deleterious materials should be 3% by mass. However, the maximum total amount of ceramic tile, bathroom porcelain, glass, wood, and paper should be 0.10%. It should be noted that ceramic tile, bathroom porcelain, and glass are especially likely to cause AAR and can be found in CDW from building demolition. Plaster, gypsum, and gypsum board are also a significant source of deleterious contamination in RCA and the maximum level should not exceed 1% based on work by Fookes and Collis (1976) where it was determined that maximum acid soluble sulphate content in aggregate should be below 0.4%.

Strict quality control procedures are required to ensure that recycled concrete aggregate material will not adversely affect the quality of the concrete product. In some cases, every truck load will need to be examined for contamination, especially when concrete is being brought to the recycling site from a variety of different sources. In cases where concrete from a single known structure or pavement is being recycled, the frequency of observation can probably be reduced.

Note: *A particular problem with recycling of curb and gutter or sidewalks is the frequent adherence of soil or earth to the bottom of the concrete slabs. Such soil can contain clays and other objectionable material. In this case, it is good practice to clean or wash away the adhering soil before the concrete is permitted to be placed in stockpile prior to crushing.*

O.3.3

Chlorides are often found in concrete exposed outdoors. This is due to the frequent application of de-icing salt to melt ice and snow. Marine exposure concrete will contain chloride if exposed to sea water. Concrete can have had calcium chloride added as an accelerating agent. For this reason it is essential to thoroughly and frequently investigate the amount of chloride in RCA if it is to be incorporated in

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structural concrete that will contain reinforcing steel or tensioning cables. The chloride ion content of the concrete produced with RCA should comply with the limits of Clause 4.1.1.2 of this Standard.

Note: *Excessive sulphate content in RCA can also initiate internal sulphate attack in concrete.*

O.4 Alkali-aggregate reaction

O.4.1

RCA produced from demolished concrete affected by alkali-silica reaction (ASR) was found to cause deleterious reaction when used in new concrete (Shehata *et al*., 2010). This was investigated using the concrete prism test (CSA A23.2-14A) for RCA from a 12-year old concrete test block that contained reactive siliceous limestone (Shehata *et al.*, 2010) and for RCA from a 20-year-old road barrier containing gravel from Sudbury that is known to be reactive (Piersanti *et al*., 2016). Similar results were found using the accelerated mortar bar test (CSA A23.2-25A) for RCA produced from three test blocks containing three aggregates from different sources (Adams *et al.* 2013). Shehata *et al.* (2010) attributed the reactivity of RCA to the exposure of fresh faces of the reactive coarse aggregate during the crushing of the concrete.

O.4.2

In terms of preventive measures, Shehata *et al*. (2010) reported that the levels of supplementary cementitious materials (SCM) required to mitigate the expansion in concrete of reactive RCA are higher than those required for concrete made with the same reactive (virgin) aggregate (Spratt). This was attributed to the elevated level of alkalis in the new concrete due to the alkalis contributed from the residual paste in RCA. The levels of SCM that were effective in mitigating the expansion were ternary blends of 5% silica fume and 25% low or intermediate-calcium fly ash or ternary blends of 20% Type F fly ash and 30% slag (Shehata *et al.,* 2011).

O.4.3

Shehata *et al.* (2011) reported another practical approach to mitigate expansion in new concrete containing reactive coarse RCA. This involved blending the RCA with virgin non-reactive aggregates, and using practical levels of SCM in the mixture. At a blending ratio of 70% reactive RCA and 30% non-reactive coarse aggregate (expressed as a total of coarse aggregate content in the mix), 25% of low or moderate calcium fly ash of Na_2O_e of 2.0% or 50% slag were effective in lowering the concrete prism expansion to less than 0.040% at 2 years.

O.4.4

In terms of accelerated test methods to evaluate the reactivity of ASR, the accelerated mortar bar test was found effective in identifying reactive RCA (Shehata *et al*., 2010; Adams *et al*., 2013; Johnson and Shehata, 2016). The accelerated mortar bar test was able to identify the reactivity of four different RCA's containing four reactive virgin aggregates. An interlaboratory study conducted by four laboratories showed a satisfactory agreement between the labs when testing to identify alkali-reactive RCA (Adams *et al*. 2013).

O.4.5

The RILEM concrete microbar test is another accelerated test that has shown promise in predicting the reactivity of RCA (Shehata *et al*., 2010; Johnson and Shehata, 2016). The capacity of this test to predict the reactivity of different types of RCA and evaluate the efficacy of preventive measures is currently under investigation.

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O.4.6

When new concrete is made with RCA it should be noted that the total alkali content of the resultant concrete will be greater than that contributed by the new cementitious materials alone because of the contribution of alkalis from the RCA. This higher alkali content might be sufficient to cause higher than expected expansion with reactive original aggregates in the RCA, or original aggregates that were marginally lower than the non-reactive limits detailed in Table 1 of CSA A23.2-27A, and as such the alkali content contribution from the RCA should be taken into account when considering mitigation measures. The accelerated mortar bar test (CSA A23.2-25A) has been shown to be effective in the identification of reactive coarse RCA (Adams *et al.*, 2013; Johnson and Shehata, 2016) and this testing should be completed for all RCA prior to use. Based on present knowledge, reactive RCA should not be used in concrete with a Level 2 or higher risk of ASR as identified in Table 3 of CSA A23.2-27A.

O.5 Concrete properties

O.5.1 General

There are a wide variety of reports on the effect of RCA on concrete properties. The report of RILEM committee (Hansen, 1992) summarizes the results of research up until about 1990. The report of the National Ready Mix Concrete Association (Obla *et al.*, 2007) provides a summary of more recent investigations. The following is only a very brief outline of some of the work in this area.

O.5.2 Effect on fresh concrete properties

Concrete mixtures produced with none pre-saturated RCA generally have lower workability for a given water content compared with concrete without RCA. This is especially the case if fine RCA is used that consists of large amounts of porous cement mortar. It is reported that the concrete made with saturated RCA obtained similar slump retention as concrete made with virgin concrete aggregates.

O.5.3 Effect on hardened concrete properties

O.5.3.1 Strength

Twenty per cent replacement of coarse aggregate was reported to give no significant reduction in compressive strength, but 100% replacement gave a reduction in order of 10–20% (de Vries, 1996). However if the RCA was of high-quality, the compressive strength was found to be higher compared to virgin aggregate concrete (Ajudukiewicz and Kliszcsewicz, 1996; Pickel *et al.*, 2014). Di Niro et al. (1996) reported that they were not able to make concrete with recycled aggregates that gave strengths in excess of 35 MPa even with low w/cm concrete. They found that tensile strength was consistent with the compressive strength. However, other studies have produced 100% coarse RCA concretes with strengths of approximately 50 MPa (Pickel *et al.*, 2014). Huda and Alam (2014) show first and second generation 100% coarse RCA concretes were comparable with reduced strengths of approximately 20%, but third generation 100% coarse RCA concretes were approximately 45% lower in strength. It is reported that tensile strength can be slightly reduced depending on the strength of the concrete and the amount of RCA replacement (Ajudukiewicz and Kliszcsewicz, 1996). Fumoto and Yamada (2006) found that when a variety of fine aggregate RCAs was used that, for equal w/cm concrete, the more porous fine aggregate RCA gave lower compressive strength.

O.5.3.2 Bond strength

For reinforced structures the bond between the concrete paste and reinforcing steel is an important consideration for load transfer. Moallemi Pour and Alam (2016) show that for concretes produced with up to 50% coarse RCA bond strength is similar to concrete produced with virgin aggregate.

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O.5.3.3 Shrinkage

It has been found that at 20% replacement of virgin aggregates with RCA that there was a negligible increase in shrinkage but 100% replacement of coarse aggregate by RCA showed increased shrinkage (de Vries, 1996). Increased shrinkage was also observed by Ajudukiewicz and Kliszcsewicz (1996). Sucic and Shehata (2017) recorded almost double the shrinkage level when 100% of the coarse aggregate was replaced by RCA in concrete of w/c of 0.62. For concrete made with a w/cm of 0.40 and 100% coarse RCA showed 40% more shrinkage than concrete with virgin coarse aggregate (Andal *et al.*, 2016). Using 30% coarse RCA per total coarse aggregate content produced 12% increase in shrinkage after 180 days, compared to mixture with 100% virgin aggregates (Andal *et al.*, 2016). RCA of lower micro-deval abrasion losses produced concrete of lower shrinkage compared with that of concrete produced with RCA of higher micro-deval losses (Andal *et al.*, 2016). Fumoto and Yamada (2006) found that when fine aggregate RCA was used, that for equal w/cm concrete the more porous fine aggregate RCA gave higher shrinkage.

O.5.3.4 Durability

For concrete of equal compressive strength and w/cm, there was found to be little difference in rate of carbonation between concrete made with virgin aggregates and RCA concrete (de Vries, 1996). In the Netherlands specifications allow up to 20% of the coarse aggregate to be replaced by RCA without a noticeable reduction on frost resistance (de Vries 1996). Fumoto and Yamada (2006) found that when fine aggregate RCA was used at a w/cm of 0.5, freeze-thaw durability was not significantly related to RCA content. At w/cm of 0.6 and above, decreased durability was found with increased amounts of fine aggregate RCA. Huda and Alam (2015) show that for concretes made with up to 50% RCA, the freeze thaw durability performance, modulus of elasticity, and Poisson's ratio were all comparable to control virgin aggregate even though compressive strength was observed to be lower for higher RCA replacement rates.

Caution should be exercised with RCA from concrete that has exhibited

a) high levels of chlorides;
b) high levels of sulphates;
c) alkali-aggregate reactivity; or
d) signs of D-cracking or damage due to freezing and thawing.

These kinds of RCA should probably be avoided for use in concrete where strength or durability are of concern but may be able to be used in other aggregate applications.

O.6 RCA as an aggregate for controlled low strength materials

Controlled Low-Strength Material (CLSMs) including unshrinkable fill is a self-levelling cementitious-based material used as a fill material. RCA can be used as aggregate for the production of CLSM, unshrinkable fill and concrete of strength < 10 MPa. CLSM and unshrinkable fill are covered under Clause 8.11. Their typical applications include utility fills, fills on bridge approaches and structural fill. According to ACI 229R, the strength requirements should not exceed 2.1 MPa for applications such as utility cut fill, where possible future excavation will occur. Strengths can reach up to about 8.3 MPa for structural fills such as bridge approaches. In Ontario, a type of CLSM known as “unshrinkable fill” is used, which is covered by Ontario Provincial Standard Specification OPSS 1359 and a number of municipal specifications. The requirements for unshrinkable fill are typically a minimum slump of 150 mm and maximum 28 d strength of 0.7 MPa. The low strength is specified to ensure that the material can be easily excavated in the future. Due to the low strength requirement, there is a high potential to use combined coarse and fine RCA to produce such material. Indeed, fill incorporating “returned-to-plant” coarse RCA was successfully produced using 25 kg of Portland cement per m^3 (Kolahdoozan *et*

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al., 2014). However, CLSM's of strength ranging from 0.4 to 8.0 MPa were also produced using RCA produced from demolished concrete structures (Achtemichuk *et al*., 2009).

The inclusion of fine RCA (< 5 mm) can increase the water retention of CLSM, particularly at early ages. This could significantly reduce any bearing capacity of the CLSM, specifically at the age of 4 h when some capacity is often required.

CLSM in general and unshrinkable fill in particular are possible applications for immediate use of RCA.

O.7 Quality control

The contractor/supplier of recycled concrete aggregate should develop and implement a quality control plan for aggregate production. The quality control plan should describe the means to be used to ensure that recycled concrete meets the requirements of the project. The QC plan should, as a minimum, describe the following in detail:

a) the inspection process upon receipt of demolished concrete prior to stockpiling;
b) the process for removal of contaminating materials;
c) the crushing and production processes;
d) sampling and testing frequencies; and
e) test methods.

Such plans will by necessity need to be more onerous for RCM and CDW than for RHC. Research has shown that RHC produced following appropriate quality control procedures to be of more consistent quality and more suitable for use in concrete applications compared to RHC produced without such procedures. (Andal *et al.*, 2016).

A concrete supplier's quality control plan for RHC should ensure proper handling and storage to prevent degradation of the RHC and the mortar fraction in particular.

O.8 Conclusions

O.8.1

This Annex shows that there are various options and types of RCA available, each of which requires differing levels of care and preparation before it can be used as aggregate in concrete. Since producers can have a better control on the quality of returned-to-plant (RHC), this type of RCA is a very promising alternative source of aggregate both for use in CLSMs and higher quality uses. RCA produced from demolished concrete structures is probably best used in CLSM since small amounts of deleterious materials are unlikely to prove harmful to what is essentially a granular fill material.

O.8.2

In general, it can be sustainably responsible to use RCA in concrete. Such situations might be feasible in areas where concrete aggregates are not readily available, in cases where a large concrete structure or pavement will be replaced, and in areas where there is no market for the RCA other than reuse in concrete. In such situations, the costs of production and quality control balanced against alternatives might allow for the economic use of RCA in concrete. There is also the possibility of substituting small to moderate amounts of coarse aggregate sized RCA for virgin aggregate for relatively low value construction.

In the future, in addition to the current use of RCA in such things as road base, use of recycled concrete and other non-traditional materials as aggregates in concrete will increase.

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Annex P (informative)
Impact of sulphides in aggregate on concrete behaviour and global approach to determine potential deleterious reactivity of sulphide-bearing aggregates

Note: *This informative Annex has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

P.1 Scope

P.1.1
This Annex provides general information regarding potential durability issues that could result from the use of concrete aggregates incorporating iron sulphide minerals.

P.1.2
Basic description of two sulphide minerals commonly found in rocks of various origins, namely pyrite and pyrrhotite, is provided. The deleterious oxidation reaction in iron sulphides and the resulting internal sulphate attack in concrete are described. Case studies of damaging effects in concrete made with sulphide-bearing aggregates are presented, while the current state of standardization regarding the use of sulphide-bearing aggregates in concrete is reviewed.

P.1.3
The second part of this Annex describes a novel performance evaluation protocol for determining the potential deleterious character, or not, of sulphide-bearing aggregates for concrete applications. This approach involves a combination of field and laboratory investigations.

P.1.4
A discussion on the interpretation of the results of the performance evaluation protocol described in this Annex is provided.

P.1.5
This Annex applies to virgin aggregates and does not apply to recycled concrete used as aggregate for new concrete.

P.2 Significance and use
This Standard requires that aggregates producing excessive expansion in concrete through reaction other than alkali reactivity not be used for concrete unless preventive measures acceptable to the owner are applied. Significant expansions can occur due to the presence of sulphides, such as pyrite, pyrrhotite, and marcasite, in the aggregate that might oxidize and hydrate with volume increase or the release of sulphate that produces sulphate attack upon the cement paste, or both.

This Annex provides information on a novel performance evaluating protocol (PEP) aiming at determining the potential for deleterious reaction/expansion in concrete due to the oxidation of sulphide minerals in aggregates. Recommendations on the interpretation of the results obtained when following the proposed PEP described hereafter are provided.

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P.3 Introduction

P.3.1 General

It has been known since at least the mid-1950s that iron sulphide minerals found in aggregate can cause disruption and deterioration of concrete. A number of papers have been published describing the damaging effects of iron sulphides in aggregate on concrete. The sulphide mineral that is reported to have caused the most damage is pyrrhotite ($Fe_{1-x}S$) with lesser problems being caused by the minerals pyrite (FeS_2) and marcasite (FeS_2). All three minerals are iron sulphides. At present there are no reports of damage to concrete being caused by other common sulphide minerals chalcopyrite ($CuFeS_2$) and sphalerite ($Zn,Fe)S$.

P.3.2 Pyrrhotite

Pyrrhotite is the second most common iron sulphide in nature. Mostly found with pentlandite ($(Fe,Ni)_9S_8$) in basic igneous rocks, as veins in different types of rocks and in metamorphic rocks, pyrrhotite is also found associated with pyrite, marcasite, magnetite and chalcopyrite (Deer *et al*, 1992; Belzile *et al.*, 2004). In hand sample, this mineral has a metallic luster and bronze brown, yellow, or reddish colour.

Pyrrhotite is a monoclinic or pseudohexagonal anisotropic mineral with a pale pink-brown to creamy brown colour with distinct birefringence under the petrographic microscope.

Pyrrhotite has an unbalanced chemical formula ($Fe_{1-x}S$), with x ranging from 0 (FeS) to 0.125 (Fe_7S_8), (Belzile *et al*., 2004). It is sometimes magnetic depending on the crystal structure.

P.3.3 Pyrite

Pyrite is the most common iron sulphide mineral in nature, as it is present in igneous, metamorphic, and sedimentary rocks. Normally, pyrite can be found in large masses or veins of hydrothermal origin. In hand sample, this mineral has a metallic luster and pale yellow colour. Microscopically, pyrite is a cubic isotropic mineral with a yellowish-white colour in reflected light (Deer *et al*., 1992).

Pyrite, with the chemical formula FeS_2, is composed by 46.55% *Fe* and 53.45% *S*, by mass. It can be crystallized in cubical, octahedron, or dodecahedron form, but is frequently found in the framboidal form in sedimentary rocks such as shale and limestone, or other rocks.

P.4 Iron sulphides oxidation reaction process

P.4.1

It is well known from literature that sulphide minerals are unstable in oxidizing conditions. Upon exposure to water and oxygen, sulphide minerals oxidize to form acidic, iron, and sulphate-rich by-products in accordance with the following equations (Belzile *et al.*, 2004):

$$Fe_{1-x}S + (2 - x/2)O_2 + xH_2O \rightarrow (1-x)Fe^{2+} + SO_4^{2-} + 2xH^+$$ **Equation 1**

P.4.2

The oxidation of ferrous iron (Fe^{2+}) produces ferric ions (Fe^{3+}) (Equation 2) that can precipitate out of solution to form ferric hydroxide, if pH is not too low. Fe^{2+} is oxidized and precipitated as ferric oxyhydroxides, principally ferrihydrite ($Fe_2O_3 \bullet 0.5(H_2O)$) and goethite ($FeO(OH)_3$) (Equation 3).

$$Fe^{2+} + 1/4O_2 + 2H^+ \rightarrow Fe^{3+} + 1/2H_2O$$ **Equation 2**

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$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{3(s)} + 3H^+$$ **Equation 3**

P.4.3

The oxidation reaction of iron sulphides occurs only in the presence of oxygen and water, and it generates various mineralogical phases (Belzile *et al*., 2004; Bérard *et al*., 1975). Steger (1982) has shown that oxidation of pyrrhotite presents two pathways to give goethite and ferric sulphate. According to Grattan-Bellew and Eden (1975) and Shayan (1988), the sulphuric acid generated through this process reacts with the solids of the cement paste, particularly with the Portlandite ($Ca(OH)_2$), to form gypsum ($CaSO_4 \bullet 2H_2O$) in accordance with the Equation 4:

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 \bullet 2H_2O \text{ (gypsum)}$$ **Equation 4**

P.4.4

The attack of concrete by sulphates resulting from the oxidation of sulphide-bearing aggregates produces the crystallization of secondary ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}{\cdot}26H_2O$) following the reaction with the alumina-bearing phases of the hydrated Portland cement paste (e.g., C_3A; Equation 5). If carbonate materials are also present in the concrete in significant amounts, either in the aggregate itself or from limestone fillers/cements, the possibility of a reaction between sulphates, silicates and carbonates to form thaumasite ($Ca_6[Si(OH)_6]_2(CO_3)_2(SO_4)_2(H_2O)_{22}$) also exists.

$$3(CaSO_4 \bullet 2H_2O) + C_3A + 26H_2O \rightarrow C_3A \bullet 3CaSO_4 + H_{32} \text{(ettringite)}$$ **Equation 5**

P.4.5

According to Divet and Davy (1996), high pH conditions, such as those found in concrete, enhance iron sulphide oxidation.

P.4.6

In a general way, secondary products most frequently generated during the oxidation of iron sulphides, are the "rust" under all its forms (ferric oxyhydroxides such as goethite, limonite ($FeO(OH) \bullet nH_2O$) and ferrihydrite), sulphates including gypsum, ettringite, and, if carbonate materials are also present, thaumasite.

The degradation of concrete is thus due to the combined mechanisms of oxidation of iron sulphides followed by sulphatation in the cement paste. Both reactions create secondary minerals that can cause expansion. According to Casanova *et al*. (1996), the latter is by far more expansive. In fact, during the formation of gypsum, the volume of the resulting products represents a little more than double of that of the starting solids.

P.5 Case studies of damaging effects in concrete made with aggregates incorporating iron sulphides

The earliest report is from Sweden and concerns the damaging effects of pyrrhotite and pyrite. (Hagerman and Roosaar, 1955):

> *It has for many years been suspected that sulphide minerals in aggregates will cause damages to concrete due to the formation of sulphate ions, which when reacting with the cement aluminates will create voluminous calcium sulphoaluminate crystals. This problem has become a matter of immediate interest in Sweden through power plant constructions in some parts of Norrland where the existence of sulphide minerals is very common.* (From the English summary).

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They found that to avoid damage, the content of easily weathered sulphides, in particular pyrrhotite, should be less than about 1% (no mention if this was on a mass or volume basis).

The first Canadian reference to potential problems with iron sulphides in concrete aggregate is found in Swenson and Chaly (1956). They noted that:

> "*Minerals such as pyrites and marcasite may first be oxidized and then hydrated to sulfuric acid and hydrated iron compounds with large increase in volume*."

Moum and Rosenqvist (1959) described problems caused by the presence of pyrrhotite in shale upon which concrete had been placed near Oslo, Norway. In some cases, the concrete structures were transformed into mush after about 9 months. When the shale had been accidently used in concrete, swelling of the shale aggregate "*…caused cracks and destruction of the concrete.*"

In 1958, Midgley at the Building Research Station in the United Kingdom published a paper in which he noted that some varieties of pyrite were more prone to oxidation than others and proposed a test. The test consisted in placing suspect aggregate in saturated limewater and observing whether or not a blue-green gelatinous stain was produced. Those particles that did not develop the stain within about 30 min were considered to be at low risk of causing staining of the outside surface of concrete if used as an aggregate.

A Canadian example of iron sulphide oxidation causing concrete deterioration is that described by Bérard *et al.* (1975). This paper described the problems brought about by the presence of pyrrhotite in shale that was used in small amounts (less than 5%) in concrete aggregate in the Montreal area of Quebec. They reported on the cracking of basement walls of houses in Montreal-East and damage to bridges in the same area. All affected structures showed map cracking, pop-outs (with fragments of shale in the centre), and, in some cases, iron oxide was seeping out the fractures. Significantly, they also found that concrete of high water-cement ratio or low cement content deteriorated more quickly than concrete of higher cement content or lower water-cement ratio. This indicated that concrete that is more permeable promotes oxidation of iron sulphides. The authors indeed suggested that the deterioration was due to the oxidation of pyrrhotite and the formation of sulphuric acid and rusty secondary minerals (*jarosite — $KFe_3(SO_4)_2(OH)_6$*, although the presence of jarosite was not confirmed by x-ray diffraction analysis). The sulphuric acid would then react with the calcite within the shale or with the Portlandite of the hydrated cement to form gypsum; the latter was believed to be the main cause of the swelling of the shale. Bérard *et al.* (1975) found that concrete that contained as little as 2% shale was damaged. They estimated that the amount of pyrrhotite in the shale was about 4.5% (no mention if this was on a volume or mass basis).

Soles (1982) reported an unusual example of oxidation of iron sulphides in concrete aggregate from the Ottawa area. In this case, pyrite found in a sound dolomite aggregate oxidized when concrete was stored for several months at temperatures of about 150 °C. The concrete expanded and cracked with the formation of gypsum as a result of the oxidation process. The concrete aggregate is perfectly sound in concrete used at normal temperatures.

Oberholster (1984a and b) conducted studies of the cause of serious cracking of house foundations in South Africa. This was caused by the use of slate aggregate containing pyrrhotite that oxidized and was the cause of the damage to both concrete floor slabs and to concrete blocks for the walls. In some cases, the houses started to show signs of deterioration within two years after construction. Examination of the concrete bricks revealed a white powdery material around the black carbonaceous aggregate, which was found to be well-crystallised hexagonal crystals containing calcium, silicon, carbon and sulphur (*thaumasite*).

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> *It is difficult to determine … how much pyrrhotite in an aggregate should be regarded as deleterious. However, an analysis for the mineral sulphur gave the pyrrhotite content as only 0.5 per cent by mass.* Oberholster (1984b).

Regourd et al. (1987) describe an unusual concrete from Arctic Canada. This concrete had been made with mine rock that contained pyrite (FeS_2), sphalerite (ZnS), and galena (PbS). They found no damage due to internal sulphate attack which they attributed to the low ambient temperature of the concrete and surroundings.

Shayan (1988) described damage to a concrete floor surface in a 10 year old building in Australia caused by aggregate (shale) containing pyrite. The expansion was sufficient to rupture overlying vinyl tiles. The blistering was found to be caused by the oxidation of the pyrite in the aggregates located near the surface of the slab, thus producing a significant amount of jarosite and smaller amounts of gypsum. In this case, no ettringite was observed.

Extensive studies were carried out on cases of deterioration of concrete structures (public buildings, houses, overpasses, and dams) incorporating pyrite-rich aggregates near Barcelona (Spain) (Chinchon *et al*., 1995). In all cases, the deterioration started with expansion with resulting cracking leading to the structures destruction. The affected concretes contained aggregates consisting of limestones and shale incorporating pyrite and pyrrhotite (Chinchon *et al*., 1990a; Chinchon *et al*., 1995). In all studies, the damage was associated with the oxidation of pyrite and pyrrhotite, resulting in internal sulphate attack, cracking and deterioration of the concrete.

Ayora *et al*. (1998) presented a case of two dams presenting map cracking in some surface areas, color changes and expansion. The aggregates consisted of schists containing minor amounts of pyrrhotite (Fe_7S_8). The total sulphur content of the rock was up to 0.8% S, by mass. The authors concluded that the main cause of concrete expansion was pyrrhotite oxidation that led to the attack of the components of the cement paste, and the formation of iron sulphates. Ettringite halos were found in the interfacial paste/aggregate zone.

Divet (1996) and Divet and Davy (1996) presented comprehensive reviews of the mechanism and control of oxidation of pyrite in concrete. They concluded that the nature of the aggregate and the permeability of the concrete played a major role in the rate of oxidation of iron sulphides and that the high pH (more alkaline) nature of concrete also increased the oxidation rate.

Tagnit-Hamou, *et al.* (2005) published a paper describing laboratory investigations on the cause of deterioration of building foundations and concrete slabs that occurred approximately 2 years after construction. The authors attributed the severe cracking in the concrete to the oxidation of pyrrhotite found in the anorthosite aggregates used to produce the concrete. Deposits of *goethite* were observed around affected aggregate particles, while *ettringite* was found in all samples, generally very close to the altered aggregate particles but also in the cement paste near sound aggregate particles.

Araújo *et al.* (2008) reported on internal sulphate attack of concrete dams in Spain caused by oxidation of iron sulphides in the aggregate. The principal sulphide mineral responsible for the reaction was pyrrhotite. They observed oxidation to iron oxides and hydroxides with ettringite formed due to internal sulphate attack. These reactions led to expansion and upstream displacement of the dams.

Duchesne and Fournier (2011) studied the same occurrence as that of Tagnit-Hamou *et al*. (2005) and reported pyrite, pyrrhotite, pentlandite and chalcopyrite in the anorthositic gabbro. They reported that the amount of sulphides was less than 5 to 10% by volume. They reported that the pyrrhotite was mainly oxidized in contrast to the pyrite that was practically unoxidized. They found iron oxides and

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hydroxides and gypsum formed as secondary minerals. They concluded that deterioration of the concrete was due to the combined action of oxidation of the iron sulphides and sulphatation reactions in the cement paste.

Schmidt *et al*. (2011) reported the results of a study carried out on a concrete dam, constructed in the early 1970s in Switzerland, that was found to suffer from steady expansion since the early 1980s. The aggregates consisted mainly of biotite-schists incorporating randomly dispersed iron sulphides, for instance pyrite/marcasite (20%) and pyrrhotite (80%), which were found at about 0.3 to 0.4% by volume. The authors concluded that "the formation of iron hydroxides can lead to expansion of particles within the aggregates, which leads to cracking of the aggregate" and that "this alone could account for the expansion observed on a macroscopic scale". Pyrrhotite was found to react much faster than pyrite in alkaline concrete environments. Also, it was unclear to what extent the formation of secondary ettringite, produced in the concrete from released sulphate, might have contributed to the expansion.

Rodrigues *et al*. (2012) presented the results of the petrographic examination of a number of specimens obtained from concrete house foundations containing sulphide-bearing aggregates in the Trois-Rivières area (Québec, Canada), Figures P.1 to P.6. The authors reported that the coarse aggregate used to produce concrete was a quarried intrusive igneous rock (anorthositic gabbro) with different degrees of metamorphism and varying proportions of sulphide minerals (mainly pyrrhotite and pyrite with smaller amounts of chalcopyrite and pentlandite). In the samples examined, the amount of sulphide minerals was, in general, less than 5 to 10% by volume. In the rock, sulphide minerals were often surrounded by a thin layer of carbonate minerals (siderite). Secondary reaction products identified in the damaged concrete include "rust" mineral forms (e.g., ferric oxyhydroxides such as goethite, limonite (FeO (OH) nH_2O) and ferrihydrite), gypsum, ettringite and thaumasite. The authors suggested that, in the presence of water and oxygen, pyrrhotite oxidizes to form iron oxyhydroxides and sulphuric acid. The acid then reacts with the phases of the cement paste/aggregate, thus inducing the formation of expansive sulphate minerals within the concrete.

Tremblay (2013) presented data at a court appearance in Trois Rivières on May 2, 2013. He (and others) had conducted a study of about 223 house basements that had been built with varying amounts of iron sulphides in anorthositic gabbro coarse aggregate. Pyrrhotite made up an average of about 75% of the sulphide minerals with lesser amounts of pyrite and chalcopyrite. Many of the pyrrhotite grains showed signs of oxidation but the pyrite and chalcopyrite were largely unaffected. Damage to the concrete basement was rated from 0 to 3 with 0 representing concrete with little or no damage and 3 the most damage. The basements were between about 3 to 9 years old at the time of the study and it has been shown that the damage is progressive and the rating increases with time. The volumetric pyrrhotite content found in the coarse aggregate and causing damage (rating of 1 or more) was from 0.23% up to 3.69%. All damaged concrete exceeded the European limit (see below) of 0.1% S by mass in the aggregate (when pyrrhotite is present) by 3 times to as much as close to 30 times.

Other cases of deterioration of concrete due to pyrrhotite oxidation of the aggregate have occurred in the state of Connecticut with many hundreds of homes being affected. Currently, much of the information available on this problem is limited to newspaper articles but the cause of deterioration has been confirmed by an investigation conducted by the University of Connecticut (Willie and Zhong, 2016) as oxidation of pyrrhotite present in the aggregate. In contrast to the problems encountered in Québec, manifestation of the damage in Connecticut has taken as much as 10 to 20 years. Typical visual deterioration was in the form of map cracking, causing deformation of the wall, reddish-brown discolouration, and whitish formation in the vicinity of surface cracking. Most of the damage to date has been linked to one quarry operating in Willington, Connecticut. The geology in the vicinity of the quarry is made up of metamorphic rocks predominantly from two to three rock types. The rock types mainly

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consist of foliated schists and gneissic rock, granofels, and a foliated quartz diorite (USGS map). Iron sulphides from this quarry are found predominantly as pyrrhotite.

P.6 Standards

The Canadian standard alerts users to the risk of using concrete aggregates incorporating iron sulphides in concrete: Clause 4.2.3.6.2 (CSA A23.1):

> *Aggregates that produce excessive expansion in concrete through reaction other than alkali reactivity shall not be used in concrete unless preventive measures acceptable to the owner are applied.*
>
> **Note:** *Although rare, significant expansions can occur due to reasons other than alkali-aggregate reaction. Such expansions might be due to the following:*
>
> a) *The presence of sulphides, such as pyrite, pyrrhotite, and marcasite, in the aggregate that might oxidize and hydrate with volume increase or the release of sulphate that produces sulphate attack upon the cement paste, or both; ...*

NF P18-301 first limited the total sulphur content to 0.4% as SO_3 (0.16% as S) by mass. This threshold was increased a first time in NF P18-541 to 0.4% as S (i.e., 1% as SO_3) by mass, and once again in the context of European standardization. NF EN 12 620 indeed specified the following:

> *the total sulfur content (S) of the aggregates and fillers, when required, shall not exceed the following limits:*
>
> a) *2% S by mass for air-cooled blast-furnace slag; and*
> b) *1% S by mass for aggregates other than air-cooled blast-furnace slag.*
>
> **Note:** *Special precautions need to be taken when pyrrhotite, an unstable form of iron sulphide FeS, is present in the aggregate. If the presence of this mineral is proven, a maximum total sulphur content of 0.1% (as S) shall apply.*

P.7 Performance evaluation protocol (PEP) for the determination of the deleterious oxidation potential of sulphide-bearing aggregates

P.7.1 Performance evaluation protocol (PEP)

The potential deleterious character of sulphide-bearing aggregates may be determined in accordance with the performance evaluation protocol (PEP) illustrated in Figure P.7.

When a decision is made to investigate a source of concrete aggregates regarding the above issue, a geological survey of the source shall be performed, with the sampling of representative rock/aggregate specimens in accordance with CSA A23.2-1A (see Clause P.7.2). The potential deleterious character of sulphide-bearing aggregates may also be determined through field performance survey of concrete structures made with aggregates from the same source (see Clause P.7.3).

Alternatively, or in the case of inconclusive results from the field performance survey, the samples collected in the source may be subjected to a laboratory testing program (see Clause P.7.4).

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P.7.2 Field evaluation of aggregate source (visual survey and sampling)

P.7.2.1

The geological survey of the source from which the concrete aggregate is produced shall be the first step in the PEP. It should be carried out by a geologist.

Note: *The visit to the source could advantageously be preceded by a survey of regional/local geological and/or testing report(s) that might have been prepared from previous investigations. Historical information of interest could include the mining plans (or location of the extracted areas/zones) over the past years/decades, the rock type(s) present, and its (their) petrographic composition (in particular details on the presence of sulphide mineral (s), its(their) type(s) and proportion(s), the total sulphur content, etc.).*

P.7.2.2

The geological survey shall then be carried out to ascertain the rock type and its distribution/proportion in the current and yearly projected extraction area.

Notes:

1) *The type(s) and proportion of sulphide mineral(s) can indeed change from one location/rock type to another in a source of aggregate, which can affect significantly the deleterious character of the material from one production level to another.*
2) *Since sulphide-bearing aggregates are susceptible to oxidation, traces of rust in the bedrock/production areas and/or in the stockpiles might be valuable observations to include in the report (Figures P.8 and P.9).*

P.7.2.3

Based on the results of the geological survey in the source, sampling should be carried out in accordance with CSA A23.2-1A, with the objective of collecting representative samples

a) from the aggregate production (stockpiles);
b) of the specific rock type(s) present in the current and/or projected exploitation area(s); or
c) both Items a) and b).

Note: *Representative samples will be further subjected to laboratory investigations (see Clause P.7.4).*

P.7.3 Field performance evaluation in concrete structures/elements

When field performance evaluation is proposed for determining the deleterious/innocuous character of sulphide-bearing aggregates proposed for use in new concrete construction, the “appropriate” concrete structure shall meet the following criteria:

a) The concrete examined shall be at least 15 years old.
b) The structure shall contain an aggregate that was produced from the same source as that proposed for use in the new concrete construction (confirmed from construction records, etc.). In the absence of conclusive documentation on the above, petrographic study shall be conducted on cores extracted from the structure to demonstrate that the aggregate in the structure is of the same petrographic/mineralogical composition as that proposed for use in the structure to build.
c) The exposure conditions of the field concrete shall be conducive to the oxidation of sulphide minerals (see Figures P.1 to P.4). It is to be noted that the oxidation of sulphide minerals in concrete aggregates requires access of water and oxygen to the concrete; however, oxidation might not proceed (or might proceed very slowly) in the case of structural elements constantly exposed to moisture, such as submerged portions of structures or parts of concrete elements totally embedded in the ground.
d) In the case of a structure meeting the requirements listed in Items a) to c), and that is not showing any significant signs of deterioration, petrographic examination shall be carried out on specimens prepared from a core (e.g., thin section, polished section, broken pieces) extracted from the

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structure to demonstrate the presence (or not) and the type(s) of sulphide mineral(s) (especially pyrrhotite) in the concrete aggregate.

e) In the case of a structure/structural element meeting the requirements listed in Items a) to c), and that is showing signs of deleterious expansion/cracking, a petrographic study shall be conducted on specimens prepared from a core (e.g., thin section, polished section, broken pieces) extracted from the above structure/structural element to confirm that the signs of deterioration are in association with the oxidation of the sulphide minerals present in the concrete aggregate, and resulting internal sulphate attack (see Figure P.6; CSA A23.2-15A; Rodrigues *et al.*, 2012 and 2014; and Tagnit-Hamou *et al.*, 2005 for examples).

Such a field performance review shall be conducted by a professional who is experienced in the assessment of concrete distresses and durability issues in structures.

P.7.4 Laboratory investigations

P.7.4.1

The material(s) collected as part of the geological survey shall be subjected to the laboratory tests included in the performance evaluation protocol (PEP) illustrated in Figure P.7.

Note: *These investigations are meant to provide information that will complement the results of the geological survey of the aggregate source. Deleterious reactions/expansions can occur in concrete due to the presence of very small amounts of pyrrhotite (or other unstable sulphide minerals) in the aggregates, which can often not be easily/readily identified from the macroscopic examination of the rock samples and/or aggregate material in stockpiles in the source.*

P.7.4.2

The laboratory investigations described in Figure P.7 involve a potential of three steps that include a measurement of the total sulfur content in percentage by mass (ST) (Step 1 — see detailed procedure in Clause P.8), and petrographic examination to determine the presence (or not) or iron sulphide minerals, particularly pyrrhotite (see CSA A23.2-15A), oxygen consumption by the aggregate tested in an air-tight container to determine oxidation potential (Step 2 — see detailed procedure in Clause P.9), and finally an accelerated mortar bar expansion test (Step 3 — see detailed procedure in Clause P.10).

Note: *Technical information on the PEP and on the oxygen consumption and mortar bar expansion tests can be found in Rodrigues et al. 2015, 2016a, and 2016b.*

P.8 Determination of sulphide sulphur content of concrete aggregates

See Attachment P1 for the test method for determination of sulphides sulphur content of concrete aggregates.

P.9 Test method for detection of the oxidation potential of sulphide-bearing aggregates by an oxygen consumption test

See Attachment P2 for the test method for detection of the oxidation potential of sulphide-bearing aggregates by an oxygen consumption test.

P.10 Test method for detection of potential reactivity of sulfide-bearing aggregates by accelerated expansion of mortar bars

See Attachment P3 for the test method for detection of potential reactivity of sulphide-bearing aggregates by accelerated expansion of mortar bars.

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P.11 Discussion, summary, and interpretation of test results from the PEP

P.11.1 Discussion

Many aggregates contain very small amounts of sulphides; thus, specifying that there be no sulphides present in the aggregate is not a realistic requirement. However, at present, there are insufficient data to provide unequivocal advice as to what amount of sulphide is likely to be harmful or safe to use. It is clear from the literature review that pyrrhotite, even in very small amounts, is potentially deleterious. Pyrite and marcasite can probably be present in small amounts without causing deleterious expansion although objectionable staining can be caused on concrete surfaces by the presence of small amounts of iron sulphide (Figure P.10). In the Trois-Rivières area, no cases of damage were identified when the volumetric pyrrhotite content found in the coarse aggregate was less than about 0.23%; however, this number is still open to debate and is likely applicable only to the aggregate material (containing high pyrrhotite-to-pyrite ratio) produced from the two local quarries identified in this case.

P.11.2 Field performance survey

A PEP has been proposed for evaluating the potential deleterious character of sulphide-bearing aggregates in concrete (Figure P.7). This can be determined through the field performance survey of concrete structures/elements made with aggregates produced from the same quarry as those proposed for the new concrete construction. Normally, concrete suppliers will be aware of reports of objectionable staining or other problems with the use of their concrete/aggregate combinations.

The results of the visual examination of selected concrete structures will be completed by the petrographic examination of concrete cores extracted from structural elements exposed to conditions conducive to the oxidation of sulphide minerals present in the aggregate. A conclusive decision on the deleterious/innocuous character of the aggregate investigated will rely on the capacity to link any signs of visual deterioration (or not) to the presence (or absence) of petrographic signs of oxidation of the aggregate in question and resulting internal sulphate attack.

P.11.3 Geological survey of the source

Alternatively, or in the case of inconclusive results from the field performance survey in concrete structures, a complementary field and laboratory investigation may be carried out.

The investigation shall start with the geological survey of the aggregate source and collection of any historical information on the source investigated (Clause P.7.2). The identification of rock type(s) and its (their) distribution/proportion in the current and yearly projected exploitation area(s) will lead to representative sampling in accordance with CSA A23.2-1A, which, in turn, will be subjected to a series of test methods in the laboratory (Clause P.7.4).

P.11.4 Laboratory investigations — Step 1 (determination of sulphide sulphur content)

Step 1 of the laboratory investigation consists in performing the chemical analysis of the aggregate proposed for use in accordance with the test procedure described in Clause P.8.

Aggregates showing a total sulphur content > 1.00% by mass shall be rejected as concrete aggregate. Aggregates with a total sulphur content less than 0.15% by mass may be used without further investigations. If the total sulphur content of the investigated aggregate is lower than 1.00% and is equal to or greater than 0.15% by mass, the sulphate sulphur content should be determined in accordance with the method provided in Attachment P1. If the sulphide sulphur content (i.e., total

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sulphur – sulphate sulphur) is less than 0.15%, the aggregate may be used without further investigations. If the sulphide sulphur content is equal to or greater than 0.15%, the nature of the sulphide mineral present should be determined by petrographic examination or other appropriate means (e.g., XRD on concentrates, Mineral Liberation Analyser (MLA)). If pyrrhotite is detected, the aggregate shall be subjected to Step 2 of the laboratory investigation program (Clause P.11.5).

If sulphide minerals other than pyrrhotite are detected and the sulphide sulphur content is no more than 1.00% by mass, the material may be used provided that the sulphide minerals are not susceptible to oxidation (Steps 2 and 3 of the laboratory test program). Midgley (1958), Ramos et al. (2016), and Guirguis and Shehata (2017) proposed staining and other quick screening tests to detect sulphide minerals that can cause objectionable staining or oxidation reactions.

Examples of rocks where the total sulphur content can reach 0.15% by mass and have satisfactory field performance (excluding potential alkali reactivity) include Ordovician limestones and dolostones of the St.Lawrence Lowlands (Québec) and Lake Ontario area that contain significant amounts of minute cubic pyrite, but no pyrrhotite.

P.11.5 Laboratory investigations — Step 2 (determination of oxidation potential — oxygen consumption test)

Step 2 of the laboratory investigation program provides a means of evaluating the oxidation potential of sulphide-bearing aggregates. It is based on the use of an oxygen consumption test developed for mine tailings, where iron sulphides oxidation is the source of acid rock drainage (ARD).

In the test, a compacted layer of aggregate material is exposed to oxygen (O_2) in a hermetic cell, and the O_2 consumption is monitored with an appropriate probe. Optimized parameters included a 100 mm compacted layer of aggregate material (particle size < 160 µm) kept at 40% saturation degree with a 100 mm headspace left at the top of the cell. The consumption of the O_2 present in the headspace is monitored over a 3 h testing period at 22 °C.

Aggregates producing an oxygen consumption of less than 4.0% may be accepted as concrete aggregate; on the other hand, O_2 consumption values greater than 4.0% shall trigger further testing though an accelerated mortar bar test (Step 3).

P.11.6 Laboratory investigations — Step 3 (mortar bar expansion test)

The accelerated mortar bar test includes two phases. Phase I aims at triggering the oxidation reaction of the aggregate investigated, thus producing oxidation products and sulphuric acid that will in turn promote internal sulphate attack and excessive expansion of the test bars. During this phase, the mortar specimens (0–5 mm aggregate particle size; cement-to-aggregate of 1:2.75; water-to-cement ratio of 0.65) are subjected to 90 days of storage at 80 °C/75% relative humidity, with two 3 h wetting cycles per week in a 6% sodium hypochlorite solution. The bars are then transferred for 90 days of storage at 4 °C/ 100% relative humidity, period over which the specimens are still subjected to two 3 h wetting cycles per week in a 6% sodium hypochlorite solution (Phase II). In the presence of carbonate material in the aggregate, excessive expansion will develop in Phase II through thaumasite attack.

The length change of the mortar bars is monitored regularly over both Phase I and II of testing. Excessive expansion of the mortar bars could also develop during phase I in the case of alkali-silica reactive aggregates; however, mortar bars containing ASR-susceptible aggregates, but that do not contain unstable sulphide mineral, will not expand significantly when exposed to Phase II test conditions.

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Based on the length change monitoring, if the difference in the expansions measured during Phase I and Phase II is equal to or greater than 0.10%, the aggregate shall be rejected for use as concrete aggregate as the deleterious expansion measured shall be attributed to the oxidation of sulphide minerals in the aggregate. The petrographic examination of the mortar bar could be carried out to confirm the presence of secondary sulphate products (gypsum, ettringite, thaumasite) in the paste surrounding sulphide-bearing aggregate particles. On the other hand, when the difference between the expansions measured during Phase I and Phase II is less than 0.10%, the following two options may be used:

a) in the case of alkali-silica reactive aggregates, the effectiveness of preventive measures against ASR shall be investigated following the recommendations of CSA A23.2-27A or 28A; or
b) non alkali-silica reactive aggregates may be accepted for use as concrete aggregates.

P.11.7 Laboratory investigations — Caveat

The oxygen consumption and accelerated mortar bar tests are still under “development” and no precision data are available at this time for those tests. The development of a database that could result from the application of those tests on a large variety of aggregates, in different laboratories and also using a reference (control) aggregate for calibration, will contribute at strengthening the approach proposed in the laboratory testing portion of the PEP and the recommendations that will result from its wider application.

P.12 Conclusion

Based on current knowledge, new or unproven sources of aggregates intended for use in concrete should be tested for sulphur content. Aggregates with a total sulphur content > 1.00% by mass shall be rejected as concrete aggregate. Aggregates with a total sulphur content less than 0.15% by mass may be used without further investigations. If the total sulphur content of the investigated aggregate is lower than 1.00% and is equal to or greater than 0.15% by mass, the sulphate sulphur content should be determined in accordance with the method provided in Attachment P1. If the sulphide sulphur content (i.e. Total sulphur – sulphate sulphur) is less than 0.15%, the aggregate may be used without further investigations. If the sulphide sulphur content is equal to or greater than 0.15%, the nature of the sulphide mineral present should be determined. If pyrrhotite is detected, the aggregate should not be used unless further laboratory testing, i.e. oxygen consumption (see Attachment P2) or mortar bar expansion test (see Attachment P3) indicates that the aggregate is suitable for use in concrete.

The owner or the contractual party having the responsibility of assessing whether or not an aggregate is suitable for use should carefully consider the following guidelines:

a) The assessment and testing for sulphide oxidation characteristics of aggregates should be carried out under the direction of an individual with considerable experience in this type of work.
b) A petrographic examination of the aggregate source is an essential step in the evaluation of the potential reactivity of an aggregate.
c) The testing laboratory responsible for the testing of the aggregates is able to demonstrate considerable experience and precision in this type of work.
d) Where possible, a field investigation of concrete structures containing the aggregate under investigation should be carried out.
e) The testing of aggregate for sulphide oxidation characteristics might not be practical on a project-by-project basis. Aggregates should be evaluated in advance of specific projects to assist in a timely decision-making process.

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A23.2-1A-14:19

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Sampling aggregate for use in concrete

A23.2-15A-14:19
Petrographic examination of aggregates

A3001-18
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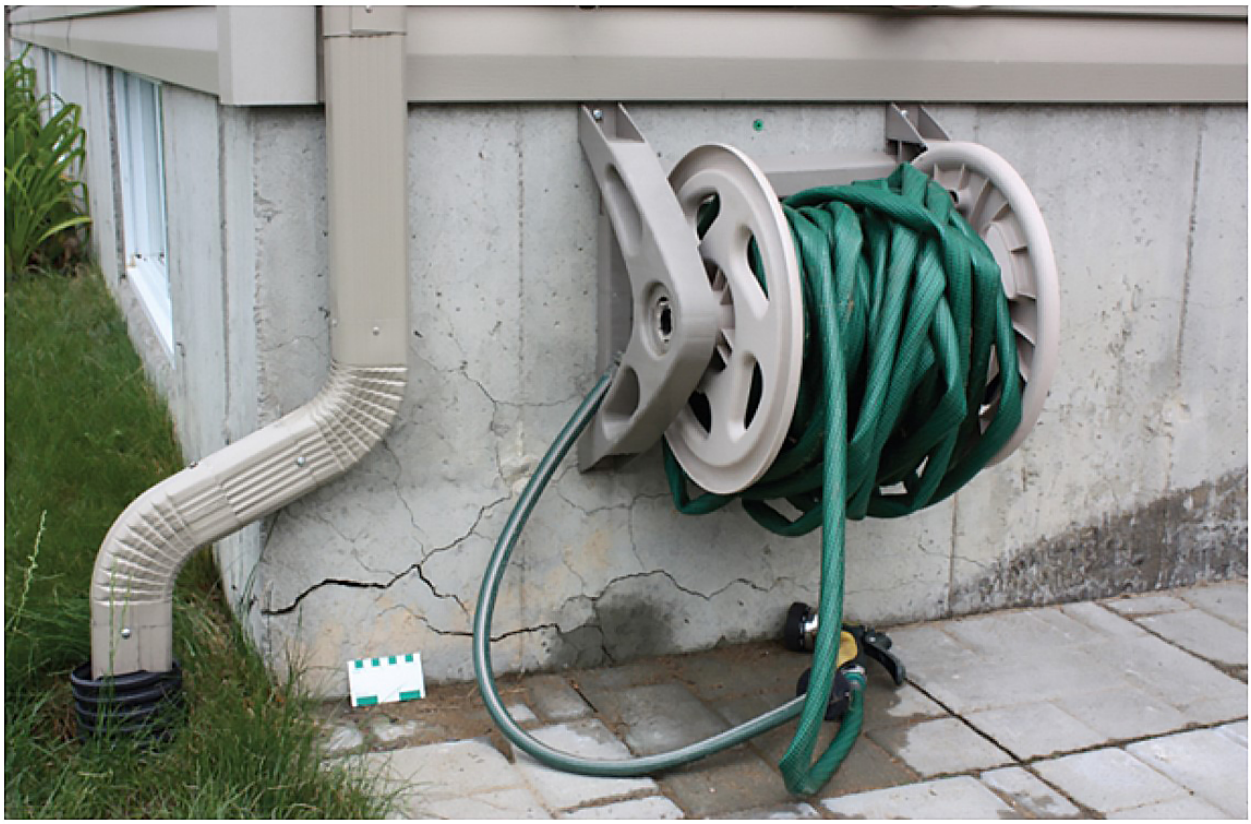
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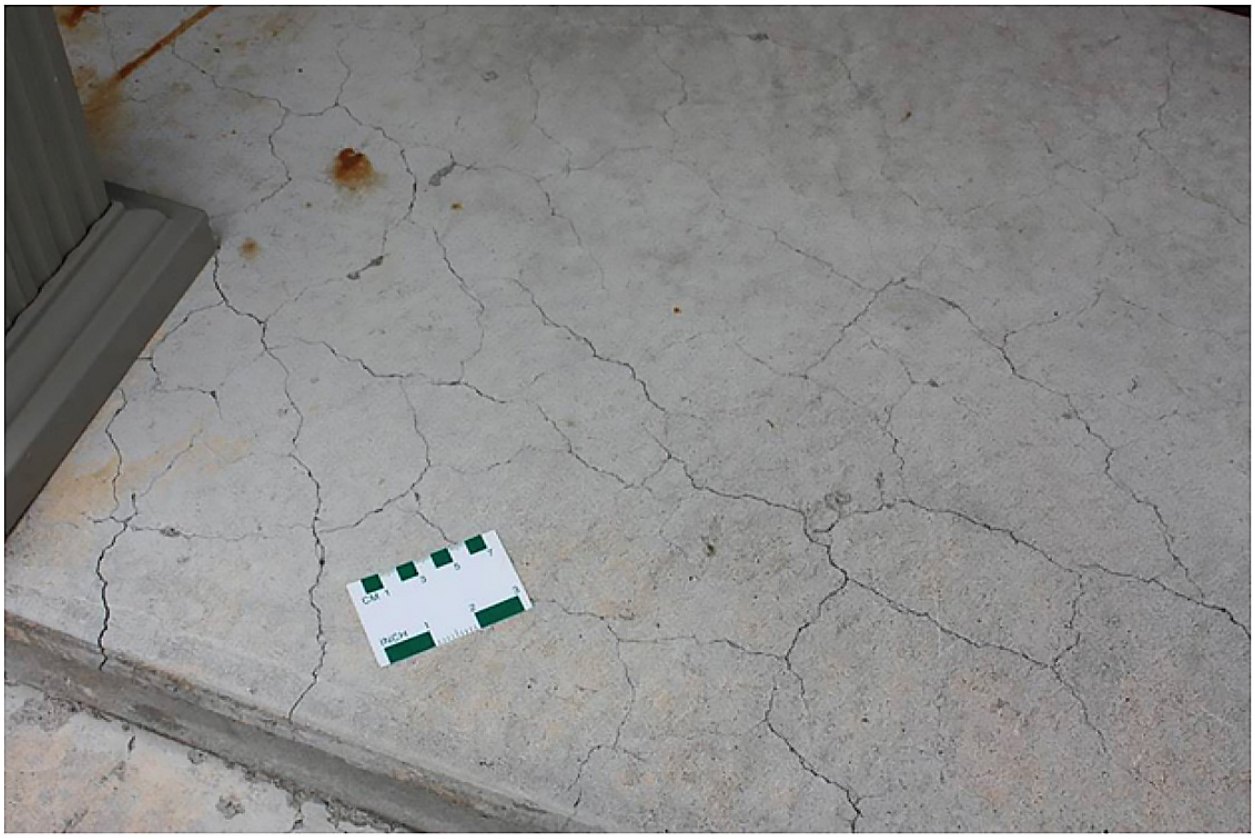
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Figure P.1
Expansion and cracking in residential basement concrete incorporating a sulphide-bearing aggregate (Trois-Rivières area, Québec, Canada)
(See Clause P.7.)



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Figure P.2
Expansion and cracking in residential concrete pavement slab incorporating a sulphide-bearing aggregate (Trois-Rivières area, Québec, Canada)
(See Clause P.7.)



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Figure P.3
Expansion and cracking of concrete block incorporating a sulphide-bearing aggregate (Trois-Rivières area, Québec, Canada)
(See Clause P.7.)



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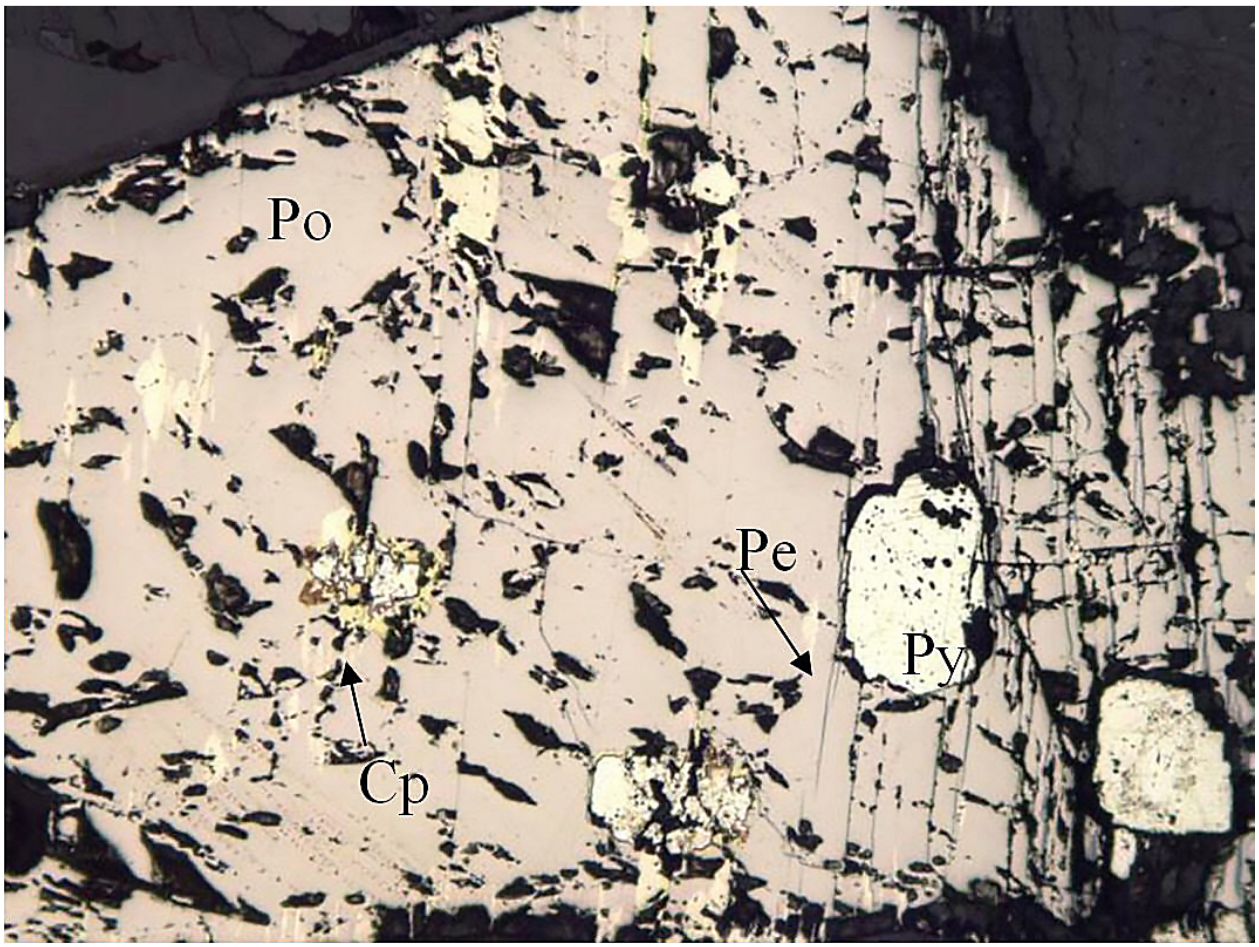
Figure P.4
Expansion and cracking of concrete block incorporating a sulphide-bearing aggregate (Trois-Rivières area, Québec, Canada)
(See Clause P.7.)



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Figure P.5
Typical pyrrhotite FeS (pink cream — Po), pyrite FeS_2 (light yellow — Py), chalcopyrite $CuFeS_2$ (yellow — Cp), pentlandite $(Fe,Ni)_9S_8$ (white cream — Pe) assemblage in a hypersthene-gabbro aggregate found in concrete showing expansion and cracking (similar to that illustrated in Figures P.2 and P.3) (polished thin section under reflected light, width of the picture = 0.9 mm)
(See Clause P.7.)



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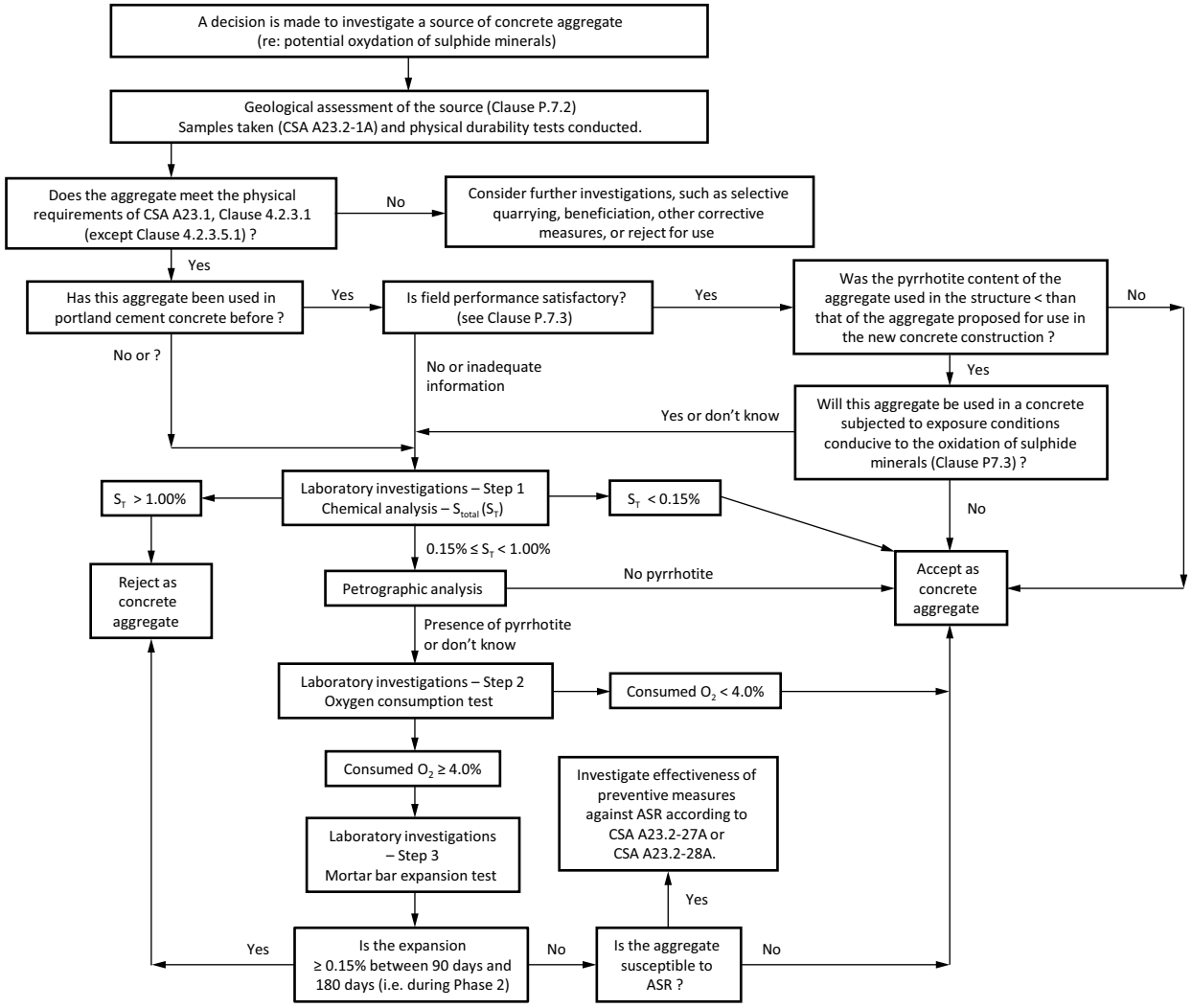
Figure P.6
Piece of broken concrete showing extensive signs of oxidation on broken surfaces of the aggregate particles
(See Clause P.7.)



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Figure P.7
Performance evaluation protocol (PEP) for evaluating the potential deleterious character of sulphide-bearing aggregates
(See Clause P.7.)



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Figure P.8
Signs of oxidation (rust) in the bedrock and large blocks of rocks
(See Clause P.7.2.)



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Figure P.9
Signs of oxidation (rust) in the stockpiles of a quarried operation
(See Clause P.7.2.)



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Figure P.10
Iron staining due to oxidation of particle of iron sulphide in concrete aggregate (Hudson's Hope area of British Columbia)
(See Clause P.11.1.)



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Attachment P1 (informative)
Determination of sulphide sulphur content of concrete aggregates

Note: *This informative Attachment has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

P1.1 Scope

P1.1.1

This Test Method describes a procedure for testing coarse and fine aggregates to determine the content of sulphur present due to the presence of sulphide minerals.

The test may also be used to characterize the sulphate sulphur content of proposed (i.e., not previously used) sources of aggregate through the testing of exploration samples (e.g., rock drill core, chunk samples, test pit/drill samples from granular deposits).

P1.1.2

Sulphur when present in iron sulphides such as pyrite, pyrrhotite, chalcopyrite, and in other forms, can oxidize and hydrate with volume increase, or the release of sulphate that produces sulphate attack upon the cement paste, or both.

P1.2 Reference publications

In addition to the references in CSA A23.1, this Test Method refers to the following publications, and where such reference is made it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A3005-18
Test equipment and materials for cementitious materials for use in concrete and masonry

Multi-laboratory study of proposed new test for determination of sulphide sulphur content of concrete aggregates, 2019
https://www.csagroup.org/article/multi-laboratory-study-of-proposed-new-test-for-determination-of-sulphide-sulphur-content-of-concrete-aggregates/

American Chemical Society (ACS)

Specifications and procedures for reagent chemicals

Other publications

Bérard, J., Roux, R., and Durand, M. (1975). Performance of concrete containing a variety of black shale. *Canadian Journal of Civil Engineering*. 2:58–65.

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Rodrigues, A., J. Duchesne, B. Fournier, P. Rivard, B. Durand, and M. Shehata. (2012). Mineralogical and chemical assessment of concrete damaged by the oxidation of sulphide-bearing aggregates: importance of thaumasite formation on reaction mechanisms. *Cement and Concrete Research*. 42:1336–1347.

P1.3 Summary

The sulphur present in the samples in excess of sulphate sulfur (HCl soluble) is measured, calculated, and reported as sulphide sulphur, even though total sulfur might also contain some organic sulphur.

P1.4 Significance and use

P1.4.1

Oxidation of iron sulphides in concrete aggregate has led to expansion and cracking of concrete in Canada (Bérard *et al.*, 1975; Rodrigues *et al.*, 2012). Different iron sulphides can oxidize at different rates. Pyrite within an aggregate can be stable in concrete for many years throughout its service life. Pyrrhotite and marcasite can oxidize relatively rapidly. Pyrrhotite has caused significant problems in concrete in Canada and elsewhere.

P1.4.2

This test measures the amount of sulphur present in an aggregate in the form of sulphide. Generally, certain sulphur-bearing minerals, such as pyrite, can be present in an aggregate without causing deleterious expansion or other effects such as staining of the concrete. However, if the sulphide is easily oxidized, usually when present in the form of fine-grained or framboidal pyrite, or as coarse crystalline pyrrhotite, the sulphur can cause adverse chemical reactions leading to expansion and cracking of the concrete. Further information regarding the reactions that can take place and a review of the literature on such reactions are found in this Annex.

P1.4.3

Sulphur can be present in the form of sulfate or sulphide minerals. This test quantifies each of these two forms of sulphur.

P1.4.4

Users are cautioned that the size of the sample selected will impact the likelihood of detecting harmful levels of sulphur. The sample sizes given in this test are judged suitable for those aggregates where the sulphides are fairly widely dispersed through the aggregate. In cases where there are very few sulphide bearing particles, such as nuggets of sulphide in otherwise sulphide-free aggregate, the sample size might be insufficient to consistently detect their presence. Such nuggets can cause popouts or objectionable staining on concrete surfaces, or both, but are unlikely to cause bulk expansion of the concrete.

P1.4.5

Samples taken from above the groundwater table are often oxidized, and sulphide minerals might not be present, or might be present in reduced amounts. Samples taken from below the permanent groundwater table will often be unoxidized because water is an effective barrier to the oxidation process. Thus, within both quarries and gravel pits, and even in the same source, consideration should be given to the location and frequency of sampling relative to the groundwater table.

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P1.5 Apparatus and supplies

P1.5.1 General

The equipment and materials, including the temperature and humidity of the testing room, dry materials, and mixing water, shall meet the requirements of CSA A3005, unless otherwise specified in this Test Method.

P1.5.2 Apparatus

Depending on the test options chosen, the following equipment shall be used for the procedure:

a) small jaw crusher or other suitable equipment capable of crushing aggregate to pass a 2.5 mm sieve;
b) pulverizer or other suitable equipment capable of grinding aggregate finer than 2.5 mm to pass a 160 µm sieve;
c) standard laboratory glassware;
d) balance, sensitive to 0.1 mg;
e) crucibles, made of porcelain, platinum, alumina zirconia, or silica, of 10 to 25 mL capacity;
f) hot plate, electric or gas heated with capability of temperature control;
g) furnace, electrically heated and capable of regulating the temperature at 800 ± 25 °C;
h) x-ray fluorescence spectrometer;
i) one of the following:
    i) High temperature Combustion Analyzer for Sulphur; or
    ii) Inductively Coupled Plasma Spectrometer (ICP).

P1.5.3 Supplies

P1.5.3.1 Water

Water conforming to the requirements of CSA A3005 shall be used for this testing.

P1.5.3.2 Concentrated reagents

All reagents shall conform to the requirements of ACS *Specifications and procedures for reagent chemicals* where such specifications are available. Where no such specification is given, the best grade obtainable shall be used.

P1.5.3.3 Dilute reagents

Concentrations of reagents, except when standardized, shall be specified as ratio of the number of volumes of the concentrated reagent to be diluted with the number of volumes of water.

Note: *Hydrochloric acid (HCl 2:3) solution for example, means 2 volumes of hydrochloric acid diluted with 3 volumes of water.*

P1.5.3.4 Non-standard solutions

Concentrations of non-standard solutions, prepared by dissolving a given mass of solid reagent in a solvent, shall be specified in grams of the reagent per litre of solution. Water shall be the solvent except if stated differently.

Note: *Barium chloride ($BaCl_2 \cdot 2H_2O$, 100 g/L), for example, means 100 g of barium chloride di-hydrate ($BaCl_2 \cdot 2H_2O$) dissolved in water and diluted to 1 L.*

P1.5.3.5 Filter paper

Filter paper used shall be Grade 40: 8 µm (medium speed, ashless) or equivalent.

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P1.6 Hazards

This Test Method does not purport to address the safety problems associated with its use. It is the responsibility of the user of this Test Method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

P1.7 Sampling and preparation of test specimens

P1.7.1 Sampling

The procedures outlined in CSA A23.2-1A shall be followed to obtain a representative sample of the aggregate to be tested (Table P1.1).

The sample, if possible, shall be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production.

Note: *Some materials to be tested may be exploration samples, such as drill cores or test pit samples, in which case there will be increased doubt as to the applicability of the results.*

P1.7.2 Test specimen preparation

The test specimen shall be prepared as follows:

a) reduce the sample obtained in accordance with Clause P1.7.1 for further processing by the use of a sample splitter or by a suitable method of quartering to obtain a representative subsample (Table P1.1). No attempt shall be made to obtain the required test subsample by adding or subtracting individual pieces. Materials proposed for use as coarse aggregates in concrete shall be processed by crushing the minimum subsample mass given in Table P1.1 to ensure that it is representative of the composition of the coarse aggregate as proposed for use;

b) crush the minimum mass of subsample (Table P1.1) to which this Test Method is applied using a small jaw crusher or other suitable means, so that the entire sample passes a 2.5 mm sieve. Take care that the jaw crusher is clean prior to use and that no material is lost;

c) mix the crushed test specimen thoroughly, and prepare, using a sample splitter or other suitable means, a representative specimen of 400 ± 10 g. Pulverize the specimen using suitable equipment so that it passes a 160 µm sieve. Further treat any material retained on the 160 µm sieve until it is able to pass the sieve. Take care that no material is lost;

   Note: *An intermediate step in sample reduction may be taken by reducing the 400 g of passing 2.5 mm sample to pass a 630 µm sieve. 40 ± 1 g of passing 630 µm, prepared by splitting or other suitable means, may then be reduced to pass 160 µm. The sequence of sample reduction will depend on equipment that is used.*

d) mix thoroughly the material passing the 160 µm sieve. Obtain specimens of a suitable size for chemical analysis.

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Table P1.1
Test specimen size
(See Clause P1.7.2.)

Nominal maximum aggregate size, mm	Minimum mass of field samples, kg (from CSA A23.2-1A)	Minimum mass of subsample, kg
14 and less	15	3
20	25	5
28	50	10
40	75	15
56	100	20
80	150	60

P1.8 Procedures

Note: *The sulphur present in the samples in excess of sulphate sulphur (HCl soluble) is calculated and reported as sulphide sulphur, even though total sulphur might contain some organic sulphur.*

P1.8.1 Total sulphur determination

P1.8.1.1 Determination of total sulphur of the base sample

The total sulphur shall be determined by high temperature combustion.

Notes:

1) *High temperature sample preparation methods such as fusion for x-ray spectrometry or inductively coupled plasma spectrometry can cause a loss of volatile sulphur.*
2) *Pyrrhotite is soluble in hydrochloric acid (HCl) and its decomposition will result in the formation and release of hydrogen sulphide gas (H_2S). Total oxidative sulphur analysis with aqua-regia therefore should not be used for total sulphur analysis.*

P1.8.1.2 High temperature combustion analysis

The total sulphur shall be determined on a separate sample aliquot by combustion at a minimum operating temperature of 1350 °C in a stream of oxygen. The high temperature combustion analyzer shall be equipped with either an acid base detection or infrared absorption detection system. The total sulphur analysis result shall be recorded as S_T. The sulphur, reported as sulphide (So), shall be calculated by difference in accordance with Equation 2.

P1.8.1.3 Total sulphur below limit

If the total sulphur content is ≤ 0.15% by mass, the sulphate sulphur determination may be omitted.

P1.8.2 Determination of sulphate sulphur

P1.8.2.1 Blank determination

A blank determination shall be run, following the same procedure and using the same amounts of reagents as the test specimen.

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P1.8.2.2 Sample digestion with hydrochloric acid (HCl insoluble residue)

The procedure shall be as follows:

a) Weigh a representative subsample of the aggregate of 5 ± 0.1 g and record the mass as M_1. Quantitatively transfer it into a 250 Erlenmeyer flask or beaker.
b) Add 50 mL of HCl (2:3).
c) Bring to and maintain at a boil for 30 min.
d) Filter the contents into a 400 mL beaker through a tared glass frit, (mass recorded as M_2) which was previously dried at 105 ± 5°C.
e) Wash the filter paper and contents with a sufficient number of hot water washings to ensure to transferal of the HCl extract to the beaker as shown by a negative chloride reaction.
f) Reserve the filtrate for the determination of sulphate sulphur (S_S).

P1.8.2.3 Determination of sulphate sulphur

The procedure shall be as follows:

a) Dilute the filtrate obtained in accordance with Clause P1.8.2.2 to 250 mL and heat to boiling.
b) Add slowly, dropwise, 10 mL of hot barium chloride solution ($BaCl_2 \cdot 2H_2O$, 100 g/L) and continue the boiling until the precipitate is well formed.
c) Digest the solution for 12 to 24 h at a temperature just below boiling.
d) Take care to keep the volume of solution between 225 and 260 mL and add water for this purpose if necessary.
e) Filter through a retentive paper, wash the precipitate thoroughly with hot water, and place the paper and contents in a tared platinum crucible (M_4).
f) Slowly dry, char, and consume the paper without inflaming.
g) Ignite at 800 to 900 °C, cool in a dissector, and weigh (M_5).
h) Calculate the sulphate sulphur in accordance with Equation 1.

Note: *Alternatively, the filtrate obtained in accordance with Clause P1.8.2.2 may be quantitatively transferred and diluted to volume in a volumetric flask. An aliquot of this dilution may then be analyzed by Inductively Coupled Plasma Spectrometry for sulphate sulphur or by x-ray analysis using a suitably equipped and calibrated x-ray fluorescence spectrometer.*

P1.9 Calculation

The following equations shall be used to calculate results:

Equation 1: Sulphate sulphur (Clause P1.8.2.2 to P1.8.2.3)

$$S_S = [(S_{M5} - S_{M4}) - (B_{M5} - B_{M4})] / M_1 \times 13.74$$

where

S_s = sulphate sulphur (as %S, by mass)

S_{M5} = sample ignited residue plus crucible, g

S_{M4} = sample tared crucible, g

B_{M5} = blank ignited residue plus crucible, g

B_{M4} = blank tared crucible, g

M_1 = sample mass, g

13.74 = molar ratio of *S* to $BaSO_4$ × 100

Equation 2: Sulphide sulphur by difference (total sulphur – sulphate sulphur)

$$S_O = S_T - S_S$$

where

S_O = sulphide sulphur, as % by mass (total — sulphate sulphur)

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S_T = total sulphur, as % by mass (Clause P1.8.1)

S_S = sulphate sulphur, as % by mass (Clause P1.8.2 – HCl soluble)

P1.10 Report

P1.10.1 Required information

The report shall include the following:

a) sample number or identification marks;
b) type and source of aggregate;
c) a description of the elevations and location of the quarry face or elevation and location within the gravel or sand pit that was sampled, and the location of the sample with respect to the groundwater table, if known;
d) nominal maximum aggregate size and the mass of specimen;
e) the percentage by mass of the sulphate sulphur to the nearest 0.01%;
f) the percentage by mass of the sulphide sulphur to the nearest 0.01%;
g) a description of the type of analytical method used;
h) identification of the certified laboratory performing the test (i.e, name and address);
i) name and signature of the person responsible for the review and approval of the test report; and
j) any deviation from the test procedure.

P1.10.2 Optional information

The following information may be included in the test report:

a) name of the person or organization who sampled the aggregate;
b) name of the technician performing the test; and
c) date the sample was taken or received by testing laboratory.

P1.11 Precision and bias

For aggregates with sulphide sulphur content of approximately 0.1% or less, the multi-laboratory standard deviation was found to be an average of 0.08%.

For aggregates with sulphide sulphur content in the approximate range of 1.2%, the multi-laboratory standard deviation was found to be an average of 0.28%.

Note: *See* Multi-laboratory study of proposed new test for determination of sulphide sulphur content of concrete aggregates *(CSA, 2019).*

P1.12 Interpretation of results

See Clause P.11.4 for the interpretation of data obtained in this Test Method.

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Attachment P2 (informative)

Test method for detection of the oxidation potential of sulphide-bearing aggregates by an oxygen consumption test

Note: *This informative Attachment has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

P2.1 Scope

P2.1.1

This Test Method describes a procedure for determining the potential deleterious oxidation of sulphide-bearing aggregates.

P2.1.2

The results of the test furnishes information helpful in judging the suitability of coarse or fine aggregate for use in concrete when information is not available from service records.

P2.2 Reference publications

In addition to the references in CSA A23.1, this Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

ASTM International

D1193-06(2018)
Standard Specification for Reagent Water

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

Other publications

Belzile, N., Chen, Y.W., Cai, M.-F., Li, Y. 2004. A review on pyrrhotite oxidation, *Journal of Geochemical Exploration*, 84: 65–76.

Bérard, J., Roux, R. Durand, M. 1975. Performance of concrete containing a variety of black shale, *Canadian Journal of Civil Engineering*, 2: 58–65.

Elberling, B., Nicholson, R.V., Reardon, E.J., Tibble, P. 1994. Evaluation of sulphide oxidation rates: a laboratory study comparing oxygen fluxes and rates of oxidation product release, *Canadian Geotechnical Journal*, 31: 375–383.

Janzen, M.P., Nicholson, R.V., Scharer, J.M. 2000. Pyrrhotite reaction kinetics reaction rates for oxidation by oxygen, ferric iron and for nonoxidative solution, *Geochim. Cosmochim*. 64: 1511–1522.

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Mikhlin, Y.L., Kuklinski, A.V., Pavlenko, N.I., Varnek, V.A., Asanov, I.P., Okotrub, A.V., Selyutin, G.E., Solovyev, L.A. 2002. Spectroscopic and XRD studies of the air degradation of acid-reacted pyrrhotites, *Geochim. Cosmochim*. Acta, 66: 4057–4067.

Rodrigues, A., Duchesne, J., Fournier, B., Rivard, P., Durand, B. and Shehata, M. 2012. Mineralogical and chemical assessment of concrete damaged by the oxidation of sulphide-bearing aggregates: importance of thaumasite formation on reaction mechanisms. *Cement and Concrete Research*, 42 : 1336–1347.

Rodrigues, A., Duchesne, J., Fournier, B., Durand, B., Shehata, M., Rivard, P. 2016a. Evaluation protocol for concrete aggregates containing iron sulfide minerals. *ACI Materials Journal*, 113 (3): 349–359.

Rodrigues, A., Duchesne, J., Fournier, B. 2016b. Quantitative assessment of the oxidation potential of sulfide-bearing aggregates in concrete using an oxygen consumption test. *Cement and Concrete Composites*, 67: 93–100.

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Tagnit-Hamou, A.; Saric-Coric, M.; and Rivard, P. 2005. Internal Deterioration of Concrete by the Oxidation of Pyrrhotitic Aggregates," *Cement and Concrete Research*, 35 (1): 99–107.

P2.3 Definitions

In addition to the definitions specified in CSA A23.1, the following definition applies in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness can be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

P2.4 Significance and use

P2.4.1

Upon exposure to water and oxygen, iron sulphides minerals, common in many rock types, oxidize to form acidic, iron, and sulphate-rich by-products (Belzile *et al.*, 2004). While pyrite within an aggregate can be stable in concrete for many years, pyrrhotite and marcasite can oxidize relatively rapidly, the former having led to expansion and cracking in concrete structures in Canada and elsewhere (Bérard and Roux, 1975; Tagnit-Hamou *et al.*, 2005; Rodrigues *et al.*, 2012).

P2.4.2

This Test Method provides a means of evaluating the oxidation potential of sulphide-bearing aggregates. It is based on the use of an oxygen consumption test developed for mine tailings, where iron sulphides oxidation is the source of acid rock drainage (ARD) that is a major concern for the mining industry (Steger, 1982; Janzen *et al.*, 2000; Mikhlin *et al.*, 2002; Belzile *et al.*, 2004).

In the technique developed by Elberling *et al.* (1994), the oxygen flux into tailings exposed to the atmosphere is evaluated using oxygen consumption assuming steady state flux prior to making any measurements.

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P2.4.3

Rodrigues *et al.* (2016b) proposed a test in which a compacted layer of aggregate material is exposed to oxygen (O_2) in a hermetic cell, and the O_2 consumption is monitored with an appropriate probe. Optimized parameters included a 100 mm compacted layer of aggregate material (particle size < 160 µm) kept at 40% water saturation with a 100 mm headspace left at the top of the cell. The consumption of the O_2 present in the headspace is monitored over a 3 h testing period at 22 °C.

P2.4.4

Criteria to determine the potential deleteriousness of expansions measured in this Test Method are given in this Annex. When O_2 consumption in excess of the proposed limit is developed in this test, supplementary information should be developed to confirm that this is actually due to the oxidation of sulphide minerals present in the aggregate particles. Sources of such supplementary information include determination of the expansive character of the aggregate through a mortar expansion test.

P2.4.5

This Test Method is not intended for evaluating the potential for sulphide oxidation of combinations of coarse and fine aggregates.

P2.5 Apparatus and supplies

The apparatus shall conform to the following requirements:

a) small jaw crusher or other suitable equipment capable of crushing aggregate to pass a 2.5 mm sieve;
b) pulverizer or other suitable equipment capable of grinding aggregate finer than 2.5 mm to pass a 160 µm sieve;
c) square hole, woven-wire cloth sieves shall conform to the requirements of ISO 3310-1;
d) a reaction cell made of acrylic (e.g., plexiglass) column 200 ± 2mm high with an internal diameter of 142 ± 2 mm and with an acrylic cap and base with a wall thickness of 10 mm*. There should be a threaded hole in the cap suitable for the oxygen sensor probe (see Figure P2.1);
e) a galvanic-cell type oxygen sensor (e.g., Apogee SO-100 & 200 series in Figure P2.2) and suitable data logger (e.g., OM-CP-IFC200; available from the probe manufacturer);
f) a supply of thread seal tape (e.g., Teflon) to seal the threaded oxygen sensor probe in the cap of the reaction cell;
g) an oven, capable of maintaining a temperature of 110 ± 5 °C;
h) a balance or scale accurate to 1 g;
i) a flat steel pestle; and
j) high vacuum grease (a silicone based grease).

Notes:

1) *Containers/cells other than that described above may be used, provided the efficiency of the system is calibrated with a standard reactive aggregate. If an alternative container is used, it should be noted in reporting the results, together with documentation proving compliance with the calibration requirements of this Clause.*
2) *The sensor measures oxygen gas in air and is capable of measuring 0 to 100% oxygen. The sensor has an integrated heater to compensate for temperature changes and to prevent condensation when used in conditions where relative humidity can reach up to 100%. The probe contains an internal bridge resistor to provide a mV output linearly proportional to O_2. The probe is calibrated (prior to testing) in ambient air and in pure N_2 gas (following instructions from the supplier).*

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P2.6 Reagents and materials

P2.6.1 Water

Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Type IV of ASTM D1193.

P2.6.2 Control aggregate

A supply of sulphide-bearing reactive control aggregate shall be prepared as described in Clause P2.8.2.

Note: *A source of reference aggregate is expected to be available in 2020.*

P2.7 Conditioning

P2.7.1

The temperature of the room where the testing is to be carried out, including the preparation of the test specimen in the apparatus/column, shall be 23 ± 2.0 °C. The temperature of the water used for reaching the required degree of saturation for the aggregate material shall be 23 ± 2.0 °C.

P2.7.2

The relative humidity of the testing room shall be maintained at not less than 50%.

P2.8 Sampling and preparation of test specimens

P2.8.1 Sampling

The procedures outlined in CSA A23.2-1A shall be followed to obtain a representative field sample of the aggregate to be tested (Table P2.1).

The sample, if possible, shall be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production. Core should be reduced by crushing to a maximal size of 28 mm before sampling.

P2.8.2 Test sample preparation

P2.8.2.1

The sample shall be dried to constant mass.

P2.8.2.2

The sample obtained in accordance with Clause P2.8.1 shall be reduced for further processing by the use of a sample splitter or by a suitable method of quartering to obtain a representative subsample (Table P2.1). No attempt shall be made to obtain the required test subsample by adding or subtracting individual pieces.

Materials proposed for use as coarse aggregates in concrete shall be processed by crushing the minimum subsample mass given in Table P2.1, as described in Clause P2.8.3, to ensure that it is representative of the composition of the coarse aggregate as proposed for use.

P2.8.2.3

When a quarried material is proposed for use both as coarse and as fine aggregate, it shall be tested by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect

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that the coarser size fractions have a different composition than the finer sizes and that these differences might significantly affect expansion due to the oxidation of sulphide minerals. In this case, the coarser size fractions shall be tested in a manner similar to that employed in testing the fine aggregate sizes.

Table P2.1
Test specimen size
(See Clauses P2.8.1 and P2.8.2.2.)

Nominal maximum aggregate size, mm	Minimum mass of field samples, kg (from CSA A23.2-1A)	Minimum mass of subsample, kg
14 and less	15	3
20	25	5
28	50	10
40	75	15
56	100	20
80	150	60

P2.8.3 Test specimen preparation

P2.8.3.1

The minimum mass of subsample (Table P2.1) to which this Test Method is applied shall be ground so as to pass the 160 µm sieve. In order to produce a sample that is representative of the original coarse or fine aggregate material, the crushing shall be done by multiple passes.

Note: *The objective is to avoid producing excessive amounts of fine material (i.e., < 80 µm) resulting from rapid size reduction of the aggregate material. The amount of material (< 160 µm) for a test, using the acrylic column described in Clause P2.5, will generally fall between 2100 and 2300 g.*

P2.8.3.2

The test specimen shall be prepared as follows:

a) Using a small jaw crusher (or other appropriate equipment), crush the material and sieve it over a 2.5 mm sieve between each pass until all material passes the sieve. Care should be exercised not to close the opening between the jaws too rapidly because this may produce excessive amounts of fine material (i.e., < 80 µm). Take care that the jaw crusher is clean prior to use and that no material is lost.
b) Mix the crushed test specimen thoroughly, and prepare, using a sample splitter or other suitable means, a representative specimen of 2500 ± 10 g. Pulverize the test specimen using a disk pulverizer or suitable equipment (e.g., roller crusher, rod mill) so that it passes a 160 µm sieve. In case using a disk pulverizer, a ceramic disk shall be used as cast iron plates can contaminate the samples with the potential of leading to high oxygen consumption. Further treat any material retained on the 160 µm sieve until it is able to pass the sieve. Take care that no material is lost.
c) Take the material passing the 160 µm sieve and mix thoroughly.

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P2.9 Procedure

P2.9.1

In this test, the total volume of ground material shall be calculated by considering a 100 mm material thickness (particles < 160 µm) within the cell, after compaction, resulting in a total ground material volume of 1577 cm³ (for a reaction cell with an internal diameter of 141.7 mm). The porosity in the ground material, which corresponds to the ratio of the volume of void-space over the total volume of ground material, shall be 50%, while the saturation degree for the ground material shall be 40%.

Note: *The volume of the ground material (corresponding to the aggregate, air void, and water) and the headspace above the latter are critical parameters to control for the test.*

P2.9.2

Based on the relative bulk density (dry) of the aggregate, the required mass of water (to reach 40% saturation degree) and the mass of aggregate shall be calculated in accordance with Equations (1) and (2).

$$\text{Mass of aggregate (g)} = \left[\left(1 - n_{gm}\right) \times V_{gm} \times \rho_{agg}\right] \quad \textbf{Equation (1)}$$

$$\text{Mass of water (g)} = \left[\left(V_{gm} \times n_{gm}\right) \times S_{gm} \times \rho_{w}\right] \quad \textbf{Equation (2)}$$

where

n_{gm} = porosity within the ground material (%) – use 50% for this test

V_{gm} = total volume occupied by the ground material (cm³)

ρ_{agg} = relative bulk (dry) density of the aggregate

S_{gm} = degree of saturation (%) of the ground material

ρ_{w} = density of water (g/cm³)

P2.9.3

The material shall be placed into the column in two layers of equal mass (i.e., two layers of about 50 mm in thickness) and consolidated until it reaches the desired thickness. The consolidation shall be carried out by using a steel pestle. The surface of the second layer shall be perfectly flat in order to obtain a good reading by the oxygen sensors.

P2.9.4

Once the preparation of the test specimen in the column is completed, the lid shall be placed and sealed at the top of the reaction cell using a layer of high vacuum grease to avoid any leaks or entry of oxygen into the system. The probe shall then be connected to the data acquisition system. The test shall then be started and the measurements carried out over a 3.5 h period. When compiling the data, the first 30 min shall be used for the system to reach stable condition and the last 3 h shall be considered as the testing period for the final measurement of the O_2 consumption.

P2.10 Calculation

The consumed oxygen content shall be calculated as follows:

$$\text{Initial obtained value (Mv) (at 30 min)} \times \text{probe calibration value } (\%O_2 / \text{mV}) = X\ \%\ O_2 \quad \textbf{Equation (3)}$$

$$\text{Final obtained value (Mv) (at 210 min)} \times \text{probe calibration value } (\%O_2 / \text{mV}) = Y\ \%\ O_2 \quad \textbf{Equation (4)}$$

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$$O_2 \text{consumed (\%)} = \frac{X - Y}{X} \times 100$$ **Equation (5)**

Notes:

1) *The values measured during the test are given in mV (millivolts).*
2) *The calibrated probe value is obtained following the procedure recommended by the manufacturer.*
3) *Example of calculation:*
   Testing of MSK, 100 mm of compacted aggregate material (< 160 µm; 40% saturation), 100 mm headspace, 3.5 h testing period
   Initial measured value (at 30 min) = 50.00 mV
   Final measured value (at 210 min) = 47.50 mV
   Probe calibration value obtained = 0.400 %O_2 /mV
   Initial value (at 30 min) x probe calibration value obtained = 50 mV × 0.400 %O_2 /mV = 20.0% %O_2 (X)
   Final value (at 210 min) x probe calibration value obtained = 47.50 mV × 0.400 %O_2 /mV = 19.0 %O_2 (Y)

$$O_2 \text{ consumed (\%)} = \frac{20.0\ \%O_2 - 19.0\ \%O_2}{20.0\ \%O_2} \times 100 = 5.0\ \%$$ **Equation (6)**

P2.11 Use of a control material

P2.11.1

When testing is conducted, the laboratory shall demonstrate its ability to conduct the test. At the time of testing or at least yearly, testing with a reference sulphide-bearing aggregate shall be conducted.

P2.11.2

As a means of validating the testing laboratory and validating the testing process, MSK aggregate shall be tested. Considering the test set-up described in this method (i.e., ground aggregate particle size of < 160 mm, 100 mm of compacted ground material at 40% saturation, 100 mm of headspace, and a test period of 3.5 h), Rodrigues *et al.*, (2016) reported a mean oxygen consumption value, based on six tests carried out on the MSK aggregate, of 22.1%, along with a standard deviation value of 0.50 and a coefficient of variation of 2.2%.

Note: *A source of reference aggregate is expected to be available in 2020.*

P2.12 Reporting

P2.12.1 Required information

The following information shall be included in the test report:

a) sample number or identification marks;
b) type and source of aggregate, location of aggregate within the source (e.g., bench level, area within a pit, etc.);
c) name of the person or organization who sampled the aggregate;
d) any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in Clause P2.8.2;
e) parameters of the test, including the compacted ground material thickness, the headspace volume thickness, the mass of aggregate (< 160 µm particle size used), and the amount of water used to achieve 40% aggregate saturation;
f) volumetric mass density of the aggregate;
g) oxygen consumption (oxygen consumption in %);
h) identification of the certified laboratory performing the test (i.e., name and address);
i) name and signature of the person responsible for the review and approval of the test report; and

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j) any deviation from the test procedure.

P2.12.2 Optional information

The following information may be included in the test report:

a) name of the person who sampled the aggregate, if known;
b) name of the technician performing the test;
c) date the sample was taken or received by testing laboratory; and
d) the total sulphide sulphur content of the aggregate under test, if known.

P2.13 Precision and bias

This is a recently developed method and as yet no formal multi-laboratory study has been conducted.

Figure P2.1
Testing set-up for the oxygen consumption test with 100 mm of compacted aggregate material and 100 mm headspace for the measurements of the consumed O_2 with the probe installed at the top of the set-up
(See Clause P2.5.)



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Figure P2.2
Probe (Apogee SO-100 and 200 series) used to measure oxygen consumption
(See Clause P2.5.)



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Attachment P3 (informative)

Test method for detection of potential reactivity of sulphide-bearing aggregates by accelerated expansion of mortar bars

Note: *This informative Attachment has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

P3.1 Scope

P3.1.1

This Test Method describes a procedure for determining the potential deleterious character of sulphide-bearing aggregates through a two-phase accelerated mortar bar test.

P3.1.2

Sulphide minerals such as pyrite, pyrrhotite, and in other forms, can oxidize and hydrate with volume increase, or the release of sulphate that produces sulphate attack upon the cement paste, or both.

P3.2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto.

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A3001-18
Cementitious materials for use in concrete

A3004-18
Test methods for cementitious materials for use in concrete and masonry

ASTM International

C151/C151M-18
Standard Test Method for Autoclave Expansion of Hydraulic Cement

C305-14
Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars for Plastic Consistency

C490/C490M-17
Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

C511-13
Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

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E104-02 (2012)
Standard Practice for maintaining constant relative humidity by means of aqueous solutions

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

Other publications

Bérard, J., Roux, R. and Durand, M. 1975. Performance of concrete containing a variety of black shale, *Canadian Journal of Civil Engineering*, 2: 58–65.

Rodrigues, A., Duchesne, J., Fournier, B., Rivard, P., Durand, B. and Shehata, M. 2012. Mineralogical and chemical assessment of concrete damaged by the oxidation of sulphide-bearing aggregates: importance of thaumasite formation on reaction mechanisms. *Cement and Concrete Research*, 42: 1336–1347.

Rodrigues, A., Duchesne, J., Fournier, B. 2015. A new accelerated mortar bar test to assess the potential deleterious effect of sulfide-bearing aggregate in concrete. *Cement and Concrete Research*, 73: 96–110.

Tagnit-Hamou, A.; Saric-Coric, M.; and Rivard, P. 2005. Internal Deterioration of Concrete by the Oxidation of Pyrrhotitic Aggregates. *Cement and Concrete Research*, 35 (1): 99–107.

P3.3 Definitions

In addition to the definitions in Clause 3 of CSA A23.1, the definitions of CSA A3001 apply in this Test Method.

P3.4 Summary

The expansion taking place in Phase 1 of the test allows detection of the potential expansion due to the oxidation of sulphide minerals in concrete aggregates. This is accomplished by means of the length-change monitoring of mortar bars subjected to 13 weeks of storage at 80 °C/75% humidity, with two 3 h wetting cycles in a 6% sodium hypochlorite solution per week (Phase I), followed by 13 weeks of storage at 4°C/100% humidity, with two 3 h wetting cycles in a 6% sodium hypochlorite solution per week (Phase 2). The latter measures the expansion caused by thaumasite sulphate attack.

P3.5 Significance and use

P3.5.1

Oxidation of iron sulphides in concrete aggregate has led to expansion and cracking of concrete structures in Canada (Bérard *et al.*, 1975; Tagnit-Hamou *et al.*, 2005; Rodrigues *et al.*, 2012). Different iron sulphides can oxidize at different rates. Pyrite within an aggregate can be stable in concrete for many years. Pyrrhotite and marcasite can oxidize relatively rapidly and pyrrhotite has caused significant problems in concrete in Canada and elsewhere. Sulphide minerals, mainly pyrite, are common and it is possible that there are undocumented cases of concrete deterioration caused by this problem in Canada.

P3.5.2

Testing carried out by Rodrigues *et al.* (2015) showed that “excessive” mortar bar expansion can be generated over 180 days of testing under conditions conducive to the oxidation of sulphide minerals present in the aggregates, especially pyrrhotite, and the formation of “rust” products. Such a reaction

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can also result in internal sulphate attack, through the formation of sulphuric acid, subsequently forming additional secondary expansive products (e.g., gypsum, ettringite).

Rodrigues *et al.* (2015) also showed that, in the presence of a source of carbonate material, "excessive" mortar bar expansion and progressive destruction of the mortar bars can be generated when the bars are subjected to low temperature (4 °C) and high humidity storage conditions (Phase II – Clause P3.11.3), through thaumasite sulphate attack (TSA). TSA had been found to be one of the causes for the rapid deterioration of concrete structures in the Trois-Rivières area (Rodrigues *et al.*, 2012).

P3.5.3

This Test Method is not intended for evaluating the potential sulphide oxidation expansivity of combinations of coarse and fine aggregates.

P3.6 Apparatus

The apparatus shall conform to the requirements of ASTM C490/C490M, except as follows:

a) small jaw crusher or other suitable equipment capable of crushing aggregate to pass a 5 mm sieve shall be used;
b) pulverizer or other suitable equipment capable of grinding aggregate finer than 5 mm shall be used;
c) square hole, woven-wire cloth sieves shall conform to the requirements of ISO 3310-1;
d) the mixer, paddle, and mixing bowl shall conform to the requirements of ASTM C305, except that the clearance between the lower end of the paddle and the bottom of the bowl shall be 5.1 ± 0.3 mm;
e) the tamper and trowel shall conform to the requirements of CSA A3004-C1;
f) the containers shall be of such a design that the bars can be placed on a "support" thus standing above a solution capable of maintaining relative humidity conditions of 75% at 80 °C (supersaturated NaCl solution) and of 100% at 4 °C (water). The containers shall be made of material that can withstand prolonged exposure to 4 °C, 80 °C, or both, and shall be inert to a salt solution (NaCl). The containers shall be so constructed that, when used for storing specimens, the loss of moisture is prevented by tight-fitting covers, by sealing, or both. The volume of free air space above the saturated salt solution shall be no more than 150 mm high. The bars shall be placed and supported so that they will never be in direct contact with the solution. It shall also be ensured that the specimens do not touch the sides of the container or each other. Illustrations of an appropriate set-up are given in Figures P3.1 and P3.2.

   Notes:

   1) *Storage containers that were found appropriate for this type of testing are 5 L rectangular plastic containers with airtight lids (e.g., Lock & Lock from Starfrit). Approximate dimensions are 370 mm long by 150 mm wide by 130 mm in depth. The seal of the lid should be sufficient to prevent loss of water by evaporation. A perforated rack should be placed in the bottom of the storage container, sitting on a stand (e.g., plastic rings cut from ABS plastic tubing/pipes) so that the bars should be 30 to 40 mm above the solution. The container should have a solution, in the bottom, to a depth of 20 ± 5 mm. The solutions consist of supersaturated NaCl solution (Phase I – storage at 80 °C/75% relative humidity) and water (Phase II – storage at 4 °C/100% relative humidity).*
   2) *Storage containers other than those specified may be used, provided the efficiency of the storage container is calibrated with a standard reactive aggregate. The expansion at one year obtained using the alternative container should be within 10% of that obtained using the specified container. If an alternative container is used, it should be noted in reporting the results, together with documentation proving compliance with the calibration requirements of this Clause.*

g) the convection oven shall have temperature control maintaining 80 ± 2.0 °C;

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h) the cold-temperature storage room or cabinet shall have temperature control maintaining 4 ± 1.0 °C; and
i) the balance shall be capable of measuring to 0.1 g accuracy.

Note: *Conventional studs used for mortar bar testing were found to be inappropriate as they suffered heavily from corrosion following the very severe storage in the sodium hypochlorite solution. Commercially available titanium threaded rods, 6.4 mm in diameter, and cut into 25 to 30 mm lengths, with one end machined to round shape, were found to perform well over the severe testing regime of this Test Method.*

P3.7 Reagents and materials

P3.7.1 Saturated sodium chloride solution

In accordance with ASTM E104, a saturated sodium chloride solution shall be used to maintain a constant relative humidity of about 75% in a closed container stored in an oven at 80 °C. The solution shall be prepared in accordance with the procedure described in ASTM E104, Clause 10.

Notes:

1) *Domestic table salt may be used to prepare the solution.*
2) *Potable water may be used to prepare the saturated sodium chloride solution.*

P3.7.2 Storage (sodium hypochlorite) solution

A 6% sodium hypochlorite solution shall be used to subject the mortar bars to two 3 h immersion periods, per week. If the 6% sodium hypochlorite is prepared from a concentrated sodium hypochlorite solution, the concentration of the concentrated solution shall be determined in order to proceed with the appropriate dilution rate.

Notes:

1) *Precaution: before using sodium hypochorite solution, review*
   a) *the safety precautions for using sodium hypochorite solution;*
   b) *first aid for burns;*
   c) *the emergency response to spills as described in the manufacturer's Safety Data Sheets or other reliable safety literature. Sodium hypochorite solution can cause burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to sodium hypochorite solution. Gloves should be checked periodically for pin holes.*
2) *Certified 6% sodium hypochlorite solution can be obtained from suppliers of chemical products.*
3) *Another option is to prepare the solution from a concentrated sodium hypochlorite solution (e.g., 12%).*

P3.7.3 Cement

A supply of cement meeting the requirement of general use Portland cement (Type GU) as specified in CSA A3001 shall be used. Portland-limestone cement (Type GUL) shall not be used in this test. The total alkali content of the cement shall be 0.90 ± 0.10%, calculated as Na2O + 0.658 K_2O (i.e., the Na_2O equivalent). In addition, the autoclave expansion determined as per ASTM C151/C151M shall be less than 0.20%.

P3.7.4 Control aggregate

A supply of sulphide-bearing reactive control aggregate shall be prepared as described in Clause P3.10.1.

Note: *A source of reference aggregate is expected to be available in 2020.*

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P3.8 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

P3.9 Conditioning

P3.9.1

The temperature of the moulding room, apparatus, and dry materials shall be determined at not less than 20 °C and not more than 26 °C. The temperature of the mixing water and of the moist closet or moist room shall be 23 ± 2.0 °C.

P3.9.2

The relative humidity of the moulding room shall be maintained at not less than 50%. The moist closet or room, if used, shall conform to ASTM C511.

P3.9.3

The storage oven in which the specimens are stored in the containers for the first 90 days of testing (Phase I) shall be maintained at a temperature of 80 ± 2.0 °C.

P3.9.4

The cold room or storage cabinet in which the specimens are stored in the containers for the second period of 90 days of testing (Phase II) shall be maintained at a temperature of 4 ± 1.0 °C.

P3.10 Sampling and preparation of test specimens

P3.10.1 Sampling

P3.10.1.1

The procedures outlined in CSA Test Method A23.2-1A shall be followed to obtain a representative sample of the aggregate to be tested (Table P3.1).

The sample, if possible, shall be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production.

P3.10.1.2

The sample obtained in accordance with Clause P3.10.1.1 shall be reduced for further processing by the use of a sample splitter or by a suitable method of quartering to obtain a representative subsample (Table P3.1). No attempt shall be made to obtain the required test subsample by adding or subtracting individual pieces. Materials proposed for use as coarse aggregates in concrete shall be processed by crushing the minimum subsample mass given in Table P3.1, as described in Clause P3.10.2, to ensure that it is representative of the composition of the coarse aggregate as proposed for use. The sample for mortar manufacturing shall then have the grading specified in Table P3.2.

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Table P3.1
Test specimen size
(See Clauses P3.10.1.1, P3.10.2, and P3.10.4.3.)

Nominal maximum aggregate size, mm	Minimum mass of field samples, kg (from CSA A23.2-1A)	Minimum mass of subsample, kg
14 and less	15	3
20	25	5
28	50	10
40	75	15
56	100	20
80	150	60

P3.10.1.3

When a given quarried material is proposed for use both as coarse and as fine aggregate, it shall be tested only by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect that the coarser size fractions have a different composition than the finer sizes and that these differences might significantly affect expansion due to the oxidation of sulphide minerals. In this case, the coarser size fractions shall be tested in a manner similar to that employed in testing the fine aggregate sizes.

Table P3.2
Grading requirements
(See Clauses P3.10.1.2, P3.10.2, and P3.10.4.3.)

Sieve size		
Passing	Retained	Mass, %
5 mm	2.5 mm	10
2.5 mm	1.25 mm	25
1.25 mm	630 µm	25
630 µm	315 µm	25
315 µm	160 µm	15

P3.10.2 Aggregate processing and grading

Aggregates in which sufficient quantities of the sizes specified in Table P3.1 do not exist shall be crushed until the required material has been produced. If aggregates contain insufficient amounts of one or more of the larger sizes listed in Table P3.2, and if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size as determined from the grading specified in Table P3.2. When such procedures are required, a special note shall be made to that effect in the test report.

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After the aggregate has been separated into the various sieve sizes, each size shall be washed with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. The portions retained on the various sieves shall be dried to constant mass and, unless used immediately, stored individually in a clean container provided with tight-fitting covers.

Note: *In order to produce a graded aggregate sample that is representative of the original coarse aggregate material, the following procedure may be used:*

a) *For a coarse aggregate with particles 5 to 20 mm in size, start with a representative subsample of 5 kg prepared by quartering or other suitable means to ensure a representative portion of the original sample collected following CSA A23.2-1A.*
b) *Using a small jaw crusher (or other appropriate equipment), crush the coarse aggregate particles by multiple passes.*
c) *Sieve the material over a 5 mm sieve between each pass until all material passes the sieve. Care should be exercised not to close the opening between the jaws too rapidly because this can produce significant amounts of fine dust.*
d) *Separate the material into the various size fractions required for the test.*
e) *If insufficient quantities of some of the fractions are produced, grind the "excess" material from the larger particle sizes using a disk pulverizer or other suitable means by progressive passes. The material can be sieved over a suitable sieve between each pass until all material passes the sieve. The material is then separated into the smaller size fractions and blended with the previously produced material.*

P3.10.3 Cement

Portland cement meeting the requirements of Clause P3.7.3 shall be used. Cement for use in this test shall be passed through a 710 µm sieve to remove lumps before use.

P3.10.4 Preparation of test specimens

P3.10.4.1

A minimum of three test specimens shall be prepared for each aggregate.

Note: *There can be advantages in making an extra bar that can be removed from the testing process for microscopic examination for signs of sulphide oxidation reactions.*

P3.10.4.2

The specimen moulds shall be prepared in accordance with the requirements of ASTM C490/C490M, except that the interior surfaces of the mould shall be covered with a release agent.* A release agent may be used if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen.

* *TFE-Fluorocarbon (Teflon) tape complies with the requirements for a mould release agent.*

P3.10.4.3

The dry materials for the test mortar shall be proportioned using 1 part cement to 2.75 parts graded aggregate by mass. The quantities of dry materials to be mixed at one time in the batch of mortar for making three specimens shall be 440 g of cement and 1200 g of aggregate made up by recombining the portions retained on the various sieves (see Clause P3.10.1) in the grading prescribed in Table P3.1. A water-to-cement ratio equal to 0.65 by mass shall be used.

Notes:

1) *Ruggedness tests indicate that mortar bar expansions were less variable at a fixed water-to-cement ratio than when gauged to a constant flow.*
2) *The water-to-cement ratios selected should give acceptable workability in most cases.*

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P3.10.4.4

The mortar shall be mixed in accordance with the requirements of ASTM C305.

P3.10.4.5

Test specimens shall be moulded with a total elapsed time of not more than 2 min and 15 s after completion of the original mixing of the mortar batch. The moulds shall be filled with two approximately equal layers, each layer being compacted with the tamper. The mortar shall be worked into the corners, around the gauge studs, and along the surfaces of the mould with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, the mortar shall be cut off flush with the top of the mould and the surface shall be smoothed with a few strokes of the trowel.

P3.11 Procedure

P3.11.1 General

Each mould shall be placed in the moist cabinet/room immediately after moulds have been filled. Alternatively, the mortar bar moulds shall be covered with wet burlap or placed over water in a sealed container, and maintained at 23 ± 2.0 °C. When burlap is used, it shall be saturated but not dripping and shall cover the top and sides of the samples without being in direct contact with the mortar surface. The burlap shall be completely covered with a polyethylene sheet in such a manner as to prevent drying of the burlap.

The specimens shall remain in the moulds for 48 ± 2 h. The specimens shall be removed from the moulds and, while they are being protected from loss of moisture, properly identified. The bars shall be placed in a moist chamber/cabinet (23 ± 2.0 °C), protected from excess (water dripping) moisture, for another 24 ± 2 h.

The bars shall be removed from the moist chamber/cabinet and, while they are protected, as far as practical, from loss of moisture, initial mass and length shall be measured. The initial and all subsequent measurements shall be measured and recorded to the nearest 0.002 mm and nearest 0.1 g.

P3.11.2 Phase I

P3.11.2.1 General

Following the 72 h curing and the initial readings described in Clause P3.11.1, the mortar bars shall be subjected to Phase I testing regime. The latter shall include two 3 h immersion periods in a 6% sodium hypochlorite solution, per week. Between the above “wet” storage sessions, the bars shall be maintained at 80 °C and 75% humidity over the 13 week testing period of Phase I. The testing regime and measurements shall be in accordance with Clauses P3.11.2.2 and P3.11.2.3.

P3.11.2.2 Zero readings

Zero readings shall be conducted as follows:

a) immerse the bars in a 6% sodium hypochlorite solution, in a close plastic container, for 3 h (± 15 min). Bars shall be well covered by the solution during the 3 h immersion period;

   Note: *Although it depends on the size of the storage container used, quantities of solution that were found appropriate when using the type of plastic containers described in Clause P3.6 f) is 2 L for 6 bars and 1.4 L for 3 bars. The volume of a mortar bar may be taken as 184 mL.*

b) remove the bars from the sodium hypochlorite solution;

c) place the bars on a tray over a dry cloth, dry and clean the measurement pins;

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d) measure the mass (*Mz* or zero mass) of each bar within 5 min following the previous step (bars saturated but surface moisture removed with a paper towel);
e) measure the length (*Lz* or zero length) immediately following the mass measurements;
f) after the above measurements, let the bar dry at room temperature (23 ± 2 °C) under the fume hood (switched on) for 3 h (± 15 min); and
g) place the bars back into the storage container, above the saturated salt (NaCl) solution, and place the container in the oven at 80 °C.

Notes:

1) *The transfer and manipulation of bars in and out of the sodium hypochlorite solution, including mass and length measurements, should be carried out using the appropriate personal protective equipment (including gloves and safety glasses), and ideally under a fume hood (switched on) to avoid exposure to corrosive vapors from the sodium hypochlorite solution.*
2) *The comparator reference bar should be measured regularly over the length change measurements of test specimens.*
3) *The lower measuring stud of the comparator should be wiped dry after each measurement to prevent corrosion.*
4) *The rubber gasket on the container's lid should be cleaned to ensure a proper seal of the containers before returning to storage condition.*
5) *The saturated solution should be agitated periodically and a solid crust of crystals should not be allowed to form on the top of the solution since this will result in a lower humidity because evaporation is impeded.*

P3.11.2.3 Main testing regime and further readings

The mortar bars shall be subjected to two 3 h wetting periods per week in the sodium hypochlorite solution, over a 13 week testing period. Twice a week (e.g., "Day 1" and "Day 4"), the containers shall be removed from "75% relative humidity 80 °C" condition. The bars shall be removed from the container and placed in a tray, on an egg crate plastic piece (in order to help air circulation around the bars) for sufficient time (approximately 30 min) in air at 23 ± 2 °C to cool the bars to 23 ± 2 °C. The procedure described in Clauses P3.11.2.2 a) to f) shall be repeated twice a week, except that the mass (*Mt* or mass at time *t*) and length (*Lt* or length at time *t*) measurements [i.e. Items d) and e) in Clause P3.11.2.2] shall only be performed once a week (i.e., after the first or the second weekly immersion period).

The sodium hypochlorite solution shall be replaced every two weeks. Between the 3 h immersion periods in the sodium hypochlorite solution, the bars shall be maintained under their main testing conditions, i.e., 80 °C and 75% humidity.

Note: *Proper planning should be done to avoid immersion periods over weekends, unless proper arrangements are made.*

P3.11.3 Phase II

P3.11.3.1 General

As described in Clause P3.4, additional testing shall be carried out following Phase I testing. During Phase II, the mortar bars shall be subjected to two 3 h immersion periods in a 6% sodium hypochlorite solution, per week. Between the above "wet" storage sessions, the bars shall be maintained at 4 °C and 100% humidity, and this over the minimum 13 week testing period of Phase II.

P3.11.3.2 Main testing regime and further readings

Following the final mass/expansion readings of Phase I testing, the mortar bars shall be stored in a similar container to that used for Phase I, except that the solution used in the bottom of the container

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is replaced with water, which will result in a 100% humidity condition surrounding the bars. The container shall then be placed in a cold-temperature storage room or cabinet maintained at 4 ± 1 °C.

Twice a week (e.g., "Day 1" and "Day 4"), the containers shall be removed from "100% 4 °C" condition. The bars shall be removed from the container and placed in a tray, on an egg crate plastic piece (in order to help air circulation around the bars) for 30 min in air at 23 ± 2 °C to heat the bars up to 23 ± 2 ° C. The procedure described in Clauses P3.11.2.2 a) to f) shall be repeated twice a week, except that the mass (Mt or mass at time *t*) and length (*Lt* or length at time *t*) measurements (i.e. Items d) and e) in Clause P3.11.2.2) shall only be performed once a week (i.e., after the first or the second weekly immersion period). The bars are then placed back in the storage container, above water, and the container placed in the cold cabinet at 4 ± 1.0 °C.

P3.12 Calculation

The difference between the zero length *(Lz)* of the specimen and the length at each period of measurement *(Lt)* shall be calculated to the nearest 0.001% of the effective length and recorded as the expansion of the specimen for that period. The average expansion of the three specimens shall be reported to the nearest 0.01% as the expansion for a given period.

P3.13 Use of a control material

P3.13.1

When testing is conducted, the laboratory shall demonstrate its ability to conduct the test. At the time of testing or at least every year, testing with a known sulphide oxidation reactive aggregate shall be conducted.

P3.13.2

As a means of validating the testing laboratory and validating the testing process, MSK aggregate shall be tested.

Note: *A source of reference aggregate is expected to be available in 2020. Average expansion limits for the reference aggregate will be established by multi-laboratory study and included in future updates of this Test Method.*

P3.14 Reporting

P3.14.1 Required information

The following information shall be included in the test report:

a) sample number or identification marks;
b) type and source of aggregate, location of aggregate within the source (e.g., bench level, area within a pit or quarry);
c) identification of the certified laboratory performing the test (i.e., name and address);
d) name of the technician performing the test;
e) name and signature of the person responsible for the review and approval of the test report;
f) type, source, and composition of Portland cement;
g) average length change percentage and mass change at each reading of the specimens;
h) any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in Clause P3.10.1;
i) any significant features revealed by examination of the specimens and the storage solution during and after the test;
j) amount of mixing water expressed as water-to-cement ratio;

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k) a graph of the length change data from the time of the zero reading to the end of the period of testing;
l) a graph of the length change data from the time of the zero reading to the end of the period of the control aggregate;
m) name and signature of the person responsible for the review and approval of the test report; and
n) any deviations from the test procedure.

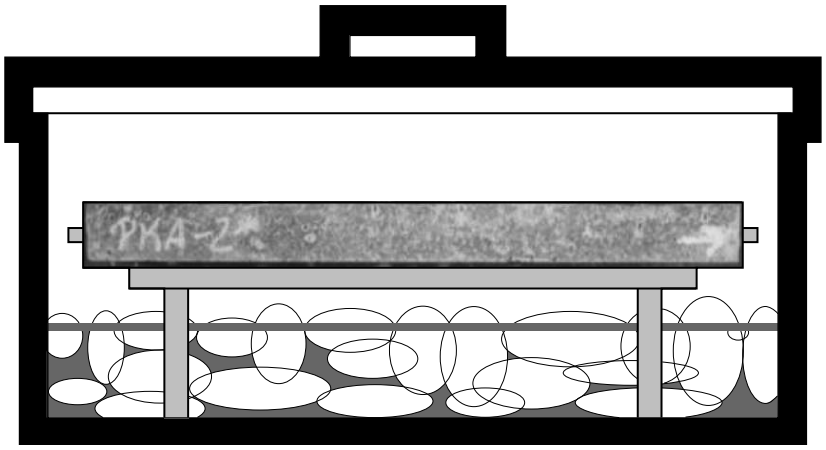
P3.14.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate; and
b) date the sample was taken or received by testing laboratory.

P3.15 Precision and bias

This is a recently developed method and as yet no formal multi-laboratory study has been conducted.

Figure P3.1
Sketch of a storage container for the expansion testing
(See Clause P3.6.)

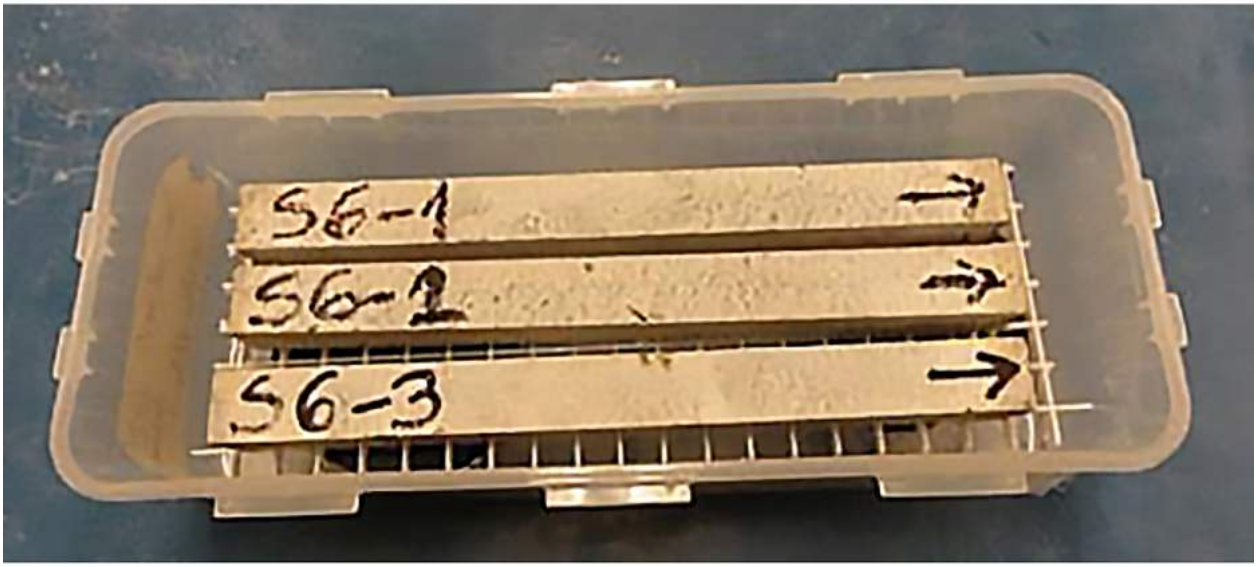


Note: *The mortar bars are placed sitting on a stand so that the prisms shall be 30 mm to 40 mm above the bottom. The container shall have a solution, in the bottom, to a depth of 20 ± 5 mm. The solution is meant to maintain the relative humidity in the container at selected levels. It is important that the saturated solution is agitated periodically and that a solid crust of crystals is not allowed to form on the top of the solution.*

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Figure P3.2
Storage container and mortar bars sitting on the stand above the salt solution
(See Clause P3.6.)



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Annex Q (informative)
Simple method to optimize combined aggregate gradation

Note: *This informative (nonmandatory) Annex has been written in normative (mandatory) language to facilitate adoption where users of the Standard or regulatory authorities wish to adopt it formally as additional requirements to the Standard.*

Q.1 Introduction

This Annex provides assistance to concrete producers who wish to determine better proportions of their various aggregate supplies in order to improve the sustainability and economy of their concrete mixes. Successful application of the method depends upon following up with trial mixes and appropriate adjustment of mix proportions prior to practical implementation.

The procedure allows the determination of the optimum combination of two or more aggregates of known gradations that produce the "best" resulting combined aggregate gradation with respect to the "ideal" gradation. "Best" is assessed by the extent of agreement between the combined gradation and the ideal "Fuller" power equation*:

$P = 100 \times (d/D)^n$

where

P = the percent passing a given sieve size, d

D = the nominal maximum aggregate size for the combined aggregate

n = the power coefficient, determined by the user

The Fuller model is based upon the assumption that aggregate particles are smooth and approximately spherical, and has been found to give good results for a wide-variety of non-angular aggregates. Determination of the usefulness of the model for angular and rough-textured aggregates will likely require significant laboratory trial batching.

Two procedures are outlined in this Annex. Procedure A is intended for lower-slump concretes where the mass of "powder" used (see definition in Clause Q.2) is not critical with respect to the flowability of the fresh concrete. In this case only aggregate particle-sizes equal to or greater than 0.630 mm are considered in the analysis. For highly-flowable and self-consolidating concretes (SCC), Procedure B should be used in which the powder is assumed to be a very fine aggregate that passes completely through all standard sieve sizes, and the analysis is determined for all sieve sizes of 0.160 mm and above.

The procedures and examples outlined in this Annex are for three chosen aggregates blended without powder (Procedure A) and with powder (Procedure B). The methods may be altered by the user to allow for optimization using two aggregates or more than three aggregates.

* *As first described by Fuller and Thompson (1907) and researched in more detail by Talbot and Richart (1923). The method has found significant use in both the concrete and asphalt industries.*

Q.2 Definitions

The following definitions are used in this Annex:

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Aggregate gradation — the percent-passing data for a given type of aggregate as measured by standard sieve analysis in accordance with CSA A23.2-2A.

Aggregate type or bin — any aggregate (coarse, fine, or combined) supplied to a concrete producer with a measured standard-gradation and a known or estimated average relative density.

Combined aggregate — the aggregate produced by the combination of various proportions of the aggregate types defined by the concrete producer.

Maximum aggregate size — the smallest standard sieve size for the combined aggregate at which 100% of the combined aggregate passes.

Nominal maximum size of aggregate — the standard sieve opening, which is one size smaller than the smallest sieve through which all of the combined-aggregate must pass.

Powder — fine particulate material in which 100% is normally expected to pass the 0.160 mm sieve, such as cement, SCM, and fine mineral filler added in significant amount.

Q.3 Procedure A for low- and intermediate-slump concretes — Determination of the mass proportions of three types of aggregate to optimize combined aggregate gradation in accordance with the Fuller power-fit

The objective of Procedure A is to determine the mass proportions M_1, M_2, and M_3 required for each of three aggregate bins, Bin 1, Bin 2, and Bin 3 that result in a combined-aggregate gradation where the fit to the Fuller power equation is optimized. Procedure A is for lower-slump concretes where the variations in the mass of powder that will be used does not appreciably affect the flowability of the concrete. The following steps shall be performed:

a) Perform a full sieve analysis of each of the three bins to determine the percent passing (PP) for each standard sieve size, tested in accordance with CSA A23.2-2A*. Estimate the average relative density (RD) of each aggregate type (bin), either from previous experience or by testing in accordance with CSA A23.2-6A or A23.2-12A†.

   * *The 0.080 mm sieve results are not used in the least-squares analysis of either Procedure A or B.*
   † *The effect on analysis of variations in RD of aggregates is found to be significant only if the range of RDs is greater than approximately 0.2.*

b) Decide the appropriate power parameter, n, to use in the analysis. For normal low- to intermediate-slump concretes, n = 0.45 is commonly used*.

   * *As data and experience with the procedure are gained, the user may determine that a different value of n gives better results for the user's particular application.*

c) Make an initial guess at the likely optimum mass proportion required for each bin (M_1, M_2, M_3), based upon experience. Failing any previous experience, for three aggregates use 1/3 (0.333) as the initial guess for each mass proportion*.

   * *The initial guess is required only as starting information for the first iteration of the optimization process. The optimization may be done by computer (usually by spreadsheet), or manually. If done by hand, time (number of iterations) will be saved if the initial guess is reasonably close to the optimized value.*

d) Calculate the volume proportions V_x (x = 1,2,3) for each bin from the estimated mass and the relative densities. For example, $V_1 = (M_1/RD_1)/(M_1/RD_1 + M_2/RD_2 + M_3/RD_3)$.

e) Using the calculated values of V_x, calculate the combined aggregate gradation, as percent passing, for all sieve sizes:

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For each sieve size, $P = PP_1*V_1 + PP_2*V_2 + PP_3*V_3$
where
P = the % passing of the combined aggregate for the given sieve size
PP_1, PP_2, PP_3 = the % passing for each of the three aggregates for this sieve size

f) Using the defined values of D and n, for each sieve size calculate the volume percent passing as determined by the Fuller model:
$P_f = (d/D)^n$
where
d = the diameter of the sieve in question (for options concerning the best choice of D for modeling purposes, see Clause Q.7)

g) For each relevant sieve size calculate the square of the error = $(P - P_f)^2$.
h) Calculate the sum of the squares of the errors, SSE, for all relevant sieve sizes greater than or equal to 0.630 mm.
i) Use manual trial and error techniques, or spreadsheet optimization tools to determine the values of M1, M2, M3 that minimize SSE*.

* *When three aggregates are being optimized the manual trial-and-error technique might require many iterations to determine the optimum values. Spreadsheet techniques using a built-in optimization package such as Excel's Solver are more appropriate.*

Q.4 Example analysis — Procedure A (Figures Q.1 and Q.2)

The mass-proportions of three supplied aggregates shall be determined to optimize the combined aggregate gradation in accordance with the Fuller power fit, for a regular 100 mm slump concrete (n = 0.45). An example spreadsheet, showing the aggregate gradations and relative densities for coarse (Bin 1), intermediate (Bin 2), Fine (Bin 3) is given Figure Q.1.

The following solution steps shall be conducted:
a) A blank table (manual or spreadsheet) is created with the configuration as shown in Figure Q.1.
b) The test data are entered in the shaded (yellow) cells at the top of the table and in columns (2) to (4). D is the maximum size of the aggregate for the coarsest aggregate (Bin 1) (see Clause Q.7).
c) Initial guesses for M1, M2, and M3 are entered in the mass proportions cells, such that M1 + M2 + M3 = 1.0. Without additional information, the guesses used in the example in Figure Q.1 are 1/3 (0.333) for each of M1, M2, M3.
d) The volume proportions V1, V2, V3 are calculated from the mass proportions and relative densities (see the example equation in Item d) of Clause Q.3 of the procedure).
e) In column (5) the combined % passing for each sieve size is calculated for each sieve size (see the example equation in Item e) of Clause Q.3 of the procedure).
f) In column (6) the Fuller Fit is calculated for each sieve size using the equation given in Item f) of Clause Q.3 of the procedure.
g) In column (7) the square of the error [column (5) – column (6)]^2 is calculated for each sieve size for sieve sizes greater than or equal to 0.630 mm.
h) The sum of square of errors (SSE) is calculated as the summation of column (7) (see bottom of column 7).
i) The values of M1, M2, and M3 are incrementally adjusted with the aim that each adjustment will reduce SSE. The solution is achieved when further small incremental changes of the three parameters do not appreciably change SSE. This procedure is greatly assisted by creating a scattergram that plots combined % passing and Fuller-Fit *vs.* log (sieve size) so that the effect of changes in M_x can be immediately observed*. The optimized solution is shown in Figure Q.2.

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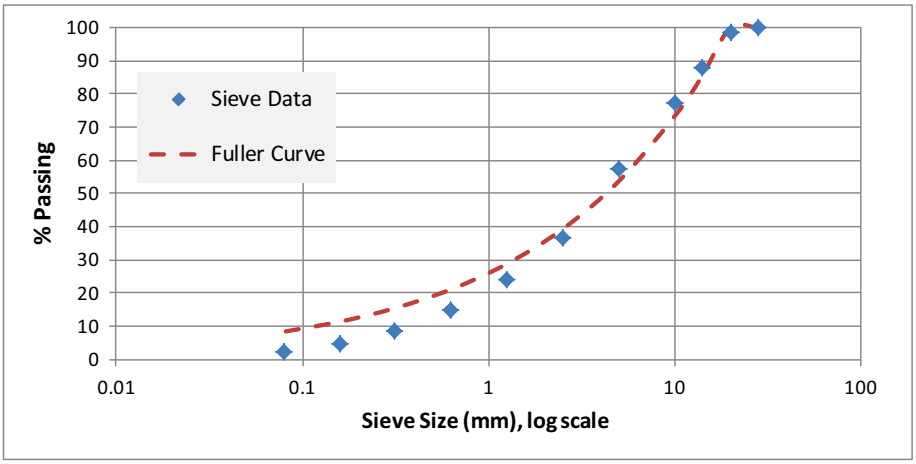
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** Various software applications exist that optimize multiple variables (such as M1, M2, and M3) to minimize an objective function, such as SSE. For example, the "Solver" optimization add-in that is supplied with Microsoft Excel® is suitable for this task.*

Figure Q.1
Example procedure A — Starting spreadsheet configuration
(See Clause Q.4.)

Shaded cells denote data input			Mass proportions		Relative densities		Volume proportions
D	20	M1	0.333	RD1	2.65	V1	0.31
Power	0.45	M2	0.333	RD2	2.30	V2	0.36
		M3	0.333	RD3	2.55	V3	0.33
		Total	1.000			Total	1.00

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	% Passing (PP)					
Sieve size mm	Bin 1	Bin 2	Bin 3	Combined % passing	Fuller fit	$[(5)-(6)]^2$
112						
80						
56						
40						
28	100	100	100	100	100	0
20	95	100	100	98	100	2.5
14	62	100	100	88	85	7.8
10	28	100	100	77	73	16
5.00	3.5	67	99	57	54	14
2.50	0.4	20	91	37	39	6.4
1.25	0	4.2	70	24	29	20
0.630	0	0.9	45	15	21	37
0.315	0	0.2	26	8.5	15	
0.160	0	0	14	4.6	11	
0.080	0	0	7.4	2.4	8.3	
Pan	0	0	0	0.0		
				SSE = sum of square of errors		104

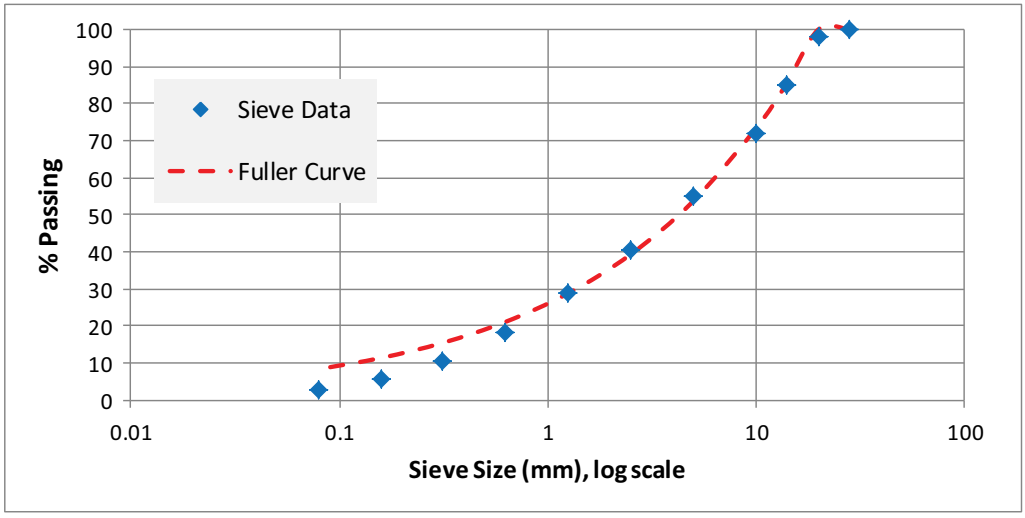


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Figure Q.2
Example solution, Procedure A optimized values of M1, M2, M3 for minimum SSE
(See Clause Q.4.)

Shaded cells denote data input		Mass proportions		Relative densities		Volume proportions
D	20	M1	0.406	RD1	2.65	V1	0.39
Power	0.45	M2	0.193	RD2	2.30	V2	0.21
		M3	0.401	RD3	2.55	V3	0.40
		Total	1.000			Total	1.00

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	% Passing (PP)					
Sieve size mm	Bin 1	Bin 2	Bin 3	Combined % passing	Fuller fit	$[(5)-(6)]^2$
112						
80						
56						
40						
28	100	100	100	100	100	0
20	95	100	100	98	100	3.77
14	62	100	100	85	85	0.01
10	28	100	100	72	73	1.81
5.00	3.5	67	99	55	54	2.01
2.50	0.4	20	91	40	39	1.47
1.25	0	4.2	70	29	29	0.00
0.630	0	0.9	45	18	21	8.41
0.315	0	0.2	26	10	15	
0.160	0	0	14	5.7	11	
0.080	0	0	7.4	2.9	8.3	
Pan	0	0	0	0	0	
			SSE = sum of square of errors			17



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Q.5 Procedure B for high flowability concretes — Determination of mass proportions of three types of aggregate and powder to optimize combined particle gradation in accordance with the Fuller power-fit

The objective of Procedure B is to determine the mass proportions of the aggregates as well as that of the powder (which is assumed to be a very fine aggregate for the analysis) that result in a combined-aggregate gradation where the fit to the Fuller power equation is optimized. Procedure B is for high-slump or self-consolidating concretes (SCCs) where the mass of powder plays a key role in determining the density and the flowability of the concrete (for additional notes pertaining to the procedure, see Procedure A). The following steps shall be performed:

a) Perform a full sieve analysis of each of the three aggregate bins to determine the % passing (PP) for each standard sieve size, tested in accordance with CSA A23.2-2A. Estimate the average relative density (RD) of each aggregate type (bin) and that of the powder*.

   * *The effect on analysis of variations in RD of aggregates is found to be significant only if the range of RDs is greater than approximately 0.2. Normally, the RD of the powder will be significantly different than the aggregates and should be taken into account.*

b) Decide the appropriate power parameter, n, to use in the analysis. For SCCs, values of n near 0.40 seem to give better results than for n = 0.45.

c) Make an initial guess at the likely optimum mass proportion required for each bin (M_1, M_2, M_3, and M_4 (powder)), based upon experience. Failing any previous experience, use 1/4 (0.250) as the initial guess for each mass proportion.

d) Calculate the volume proportions V_x (x = 1,2,3,4) for each bin from the estimated mass and the relative densities. For example $V_1 = (M_1/RD_1)/(M_1/RD_1 + M_2/RD_2 + M_3/RD_3 + M_4/RD_4)$.

e) Using the calculated values of V_x, calculate the combined aggregate gradation, as % passing, for all sieve sizes:

   For each sieve size, $P = PP_1*V_1 + PP_2*V_2 + PP_3*V_3 + PP_4*V_4$

   where

   P = the % passing of the combined aggregate for the given sieve size and

   PP_1, PP_2, PP_3, PP_4 = the % passing for each of the three aggregates and the powder for this sieve size.

f) Using the defined values of D and n, for each sieve size calculate the volume % passing as determined by the Fuller model:

   $P_f = (d/D)^n$

   where

   d = the diameter of the sieve in question (see Clause 7 for a discussion of the correct choice of D for modeling purposes).

g) For each relevant sieve size calculate the square of the error = $(P - P_f)^2$.

h) Calculate the sum of the squares of the errors, SSE, for all relevant sieve sizes greater than or equal to 0.160 mm*.

   * *Inclusion of the 0.160 and 0.315 mm sieve sizes in the least squares analysis reflects the importance of the fine particle fraction in determining optimum packing and flowability of these concretes.*

i) Use manual trial and error techniques, or spreadsheet optimization tools (e.g., Microsoft Excel® Solver tool) to determine the values of M_1, M_2, M_3, M_4 that minimize SSE.

Q.6 Example analysis, procedure B (Figures Q.3 and Q.4)

The mass-proportions of three supplied aggregates and powder shall be determined to optimize the combined gradation in accordance with the Fuller power fit, for an SCC concrete (n = 0.40). An example

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spreadsheet, showing the aggregate gradations and relative densities for coarse (Bin 1), intermediate (Bin 2), Fine (Bin 3) and powder (Bin M4_Powder) is given in Figure Q.3.

The following solution steps shall be conducted:

a) A blank table (manual or spreadsheet) is created with the configuration as shown above. In comparison to Procedure A, an extra column for "Powder" has been added where the % passing for all sieve sizes is 100%.

b) The aggregate test data are entered in the shaded (yellow) cells at the top of the table and in columns (2) to (4). D is the maximum size of the aggregate for the coarsest aggregate (Bin 1) – see Section 7.0 for discussion.

c) Initial guesses for M1, M2, M3, and M4_Powder are entered in the mass proportions cells, such that M1+M2+M3+M4_Powder = 1.0. Without additional information, the guesses used here are 0.25 for each.

d) The volume proportions V1, V2, V3, V4 are calculated from the mass proportions and relative densities (see the example equation in Item d) of Clause Q.5 of the Procedure).

e) In column (6) the combined % passing for each sieve size is calculated for each sieve size* (see the example equation in Item e) of Clause Q.5 of the Procedure).

   * *In the spreadsheet shown, the 0.080 mm sieve data are also given but are not used in the least-squares analysis.*

f) In column (7) the Fuller Fit is calculated for each sieve size using the equation given in Item f) of Clause Q.5 of the procedure.

g) In column (8) the square of the error [column (6) – column (7)]^2 is calculated for each sieve size for sieve sizes greater than or equal to 0.160 mm.

h) The sum of square of errors (SSE) is calculated as the summation of column (8) [See bottom of column (8)].

i) The values of M1, M2, and M3 and M4_Powder are incrementally adjusted with the aim that each adjustment reduces SSE. The solution is achieved when further small incremental changes of the four parameters do not appreciably change SSE. This procedure is greatly assisted by creating a scattergram (shown below the table) that plots combined percent passing and Fuller-Fit *vs.* log (sieve size) so that the effect of changes in M_x can be immediately observed. The optimized solution is shown in Figure Q.4.

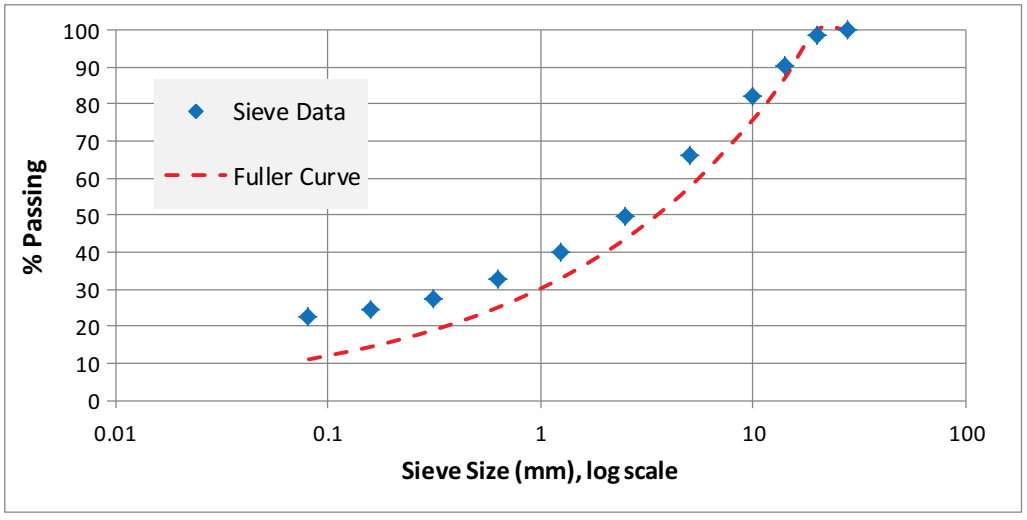
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Figure Q.3
Spreadsheet configuration, Procedure B
(See Clause Q.6.)

Shaded cells denote data input			Mass proportions		Relative densities		Volume proportions
D	20	M1	0.250	RD1	2.65	V1	0.25
Power	0.40	M2	0.250	RD2	2.30	V2	0.29
		M3	0.250	RD3	2.55	V3	0.26
		M4_Powder	0.250	RD4	3.15	V4	0.21
		Total	1.000			Total	1.00

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	% Passing (PP)						
Sieve size Mm	Bin 1	Bin 2	Bin 3	Powder	Combined % passing	Fuller fit	$[(5)-(6)]^2$
112							
80							
56							
40							
28	100	100	100	100	100	100	0
20	95	100	100	100	99	100	2
14	62	100	100	100	90	87	14
10	28	100	100	100	82	76	38
5.00	3.5	67	99	100	66	57	78
2.50	0.4	20	91	100	50	44	41
1.25	0	4.2	70	100	40	33	49
0.630	0	0.9	45	100	33	25	59
0.315	0	0.2	26	100	28	19	74
0.160	0	0	14	100	25	14.5	101
0.080	0	0	7.4	100	23	11.0	
Pan	0	0	0	0	0		
				SSE = sum of square of errors			456



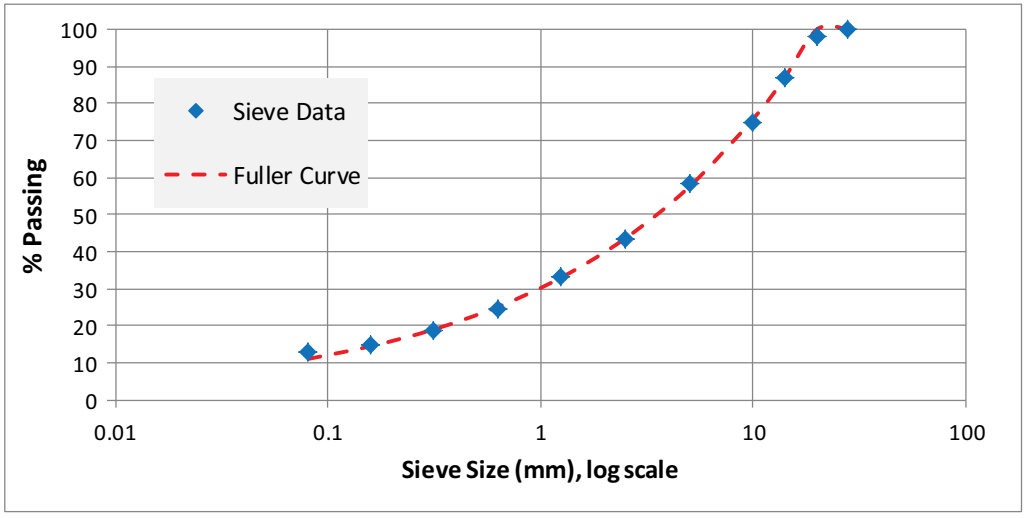
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Figure Q.4
Example solution, Procedure B — Optimized values of M1, M2, M3, and M4 powder for minimum SSE

(See Clause Q.6.)

Shaded cells denote data input		Mass proportions	Relative densities	Volume proportions
D	20	M1 0.352	RD1 2.65	V1 0.34
Power	0.40	M2 0.216	RD2 2.30	V2 0.24
		M3 0.302	RD3 2.55	V3 0.31
		M4_Powder 0.130	RD4 3.15	V4 0.11
		Total 1.000		Total 1.00

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	% Passing (PP)						
Sieve size Mm	Bin 1	Bin 2	Bin 3	Powder	Combined % passing	Fuller fit	$[(5)-(6)]^2$
112							
80							
56							
40							
28	100	100	100	100	100	100	
20	95	100	100	100	98	100	2.95
14	62	100	100	100	87	87	0.009
10	28	100	100	100	75	76	0.498
5.00	3.5	67	99	100	58	57	0.911
2.50	0.4	20	91	100	43	44	0.049
1.25	0.0	4.2	70	100	33	33	0.001
0.630	0.0	0.9	45	100	25	25	0.130
0.315	0.0	0.2	26	100	19	19	0.111
0.160	0.0	0.0	14	100	15	14	0.270
0.080	0.0	0.0	7.4	100	12.9	11	
Pan	0.0	0.0	0.0	0.0	0.0		
					SSE = sum of square of errors		4.9



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Q.7 Discussion of optimum choice for D

The usefulness Procedures A and B to produce an optimum combined gradation is strongly dependent on the user's choice of D in the Fuller equation. There is some uncertainty about whether D should be chosen as

a) the "maximum aggregate size" – the smallest standard sieve size where 100% aggregate passes; or
b) the "nominal maximum aggregate size" – the smallest standard sieve size at which less than 100% of the aggregate passes* some value in between.

* *This choice of D has been used in the examples of this Annex.*

Practitioners should experiment to determine which definition of D best fits their operations and gives the best practical results. As a guideline, if more than 15% of the combined aggregate is retained on the "nominal maximum aggregate" sieve, then the procedure produces better results if D corresponds to the maximum combined-aggregate sieve size; otherwise, the user should choose D equal to the nominal maximum combined-aggregate sieve size. If the user has a spreadsheet application readily available, more accurate results can be obtained by calculating D as a non-standard value obtained by the extrapolation of sieve data from smaller sizes back to the intercept at 100% passing.

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Annex R (informative)
Residential concrete construction

Note: *This Annex is not a mandatory part of this Standard.*

R.1 General

This Annex is intended to provide additional information regarding the use of concrete for housing and small buildings. This Annex was developed to address changes in Tables 1 and 2 as they pertain to residential construction as well as to offset the discontinuation of CAN/CSA-A438.

It is acknowledged that quality control and enforcement measures, including but not necessarily limited to concrete testing, and site review by suitably experienced personnel will help to ensure that concreting practices in residential construction will produce the serviceability requirements.

Mandatory requirements for concrete construction for residential structures are provided in the body of this Standard. The concrete mix selection and performance requirements now match those of other buildings, and are determined based on exposure conditions.

These changes have been adopted voluntarily in whole or in part in various regions of the country by the ready mixed concrete and home construction industries prior to the changes to this Standard to address commonly occurring problems. The changes to this Standard formalize what is accepted in the industry as good practice.

Incorporation of the R-classes into Table 2 reflects a consensus reached by the Technical Committee.

Technical consideration has been given to
a) the industry being serviced by R class concrete; and
b) the responsibility of the committee to provide guidance to building codes and specifiers regarding the correct product for their application.

The resulting discussion concluded there was no technical support to justify a reduction in the minimum requirements for R-1 and R-2 class compared to those required for F-2 exposure class currently in place and provided for in this Standard. Moving from one segment of the construction industry (commercial-industrial) to the residential segment does not offer technical reasons to reduce the minimums in place for the specified exposure conditions.

Concrete for R-1 and R-2 is now required to meet the same criteria as F-2 class concrete – designed to have a 28 d strength of 25 MPa and a maximum water-to-cementitious materials (w/cm) ratio of 0.55, as required by Table 2. Exposure class R-3, for interior slabs not exposed to freeze-thaw, must meet the criteria for strength and w/cm outlined in Table 2. Concrete used in residential construction which does not fall within one of R classes will have to meet the applicable strength for the relevant exposure condition

This Annex describes the major forces that shaped the inclusion of R-class concretes into this Standard and the changes, described above, that were made.

R.2 Objectives

In this edition of CSA A23.1, the Technical Committee resolved to address the technical discrepancies between the concrete traditionally specified in the residential market (concrete included in Part 9 of the *National Building Code of Canada* (NBCC)) and the minimum requirements for concrete with the same

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service and durability requirements falling under the umbrella of this Standard. Construction techniques that are addressed by other industry standards and building codes applicable in jurisdictions in Canada are not repeated within this document.

A wealth of technological, scientific, and experiential information shows clearly that concrete with a water-to-cementitious materials (w/cm) ratio as high as 0.70, when exposed to aggressive climate, groundwater and soils, has significantly reduced service life when compared to lower w/cm concretes. Concrete quality and durability issues that are related to performance failures (e.g., accelerated freeze-thaw deterioration, increased shrinkage-cracking, accelerated wear, increased dusting, excessive salt scaling, accelerated sulphate attack, and the larger potential for health-related risks due to excessive evaporative water that can initiate the growth of mould in basements) are expected to show improvement through the implementation of this Standard. The issues of potential for abuse in installation of the product is dealt with by defining lower w/cm ratios such that, if the concrete is abused the consequences of the abuse will be substantially less than concrete at higher w/cm.

R.3 Context for inclusion in this Standard

R.3.1 Scope and defining minimums

Standards are only binding when referenced by mandatory regulations. The *NBCC* forms the basis for all building codes in Canada. The *NBCC* aims to provide requirements that define minimum acceptable performance, primarily for health and safety. For the *NBCC* to accept a standard as a referenced document, the standard must also specify accepted minimums for the purpose of limiting health and safety hazards.

For reasons related to safety in use, Part 9 of *NBCC* requires that floors be smooth, even, and free from roughness or open defects. This Standard, therefore, includes requirements that address excessive rates of deterioration under normal use.

Part 9 of the *NBCC* is understood, and to a large degree expected, to go somewhat beyond health and safety concerns and to address social expectations. Material that suffers from excessive shrinkage-cracking is undesirable, even if the cracking has only aesthetic consequences. Shrinkage-cracking is also linked to water or soil gas ingress through foundation walls, which can pose health and safety problems. As airborne particulates can also adversely affect health, dusting of concrete floors is a potential health issue. The Standard addresses these issues by defining material quality.

The Technical Committee included specifying, user, producer, code writing, home warranty, and consumer representatives, to bring all viewpoints to the consensus process, so that appropriate minimum levels of performance could be determined.

R.3.2 Cost of compliance versus flexibility

Specifying requirements for concrete in clear prescriptive terms simplifies compliance. Such requirements direct all producers to provide the same product or range of products to the market. For example, requiring the addition of superplasticizers in all cases would address a number of performance requirements. Compliance and determination of compliance would be straightforward. The approach, however, is inconsistent with the aim of specifying minimums, in that superplasticizers are not needed in all cases: for example, where there is adequate access to the forms, or where the product is placed with pumps or with cranes and buckets.

Specifying concrete properties in performance terms provides more flexibility in devising appropriate, cost-effective solutions and is more likely to achieve the aim of specifying acceptable minimums.

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R.3.3 Affordability — Material and installed costs

For the end-user, the cost of the product is a critical issue.

The cost for repair of cracks and leaks through walls and of deterioration of concrete floors and walls constructed of inadequate or noncompliant concrete was contemplated by the Technical Committee and was considered to be a cost to the end-user that would be reduced if proper concrete mixes and concrete practices were used.

R.3.4 Compliance and enforcement

Possibly the most significant cause of problems that arise in residential concrete construction is noncompliance with this Standard. Specification of a material that is inappropriate for placement from a single location and the subsequent addition of water, for example, has serious implications for the performance of the material. The Technical Committee recognizes that revisions to a building code or standard will not address this issue. Builders, forming contractors, and concrete suppliers must establish a baseline for acceptable practice that is consistent with the requirements of this Standard. This Standard has been developed to facilitate adoption by regulatory authorities to be incorporated in local regulations. Without this willingness and participation by the industry as a whole, the performance level of residential concrete in practice will not increase.

R.4 Responsibilities

The responsibility for following the requirements of this Standard are specified in Clause 4.4.1.

R.5 Dimensions of footings, foundation walls, and slabs

The dimensions of concrete foundation walls, footings, and slabs should be determined in accordance with the applicable building code and geotechnical considerations.

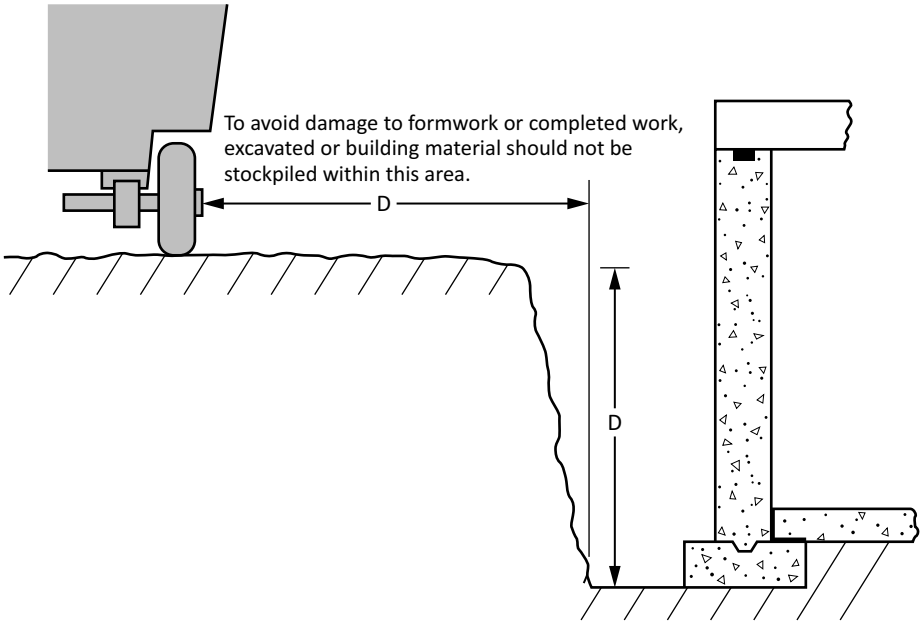
R.6 Distance from excavation

To avoid possible damage to formwork, no excavated material should be stockpiled within a distance from the toe of the slope equal to the depth of the excavation (see Figure R.1).

Note: *The authority having jurisdiction might impose additional requirements.*

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Figure R.1
Minimum distance from excavation
(See Clause R.6.)



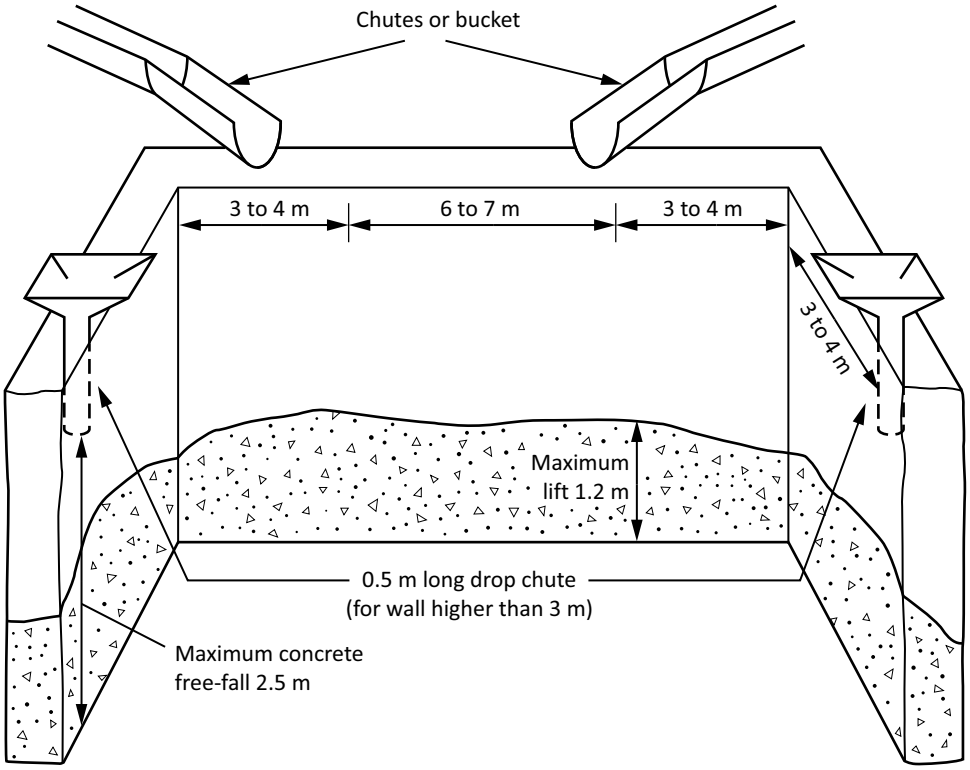
R.7 Access and deposition

Concrete for walls should be deposited continuously in approximately equal horizontal lifts not exceeding 1.2 m high. Where only delivery chutes are used to transport the concrete, sufficient access should be provided to several locations to prevent segregation. If sufficient access points cannot be provided, the concrete should be transported by pumps, buggies, wheelbarrows, crane and buckets, or other methods that will not cause segregation. The spacing of the access points should be a maximum of 4 m from corners and a maximum of 7 m along the walls, as illustrated in Figure R.2. For high-drop applications, such as walls or columns in excess of 3 m high, concrete should be placed using suitable vertical pipes or drop chutes to limit the concrete free-fall height to 2.5 m.

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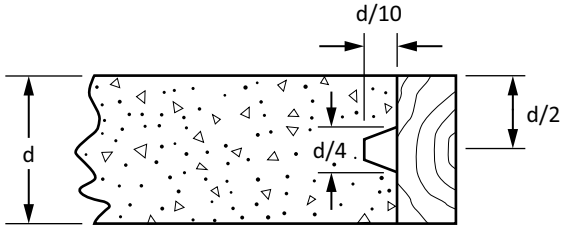
Figure R.2
Access and deposition
(See Clause R.7.)



R.8 Cold joints

When depositing of the concrete is interrupted for a period of time that will allow the concrete to achieve initial set, thus forming a cold joint, the concrete in place in flatwork should be struck off and levelled, and a construction joint should be made. Cold joints in walls should not be used unless the joint is reinforced to provide the full cracking strength of the wall and measures are taken to prevent water penetration through the cold joint. For flatwork, the construction joint should be straight, vertical, and of full depth with a keyway, as shown in Figure R.3.

Figure R.3
Construction (cold) joints
(See Clause R.8.)



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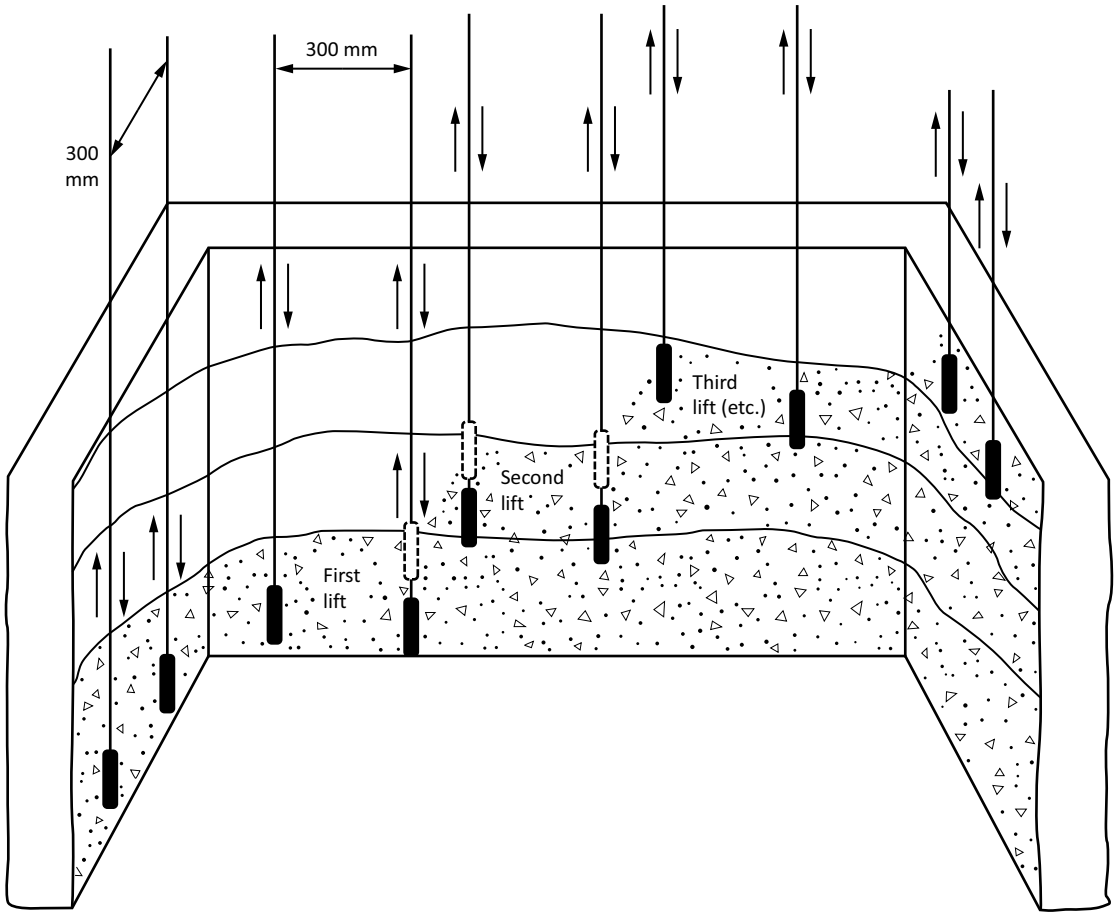
R.9 Consolidation

Mechanical vibrators should be used if the concrete cannot be consolidated using hand methods. Mechanical vibrators should penetrate the concrete in a vertical direction under their own weight without being forced into the concrete. The time for insertion should be from 5 to 10 s until a smooth mortar surface appears around the vibrator head or cable. Each lift of concrete should be consolidated by the use of a mechanical vibrator or a handheld puddling stick inserted at regularly spaced intervals using an up and down motion. The complete lift should be consolidated before the next lift is deposited. When consolidating subsequent lifts, the vibrator or puddling stick should completely penetrate the lift and extend into the upper portion of the previously placed lift to ensure mixing of the concrete at the interface between lifts.

Notes:

1) *The vibrator or puddling stick should be inserted at intervals of not more than 300 mm, as illustrated in Figure R.4.*
2) *Concrete in thin section flatwork is usually consolidated by the action of the finishing tools, such as a strike-off board, float, or trowel.*

Figure R.4
Consolidation of concrete
(See Clause R.9.)



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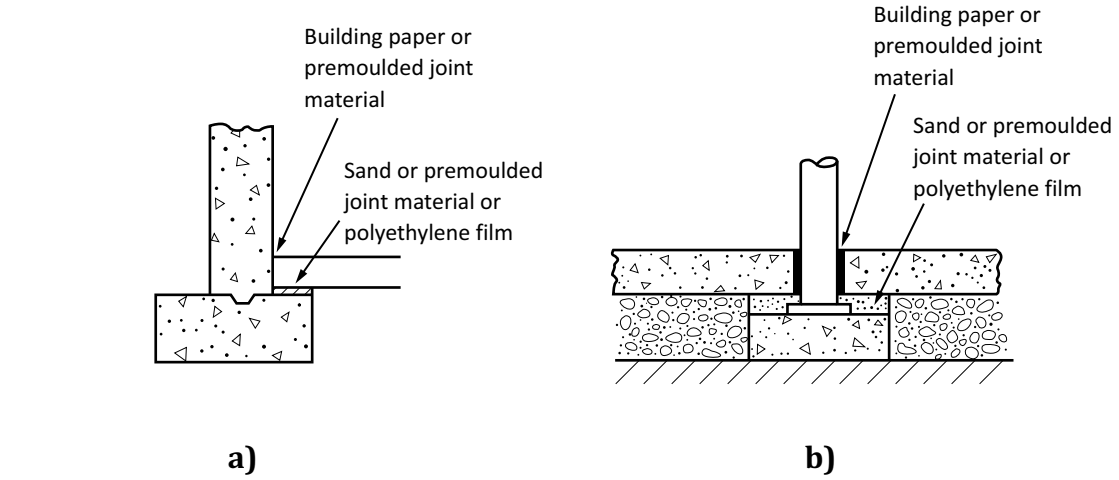
R.10 Joints in flatwork

Slabs on ground should not bear directly on wall or column footings, but should be isolated from these supports by a minimum 25 mm thick sand cushion, a premoulded joint filler, polyethylene or two layers of building paper (see Figures R.5 a) and b)). In order to allow for slight movement of the concrete flatwork due to drying shrinkage of the slab, a layer of pre-moulded joint filler or a double layer of building paper should be used to isolate the slab from the vertical faces of walls, columns, or other structures within the slab. As random cracking of flatwork is generally objectionable, such cracking may be controlled by the use of contraction joints to subdivide the flatwork into square sections [see Figure R.5 c)]. For walkways the joint spacing should be 1.2 to 1.5 m; for patios and driveways 3.5 to 4.5 m; and for floor slabs refer to Clause 7.3.2. It is essential that the depth of such joints be a minimum of 1/4 the depth of the slab. Joints should be formed by cutting grooves in the freshly placed concrete with a jointing tool or by cutting joints with a saw within 4 to 18 h or as soon as the concrete is sufficiently firm to resist ravelling. They may also be formed with strips of plastic or other suitable material, provided there is sufficient depth to the joint material.

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Figure R.5
Joints in flatwork
(See Clause R.10.)



R.11 Contraction joints in walls

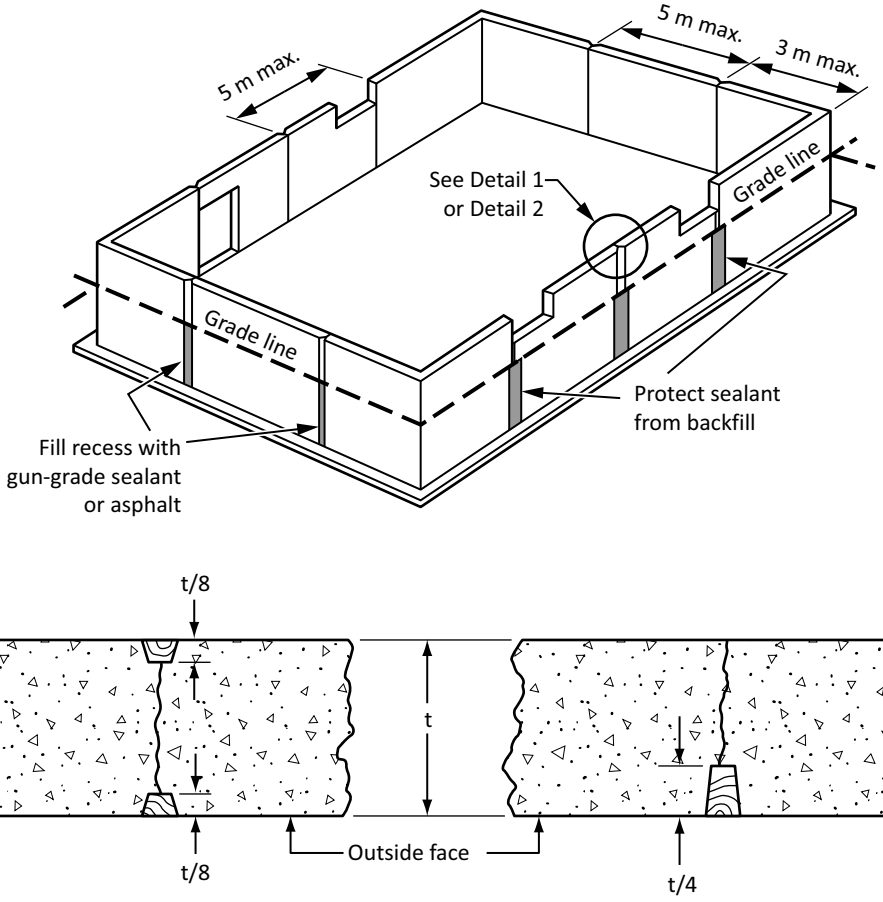
All cast-in-place concrete walls crack as a result of normal drying shrinkage. Uncontrolled shrinkage cracks provide an easy route for water to penetrate. A practical method of controlling the water through the wall is to construct vertical contraction joints at window or door openings and other locations, as shown in Figure R.6. Vertical contraction joints should have a total depth equal to 1/4 the wall thickness, and should be made at the same location on both the inside and outside wall faces or on just the outside face. The joints on the exterior wall face should be filled with a gun-grade sealant compatible with installed damp-proofing or waterproofing and with insulation. The sealant should be protected from damage from backfilling. Where exposed, it should not be susceptible to ultraviolet degradation.

Contraction joints, as shown in Figure R.6, should be used to control unsightly shrinkage cracks, which can permit water penetration in walls.

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Figure R.6
Suggested location of vertical contraction joints
(See Clause R.11.)



Detail 1

Wood strips removed and cavity filled with gun-grade sealant compound

Detail 2

Fill with gun-grade sealant compound

Vertical contraction joint detail for foundation walls

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Annex S (informative)
Concrete made with carbon dioxide as an additive

Note: *This Annex is not a mandatory part of this Standard.*

S.1 Introduction

This Annex provides information about the use of limited amounts of carbon dioxide as an additive during concrete production. This innovative process is being used by a growing number of concrete producers both in Canada and the US to reduce the carbon footprint of cement and concrete. This process provides the industry with a means to help meet emission reduction targets and in so doing provides additional benefits for concrete construction. This Annex provides the industry with guidance on the appropriate use of this technology.

S.2 Background

A limited dose of carbon dioxide can be optimised for a particular mixture for addition to concrete during batching and mixing to achieve performance benefits in ready-mixed concrete (Monkman and MacDonald, 2017). Carbon dioxide forms nanoscale calcium carbonate reaction products that act as heterogeneous nucleation sites for subsequent hydration product development.

Note: *The hydration products, pore solution pH, and passivity of embedded steel reinforcement are generally unaffected (Monkman et al., 2015). The amount of carbon dioxide, timing of reaction, and reacting phases ensure that the small addition of carbon dioxide does not result in carbonation of the hardened concrete.*

S.3 Implementation

S.3.1 Adding carbon dioxide

Carbon dioxide can be injected at various points during the concrete production cycle:

a) in a wet batch system, carbon dioxide can be injected into a central batch mixer; or
b) in a dry batch system, carbon dioxide can be batched into a truck mixer alongside the other mix components. Mobile carbon dioxide injection can take place on a truck or at a job site prior to placement.

Carbon dioxide is provided in either a gaseous or liquid form. In the latter case, liquid carbon dioxide is unstable at atmospheric conditions; upon discharge from the injection hardware, carbon dioxide converts to a mixture of solid flakes (snow) and gas.

The performance-enhancing properties of the carbon dioxide addition are associated with the use of an optimal dose. This dose is determined through preliminary testing and, akin to conventional concrete admixtures, varies depending on the cementitious binder. An optimal dose is typically lower than 0.5% CO_2 by mass of cement.

Proper batching procedures are important when utilizing carbon dioxide as an additive in concrete in order to achieve the expected performance benefit in the concrete mix.

When implementing this technology, the assistance of personnel experienced in this process should be sought to ensure the successful application of carbon additions to concrete.

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S.3.2 Effects on fresh concrete properties

An optimal dose of carbon dioxide has little impact on concrete workability (slump) or on fresh air content. In certain cases the slump and setting time might be reduced, in which case corrective measures can be taken to achieve the desired characteristics of the plastic concrete (Monkman et al., 2016a).

S.3.3 Effects on compressive strength

In some cases, an optimal dose of carbon dioxide has been observed to improve both early (1, 3, and 7 day) and late (28 and 56 day) compressive strength.

S.3.4 Effects on durability

The reaction of carbon dioxide with hardened concrete is conventionally acknowledged to be a durability issue due to effects such as shrinkage, reduced pore solution pH, and carbonation induced corrosion. In contrast, adding a limited amount of carbon dioxide shortly after first interaction of cement and water during concrete production only reacts carbon dioxide with initially formed calcium hydroxide to form a number of nano-calcium carbonate crystals that act to accelerate subsequent normal cement hydration. The hydration phases present in mature concrete are not affected, and consequently, there is no negative impact on durability (Monkman *et al.*, 2016b).

Durability studies have confirmed that an optimal carbon dioxide addition has a neutral effect on measured durability properties, including rapid chloride ion penetrability (ASTM C1202, CSA A23.2-23C), rapid chloride migration (Nordtest NT Build 492), bulk resistivity, deicing salt scaling resistance (MTO LS-412, CSA A23.2-22C), freeze-thaw durability (ASTM C666), linear shrinkage (MTO LS-435, CSA A23.2-21C), and hardened air void characteristics (ASTM C457). The limited and early carbon dioxide addition does not result in carbonation of the hardened concrete, nor does it change the pore solution pH and therefore does not result in depassivation of steel reinforcement (Monkman *et al.*, 2015).

S.3.5 Mix optimization

Some producers who have realized a strength benefit from carbon dioxide addition have responded by optimizing their mix designs, for example by reducing the cement content (3 to 7%) and increasing the proportion of fine aggregate, thereby reducing carbon dioxide emissions (Monkman and MacDonald, 2017).

S.3.6 Health and safety

Carbon dioxide that is added to the concrete but not absorbed immediately is likely to stay with the concrete in the mixing drum since the gas is heavier than air. Due to its density, unreacted carbon dioxide will generally sit in the mixer until it reacts with the concrete. Also, since the gas is metered and only a limited amount is added, the impact of any injected portion that might spill from the mixing drum can be monitored by carbon dioxide safety alarms in the case the injection is conducted in an enclosed space.

Being in an enclosed space with elevated carbon dioxide is hazardous. There is a risk with carbon dioxide exposure with this technology, but the dose of carbon dioxide being used is small and most of it is absorbed into the concrete. Personnel should be properly trained in accordance with the manufacturer's instructions.

There is also the potential for cold injury when dealing with carbon dioxide in its liquid or solid form. Hand protection in the form of insulated cryogenic gloves should be worn when dealing with cold

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carbon dioxide hoses and piping. Alternatively, all liquid carbon dioxide lines may be insulated to reduce the risk.

S.4 References

CSA Group

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Test Method for length change of hardened concrete

A23.2-22C:19
Scaling resistance of concrete surfaces exposed to deicing chemicals using mass loss

A23.2-23C:19
Electrical indication of concrete's ability to resist chloride ion penetration

ASTM International

C457-16
Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C1202-19
Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

C666/C666M-15
Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

MTO (Ontario Ministry of Transportation)

LS-412
Method of Test for Scaling Resistance of Concrete Exposed to Deicing Chemicals

LS-435
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Annex T (informative)
Mass concrete

Note: *This Annex is not a mandatory part of this Standard.*

T.1 Introduction

This Annex provides guidance about mass concrete. The information provided herein is relevant to the assessment of material properties and their effect on the temperature rise and resistance to thermal cracking, measures to control and monitor temperature, temperature limits for maximum concrete temperature and maximum temperature difference for concrete in mass placements, and best practices to protect and cure mass concrete.

T.2 Mass concrete

Mass concrete can be any body of concrete for which consideration is given to temperature rise caused by the hydration of the cementitious materials. Mass concrete can also require taking measure to cope with attendant volume change to minimize cracking (ACI 207.1R). Other considerations that play a role in defining placements as mass concrete are the concrete mixture proportions and properties, ambient temperature and exposure, placement conditions, configuration and restraints, temperature limits specified, cracking criteria, serviceability, and long term durability requirements, among others. ACI Concrete Terminology Standard (CT-18) defines mass concrete as “any volume of structural concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration”. For practical purposes, mass concrete placements are commonly identified as placements where the minimum dimension is large, such as 1 m thick or greater.

Concrete temperature and volume changes associated to the thermal behaviour of mass concrete need to be controlled to mitigate potential thermal and volume changes that, if not accommodated, can lead to detrimental issues. Some of the main components and variables that affect the concrete temperature rise and temperature differentials that can lead to early age thermal cracking in mass placements are (BA 24/87):

a) placement dimensions;
b) cementitious materials;
c) concrete mixture proportions;
d) formwork and insulation;
e) restraining conditions; and
f) ambient and concrete placing temperature.

In practical terms, concrete with larger dimensions will exhibit greater thermal risk, higher temperature rise, and higher concrete temperatures. Mitigation of thermal cracking is typically achieved by reducing the concrete temperature rise, reducing thermal movements, and reducing temperature differentials.

Mass concrete placements are expected to be performed following the preparation of a thermal control plan to limit the concrete temperature rise, reduce maximum concrete temperature, and mitigate concrete temperature differentials. A thermal control plan should include recommended practices to control and monitor concrete temperatures.

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T.3 Temperature rise

T.3.1 Adiabatic temperature rise

The interior core of a concrete mass placement can experience a large temperature rise. Mass concrete placements are typically under semi-adiabatic conditions because some of the internal heat is dissipated to the exterior of the concrete; however, some large placements can reach high temperatures near adiabatic conditions. Under semi-adiabatic conditions, a great portion of the heat generated by the concrete is trapped, but heat losses to the exterior of the concrete occur. Under adiabatic conditions, there are no heat gains or losses to the exterior of the concrete, in which case the heat generated by the concrete is fully trapped.

The temperature rise of concrete in adiabatic conditions is mainly dictated by type and quantity of cementitious material in the concrete. Under field conditions, the temperature rise of concrete in mass placements is mainly influenced by the dimensions of the placement, fresh concrete temperature at time of discharge, and the exposure conditions surrounding the concrete during the curing and protection phase. Temperature rise of concrete can be reduced by lowering the total amount of cementitious materials and by replacing a portion of the cement with low heat cements and/or supplementary cementitious materials such as fly ash and slag. Field ambient conditions, dimensions and geometry of the mass placement, as well as the fresh concrete placing temperature can also affect temperature rise of concrete. For example, a higher concrete temperature rise would be expected at a higher placing concrete temperature, and vice versa. Active cooling of concrete with embedded pipes reduces temperature rise and differentials in the mass placement by allowing active removal of heat from the interior of the concrete.

Knowing the adiabatic temperature rise of the concrete is necessary to properly assess the potential behaviour of the concrete in a mass placement to be considered when developing a thermal control plan. This is also important when evaluating different concrete mixes or alternatives to optimize a concrete mix for mass placements. Lowering temperature rise of concrete provides benefits in reducing the cooling efforts required to meet temperature limits plus lowering the risk for thermal cracking. Lowering the temperature rise of the concrete usually reduces the peak and differential temperatures and results in implementation of thermal control measures that are less costly and have a shorter duration in comparison to scenarios with a higher temperature rise. A high temperature rise in concrete can require increasing cooling efforts as well as presenting a higher risk for thermal cracking.

T.3.2 Assessing adiabatic temperature rise

T.3.2.1 Tests and analytical methods

The adiabatic temperature rise of concrete can be determined by using tests and analytical methods. The objective is to determine an adiabatic temperature rise to provide a template for estimating temperature rise and assessing the potential of the concrete to generate heat in mass placements, which will be used for thermal control planning. The thermal control plan should contain the necessary information to describe the method used to estimate temperature rise of the concrete for mass placements, monitor field temperatures, and validate the estimated temperatures with field data. Concrete producers may decide to identify a method to calculate adiabatic temperature rise that would not require revealing proprietary mix design information. The following are some of the tests and analytical methods that may be used to assess adiabatic temperature rise:

a) adiabatic testing;
b) semi-adiabatic testing;
c) simplified equation;

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d) field placements;
e) computer modeling; and
f) theoretical methods.

The results on adiabatic temperature rise from using the tests and analytical methods described above are intended to provide initial information to be used for the development of thermal control plan. Because these methods are mostly approximations, a verification of the adiabatic temperature rise can be achieved by revising the thermal analysis once the field thermal data is available. The actual temperature rise of the concrete in each mass placement will be determined with field monitoring thermal data.

T.3.2.2 Adiabatic testing

A heavily insulated box or vessel is filled with concrete and sealed to be evaluated under adiabatic conditions in the lab (no heat losses allowed). A test procedure for this laboratory adiabatic test method is US Army Corps of Engineers CRD-C 38. The use of this test procedure in the industry is limited to only some special large projects with massive placements. This test is only performed by a few certified testing labs in North America. The test takes more than 28 days, in average 40 to 50 days, and can be extended for 90 days or longer depending on the mixture proportions. The result of this test is the adiabatic temperature rise of the concrete.

T.3.2.3 Semi-adiabatic testing

A heavily insulated box or vessel is filled with concrete and sealed to be evaluated under semi-adiabatic conditions in the lab or field (minor heat losses are allowed). This test can be performed using a lab or field fabricated insulated test block, a commercially available semi-adiabatic test chamber, or a combination thereof. This non-standardized test procedure is most commonly performed by testing agencies in the lab or contractors in the field, and it only takes 7 to 14 days to get results. The results obtained from this test show a semi-adiabatic temperature rise of the concrete, which then is analyzed with the thermal model in consideration to the conditions surrounding the test block to approximate the adiabatic temperature rise of the concrete.

The test procedure commonly used for semi-adiabatic temperature rise testing typically consists of a large, heavily insulated box (Bamforth and Price, 1995). Different size of box or insulation may be used. A test block is built for each concrete mix to be evaluated in the thermal control plan. After placing the concrete in the test block, temperatures will be recorded for 7 to 14 days to get thermal data for analysis and modeling purpose to determine the adiabatic temperature rise.

For this example, the test consists of 1 m × 1 m × 1 m (e.g., 1 m^3 of concrete) block that is insulated on all six sides with 150 mm of extruded polystyrene board insulation to provide an equivalent to R-30 insulation on each side. To build the test block, a box is formed with dimensions that can accommodate the concrete, insulation, and forms. All six sides (four sides, one top, and one bottom) are insulated with 150 mm thick (e.g., three 50 mm thick layers) of extruded polystyrene board insulation on the inside of the formwork to make a 1 m × 1 m × 1 m space for a concrete cube. Expanding, liquid foam sealant is used at the corners, gaps, or any joints in the inside of the insulated box to seal the board insulation from potential for air leakage. Steel ties or holes to penetrate through the box are not used because that can invalidate the results.

For each test block, temperature sensors are installed at five locations (four inside the block within the concrete plus 1 outside the block for ambient), as follows:
a) at the center of the bottom surface (taped to the board insulation);
b) at the center of the block (attach to a fix support);

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c) at the center of a side surface (taped to the board insulation);
d) at the center of the top surface of the concrete (under the insulation); and
e) outside of the formwork, off the ground to record ambient temperature.

For quality control purpose, the concrete batch records and fresh concrete properties should be documented. Photographs and measurements of the test blocks on the outside and on the inside should be taken. To ensure appropriate consistency and representative mixture proportions of the mix, a truck load of 2 to 3 m^3 of fresh concrete is the minimum volume requested for a 1 m^3 test block. The insulated cube is covered with plastic sheeting to keep it out of the rain, snow, and wind. Concrete temperature should be recorded on an hourly basis. The total time of temperature logging for the test blocks should be between 7 to 14 days. Once the concrete temperature data is completed, these results are analyzed with the thermal model to determine the adiabatic temperature rise of the concrete for thermal control planning (Bamforth, 2007).

T.3.2.4 Simplified equation

This method consists of using a non-complex mathematical expression; no test is performed. The simplified equation provides an estimate of the adiabatic temperature rise of the concrete based on the type and quantity of each cementitious material (Gajda, 2007; Gajda *et al.*, 2014). This method is most commonly used in the industry to get a quick, rough estimate of the adiabatic temperature rise of the concrete when no other data is available.

When no thermal data from testing of the concrete is available, the adiabatic temperature rise of concrete can be roughly estimated using a simplified equation adapted for cementitious materials. No proprietary mix design information such as materials proportions is required to be reported by the concrete producer. Only the adiabatic temperature rise value and reference to the equation form used for the calculation is reported in the mix design submittal. An example of a simplified equation is shown below in Equation 1 (adapted from Gajda, 2007; Gajda *et al.*, 2014).

$$\text{Rise} = 0.15 * (A*\text{Cem} + 0.5*\text{FAsh} + 0.7*\text{CIAsh} + 0.8*\text{CHAsh} + 1.2*\text{SFMK} + B*\text{Slag}), °C \quad \textbf{Equation 1}$$

where

Cem = GU or MH Portland cement, kg/m^3

A = factor depending on the type of cement:
- = 1.4: HE cement
- = 1.0: GU cement
- = 0.9: MS and MH cement
- = 0.8: LH and HS cement

FAsh = Class F fly ash, kg/m^3

CIAsh = Class CI fly ash, kg/m^3

CHAsh = Class CH fly ash, kg/m^3

SFMK = silica fume or metakaolin, kg/m^3

Slag = slag cement, kg/m^3

B = factor depending on the percentage of cement replaced with slag:
- = 1.1: for 0 to 20% cement replacement
- = 1.0: for 20 to 45% cement replacement
- = 0.9: for 45 to 65% cement replacement
- = 0.8: for 65 to 80% cement replacement

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The documentation of the calculated temperature rise in the mix design submittal as estimated by the concrete producer from using the simplified equation allows for proper consideration of the concrete temperature rise when selecting a concrete mix for mass placements. When more precise values are required, further testing or analysis should be performed.

T.3.2.5 Field placements

An early field mass placement, such as a crane footing placement or a mock-up placement, can used with the proposed concrete mix, instrumented with thermal monitoring devices and protected with surface insulation to assess the temperature rise of concrete. In this method, the field temperature data from the mass placement is analyzed with the thermal model in consideration to the field conditions to approximate the adiabatic temperature rise of the concrete.

T.3.2.6 Computer modelling

Use of an analytical modelling software program can be used to evaluate concrete temperatures in a mass placement under different conditions. The results from the computer analysis under adiabatic conditions are entered into the thermal model to approximate the adiabatic temperature rise of the concrete.

T.3.2.7 Theoretical method

A method such as the Schmidt's method described in ACI 207.2R or other theoretical historic data or analytical method presented in technical literature can be used to perform calculations to approximate the adiabatic temperature rise of the concrete.

T.4 Concrete temperature

T.4.1 Fresh concrete placing temperature

Lowering the placing concrete temperature is beneficial to mass concrete placements to reduce temperature rise of concrete that can lead to high concrete temperatures and large temperature differentials. Targeting a low concrete placing temperature might be necessary to meet temperature limits; however, a low concrete placing temperature is not always practical and might not be sufficient to meet temperature limits. Thermal analysis should be used to determine appropriate fresh concrete temperature at time of placement.

Pre-cooling of fresh concrete at the batch plant prior to placement can be achieved by, for example, reducing the temperature of the aggregates with sprinkling and/or shading of stockpiles, washing of aggregates prior to entering the batch plant or using wet belts, and using chilled water or ice as part of the mixing water. Liquid nitrogen can also be used to cool aggregates and cementitious materials in transfer, but it is more commonly used in the industry by direct application in the concrete drum mixer.

T.4.2 Maximum temperature

The maximum concrete temperature after placement is mainly influenced by the temperature rise of concrete and fresh concrete placing temperature at time of placement, which is often limited for the following reasons:

a) Thermal cracking: High concrete temperatures can increase risk of cracking due to large volume changes under external restraints (Bamforth, 2007).
b) Ultimate strength: Concrete exposed to temperatures above 85 °C can be susceptible to a reduction in its potential to achieve ultimate strength (Gajda, 2007).

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c) Long-term durability: Some cements and concrete mixtures exposed to certain early age curing regimes with very high temperatures can be susceptible to a durability issue identified as delayed ettringite formation, commonly referred to as DEF (Day, 1992).

The maximum temperature of mass concrete after placement is commonly specified to not exceed 70 °C (ACI 301; Bamforth and Price, 1995). Lower maximum concrete temperature limits may be specified depending of the level of risk for especially large mass concrete placements with the intent of reducing thermal cracking or when cementitious materials exhibit high potential risk to DEF that require more stringent level of prevention (LCPC *Recommendations for Preventing Disorders due to Delayed Ettringite Formation*).

Not all concrete mixtures have the same risk for DEF when these are exposed to high temperatures during the curing period. Concrete temperatures higher than 70 °C but not greater than 85 °C might be justified for some mass placements when using concrete containing certain types and quantities of SCM. Additional details and recommendations for temperature limits during curing to minimize risk associated with exposure to elevated concrete temperatures during curing can be found in technical literature (ACI 308R, ACI 201.2R, LCPC *Recommendations for Preventing Disorders due to Delayed Ettringite Formation*). Further information about DEF and its prevention by use of SCM in concrete can be found in technical literature (Day, 1992; Thomas, 2001; Ramlochan *et al.*, 2004; Ramlochan *et al.*, 2003).

T.4.3 Maximum temperature difference

T.4.3.1 Specifying maximum temperature difference

The maximum temperature difference in mass concrete can be specified different ways. The most common way is to specify an empirical fixed 20 °C temperature difference limit regardless of the concrete properties or placement conditions (Fitzgibbon, 1976). Using a fixed limit can be simple, but it does not recognize that concrete will get stronger with time as it matures and that higher temperature difference can be permitted as concrete matures. Concrete resistance to cracking also varies based upon the materials properties. In consideration of the development of concrete properties with time, other alternatives typically considered when specifying temperature difference in mass concrete, such as incremental limit based on time or strength and a performance based limit based on concrete properties, are described below.

T.4.3.2 Fixed temperature difference limit

The maximum temperature difference in mass concrete is often limited between the core of a massive placement and the concrete near the concrete surface with the intent to control restraint of large volume changes and increase in thermal movements that can cause thermal cracking when large thermal gradients form. Temperature differentials can be reduced by reducing maximum concrete temperature, but it is also controlled by mitigating rapid heat loss from exterior surfaces using surface insulation over the concrete.

Using a 20 °C fixed limit to specify a maximum value to control maximum temperature difference in mass concrete is a simplified approach that can be conservative (Bamforth and Price, 1995). This fixed value is based on experiences from over 75 years ago for construction of small dams in Europe, where it was observed that cracking was decreased and temperature differences kept within 20 °C when protection was implemented during the curing period (Gajda, 2007).

Technical literature (Bamforth, 1984; Crook, 2006; and Bamforth, 2007) provides guidance into mass concrete placements, which also include information to determine allowable temperature difference

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limits depending on concrete properties such as thermal expansion and strain capacity as well as placement attributes, among others. These technical reports also documented evidence of mass concrete placements where concrete improved resistance to thermal cracking when using low coefficient of thermal expansion (CoTE) and remained free of cracks when temperature difference was near 35 °C.

T.4.3.3 Incremental temperature difference limit

The use of an incremental temperature difference limit is intended to take in consideration that concrete has the ability to increase resistance to temperature differentials as properties are developed with time, as concrete matures and gets stronger. As an example, the incremental temperature difference limit can be specified by time or strength, as follows:

a) When specified with time, the allowable temperature difference limit will be higher at later ages, for example, the incremental temperature difference by time can be as follows:
   i) 15 °C during the first 24 h;
   ii) 20 °C between 24 and 72 h; and
   iii) 25 °C after 72 h.
b) When specified by strength, the allowable temperature difference limit will be higher at higher strengths for example, the incremental temperature difference by strength can be as follows:
   i) 15 °C until 15 MPa;
   ii) 20 °C between 15 and 20 MPa; and
   iii) 25 °C after 20 MPa.

Note: *These are examples. Specific requirements will vary in projects on a case by case basis.*

With the incremental limit approach, there is little or no testing performed to evaluate the concrete properties, but testing may be used to develop the more specific increments. When a more comprehensive approach is desired, the performance based approach is preferred.

T.4.3.4 Performance based temperature difference limit

Restraint of large volume changes due to temperature differentials can lead to thermal cracking. Concrete compressive and tensile strength develop with time allowing concrete to get stronger as it matures. The tensile strain capacity of concrete also increases with time, which improves the ability of the concrete to resist tension as concrete matures, thus reducing the likelihood of thermal cracking to occur.

An assessment of the risk of thermal cracking in terms of temperature differential can be performed by evaluating the tensile strain capacity of the concrete. To avoid thermal cracking, the strain capacity of the concrete must be greater than the resulting strain. The tensile strain capacity is mainly a function of the tensile strength and the modulus of elasticity of concrete. A simple equation to calculate the allowable temperature differential in the concrete using this concept is shown in Equation 2.

$$T_{diff} = \frac{f_t'}{E \times CoTE \times R \times C}$$ **Equation 2**

where

T_{diff} = allowable temperature difference

f_t' = tensile strength of concrete

E = modulus of elasticity of concrete

CoTE = coefficient of thermal expansion

R = restraint factor

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C = creep factor

This expression is adapted from technical literature (Bamforth, 1984; Crook, 2006; and Bamforth, 2007) and permits the evaluation of the concrete capacity to tolerate temperature differentials and reduce thermal cracking risk. The concrete is capable of tolerating a higher temperature difference as it matures and gets stronger with time as thermal control progresses. Taking this in consideration, larger temperature differentials at later age can be tolerated while controlling the risk for thermal cracking (Gajda, 2007).

Concrete properties are evaluated with testing to develop an appropriate performance based temperature difference limit for each concrete mix. Lab testing of the concrete properties, such as compressive strength, tensile strength (splitting or direct), and modulus of elasticity (compressive or tensile) are used to determine best-fit curves for each concrete mix. Additionally, CoTE of concrete is also confirmed with lab testing. The factors associated with restraint and creep can be obtained from technical literature for the applicable conditions (Bamforth, 2007).

To improve the efficiency of implementing this performance based approach, field concrete temperatures should also be monitored using temperature data loggers capable of monitoring maturity. A strength-maturity relationship should be developed for the proposed concrete mix to implement use of maturity in the field. By doing this, maturity values can be assessed in the field at the different temperature monitoring locations to estimate the in-place compressive strength of the concrete and, therefore, determine the applicable allowable temperature difference limit based on in-place strength using the performance based curve.

When using maturity, the in-place strength should be determined from the monitoring location with the lowest maturity value, which is likely to be located near the surface. If assessment of in-place concrete strength with maturity is not possible, strength data from field cured cylinders under the thermal blankets should be used. In such case, field cured specimens should be prepared from concrete placed towards the end of the placement.

T.5 Thermal control planning

T.5.1 Scope and limitations

Thermal control plans are intended to describe best practices to monitor and control maximum temperature and temperature difference in mass concrete. A thermal control plan should be used as a tool to guide the contractor in planning and executing mass concrete placements. Thermal control plans should provide reasonable and practical measures to control concrete temperature, reduce thermal contraction, and mitigate potential thermal related cracking. The control of cracking associated to non-thermal related mechanisms, such as moisture drying or autogenous shrinkage, is not expected to be part of the thermal analysis used to prepare thermal control plans. Excessive restraining conditions inherent of the design or construction of the mass structure are likely to increase risk of cracking, and sometimes are difficult to avoid when standard thermal control measures are implemented. When specific performance specifications require cracking to be avoided, special thermal control measures and significant cost implications should be discussed (Bamforth, 2007).

T.5.2 Insulation

Insulation should be implemented when necessary during construction to mitigate heat loss from the exterior surfaces to thereby reduce and control temperature differentials within the concrete. Insulation is used in mass concrete to reduce the rate of heat loss from the concrete near the surface, and thus provide means to control temperature difference within the concrete. When insulation is required,

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insulating materials should be placed over the curing method on top of the surface of the concrete (or, where applicable, over the exterior of the formwork).

Different levels of insulation are typically evaluated to represent a range of possible insulating conditions to be considered for construction. If no insulation is required, the concrete surface should be covered with plastic or another acceptable covering material with little to negligible insulating properties to help minimizing the direct effect of varying weather conditions, such as wind, rain, or snow, which can affect thermal control.

For practical purposes, 20 mm thick plywood forms protect the concrete given their insulating capacity, but steel forms have negligible insulating capacity. Any gaps between the forms and insulating blankets are considered negligible with no insulating capacity. Covering concrete with plastic sheeting does not provide insulating capacity; however, it helps mitigate effects from varying weather conditions in the field.

The specific requirements for insulation should be assessed on a case-by-case basis. The required insulation should be installed to cover all concrete surfaces and, when required, to cover the formwork during the thermal control period. Insulating blankets should be installed as soon as practically possible after concrete placement is completed. Special attention should be employed when overlapping or layering insulating blankets to minimize gaps or openings that could allow wind, rain, or snow to counteract the effects of the insulation.

Field conditions that might result in additional heat loss, such as protruding rebar, steel brackets, or steel formwork bracing, can be difficult to insulate. Reasonable efforts to provide appropriate protective measures should be implemented in the field to protect these locations. In steel formed surfaces, it is of utmost importance to have all forms and connecting brackets properly insulated to minimize forms exposed to ambient conditions without insulation. Access and field conditions should be evaluated to determine suitable alternatives to implement when insulating mass concrete. The key to provide adequate insulation is to ensure proper installation of the insulation around the concrete placement. Insulation should cover the concrete surfaces including protruding surfaces described above. Routine visual inspection and monitoring is important to assess insulation in the field.

Insulation may be temporarily removed during construction. When temporary removal of insulation is necessary, for example, to remove forms or provide access to perform field work, it should be scheduled during times that will not exacerbate or accelerate a detrimental heat loss from the concrete surface. Temporary removal of insulation for long periods prior to completion of thermal control should be minimized, in particular during cold weather. Insulation temporarily removed should be restored as soon as practically possible. Closely monitoring concrete temperatures and forecasting ambient temperatures is of utmost importance in case it is necessary for insulation to be reinstalled sooner.

Additional insulation and thermal protection might be required to protect concrete in cold weather to minimize rapid heat loss from concrete surfaces.

T.5.3 Temperature monitoring

T.5.3.1 General

A temperature monitoring system should be used to monitor temperatures of mass concrete placements. The recommended locations to monitor temperature of the concrete placements and type of monitoring devices should be identified in the thermal control plan.

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T.5.3.2 Temperature monitoring locations

The maximum concrete temperature is expected to be located near the center of the largest cross-section of the mass placement; however, such temperature might not be in the geometric centre of the mass placement. The near surface locations within the concrete are typically located 50 to 75 mm from the concrete surface (e.g., temperature measuring device tied to reinforcing bar near the surface). A backup temperature sensor should be installed in the monitoring locations described above in the event one of the temperature sensors fails. Unless otherwise required, it may be assumed that two temperature sensors will be used at each monitoring location per mass placement.

Temperature monitoring should be performed with the intent of minimizing volume changes and thermal movement associated to the heat flow in the mass placement. Thermal monitoring at locations such as edges and corners of a mass placement is not a recommended standard practice representative of the concrete mass thermal behaviour.

Additional temperature monitoring locations might be required to monitor concrete in cold weather.

T.5.3.3 Temperature monitoring devices

Temperature should be monitored and recorded every hour using electronic temperature sensors capable of measuring temperature from 0 to 100 °C to an accuracy of 1 °C. Installation of temperature sensors should be verified before placing concrete to ensure these are secured, working properly, and installed at the correct monitoring location. Unless otherwise required, daily verification of the thermal data should be performed until thermal control measures are terminated. Wireless temperature monitoring systems are an alternative to facilitate the verification of thermal data in the field.

T.5.4 End of thermal control

The time required to end thermal control is mainly dependent on the actual field concrete temperatures at monitoring locations and ambient temperatures at the time expected to remove insulation. At the time thermal control is terminated, insulation can be removed and temperature monitoring is no longer required. The risk of thermal cracking is expected to be reduced once thermal control is terminated; however, the time insulation is removed should be carefully planned to avoid causing a thermal shock from an abrupt, rapid change in concrete temperature near the surface. To reduce a potential thermal shock, a gradual temperature change should be provided in the concrete near the surface. It is important to forecast ambient conditions for several hours or even days from the time thermal control is terminated. Removal of insulation should be performed during a period of time that will minimize the potential for a thermal shock.

The termination of thermal control measures should be based in consideration of the specified temperature requirements and, for example, as described below:

a) Thermal control: At least a certain period of thermal control has been completed.
b) Maximum temperature: The maximum temperature monitored in the concrete has peaked and is decreasing.
c) Temperature differential within the concrete: The maximum temperature difference monitored in the concrete between the concrete core and the concrete near the surface is within the applicable temperature difference value and is decreasing.
d) Difference between maximum concrete temperature and ambient temperature: The difference between the maximum temperature monitored in the concrete core and the daily average ambient temperature forecasted for the 24 h following the insulation removal will not result in a temperature differential within the concrete larger than applicable temperature difference value at the time insulation is removed.

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e) Difference between concrete temperature near the surface and ambient temperature: The difference between the concrete temperature near the surface and the daily average ambient temperature forecasted for the 24 h following insulation removal will not result in a concrete temperature drop near the surface larger than the corresponding value described in Table 20.

Additional precautionary measures might be required during cold weather.

T.5.5 Corrective measures

T.5.5.1 Adjustments to thermal control measures

Potential adjustments during construction are expected to be necessary as field work progresses and field thermal data is available. Care should be exercised to minimize adversely affecting thermal control of the concrete.

If maximum temperature is an issue and insulation has been installed in layers, the removal of one layer of insulation can help mitigate further increase in the concrete core temperature; however, it can increase the risk to exceed the temperature difference. And, if the maximum concrete temperature difference is an issue, an additional layer of insulation may be added to mitigate a potential further increase in temperature difference at a certain locations. Other measures that can control the temperature near the surface such as heating, hoarding, and enclosures could be evaluated to mitigate further increase in temperature differential.

In some cases, adjusting the insulation and reducing the placing concrete temperature does not provide a reasonable solution, thus other corrective measures may be considered for future placements. Concrete pre-cooling, mix adjustments and/or active cooling with embedded pipes may be evaluated in future placements. (See ACI 207.4R for guidance). Optimizing or selecting a concrete mix that produces lower temperature rise can be a solution to evaluate in future placements.

Adjustments or changes to any or all of the following that are not described in the thermal control plan should be evaluated to determine if a change to the thermal control plan is required:

a) mix design proportions, materials sources, or properties;
b) insulation;
c) placement dimensions;
d) ambient conditions;
e) cooling pipe operations (if applicable); or
f) field conditions.

The specified temperature limits described herein are intended to protect against the possibility of cracking resulting from an excessively high temperature difference within a mass placement and to protect against the possibility of long term durability issues that may occur in some concretes cured at very high temperatures. If the specified temperature limits are exceeded, the risk increases. At that point the available options to mitigate these potential risks during construction are limited, and in many cases there will be not many practical or economical options available. It is important that the planning and execution of effective thermal control measures be implemented to prevent non-conformances with the applicable thermal limits.

T.5.5.2 Revision of thermal control plan

The initial mass placements should serve as an opportunity to perform field observations to document visible signs of thermal control implementation issues, collect field data to revise thermal analysis, and validate assumptions considered in preparing the initial thermal control plan. Field observations and

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continuous monitoring of the temperature and insulation will allow for adjustments to the thermal control measures to ensure temperature limits are met. Mass placements after this revision should proceed as per the revised thermal control plan.

T.6 Curing

Continuous water curing (running water) for mass concrete should not be used. Continuous water curing with cold water can result in uncontrolled cooling of the concrete surface and difficulties mitigating temperature differentials in the field that can promote thermal cracking. When required, water curing can be achieved by using a ponded water layer between the concrete and the insulating blanket. Curing alternatives for mass concrete placements include moisture retaining coverings such as plastic sheeting, burlap with plastic sheeting, burlene coverings, forms in place, or curing compound, where applicable. Insulating blankets should be installed over the selected curing method.

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Annex U (informative)
Ultra-high performance concrete (UHPC)

Note: *This informative Annex has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

U.1 Scope

U.1.1 General

This Annex provides information for materials and methods of construction for the use of UHPC in cast-in-place concrete and precast concrete.

All of the requirements of this Standard apply, except as stated in this Annex.

U.1.2 Significance and use

This Annex is intended to be used in its entirety. Caution should be exercised in extracting individual clauses and using them in project specifications, since taking them out of context can change their meaning.

This Annex was developed to provide guidance to suppliers, specifiers, and users of UHPC technology. The Annex establishes boundaries on the properties of UHPC, how to characterize the material within given categories and how to batch, transport, place, and cure the material. The Annex is intended to provide limits on what materials may be classified and how to use UHPC, without restricting innovation in the development of new uses or material formulations.

U.1.3 Exclusions

This Annex does not provide the following:

a) requirements for the design of UHPC structures; or
b) all of the required test methods for UHPC.

Note: *For information on the structural design for bridges, refer to the annex on fibre reinforced concrete (FRC) in CSA S6 (Annex A8.1).*

U.2 Symbols

The following symbols are used in this Annex:

f_c = compressive strength

f_{cc} = characteristic compressive strength

$f_{cc,req}$ = required compressive strength

f_{cm} = mean compressive strength

f_{cd} = design compressive strength

f_{cr} = direct tensile strength of the cementitious UHPC matrix

f_{ti} = direct tensile strength after crack localization corresponding to a crack with w_i

f_{fu} = maximum direct tensile strength of the fibre reinforced UHPC

E_c = Modulus – Young's modulus in compression

ε = strain

ε_{fu} = tensile strain corresponding to f_{fu}

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ε_{cr} = tensile strain corresponding to f_{cr}

H = tension hardening UHPC

N = non-fibre UHPC

P = load

S = tension softening UHPC

σ = stress

TA = "thermally induced" accelerated curing conditions for early strength development. The temperature of the element shall not exceed 60 °C during setting

TN28 = no thermal treatment. Ambient curing conditions of 23 ± 2 °C in > 95% relative humidity (RH) for 28 d

TN56 = no thermal treatment. Ambient curing conditions 23 ± 2 °C in > 95% RH for 56 d

TP = an element which has an applied continuous static pressure to assist with consolidation and/or removal of entrapped air

T1 = an element, post setting, which receives a thermal treatment of > 90 ± 5 °C in > 95% RH for > 48 h

T2 = an element, post setting, which receives a thermal treatment of 60 ± 5 °C in > 95% RH for > 72 h

T3 = an element, post setting, which receives both a TA and T1 or T2

w_i = crack width

U.3 Definitions

In addition to the definitions in Clause 3, the following definitions apply in this Annex:

Batch — a volume of materials placed into a mixer and uniformly blended, then discharged.

Characteristic value — the result obtained from tests that corresponds to a statistical 95% probability of meeting or exceeding.

Creep coefficient — the ratio of the load-induced strain per unit of stress at any time difference after the immediate loading compared to the immediate loading.

Ductility — the ability to deform without failure after yielding.

Failure — a state in which rupture, severe distortion or displacement, or loss of strength has occurred as a result of load-carrying capacity of a component or connection having been exceeded.

Fibre — a discrete, elongated element that imparts tensile and crack resistant properties.

Material identity card — a document that provides the details of the components, mixing instructions, curing instructions and properties of a specified UHPC mix.

Matrix — that portion of the UHPC not including fibres or reinforcing elements.

Particle packing — the process where the voids between larger sized materials are filled with smaller sized materials to the maximum, providing the minimum void space in the matrix.

> **Modified particle packing** — adjusting the particle packing to improve flowability of the matrix by over filling the voids between the larger sized materials.

Post setting — the time following setting when an element has sufficient strength to be self-supporting.

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Pre-blend — a mixed combination of the powder mineral components, to which water, admixtures and fibres are added at the concrete mixer.

Partial pre-blend — a pre-blend where not all of the powder mineral components are pre-blended.

Specified property — the value required in the contract specifications.

Strain — deformation.

Tension hardening — the ability to carry increasing direct tensile load beyond the first crack.

Tension softening — the ability to carry a direct tensile load which is less than the first cracking load.

Thermal treatment — a process of heating the UHPC to an elevated temperature, above normal heat of hydration, in the presence of high relative humidity, holding the elevated temperature for a period of time to complete the hydration process, and then slowly cooling to ambient temperature.

Ultra-high performance concrete (UHPC) — a cementitious composite material with enhanced strength, durability, and ductility compared to high performance concretes.

Note: *UHPC can contain fibres for post-cracking ductility, have a specified compressive strength of at least 120 MPa at 28 days, and are formulated with a modified multi-scale particle packing of inorganic materials of less than 0.6 mm diameter (larger sizes can be used).*

Working time — the period of time which the mix maintains a flow within the specified flow limits and without negative impact on the in-situ hardened properties.

U.4 Materials, categories, and properties

U.4.1 Categories of UHPC and characterization

U.4.1.1 General

UHPC shall be classified and characterized in accordance with Clauses U.4.1.2 to U.4.1.9.

U.4.1.2 Strength

U.4.1.2.1 Compressive strength

U.4.1.2.1.1

The compressive strength of UHPC shall meet the limits of one of the categories in Table U.1 at 28 days, following a TN28 curing in accordance with Clauses U.4.1.6 and U.4.5.4.5.

Table U.1
Minimum required compressive strength
(See Clause U.4.1.2.1.1 and Table U.5.)

Category	Minimum compressive strength (MPa)
120	120
150	150

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U.4.1.2.1.2

The compressive strength shall be determined using cylinders or cored specimens prepared and tested in accordance with CSA A23.2-9C and Clause U.4.1.5, with the exceptions described in this Annex.

U.4.1.2.1.3

Only 75 mm diameter × 150 mm long cylindrical specimens shall be used for compressive strength testing.

Notes:

1) *Due to the high compressive strength of UHPC, the cylindrical specimen size is 75 mm × 150 mm in order to be tested on typical laboratory compression machines.*
2) *For fibre lengths greater than 15 mm, in order to minimize any impact on the compressive strength due to fibre clumping in the cylinder specimen, after mixing all of the matrix materials and before adding the fibres to the matrix, a sample should be collected for specimen testing. Alternatively, drilled core specimens may be used. See Graybeal and Davis, 2008.*
3) *Large diameter testing machine platens with the spherical seat could be too large for testing 75 mm × 150 mm cylinders (See CSA A23.2-9C Clause 4.1.2.3.1 a) and Table 1.)*

U.4.1.2.1.4

Prior to testing, all cylindrical specimens shall be end ground such that neither end of the test specimens shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to 1 mm in 100 mm). The ends of compression test specimens that are not plane to within 0.050 mm shall be ground to meet this tolerance.

Note: *The end preparation of cylindrical specimens require end grinding to ensure flat and parallel surfaces in order to obtain accurate test results.*

U.4.1.2.1.5

The diameter used for calculating the cross-sectional area of the cylindrical test specimen shall be determined to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about mid-height of the specimen.

U.4.1.2.1.6

The load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a stress rate on the specimen of 1.0 ± 0.1 MPa/s.

U.4.1.2.2 Tensile strength

U.4.1.2.2.1

Tensile properties shall be obtained from flexural tests in accordance with an inverse analysis of AFNOR NF P 18-470, Appendix D, or SIA Design Guideline 2052, Appendix E. Alternatively, direct tensile tests may be used for category H only. The method used shall be stated on the material identity card.

Note: *The state-of-the-art on tensile testing methods is still evolving. The methods stated in this Annex provide the state-of-the-art at the time of writing.*

U.4.1.2.2.2

The tensile strength shall be determined on prismatic specimens moulded in accordance with Clause U.4.1.5, tested in accordance with ASTM C1609/C1609M and calculated in accordance with Clause U.4.1.2.2.1, with the exceptions described in Clauses U.4.1.2.2.3 to U.4.1.2.2.8.

Note: *This modification is consistent with ASTM C1856/C1856M.*

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U.4.1.2.2.3

The fixtures, except a single one of the two lower or upper supports of the specimen, shall not restrain horizontal translations.

Note: *The following Figures U.1 and U.2 show a schematic and photo example of an unrestrained support.*

Figure U.1
4-point bending test set-up (schematic)
(See Clause U.4.1.2.2.3.)

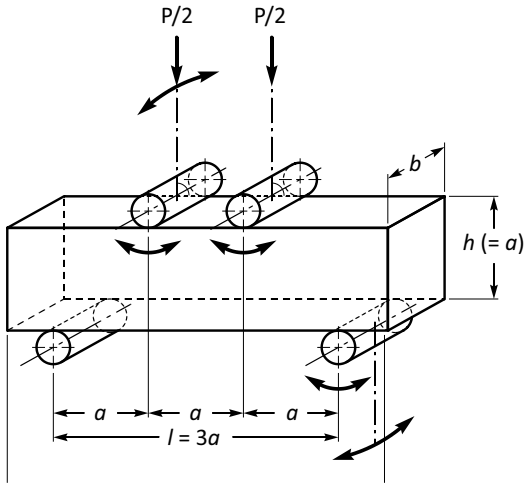
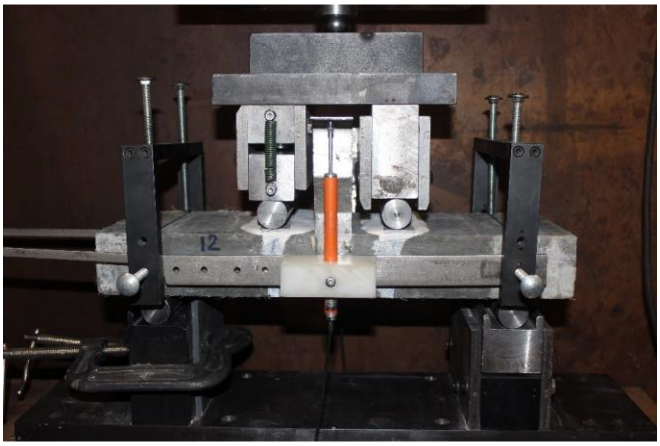


Figure U.2
Test set-up at Polytechnique Montréal
(See Clause U.4.1.2.2.3.)



U.4.1.2.2.4

The prism specimens for measuring the flexural strength shall comply with Table U.2.

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Table U.2
Fibre length vs. prism size
(See Clause U.4.1.2.2.4.)

Fibre length (l_f)	Nominal prism size
≤ 15 mm	75 mm × 75 mm × 280 mm
> 15 mm to 20 mm	100 mm × 100 mm × 370 mm
> 20 mm to 25 mm	150 mm × 150 mm × 550 mm
> 25 mm to 60 mm	200 mm × 200 mm × 720 mm

U.4.1.2.2.5

The owner may specify direct tensile tests methods to determine the tensile strength of UHPC.

Note: *The development of proper design procedures for UHPC requires the use of the direct tensile strength of the material covering the elastic range and the fibre capacity post cracking. While uniaxial tension tests provide the most direct method to obtain these properties, the tests are difficult to conduct; therefore, methods based on indirect measurement of tensile properties using flexural tests are often used. Currently there is no uniformly accepted method to determine the direct tensile strength of concretes. Several methods have been proposed by the US Federal Highway Authority, the Swiss Association of Engineers and Architects (SIA 2052), and RILEM TC 162 Test.*

U.4.1.2.2.6

The specimens for the testing of the tensile strength of UHPC shall be tested following a TN28 curing in accordance with Clauses U.4.1.6 and U.4.5.4.5, unless otherwise specified by the owner.

U.4.1.2.2.7

A minimum of 3 points in the elastic range and a minimum of four intermediate w_i-f_{ti} points (w_1-f_{t1} to w_4-f_{t4}) with f_{ti} corresponding to 80%, 60%, 40%, and 20% of f_{tu} respectively shall be provided in accordance with Figure U.3 a), for a tension hardening (H) UHPC.

U.4.1.2.2.8

A minimum of 3 points in the elastic range and a minimum of six intermediate w_i-f_{ti} points (w_1-f_{t1} to w_6-f_{t6}) corresponding to w_1 = 0.15 mm, w_2 = 0.25 mm, w_3 = 0.50 mm, w_4 = 1.5 mm, w_5 = 2.5 mm, and w_6 = 3.5 mm respectively shall be provided in accordance with Figure U.3 b), for a tension softening (S) UHPC.

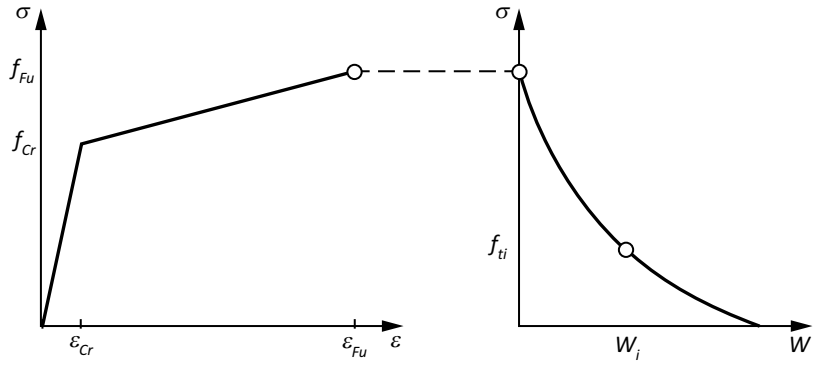
Notes:

1) *The results obtained using different moulded specimens might not correspond to the performance of larger or smaller moulded specimens, large structural units, or specimens sawn from structures. This difference could occur because the degree of preferential fibre alignment becomes more pronounced in moulded specimens containing fibres that are relatively long compared with the cross-sectional dimensions of the mould. Moreover, structural members of significant different thicknesses experience different maximum crack widths, for a given mid-span deflection, with the result that fibres undergo different degrees of pull-out and extension.*
2) *Casting methods used in the making of moulded prisms will impact the tensile strength properties.*

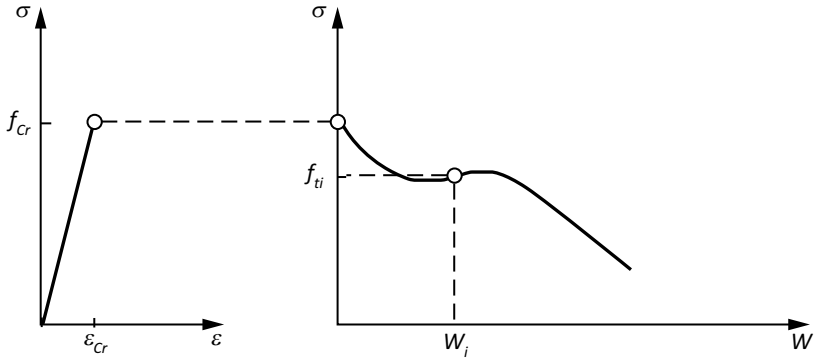
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Figure U.3
Stress-strain diagrams
(See Clauses U.4.1.2.2.7 and U.4.1.2.2.8.)



a) Tension hardening (H)



b) Tension softening (S)

(NTS)

U.4.1.2.2.9

UHPC categories H and S shall meet the requirements of Table U.3, from inverse analysis of flexural tests in accordance with Clause U.4.1.2.2.1 or direct tension tests.

Table U.3
UHPC direct tensile strength categories
(See Clause U.4.1.2.2.9 and Table U.5.)

Property	Parameter	Hardening (H)	Softening (S)	No fibres (N)
Tensile strength (MPa)	f_{cr}	≥ 5.0	≥ 4.0	≥ 4.0
Hardening strength ratio	f_{fu} / f_{cr}	≥ 1.1	N/A	N/A

(Continued)

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Table U.3 (Concluded)

Property	Parameter	Hardening (H)	Softening (S)	No fibres (N)
Ultimate strain (%)	ε_{fu}	≥ 0.1	N/A	N/A
Post-cracking strength	f_{ti}	Clause U.4.1.2.2.7	Clause U.4.1.2.2.8 and $f_{ti} > 0.4\ f_{cr}$, where w_{ti} is greater of 3.5 mm or $L_f/4$	N/A

Note: *UHPC is expected to have higher tensile properties than conventional concrete with high compressive strength. The inclusion of Category N UHPC allows for matrices developed and used for applications that do not require or use fibres – i.e., UHPC slurry injected into 2-D or 3-D meshes.*

U.4.1.2.2.10

UHPC categories H and S shall have mean, standard deviations and characteristic values for f_t, f_{ti} and f_{fu}; mean, standard deviations and minimum values for w_i, ε_{fu} and ε_{cr} shown on the material identity card.

U.4.1.3 Static modulus of elasticity and Poisson's ratio

The static modulus of elasticity and Poisson's ratio shall be determined in accordance with ASTM C469/C469M on specimens prepared in accordance with Clause U.4.1.5, with a modified Compressometer and Extensometer using displacement transducers for measuring displacement.

Note: *This modification is consistent with ASTM C1856/C1856M.*

U.4.1.4 Consistency properties

U.4.1.4.1

The flow of UHPC shall be determined in accordance with ASTM C1437 with the exceptions stated in Clauses U.4.1.4.2 to U.4.1.4.8.

Note: *This modification is consistent with ASTM C1856/C1856M.*

U.4.1.4.2

The viscosity of UHPC with aggregate greater than 5 mm in size shall be determined in accordance with CSA A23.2-1B.

U.4.1.4.3

The mould shall be filled in a single layer with fresh UHPC, within 1 min after discharging from the mixer.

U.4.1.4.4

The UHPC shall not be tamped in the mould and the table shall not be dropped.

U.4.1.4.5

After lifting the mould, a time of 2 min ± 5 s shall be allowed to elapse.

U.4.1.4.6

The diameter of the UHPC shall be measured along the lines of maximum and minimum diameter, recording each diameter to the nearest millimetre.

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U.4.1.4.7
The average of the two diameters measured shall be calculated.

U.4.1.4.8
The flow value shall be the average calculated in accordance with Clause U.4.1.4.7.

U.4.1.5 Fabricating and moulding of test specimens

U.4.1.5.1
Fabricating and moulding of specimens shall be in accordance with CSA A23.2-3C, with the exceptions described in Clauses U.4.1.5.2 to U.4.1.5.6.

U.4.1.5.2
Prisms and cylinders shall be filled from a single end, in one layer.

U.4.1.5.3
Tamping rods and internal vibrators shall not be used in fabricating and consolidating specimens.

U.4.1.5.4
Specimens may be consolidated by external vibration.

U.4.1.5.5
For UHPC with a flow of greater than 200 mm, specimens shall be consolidated by tapping the sides of the mould 30 times with a mallet.

U.4.1.5.6
For UHPC with a flow of equal or less than 200 mm, specimens shall be consolidated by dropping the filled moulds from at least 30 mm height onto a hard, level surface, 30 times, followed by tapping the sides of the mould 30 times with a mallet.

U.4.1.6 Curing conditions and thermal treatments

U.4.1.6.1
Curing of specimens shall be in accordance with CSA A23.2-3C, with the exceptions described in Clauses U.4.1.6.2 and U.4.1.6.3.

U.4.1.6.2
All UHPC shall be protected to prevent dehydration from moisture loss to the atmosphere or absorption into the moulds.

Note: *The surface of UHPC should be immediately covered and in full contact with polyethylene to prevent surface dehydration, plastic shrinkage cracking and crusting.*

U.4.1.6.3
UHPC specimens or elements

a) shall be cured in accordance with one of the following methods:
   i) TN28 – no thermal treatment. Ambient curing conditions of 23 ± 2 °C in > 95% relative humidity (RH) for 28 days; or

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ii) TN56 – no thermal treatment. Ambient curing conditions 23 ± 2 °C in > 95% RH for 56 days; and

b) may be thermally treated with one of the following methods:

i) TA – "thermally induced" accelerated curing conditions for early strength development. The temperature of the element shall not exceed 60 °C during setting.

Note: *This curing is normally completed while the UHPC is still in the mould and before developing sufficient strength to be self-supporting.*

ii) TP – a specimen or element which has an applied continuous static pressure to assist with consolidation and/or removal of entrapped air.

iii) T1 – a specimen or element, post setting, which receives a thermal treatment of 90 ± 5 °C in > 95% RH for > 48 h.

iv) T2 – a specimen or element, post setting, which receives a thermal treatment of 60 ± 5 °C in > 95% RH for > 72 h.

v) T3 – a specimen or element, post setting, which receives both a TA and T1 or T2.

Notes:

1) *UHPC is typically a Portland cement based product and requires the retention of mixing water to complete the hydration and provide the hardened properties. The early strength development and final hardened properties are impacted by the curing and thermal treatments.*
2) *The potential detrimental effects of DEF from thermally treated UHPC should be checked. Refer to ACI 308R, Clause 3.10 or ACI 201.2R for further information and Clause U.4.1.8.7.*
3) *During a T1 or T2 thermal treatment the rate of specimen temperature increase or decrease should not exceed 10 °C/h.*
4) *Currently, the only thermal treatments validated are for T1 and T2; however, other thermal treatment temperatures and times can be used if data shows them to be effective in achieving the desired mechanical properties.*
5) *A specimen refers to test specimen and an element refers to a precast or CIP component.*

U.4.1.7 Fire properties

When specified, the following categories shall apply to UHPC:

a) FN – Non-fire-exposed UHPC: Conventional UHPC may be used in non-fire exposure applications without the use of accelerated curing or the inclusion of polypropylene fibres.

b) F1 – Fire Exposed UHPC: UHPC that could be exposed to fire shall contain as a minimum 0.2% by volume of polypropylene fibres.

c) F2 – Hydrocarbon fire exposure: UHPC that could be exposed to a hydrocarbon fire shall contain as a minimum 0.3% by volume of polypropylene fibres with an aspect ratio ≥ 65.

Notes:

1) *Code specified fire resistance ratings are assigned to an assembly based on the performance of that assembly in a standard fire test such as the ULC S101 Fire Test and are not assigned on a material basis. UHPC has very low permeability and as a result could be susceptible to explosive spalling when exposed to fire unless mitigating measures are taken. While UHPC has been found to perform better than conventional HPC when exposed to fire, the curing status (internal moisture content) and mix design of UHPC can influence the performance of UHPC under fire exposure conditions.*
2) *The fire resistance of UHPC that has been heat cured at 90 °C for 48 h is generally superior to UHPC that has not received accelerated curing. Heat curing serves to remove any free water in the concrete matrix, reducing the potential for spalling. The use of at least 0.1% by volume of polypropylene fibers has also been shown to significantly reduce spalling in UHPC by reducing the build up of hydrostatic pore pressure at elevated temperatures. The use of steel fibres has not been found to reduce spalling but does serve to retain the spalled sections of concrete once the hydrostatic pressure exceeds the tensile strength of the UHPC.*
3) *Additional benefit can be obtained from utilizing a thermal treatment (accelerated curing) of 90 ± 5 °C in > 95% RH for > 48 h.*

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4) *Residual strength studies at elevated temperatures have shown that a variety of UHPC mixes will perform similarly to EC2 Class 1 and Class 2 concrete. Other UHPC mixes however have fallen outside this range and as a result, no prescriptive residual strength values for UHPC are offered at this time.*
5) *Artificial pore structures can be added (polypropylene fibres) to UHPC to improve fire resistance and caution should be taken as this pore structure will impact the other properties of UHPC.*
6) *If test data to support the F1 and F2 exposure class requirements above is not available on the UHPC specified, testing should be conducted on the specific UHPC mix design to ascertain its suitability for the intended fire exposure condition.*

U.4.1.8 Durability properties

U.4.1.8.1 Categories

UHPC shall meet all of the limits for one of the categories listed in Table U.4.

Table U.4
Durability limits (DL)
(See Clauses U.4.1.8.1 and U.4.2.2.3 and Table U.5.)

	Abrasion loss (g)	Salt-scaling (kg/m²)	Absorption (%)	Chloride ion penetration (coulombs passed)*	Sulphate resistance (% expansion maximum at 12 months)
Test method	ASTM C9444/ C944M (see U.4.1.8.2)	CSA A23.2-22C (see U.4.1.8.3)	CSA A23.2-11C (see U.4.1.8.4)	CSA A23.2-23C (see U.4.1.8.5)	CSA A3004 (see U.4.1.8.6)
DL50	< 5.0	< 0.4	< 3.0	< 500	< 0.05
DL100	< 1.0	< 0.2	< 3.0	< 300	< 0.05
DL200	< 0.5	< 0.1	< 3.0	< 100	< 0.05

* *Test to be conducted following a T1, T2, or TN56 curing condition in accordance with Clause U.4.1.6.*

Notes:
1) *The design service life of a structure requires a holistic approach and is not only dependent on materials properties; however, UHPC can facilitate a longer design service life. The above information is for material characterization.*
2) *The durability limits for the acceptance of field testing have not been established. Insufficient data has been collected to provide specific limits at this time.*

U.4.1.8.2 Abrasion loss

The abrasion loss of UHPC shall be determined on specimens with a TN28 curing, unless otherwise specified by the owner, in accordance with ASTM C944/C944M using a double load of 197 ± 2 N on the test specimen.

Note: *This modification is consistent with ASTM C1856/C1856M.*

U.4.1.8.3 Salt-scaling

The salt-scaling of UHPC shall be determined on specimens with a TN28 curing, unless otherwise specified by the owner, in accordance with CSA A23.2-22C.

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U.4.1.8.4 Absorption

The absorption of UHPC shall be determined on specimens with a TN28 curing, unless otherwise specified by the owner, in accordance with CSA A23.2-11C.

U.4.1.8.5 Chloride ion penetration

U.4.1.8.5.1

The chloride ion penetration of UHPC shall be determined on moulded or cut specimens in accordance with CSA A23.2-23C.

U.4.1.8.5.2

The test specimen may be fabricated from the matrix with or without fibres.

Note: *Chloride ion penetration test results could be adversely affected due to the electrical current being conducted through steel fibres. For specimens where electrical short circuit could occur, in order to minimize any impact on electrical conductivity, after mixing all of the matrix materials and before adding the fibres to the matrix, a sample should be collected for specimen testing.*

U.4.1.8.6 Sulphate resistance

U.4.1.8.6.1

The sulphate resistance of UHPC shall be determined, on specimens without fibres, in accordance with CSA A3004-C8, for 12 months.

U.4.1.8.6.2

The test specimen shall be fabricated in accordance with the requirements of Clause U.4.1.5.

Note: *The matrix of UHPC has a low permeability and discontinuous pore structure resulting in a high level of resistance to sulphate attack, typically in excess of the requirements of Table 2, Class of Exposure S-1.*

U.4.1.8.7 Delayed ettringite formation

U.4.1.8.7.1

UHPC receiving a thermal treatment with an internal material temperature greater than 70 °C shall contain supplementary cementitious material.

U.4.1.8.7.2

UHPC receiving a thermal treatment with an internal material temperature greater than 70 °C shall include measures to control the potential for delayed ettringite formation.

Note: *More information for potential DEF Mitigation can be found in ACI 201.2R and ACI 308R, Clause 3.10.*

U.4.1.9 Time dependent properties

U.4.1.9.1 Creep coefficient

U.4.1.9.1.1

The creep coefficient in compression shall be measured on 75 mm x 150 mm cylindrical specimens prepared in accordance with Clause U.4.1.5 and in accordance with ASTM C512/C512M.

Note: *This modification is consistent with ASTM C1856/C1856M.*

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U.4.1.9.1.2

Creep testing shall be conducted at a sustained load of 40% of specified strength of the UHPC.

U.4.1.9.1.3

Creep testing shall be conducted on specimens following a TN28 curing in accordance with Clause U.4.1.5, unless otherwise specified by the owner.

Note: *UHPC exhibits very low creep coefficients in the range of 0.3 to 0.8 if thermally treated. Refer to FHWA-HRT-06-103 for more information on creep.*

U.4.1.9.2 Shrinkage

U.4.1.9.2.1

Shrinkage testing shall be conducted on prisms of 75 mm × 75 mm × 280 mm, prepared in accordance with Clause U.4.1.5.

U.4.1.9.2.2

The change in length of the UHPC specimens shall be measured in accordance with CSA A23.2-21C, at 1 d, 4 d, 7 d, 14 d, 28 d, 56 d, and 90 d.

U.4.1.9.2.3

When early shrinkage potential during the first 24 h is required, testing shall be in accordance with ASTM C1581.

U.4.1.9.3 Coefficient of thermal expansion

U.4.1.9.3.1

The coefficient of thermal expansion shall be measured on 75 mm x 150 mm cylindrical specimens prepared in accordance with Clause U.4.1.5.

U.4.1.9.3.2

The coefficient of thermal expansion shall be determined in accordance with AASHTO T 336.

Notes:

1) *Coefficient of thermal expansion of UHPC typically ranges from 10 to 16 × 10^{-6}/°C. If no other value is provided, 13 × 10^{-6}/°C may be used.*
2) *Refer to FHWA-HRT-06-103 for more information on the coefficient of thermal expansion.*

U.4.2 Requirements and methods for specifying UHPC

U.4.2.1 General

The owner shall specify the category of UHPC in accordance with Clause U.4.1.

U.4.2.2 Material identity card

U.4.2.2.1 General

UHPC shall be categorized in accordance with Clause U.4.1 and a material identity card shall be provided for a pre-blend or mix design.

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U.4.2.2.2 Conformance with this Annex

The material identity card shall state that the material is in conformance with this Annex.

U.4.2.2.3 Pre-blended UHPC

The manufacturer of pre-blend shall provide a material identity card that shows

a) the mix components;
b) quantity and description of components;
c) special storage instructions;
d) shelf-life;
e) mixing instructions;
f) curing type required and instructions;
g) the properties in accordance with Clauses U.4.1 and U.4.5.4, and Table U.5; and
h) name, address, and contact information of the manufacturer of the pre-blend.

Note: *The mix components for pre-blend are quantities of blended powders, fibres, admixtures, water, and other items to be added to the mixer.*

U.4.2.2.4 Non pre-blended, partial pre-blended, batched-on-site UHPC

The designer of UHPC mix-design shall provide a material identity card that shows

a) the mix components;
b) quantity and quality of raw materials;
c) mixing instructions;
d) curing instructions; and
e) the properties in accordance with Clauses U.4.1 and U.4.5.4, and Table U.5 and as follows:
   i) date of testing;
   ii) number of tests, mean result, and standard deviation; and
   iii) name, address, and contact information of the laboratory where the mix-design validation testing was completed.

Table U.5
Material identity card
(See Clause U.4.2.2.4.)

Property	Symbol	Minimum required values	Clauses
Compressive strength	f_c	Category, standard deviation and characteristic value	U.4.1.2.1 and U.4.5.4.5
Tensile strength	f_{cr}	Category, mean, standard deviation and characteristic value	U.4.1.2.2 and U.4.5.4.5
Hardening strength	f_{fu}/f_{cr}	Category, mean, standard deviation and characteristic value	U.4.1.2.2 and U.4.5.4.5
Post-cracking strength	f_{ti}	Category, mean, standard deviation and characteristic value	U.4.1.2.2 and U.4.5.4.5
Strain	w_i, ε_{cr}, ε_{fu}	Category, mean, standard deviation and characteristic value	U.4.1.2.2 and U.4.5.4.5
Static modulus of elasticity	Ec	Mean	U.4.1.3 and U.4.5.4.5

(Continued)

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Table U.5 (Concluded)

Property	Symbol	Minimum required values	Clauses
Poisson's ratio	—	Mean	U.4.1.3 and U.4.5.4.5
Abrasion	—	Category, mean	U.4.1.8.2
Salt-scaling	—	Category, mean	U.4.1.8.3
Absorption	—	Category, mean	U.4.1.8.4
Chloride ion penetration	—	Category, mean	U.4.1.8.5
Sulphate resistance	—	Category, mean	U.4.1.8.6
Creep coefficient	—	Mean	U.4.1.9.1
Shrinkage	—	Mean	U.4.1.9.2
Coefficient of thermal expansion	—	Mean	U.4.1.9.3

Notes:

1) *The naming of UHPC should be as follows: "UHPC Category 120-H-DL100". This would be a 120 MPa compressive strength (Table U.1), strain hardening (Table U.3) with the durability limits of DL100 (Table U.4).*
2) *The characteristic value is calculated in accordance with Clause U.4.5.4.5.*

U.4.2.3 Substitutions

Substitutions of raw materials shall not be used, unless the mix with the substituted materials is retested and recertified in accordance with the requirements of Clause U.4.

U.4.2.4 Recertification

Mixes shall be retested and revalidated in accordance with Clause U.4 every 24 months and a new material identity card shall be issued showing any changes.

Note: *During the retesting, certain mechanical properties such as strength might increase with change in raw materials and it is acceptable not to increase the properties shown on the material identity card.*

U.4.3 Raw materials

Note: *The raw materials used in the production of UHPC are similar to those commonly found in traditional concrete, however, they require a higher level of uniformity. Variations in uniformity in the raw materials properties will magnify the standard deviation in the hardened properties of UHPC. Constituent materials are selected based on their mechanical properties and particle size to optimally pack the matrix to reduce voids between the particles. Low strength aggregates should be avoided.*

U.4.3.1 Cement

Cement complying with CSA A3001 shall be used.

U.4.3.2 Supplementary cementitious materials

Supplementary cementitious materials shall comply with the requirements of CSA A3001 and shall be one or more of the types specified in Table 8 of this Standard.

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U.4.3.3 Aggregates

Aggregates for the manufacture of UHPC shall meet the requirements of this Standard, except the requirements of Tables 10 and 11 for grading.

Notes:

1) *Fine aggregates such as silica sand, silicon carbide sand, bauxite sand, and others may be used.*
2) *It is a common practice that the maximum coarse aggregate size is less than 1/3 of the fibre length to ensure fibre efficiency and ductility.*

U.4.3.4 Mineral fillers

Mineral materials, processed or natural, suitable for use in concrete, with a nominal maximum particle size smaller than 80 µm may be used in UHPC.

Note: *Mineral fillers such as silica flour or quartz powder, ground limestone, or others may be used.*

U.4.3.5 Fibres

U.4.3.5.1

The fibres may be metallic or non-metallic.

U.4.3.5.2

Each lot of metallic fibres supplied shall meet Clause 4.2.5.1.

U.4.3.5.3

Each lot of non-metallic fibres supplied shall have a manufacturer's certificate of compliance and test reports.

U.4.3.6 Admixtures

Chemical admixtures shall comply with the applicable requirements of ASTM C494/C494M, ASTM C1017/C1017M, ASTM C1622/C1622M, and ASTM C260.

Note: *Air entraining admixtures conforming to ASTM C260 are normally not used in UHPC.*

U.4.4 Proportioning

U.4.4.1 General

Mix proportions shall be selected to provide

a) workable material consistent with placement and finishing requirements;
b) durable concrete meeting the requirements of Clauses U.4.1.2 to U.4.1.8;
c) the specified strength, which shall be such that both durability and structural requirements are met; and
d) other properties specified by the owner.

Note: *The compatibility of concrete materials meeting the requirements of this Standard should be ascertained when selecting the mix proportions. For example, the compatibility of admixtures with cement should be checked for stability of setting times or workability, segregation and fibre orientation.*

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U.4.4.2 Matrix

The matrix of UHPC shall be designed to provide an optimized particle packing, a minimum void space, the maximum number of contact points between particles, and a discontinuous pore structure.

Notes:

1) *To achieve the high strengths and superior performance of UHPC, it is necessary to reduce the void space in the matrix and properly select the components based on both the particle size and mechanical properties. Generating the maximum number of contact points between particles distributes the stress transferred between particles and through the paste. This reduction and levelling of force alleviates the formation of micro-cracks in the matrix and ultimately results in improved mechanical properties.*
2) *The matrix of UHPC is optimized for particle packing (i.e., the mixture proportions of typical components such as sand, silica fume and cement are optimized to achieve the densest packing possible). Another aspect of UHPC is that some cementitious material particles may not take part in the hydration process, but merely serve as fine aggregate in the overall matrix. Due to the low water content, it is common for hydration in UHPC to be only about 30 to 50% complete.*

U.4.4.3 Fibres

U.4.4.3.1

The fibre type, tensile strength, surface aspect, aspect ratio, size, and quantity shall be optimized within the matrix to provide isotropic hardened properties (random orientation).

U.4.4.3.2

For UHPC Categories H and S, the fibre content shall be sufficient to provide the minimum post-cracking tensile strength as specified in Clause U.4.1.2.2.

Note: *UHPC by definition can have ductile capacity such as to restrain or resist cracking due to its utilization of fibre reinforcing. Fibres vary in concentration but are mostly utilized in ratios of 1 to 3% by volume. These fibres are in most cases high strength carbon steel.*

U.4.5 Laboratory quality control and testing

U.4.5.1 General

U.4.5.1.1

The testing laboratory technicians conducting UHPC mixture proportioning shall be qualified.

Notes:

1) *Typically, a qualified laboratory technician should receive training on UHPC mixture proportioning and testing methods by a person having a minimum of 3 years' experience in UHPC materials technology.*
2) *The proportioning methods used for UHPC require a knowledge of modified compact grading and specific understanding of the matrix-fibre interactions so as to provide a dense, flowable mix with proper fibre dispersion and orientation, while ultimately providing the required hardened properties.*

U.4.5.1.2

The testing laboratory technicians conducting UHPC field quality control and quality assurance testing shall be qualified.

Notes:

1) *Typically, a qualified laboratory technician should receive training on UHPC testing methods by a person having a minimum of 3 years' experience in UHPC materials technology.*
2) *Due to UHPC's high strength, low permeability, and high durability properties, the material requires largely modified testing equipment and procedures, which demand a higher standard of precision.*

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U.4.5.2 Laboratory testing

The laboratory conducting UHPC mixture proportioning, field quality control, and quality assurance shall have the equipment and facilities necessary to conduct the tests on the fresh and hardened UHPC in accordance with Clause U.4.1.

U.4.5.3 Fresh properties

Fresh property test shall be started within the first minute after discharging from the mixer.

U.4.5.4 Hardened properties

U.4.5.4.1

When developing the mixture proportions of UHPC, the specimens tested to validate the hardened properties shall be in accordance with Clause U.4.1.

U.4.5.4.2

The size of specimens cut from structures shall comply with Clauses U.4.1 and U.7.6.

Note: *Specimens cut from full sized structures can have a different fibre orientation and dispersion compared to specimens cast in laboratory moulds, and hence different tensile properties. Casting methods, flowability of the fresh UHPC, and element shape could impact the fibre orientation and dispersion in the full sized element.*

U.4.5.4.3

The field validation of the tensile strength of the UHPC may be in accordance with ASTM C293/C293M, with specimens prepared in accordance with Clause U.4.1.5.

U.4.5.4.4

The UHPC supplier shall provide the strength properties in accordance with Clauses U.4.1.2 and U.4.5.4.5.

U.4.5.4.5

All strength properties of UHPC listed in Clause U.4.1.2 on the material identity card shall be based on at least 30 consecutive strength tests of specimens coming from a minimum of 3 separate batches of a single mix design. A minimum of 3 and a maximum of 10 specimens per batch shall be used. The provided values of each parameter shall be equal to the average minus 1.4 times the standard deviation of the 30 consecutive strength tests.

U.5 Production and delivery

U.5.1 Storage, handling, and processing

U.5.1.1

Raw materials, including aggregates, fillers, and fibres, shall be stored, handled, and processed in a way that protects from moisture exposure, contamination, and/or deterioration.

U.5.1.2

Non-metallic fibres shall be protected from UV exposure during shipping and storage prior to batching.

Note: *Discolouration of some non-metallic fibres could be an indication of UV exposure. In this case, the fibres should be rejected.*

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U.5.1.3

Metallic fibres with some surface oxidation may be used in UHPC provided that they remain as individual strands and free flowing.

Notes:

1) *Rust of steel fibre should be noted and severity assessed.*
2) *Rusted clumps of fibres will affect proper dispersion and should be rejected.*

U.5.1.4

Alkali-resistant bundled glass fibres shall be protected such that they remain in bundled form.

Note: *If glass fibre bundles do not remain intact (during shipping, storage, or mixing), they will not provide the intended mechanical properties and should be rejected.*

U.5.1.5

All liquid raw materials shall be protected from freezing and moisture changes. Liquid raw materials that have segregated shall be sufficiently mixed prior to use.

U.5.2 Manufacture of pre-blended UHPC

Note: *This Clause applies to pre-blended materials supplied to a concrete producer by a supplier of pre-blended UHPC and partial pre-blended UHPC.*

U.5.2.1 Pre-blending equipment

U.5.2.1.1 Cleaning

The pre-blending equipment shall be thoroughly cleaned prior to manufacturing the pre-blended UHPC to avoid cross contamination.

U.5.2.1.2 Calibration

The first dry blend in a new blending facility shall be sampled and calibrated to determine the minimum blending time. Any new blend design shall be sampled in the same fashion as a first dry batch. The samples shall be obtained at 1 min intervals then tested for flow and compressive strength, in accordance with Clauses U.4.1.2 and U.4.1.4.

U.5.2.2 Blending of pre-blended UHPC

Prior to blending, the raw materials shall be stored in accordance with Clause U.5.1. Each raw material shall be introduced into the blender in accordance with the tolerances specified in Clause U.5.3.4. The manufacturer shall maintain a record of all batch weights for each raw material on a per batch basis.

U.5.2.3 Quality control

The pre-blend manufacturer shall take a minimum of one sample, or one sample of the pre-blend, every five batches, whichever is more frequent. Half the volume of each sample shall be provided to the UHPC manufacturer for testing while the other half shall be retained by the pre-blend manufacturer for 2 years. The sample shall be a minimum of 20 L.

U.5.2.4 Packaging

The mass variation of packaged UHPC pre-blend shall be within ±2% of the mass stated on the packaging and shall have a lot number for cross reference to any testing at the blending facility.

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U.5.2.5 Shelf life of pre-blended UHPC

The pre-blended UHPC shall be used by the expiration date in accordance with the manufacturer guidelines and as stated on the material identity card in accordance with Clause U.4.2.

Note: *Depending on storage practices, UHPC pre-blend can remain usable for up to 2 years.*

U.5.3 Batching of UHPC

U.5.3.1 Mixing equipment

U.5.3.1.1

One of the following styles of mixers shall be used to batch UHPC:

a) pan;
b) planetary;
c) horizontal shaft drum; or
d) ready mix truck.

Notes:

1) *UHPC batching requires high shear to optimize mixing efficiency and keep mixing time short.*
2) *When satisfactory performance is found in one mixer, the performance of mixers of substantially the same design and blade condition may be regarded as satisfactory for batching the same quantity of UHPC.*
3) *The mixer should be approved for use by the UHPC supplier as proper mixing is critical and most systems are not designed specifically for UHPC.*
4) *Ready mix trucks may be used to mix UHPC, however mixing times are much longer, which can result in higher concrete temperatures. The UHPC producer should use caution when using fast setting UHPC.*
5) *Batch sizes should be optimized and confirmed for the mixer type being used. Typically batch size should not exceed 70% of mixer volume.*

U.5.3.1.2

The mixer shall have sufficient torque to handle the transition of UHPC from dry to fluid state.

U.5.3.1.3

The mixer shall have a screen at the opening of the charging point to sieve out any lumps. The screen mesh size shall prevent particles greater than 35 mm from passing.

Notes:

1) *The screen at the opening of the charging point is required to collect lumps. Lumps that make it through the process should be further screened or removed from the UHPC ensuring no detriment to performance such as flow. UHPC pre-mix that has become lumpy due to partial hydration or dampness should be avoided. After removal of any lumps the flow should be assessed to ensure the batched UHPC is consistent with previous batches. Compressive strength should be confirmed when a high proportion of lumps are present.*
2) *Due to the fine gradation of UHPC pre-mix certain raw materials are susceptible to packing. As there is typically no coarse aggregate in UHPC to pulverize lumps and some lumps may make it all the way through to the final product.*
3) *If the batch is still in the mixer, extra premixed powder may be added to reduce the flow to the acceptable range.*

U.5.3.1.4

Mixers shall be examined daily for accumulation of concrete. Build-up of concrete on the fins or blades shall be removed.

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U.5.3.1.5

Mixers shall be examined daily for wear. Blades, fins, or paddles with more than 15% wear shall not be used.

U.5.3.1.6

The spacing tolerances of pan, planetary, and horizontal shaft drum mixers, particularly the gap between paddles and the mixer wall and floor, shall satisfy the manufacturer's specifications or be no more than 6 mm, whichever is less.

U.5.3.1.7

All safety features on the mixer shall be operable and conform to the local safety standards.

U.5.3.2 Operation of mixers

The entire batch of UHPC shall be discharged before recharging.

Notes:

1) *Cleaning the mixer between batches is not required if the mixer is reloaded within the working time of the mix.*
2) *Due to the variance in UHPC setting characteristics, a wide variety of mixing times can be acceptable. It is the responsibility of the UHPC supplier to determine the appropriate batching method.*

U.5.3.3 Materials tolerance and accuracy

U.5.3.3.1 Dry ingredients

U.5.3.3.1.1

Pre-blend, cement, aggregate, filler, SCMs, dry admixtures, and fibre shall be measured by mass by means of a scale to meet the accuracy listed in Table U.6.

U.5.3.3.1.2

Tolerance (by mass), if delivered in bags, shall be checked every fifth bag to meet the accuracy listed in Table U.6.

U.5.3.3.2 Wet ingredients

Liquid admixtures and water/ice shall be measured by mass by means of a scale. Volumetric methods for measuring may be used but shall meet Table U.6.

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Table U.6
Material batching tolerances
(See Clauses U.5.3.1.1, U.5.3.1.2, and U.5.3.3.2.)

	Pre-blended UHPC(by mass)	Non pre-blended UHPC (by mass)
Dry materials	±2%	Individual materials ±1% and Sum of all must be < ± 2%
Water	±2%	±2%
Admixture	±1%	±1%
Fibre	–2%/+4%	–2%/+4%

Note: *100% pre-blended UHPC is any pre-blended mixture that requires no extra cement, aggregate, filler, or SCM to batch UHPC.*

U.5.3.4 Mixer batching procedures

U.5.3.4.1

Batching procedures shall be determined and validated from samples taken and tested for flow, compressive strength, and tensile strength in accordance with Clause U.4.1.

U.5.3.4.2

Any changes to the batching procedures determined in accordance with Clause U.5.3.4.1 shall be revalidated in accordance with Clause U.5.3.4.1.

Notes:

1) *During transportation of pre-blended UHPC, segregation of the constituent materials could occur. Ensure adequate dry mixing of the pre-blend in the mixer before adding liquids.*
2) *Typically all dry components are added to a dry mixer first, followed by water and admixtures. Once the mix is fluid, or adequately plastic, the fibres are added.*

U.5.3.4.3

It shall be the responsibility of the pre-blended mixture supplier or the UHPC supplier to determine the mixing procedures in accordance with Clause U.5.3.4.1.

Note: *Testing and technical expertise of the UHPC supplier and mixer manufacturer should be sufficient to determine the mixing efficiency, mixing time and maximum/minimum batching size for specific mixing equipment.*

U.5.3.5 UHPC batching quality control

U.5.3.5.1 Pre-batching checks

Inspection shall be conducted prior to batching of UHPC and shall cover the following:

a) Confirm that the mixer has a screen on the charging point of the mixer.
b) Confirm the mixers are free of excess wearing of blades, fins, or paddles and accumulation of hardened concrete.
c) Confirm that the correct raw materials are being used.
d) Check for any colour changes as a sign of deterioration for the fibres and admixtures.
e) Confirm specific gravity of liquid materials.
f) Confirm fibre complies with Clause U.5.1.
g) Check pre-blended materials for any signs of lumps or ageing.

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h) Confirm inspection personnel and laboratory equipment meet the requirements of Clauses U.4.5.1.1 and U.4.5.1.2.

Note: *The visual inspection is required to minimize the risk of incorrect, damaged materials or other problems during batching. The inspection should review the following:*

a) *correct materials that comply with the project specifications;*
b) *sufficient materials to complete the project; and*
c) *any damage or deterioration of the raw materials or packaging.*

U.5.3.5.2 Plastic properties

Every UHPC batch shall have the following documented information retained by the contractor responsible for batching:

a) name and location of batch plant (if not batched on-site);
b) date;
c) name of contractor (if applicable);
d) specific job designation;
e) amount of uhpc in cubic metres (per batch and total);
f) mass of each material component added to mixer;
g) mixer id and/or batch number;
h) time of water addition;
i) time of discharge;
j) mixing time;
k) temperature (batch and ambient);
l) flow;
m) material identification and supplier;
n) amount of water added after initial batching;
o) amount of admixture added after initial batching;
p) amount of powder added after initial batching; and
q) batch from which the hardened properties were obtained.

Note: *The mix components for pre-blend are quantities of blended powders, fibres, admixtures, water, and other items to be added to the mixer.*

U.5.3.5.3 Hardened properties

U.5.3.5.3.1

At least once per production shift the following tests shall be performed:

a) three cylinders for early compressive strength (UHPC loading strength, as specified by the owner);
b) three cylinders for 28 day compressive strength;
c) three cylinders for compressive strength when thermal treatment is specified; and
d) five cylinders for 56 day compressive strength, when specified.

U.5.3.5.3.2

If specified, at least once per production shift, three prisms shall be taken for determination of flexural strength in accordance with Clause U.4.5.4.3.

Notes:

1) *The owner should specify any requirements for flexural testing.*
2) *To validate the effects of casting methods on the hardened properties of the UHPC, see Clause U.7.1.4.9.*

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U.5.3.5.3.3

The batch from which the hardened properties were taken shall be noted on the daily QC report and on the cylinders or prisms.

U.5.3.6 Placing temperature

U.5.3.6.1

The temperature of the UHPC when placed shall be between 5 and 30 °C.

Note: *See Clause U.7.2.2, Note 4).*

U.5.3.6.2

Temperature shall be tested in accordance with CSA A23.2-17C.

Notes:

1) *Pre-heating of the pre-mix and longer batch times may be used to raise the placing temperature. Chilled pre-mix and ice in the mixer may be used to lower placing temperature.*
2) *Acceptable placing temperature ranges can be narrower than Clause U.5.3.6.1 depending on the characteristics of the UHPC mix design.*
3) *Control of the material temperature during batching will provide the ability to accelerate or slow the working time, setting times, and rate of early strength gain.*
4) *Cooler placing temperatures increase workability and pot life. Flows should be adjusted to avoid segregation or fibre settlement during cooler placing temperatures.*

U.5.3.7 Mix adjustments and retempering

U.5.3.7.1

UHPC mix adjustments and retempering at the time of batching shall only be conducted by qualified UHPC technicians.

Note: *Mixer type, mix design, and temperatures all play important roles in what adjustments can be made (i.e., powder addition, water/ice addition, admixture addition).*

U.5.3.7.2

Qualified technicians should be trained by an individual having a minimum of 3 years' experience in UHPC material technology.

U.5.3.7.3

The adjusted water content shall not exceed that specified on the material identity card. If adjustments or retempering exceed the design water-to-cementitious materials ratio, the batch shall be discarded.

U.5.3.7.4

The addition of admixtures for retempering of the UHPC shall not exceed the dosages stated on the material identity card.

U.5.3.7.5

Mix water or admixtures shall not be added to the UHPC after discharging from the mixer.

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U.5.4 Time of delivery and placement of UHPC

U.5.4.1 Delivery of UHPC batched on-site

U.5.4.1.1
UHPC shall be transported from mixer to point of delivery as rapidly as practicable.

U.5.4.1.2
The time from the ending of mixing to the end of placement shall be in accordance with Clause U.5.4.3.

U.5.4.1.3
The equipment used to transport the UHPC shall be smooth, watertight metal or plastic containers with the ability to guide the flow of UHPC as it is placed. Covers shall be available to provide protection against inclement weather and dehydration.

U.5.4.2 Delivery of UHPC batched off-site

U.5.4.2.1
UHPC batched off site shall be transported by ready-mix concrete truck.

U.5.4.2.2
The time from start of mixing to the end of placement shall be in accordance with Clause U.5.4.3.

U.5.4.2.3
Each load shall be documented and tested in accordance with Clauses U.5.3.5.2 and U.5.3.6 prior to placement.

U.5.4.3 Delivery time
The UHPC supplier shall provide pre-pour testing, for flow, to determine the maximum allowable delivery time.

Note: *The time limit for UHPC delivery is dependent on the mix design and temperature. It is typically 1 to 2 h; however, there have been experiences where UHPC has been successfully placed following significantly longer periods after initial water addition.*

U.6 Formwork, reinforcing, and prestressing

U.6.1 Macro reinforcement

U.6.1.1
Minimum clear spacing between any reinforcing bars, tendons, or mesh shall be 1.5 times the length of the fibre reinforcement or 1.5 times the maximum coarse aggregate diameter, whichever is the greater.

Note: *Fibre orientation should be validated at the contact surface of the flow when casting UHPC around any embedments or reinforcing elements within the flow of the UHPC.*

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U.6.1.2

Minimum clear spacing between the face of the formwork and any reinforcing bars, tendons, or mesh shall be 1.5 times the length of the fibre reinforcement or 1.5 times the maximum coarse aggregate diameter, whichever is the greater.

U.6.1.3

UHPC shall have a minimum of 110 MPa compressive strength at the time of releasing prestressing loads into the element, unless a prior validation of an alternative compressive strength is determined.

U.6.2 Construction tolerances

Construction tolerances shall comply with MNL 135 except for elements with a dimension of less than 50 mm thickness, where the tolerance shall be as follows:

a) For a thickness dimension of 25 mm to 50 mm, the tolerance shall be ± 3 mm.
b) For a thickness dimension of equal to or less than 25 mm, the tolerance shall be ± 2 mm.

Notes:

1) *In most cases tolerances as described in Clause 6.4 and in MNL 135 may be used as a guideline when forming and producing UHPC. UHPC applications have a significantly reduced construction tolerance. The owner will need to bring this to the attention of the constructor.*
2) *Tolerance should also be checked for structural requirements to minimize the risks of buckling, induced off-centre loads, unsymmetrical prestressing forces or aesthetics.*

U.6.3 Formwork

U.6.3.1

Formwork shall be designed and constructed grout tight to withstand the fluid static pressure head.

Notes:

1) *Fluid static pressure head is the UHPC density x the height of the formwork. Typically, UHPC has a density of between 2400 and 2800 kg/m³.*
2) *Grout tight formwork and chamfered corners and edges help mitigate the potential for fibre protrusion.*

U.6.3.2

Formwork deflections shall take into consideration construction tolerances in accordance with Clause U.6.2.

Note: *Prolonged fluid and plastic states should be taken into consideration in the formwork and sealant design.*

U.6.3.3

The sealant used in the formwork shall be capable of bridging the differential deflection, shearing action, and the fluid pressure.

U.6.3.4

Formwork shall be constructed to minimize restraint of fresh and setting UHPC during shrinkage.

U.6.3.5

Formwork that is released to accommodate shrinkage shall be designed to support the elements until it has attained sufficient strength to be self-supporting.

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U.6.3.6

The formwork material in contact with UHPC shall not be constructed of aluminium or magnesium.

Notes:

1) *Compressible materials or other methods may be utilized to limit restraint of UHPC shrinkage.*
2) *Stress concentrations due to shrinkage may be reduced by incorporating gradual transitions between different angles in the element.*
3) *Partially demoulding the restrictive areas during UHPC's initial hydration can allow for unrestrained shrinkage.*
4) *Formwork should be designed to support the element during the partial demoulding phase and full demoulding phase.*
5) *Formwork design should accommodate thermal dilation due to different heating rates caused, in part, by significant differentials in mass within the element or the cross section.*
6) *The contact surfaces should allow for unrestrained shrinkage. Use of a highly hydrophobic, low friction mould surface, with no indentation that could act as micro or macro anchor point, combined with a slippery mould release agent are recommended.*
7) *Non-prismatic cross sections: Adjacent portions of a monolithic cross section that have greater than 30° changes in direction should incorporate a concave transition zone with a radii greater than 3x the largest thickness of the adjacent intersecting planes.*
8) *The formwork material may be metal (except aluminum or magnesium), plastic, rubber, wood (with appropriate surface treatment), urethane, or other material capable of producing a finish without bonding to or removing moisture from the UHPC.*

U.7 Placing, finishing, and curing UHPC

U.7.1 Placing of UHPC

U.7.1.1 General

U.7.1.1.1

UHPC placing methods and equipment shall convey and deposit the material without segregation, ensuring that the fibres maintain a continuous overlap, and without changing or adversely affecting the specified fresh or hardened properties.

Note: *UHPC requires different methods compared to conventional concretes or HPC and normal best practices will be insufficient to achieve a satisfactory finished product.*

U.7.1.1.2

Placing methods shall consider the impact of internal reinforcing and other cast in elements.

Note: *The inclusion of normal reinforcing (rebars or strands) could interfere with the placing of the UHPC and cause a separation of the fibres when flowing around the reinforcing.*

U.7.1.2 Bonding fresh UHPC to hardened concrete

U.7.1.2.1

When bonding fresh UHPC to hardened UHPC, the hardened UHPC surface shall be roughened to expose the fibre matrix and cleaned to create a mechanical bond, then pre-wetted to saturated surface dry (SSD), prior to placing the fresh UHPC. Dowel bars or mechanical bond may also be used.

Note: *Chemical bonds to UHPC can be achieved with products such, as epoxy based compounds. The performance of the bonding agent should be verified.*

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U.7.1.2.2

When bonding fresh UHPC to hardened HPC or normal concrete, the hardened HPC or normal concrete surface shall be roughened to expose the aggregate by removing matrix material and cleaned to create a mechanical bond, then pre-wetted to SSD, prior to placing the fresh UHPC. Dowel bars or mechanical bond may also be used.

U.7.1.3 Handling

Placing equipment shall provide for the vertical deposition of the UHPC into the form. Elevation drops shall not exceed 1 m and shall be validated by the contractor and supplier prior to use.

Notes:

1) *Rather than elevation drops, different methods, such as injection from the bottom of the form, or incorporating the use of a tremie pipe, should be used.*
2) *Free fall drops can result in segregation of fibres.*
3) *Pressure injection using gravity to create a hydraulic head can be used to place UHPC in confined spaces.*
4) *Mechanical pumping should not be used for UHPC.*

U.7.1.4 Depositing

U.7.1.4.1

UHPC shall be deposited in the forms in a manner that prevents segregation.

Notes:

1) *UHPC should be placed in a location as close as practicable to its final position.*
2) *Manipulation of UHPC in the form should be avoided.*

U.7.1.4.2

UHPC shall be placed monolithically, except if conditions do not allow for monoliths, then Clause U.7.1.4.3 shall apply.

U.7.1.4.3

If UHPC cannot be placed monolithically, casting procedures shall be modified to ensure that the interface between the two pours acts monolithically and samples shall be cut from the full sized element to validate the hardened properties, in accordance with Clause U.4.1.2.2.

Notes:

1) *The pouring or injection of UHPC should be planned and executed to avoid two or more wave fronts intersecting and reducing the potential for discontinuity of fibre overlap and promote isotropic fibre distribution.*
2) *In situations where multiple wave front intersection is unavoidable, internal mixing should be applied using a slow rotating propeller submerged at the intersection borders, immediately after casting.*
3) *A 6 to 10 cm diameter propeller attached to a shaft or "L" shaped rod should be inserted full depth. This propeller or rod should be gradually extracted while being rotated.*
4) *Casting sequences should also consider procedures to ensure that the preferential flow of fibre does not conflict with the stress orientation.*

U.7.1.4.4

UHPC in place shall not be subjected to injurious vibration or shock that may cause fibre segregation or misalignment.

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U.7.1.4.5

The depositing of UHPC shall be as continuous as possible until the placing of the section is completed. UHPC shall be cast into plastic UHPC.

U.7.1.4.6

The pour point of UHPC shall not advance ahead of the leading edge of the wave front in the formwork or mould. The UHPC shall be poured from one end of the formwork or just behind the wave front of the UHPC.

U.7.1.4.7

When UHPC is placed by pumping, the entire length of line shall be moistened with water to attain and maintain a moist, with no excess water, condition. The length of the line shall be 3 m maximum, except as stated in Clause U.7.1.4.8.

U.7.1.4.8

UHPC may be pumped in lines greater than 3 m in length if prior validation shows no negative impact on the fresh and hardened properties of the UHPC.

U.7.1.4.9

For Categories H and S, the effects of the casting methods on the tensile properties of the UHPC shall be validated in accordance with Clause U.4.1.2.2 on prismatic specimens cut from the full size structure.

U.7.1.5 Consolidation

U.7.1.5.1 General

UHPC shall be consolidated in a manner that prevents segregation and fibre redistribution.

U.7.1.5.2 Vibration

U.7.1.5.2.1

Internal vibration shall not be used, except for Category N UHPC.

U.7.1.5.2.2

External vibrators may be used only after validating that the fibre distribution and orientation is not negatively impacted. Vibrators shall be applied systematically and at such spacing intervals that the zones of influence overlap.

Notes:

1) *The preferred approach for placement is the proper design of the mix to provide adequate flow to fill the formwork and moulds while maintaining isotropic fibre orientation.*
2) *Internal vibrators will cause segregation and misalignment of the fibres.*
3) *A sufficient number of vibrators should be provided to compact the UHPC properly at the rate that it is being placed.*
4) *The vibrator(s) may be placed on or attached to the formwork or mould of the UHPC. Alternatively, the entire formwork or mould may employ integral vibration.*
5) *Excessive vibration causes segregation of fibres that possess different densities relative to the UHPC matrix; higher densities sink while lower densities rise.*
6) *Alternative consolidation can include displacement, spraying, or vacuum techniques.*

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U.7.2 Protection and curing

U.7.2.1 Protection of fresh UHPC

UHPC shall be protected against excessive loss of moisture.

Notes:

1) *UHPC normally does not exhibit bleeding and should be protected from surface dehydration and potential plastic shrinkage cracking.*
2) *Failure to protect against moisture loss could result in crusting, blistering, cracking and delamination.*
3) *The following measures may be taken:*
   a) *lowering the UHPC or ambient temperature;*
   b) *increase humidity at the surface;*
   c) *immediate full contact covering of the UHPC surface with waterproof sheeting; or use a roll-on or spray applied curing compound at a rate prescribed in the manufactures recommendations and deemed appropriate by the manufacturer.*

U.7.2.2 Temperature effects

The UHPC material shall be protected against differential thermal stresses that could potentially cause cracking.

Notes:

1) *Due to the composition of UHPC and the type of form or mould construction, high temperatures similar to mass concrete effects are present in elements with much smaller volumes or cross sectional areas compared to HPC or conventional concrete.*
2) *Care should be taken to prevent the build-up of internal heat.*
3) *Elements with different mass/surface area ratios transfer heat at different rates. Caution should be taken to minimize the differential thermal stress throughout the element.*
4) *When the internal temperature of the UHPC as placed is consistently above 25 °C (depending on raw materials and humidity), consideration should be given to the use of ice as a replacement for some or all of the water in the UHPC mix to reduce the total temperature of the material. At 25 °C, the replacement of part of the mix water with ice should be considered, as the temperature reaches 30 °C full replacement should be considered.*

U.7.2.3 Curing

U.7.2.3.1 General

Curing requirements for field cast and precast UHPC shall begin immediately following the placing and finishing operations and shall provide the temperature and moisture conditions for the period of time necessary for UHPC to develop its strength, durability, and other properties. All materials and equipment needed for adequate protection and curing shall be on hand and ready for use before each UHPC placement is started. Curing requirements for plant cast precast elements shall comply with CSA A23.4, Clause 23.

Notes:

1) *UHPC strength can be assessed by testing field-cured cylinders or by using nondestructive testing methods, provided they have been calibrated in relation to the reference characterization procedure.*
2) *UHPC continues to gain strength under moist conditions and favourable temperature conditions. Following the cessation of moist curing, the development of strength continues provided that temperature conditions are favourable.*

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U.7.2.3.2 Methods and materials

U.7.2.3.2.1 Methods

Curing of UHPC surfaces shall be achieved by immediately using one or more of the following methods:

a) curing compounds of a type and with a method and a rate of application, approved by the owner;
b) waterproof plastic film placed in full contact with the UHPC surface; or
c) forms in full contact with UHPC surface.

U.7.2.3.2.2 Curing for accelerated strength development

U.7.2.3.2.2.1

When it is desired to reduce the curing period by developing the required level of strength within a shorter period, the owner's permission shall be required.

U.7.2.3.2.2.2

The UHPC supplier shall provide a protocol to follow in order to achieve the accelerated strength development with no detrimental effect to the final properties and in accordance with Clause U.4.1.6.

Note: *Acceleration of strength development can be obtained by the use of accelerating admixtures or heat.*

U.7.3 Demoulding: timing and sequencing

U.7.3.1 General

The timing and sequencing of the demoulding phase of UHPC construction shall accommodate the high early age shrinkage attributes of this class of material and the required minimum strength to support the self-weight of the element without damaging the material properties.

Note: *UHPC typically exhibits a shrinkage of 500 to 1000 microstrains. This is due to the high proportion of cementitious paste, low water to cement ratio, and absence of coarse aggregate. When planned and executed correctly, the UHPC element is allowed to shrink without restraint, resulting in a crack free surface. For thin bonded overlays strain-hardening UHPC should be used in order to obtain a surface with minimal visible cracking.*

U.7.3.2 Minimum compressive strength at demoulding

UHPC shall have a minimum of 100 MPa compressive strength before full demoulding, unless prior validation of an alternative strength is determined.

Note: *Where curing is being supplied by the formwork, form removal or demoulding may require application of a replacement curing regimen for the newly demolded concrete.*

U.7.4 Thermal treatment

If specified by the owner, precast UHPC elements shall receive thermal treatment in accordance with Clause U.4.1.6.3.

U.7.5 Surface treatments

U.7.5.1

The application of surface treatments after demoulding shall be validated for bond, performance, and compliance with the manufacturer's recommendations.

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U.7.5.2

Prior to the application of surface treatments, the UHPC shall be clean and free of contaminants with the surface texture to enhance the bond and conform to the desired finish.

Note: *Due to the low permeability of UHPC, any surface sealant should be validated to ensure that it will adhere and will not peel prematurely.*

U.7.6 Grinding, cutting, and coring

Grinding, cutting, and coring shall not damage the continuity of embedded reinforcements nor reduce the minimum required cover over the embedded reinforcements.

Notes:

1) *UHPC may be cored or surface ground by using diamond bladed equipment.*
2) *Although UHPC has improved abrasion resistance, grinding and coring can be done with the proper equipment and potentially longer duration. Typically, grinding and coring should be done when the UHPC is in the range of 100 to 120 MPa compressive strength. At higher strength it is still manageable but will consume more time and equipment.*
3) *Proper personal protective equipment and procedures should be employed at all times.*

U.7.7 End of life treatment

At the end of the service life, the element shall be considered for reuse.

Notes:

1) *Although there are no significant safety or environmental considerations for UHPC that are different from regular concrete, end of life reuse, recycling, or disposal options do have special considerations. Due to the nature of UHPC, it is extremely challenging to demolish UHPC elements as it is designed to be highly resistant to such intentional destructive treatment.*
2) *Primary consideration should be given to reuse of structural elements if the element meets the required mechanical performance characteristics and this can be achieved with minor physical modifications. If UHPC does need to be disposed of, diamond cutting large elements into smaller, more manageable sizes should be undertaken.*

U.8 Additional references

ACI (American Concrete Institute)

239 A (under development)
ETR on Ultra-High Performance Concrete

AFGC (Association Française de Génie Civil)

Bétons Fibrés Á Ultra-Hautes Performances: Recommandations (2013)

AFNOR (Association française de normalisation)

NF P18-710 (2016)
National addition to Eurocode 2 — Design of Concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC)

NF P18-470 (2016)
Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC): Specifications, performance, production and conformity

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ASTM International

C39/C39M-18
Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

C138/C139M-13
Standard Test Method for Density (Unit Weight), yield, and Air Content (Gravimetric) of Concrete

C157/C157M-08
Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

C191/C191M-13
Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle

C231/C231M-17a
Standard Test Method for Air Content of Freshly Mixed concrete by the Pressure Method

C642/C642M-13
Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

C666/C666M-15
Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C672/C672M-12
Standard Test Method for Scaling Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method

C1202-19
Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

FHWA (Federal Highway Administration)

FHWA-HRT-13-060 (2013)
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JSCE (Japan Society of Civil Engineers)

Guidelines for Concrete No. 9, 2006
Recommendations for Design and Construction of Ultra High Strength Fiber Reinforced Concrete Structures (Draft)

PCI (Precast/Prestressed Concrete Institute)

MNL 135-00
Tolerance Manual for Precast and Prestressed Concrete Construction

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De Larrard, F., T. and Sedran. 1994. Optimization of Ultra-High-Performance Concrete by the Use of a Packing Model. *Cement and Concrete Research.* 24(6):997–1009.

Habel, K., J-P. Charron, E. Denarié, and E. Brühwiler. 2006. Autogenous deformations and viscoelasticity of UHPFRC in structures — Part I: Experimental results. *Magazine of Concrete Research*. 58(3):135–145.

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National Standard of Canada

CSA A23.2:19

Test methods and standard practices for concrete



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CSA A23.2:19
Test methods and standard practices for concrete

1 Scope

1.1 General

This Standard covers the principal test methods for hardened and freshly mixed concrete and for concrete materials, as specified in CSA A23.1 and CSA A23.4. The test methods are organized as follows:

a) aggregate test methods;
b) miscellaneous;
c) concrete test methods; and
d) dimensional (moulds).

1.2 Hazards

This Standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this Standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Note: *Since many users provide individual copies of the test methods for use in the laboratory, the "Hazards" clause is repeated in each test method.*

1.3 Dimensions

This Standard is presented in metric units in accordance with CAN/CSA-Z234.1.

Note: *The ASTM Standards that are referenced herein are often based on the imperial system, with soft metric equivalents. Where ASTM Standards are referenced, the appropriate metric units in the ASTM Standards should be used wherever possible. When the ASTM Standards refer to other ASTM Standards for which there are equivalent CSA Standards, the latter Standards should be used to ensure a continuity in such things as sieve sizes, metric units, and other particular differences between the Standards.*

1.4 Terminology

In this Standard, "shall" is used to express a requirement, i.e., a provision that the user is obliged to satisfy in order to comply with the Standard; "should" is used to express a recommendation or that which is advised but not required; and "may" is used to express an option or that which is permissible within the limits of the Standard.

Notes accompanying clauses do not include requirements or alternative requirements; the purpose of a note accompanying a clause is to separate from the text explanatory or informative material.

Notes to tables and figures are considered part of the table or figure and may be written as requirements.

Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

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2 Reference publications

Publications to which this Standard makes reference are listed in Clause 2 of CSA A23.1. For user convenience, relevant publications have also been added to the test methods in which they are referenced.

3 Definitions

For definitions of terms used in this Standard, see Clause 3 of CSA A23.1. For user convenience, relevant definitions have been included in the test methods in which they apply.

4 Reporting

The reporting section of each test method is typically divided into two sections, Required Information and Optional Information. If required information is not known at the time of testing, it shall be identified as “unknown” on the test report.

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A23.2-1A
Sampling aggregates for use in concrete

1 Scope

This Standard Practice specifies the procedures for sampling fine and coarse aggregate for use in concrete.

Notes:

1) *Such sampling is intended for preliminary investigation of supply source, acceptance or rejection of supply source, inspection of shipments of materials, and inspection of materials on the work site.*
2) *Acceptance and control tests vary with the type of construction in which the material is used.*

2 Reference publications

This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-14A:19
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-15A:19
Petrographic examination of aggregates

A23.2-25A:19
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-7B:19
Random sampling of construction materials

3 Significance and use

This Standard Practice is intended to provide standard requirements for sampling aggregates for use in concrete. It also identifies responsibilities of all parties involved in the sampling of aggregate.

4 Hazards

This Standard Practice does not purport to address health and safety aspects or requirements as might apply at the sampling location. It should be recognized that local, regional, and/or provincial health and safety requirements within aggregate processing locations can vary, and that working in a pit or quarry can involve mobile equipment and stationary equipment with specific safety precautions. Work at a construction site is likely to involve similar yet distinct safety precautions. Sampling at greenfield sites will likely have its own safety issues. Persons undertaking sampling should familiarize themselves with health and safety requirements at the site of interest, as appropriate and applicable to the authority having jurisdiction.

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5 Sampling responsibility

Samples for preliminary investigation tests shall be obtained by the party responsible for the development of a potential source, or their delegates. Samples of materials for quality control purposes of the production at the source or control of the work at the site shall be obtained by the manufacturer, contractor, or other parties responsible for accomplishing the work, or their delegates. Samples to be used in tests for the acceptance or rejection decisions by the owner shall be obtained by the owner or their delegate.

Notes:

1) *For guidance on sampling aggregate from stockpiles or transportation units, see Attachment A1.*
2) *The sampling for preliminary investigation of potential aggregate sources and types is centrally important in determining the availability and suitability of the largest single constituent entering into construction. It influences the type of construction from the standpoint of economics and governs the necessary material control to ensure durability of the resulting structure from the aggregate standpoint. This sampling should be performed only by an experienced person. For more guidance, see Attachment A2.*

6 Securing and obtaining samples

6.1 General

6.1.1

Every precaution shall be used when obtaining samples so that samples reflect the nature and condition of the materials they represent.

6.1.2

Where practicable, samples that will be tested for quality shall be obtained from the finished product. Samples obtained from the finished product to be tested for abrasion loss shall not be subject to further crushing or manual reduction in particle size in preparation for the abrasion test, unless the size of the finished product is such that it requires further reduction for testing purposes.

6.2 Sampling plan and procedures

6.2.1

The number of samples required shall depend on the intended use of the material, the quantity of material involved, and the variation both in quantity and size of the aggregate. A suitable number of samples shall be obtained so as to represent the possible range of variations in the material. Samples shall be taken from suitable locations based on a sampling plan that will give confidence in results and that is agreed upon by all parties. The sampling plan shall define the number of samples necessary to represent the lots and sublots of specific size.

Note: *A method of determining the sampling points is given in CSA A23.2-7B.*

6.2.2

Separate samples shall be obtained at different times while the material is being loaded or discharged, in order to determine the variation in grading of material.

6.2.3

Separate samples shall be obtained from as many points in the unit of shipment as is necessary to represent the material. The separate samples may be combined to form a composite sample and this

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1A

composite sample, if necessary, may be reduced by quartering or other suitable means before testing. When information on variations is desired, these samples shall be tested separately.

Note: *The sample sizes specified in Table 1 will provide adequate material for routine grading analysis. The quantities should be predicated on the type and number of tests to which the material is to be subjected and sufficient material obtained to provide for the proper execution of these tests.*

Table 1
Size of samples
(See Clauses 6.2.3 and A2.5.)

Type	Nominal maximum size of aggregate, mm	Minimum mass of field samples, kg
Fine aggregate	2.5	10
	5	10
Coarse aggregate	10	10
	14	15
	20	25
	28	50
	40	75
	56	100
	80	150

6.3 Inspection

6.3.1
The material shall be inspected to determine whether discernible variations exist between individual samples, which shall be considered in the sampling plan.

6.3.2
A record shall be made of the observed variations.

7 Marking and shipping of samples

7.1 Marking
Each sample or container shall be accompanied by a suitable card or form, preferably in the container, having the following information:

a) name of the person who sampled it;
b) name of the person who submitted it;
c) source of supply or appropriate sample identification;
d) proposed use for the material, if known/applicable;
e) sample number or identification marks; and
f) date sample was taken.

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7.2 Shipping of samples

7.2.1

Coarse aggregate samples shall be shipped in a clean (i.e., uncontaminated) secure container or sample bag. Corroded steel containers or containers with residual petroleum products or food products shall not be used for sampling aggregates.

7.2.2

Fine aggregate or samples containing fine sizes shall be shipped in a container suitable for preventing the loss of the finer particles.

8 Precision and bias

Precision and bias information for this Standard Practice is not applicable.

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Attachment A1 (informative)
Sampling aggregate from stockpiles or transportation units

Note: *This Attachment is not a mandatory part of this Standard Practice.*

A1.1 Introduction

In some situations, it is necessary to sample aggregates that are stored in stockpiles or loaded into rail cars, barges, or trucks. In such cases the procedure should ensure that segregation does not introduce a serious bias in the results.

A1.2 Sampling from stockpiles

A1.2.1

In sampling material from stockpiles, it is difficult to ensure unbiased samples, due to the segregation that often occurs when material is stockpiled, with coarser particles rolling to the outside base of the pile. For coarse or mixed coarse and fine aggregate, every effort should be made to employ power equipment to develop a separate, small sampling pile composed of materials drawn from various levels and locations in the main pile. After the pile is created, several increments may be combined to compose the field sample. If it is necessary to indicate the degree of variability existing within the main pile, separate samples should be drawn from separate areas of the pile.

Some aggregate operations have developed provisions specifically for the purposes of sampling from conveyor belts. These designs enable a statistically representative sample to be obtained in a safe manner, and with minimal interruption of the plant operation. In such cases, sampling at the belt-sampling location should be noted on the sample record.

A1.2.2

Where power equipment is not available, samples from stockpiles should be made up of at least three portions taken from the top third, the midpoint, and the bottom third of the pile. A board pushed vertically into the pile just above the sampling point aids in preventing further segregation. In sampling stockpiles of fine aggregate, the outer layer, which might have become segregated, should be removed and the sample taken from the material beneath. Sampling tubes approximately 30 mm in diameter by 2 m in length may be inserted into the pile at random locations to extract a minimum of five portions of material to form the sample.

A1.3 Sampling from transportation units

In sampling coarse aggregates from railroad cars or barges, an effort should be made to employ power equipment capable of exposing the material at various levels and at random locations. Where power equipment is not available, a common procedure requires excavation of three or more trenches across the unit at points that will, from visual appearance, give a reasonable estimate of the characteristics of the load. The trench bottom should be approximately level, at least 0.3 m wide and at least 0.3 m below the surface. A minimum of three portions from approximately equally spaced points along each trench should be taken by pushing a shovel downward into the material. Coarse aggregate in trucks should be sampled in essentially the same manner as that in rail cars or barges, except for adjusting the number of portions according to the size of the truck. For fine aggregate in transportation units, sampling tubes as described in Clause A1.2.2 may be used to extract an appropriate number of portions to form a combined sample.

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Attachment A2 (informative)
Exploration of potential aggregate sources

Note: *This Attachment is not a mandatory part of this Standard Practice.*

A2.1 Introduction

Sampling for evaluation of potential aggregate sources should be performed or directed by a responsible, trained, and experienced person. Because of the wide variety of conditions under which sampling can be done, it is not possible to describe detailed procedures applicable to all circumstances. This Attachment is intended to provide general guidance.

A2.2 Sampling stone from quarry faces or ledges

A2.2.1 Inspection

The ledge or quarry faces should be inspected to determine discernible variations or strata. Differences in colour, lithology, and structure should be recorded.

A2.2.2 Sampling and size of sample

Separate samples having a mass of at least 25 kg each should be obtained from each discernible stratum. The sample should not include material weathered to such an extent that it is no longer suitable for the purpose intended. One or more pieces in each sample should be at least 150 mm × 150 mm × 100 mm, with the bedding plane plainly marked, and free of seams or fractures.

A2.2.3 Record

In addition to the general information accompanying all samples, the following information should accompany samples taken from ledges or quarry faces:

a) approximate quantity available (if the quantity is very large, this may be recorded as practically unlimited);
b) quantity and character of overburden; and
c) a detailed record showing boundaries and location of material represented by each sample.

Note: *A sketch of plans and elevations should be made showing the thickness and location of the different layers.*

A2.3 Sampling from prospective quarries or sand and gravel pits

A2.3.1 General

Exploration of sites that are under consideration for development of new quarry or sand and gravel pit aggregate resources should be undertaken by qualified professional geologists or geological engineers who have familiarity with assessment of these deposits. Depending on the nature of the site, its regional context (e.g., presence/absence of nearby aggregate sites, previous successful operations nearby), the knowledge of the geology of the site is paramount in importance in a successful exploration and sampling program.

In general terms, the exploration program should be of an appropriate scale and level of effort to the size of the site and to its geology. If the geology is largely unknown, the expectation for additional exploration efforts should be recognized.

A2.3.2 Quarry site exploration

Exploring a quarry site should involve diamond drilling to extend boreholes into the rock to a depth equivalent to the anticipated depth of the proposed quarry; typically, “NQ” or “HQ” sized core are

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preferred, so that the rock can be characterized in terms of lithology, structure (joints, cracks, and faults), and physical attributes (strength, physical properties, and durability). Hole spacing should be adequate to characterize the site to the degree desired or necessary for the objectives stated by the owner or developed of the site.

Sufficient core should be obtained so that samples adequate to enable the desired characterization work can be completed. This will usually include determination of unconfined compressive strength, and conducting the regimen of tests described in CSA A23.1, Table 12, and CSA A23.2, Test Methods 12A, 14A, 15A, and 25A, and any others considered appropriate for the exploration objectives.

A2.4 Sampling roadside, bank run, or undeveloped sand and gravel deposits

A2.4.1 Inspection

Potential sources of bank run sand and gravel may include previously worked pits at which there is an exposed face. Potential (Greenfield) deposits may be identified through air-photo interpretation, geophysical exploration, or other types of terrain investigation.

A2.4.2 Sampling — Bank run locations/previous pit workings

Sampling should be conducted as follows:

a) Samples should be chosen from each stratum in the deposit discernible to the sampler, as judged to be practical. An estimate of the quantity of the different materials should be made.
b) If the deposit is worked as an open-face bank or pit, samples should be taken by channelling the face vertically, bottom to top, so as to represent the materials proposed for use.
c) Overburden or disturbed material should not be included in the sample.
d) Test holes should be excavated or drilled at a sufficient number of locations in the deposit to determine the quality of the material and the extent of the deposit beyond the exposed face, if any. The number and depth of test holes will depend upon the quantity of the material needed, the topography of the area, the nature of the deposit, the character of the material, and the potential value of the material in the deposit.
e) If visual inspection indicates that there is considerable variation in the material, individual samples should be selected from the material in each well-defined stratum.
f) Each sample should be thoroughly mixed and quartered if necessary so that the field sample thus obtained will be at least 12 kg for sand and 35 kg if the deposit contains an appreciable amount of coarse aggregate.

Note: *The use of geopositioning satellite (GPS) or georeferencing systems can be useful to locate the sample(s).*

A2.4.3 Sampling — Greenfield sites

A similar approach as that used for assessing a prospective quarry site should be employed for assessment and exploration of a Greenfield sand and gravel pit development. Reference should be made, if possible, to neighbouring current or past-producing sites, and to available geological mapping.

The selection of drilling methods or test pitting methods for exploration of the site should take into account the objectives of the developer of the site, the size of the resource and the (potential) complexity of the site's geology, and physical constraints (e.g., access, roads/trails, topography, watercourses, etc.). While test pit exploration is typically inexpensive, fast, and produces large samples, it might only expose a small portion of the overall site due to depth constraints. On the other hand, drilling is expensive and slower than test pitting, and — depending on which method is used — might only retrieve samples to a maximum of 10 to 20 cm nominal size.

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Characterization of a sand and gravel site should thus be done with an appreciation of the limitations of the investigation, based on the foregoing factors.

A2.4.4 Record

In addition to the general information accompanying all samples, the following information should accompany samples of bank run sand and gravel:

a) location of supply;
b) estimate of the approximate quantity available, if appropriate;
c) quantity and character of overburden, if appropriate;
d) length of haul to the proposed site of work;
e) character of haul (e.g., kind of road, maximum grades, etc.);
f) details of the extent and location of material represented by each sample; and
g) date of the sampling.

Notes:

1) *A sketch of plans and elevations showing the thickness and location of different layers should be made for this purpose.*
2) *The use of geopositioning satellite (GPS) or georeferencing systems can be useful to locate the sample(s).*

A2.5 Sampling for evaluation of potential for alkali-aggregate reactivity

To enable concrete mixtures to be made for the purpose of evaluating the potential alkali reactivity of aggregates, sample masses considerably in excess of those shown in Table 1 will be needed. Because small variations in the composition of rocks might have a major impact on the potential alkali-aggregate reactivity of an aggregate source, it is important that care be taken in obtaining representative samples. In operating aggregate sources, the material sampled should be taken from production stockpiles manufactured from material similar to that of future production and in the same manner as anticipated for future production. When the aggregate source is undeveloped, special care should be taken to ensure that material sampled is representative of the source at the anticipated time of production. In the case of aggregates sampled from bedrock quarries, the specific locations and elevations of production of the material represented by the sample should be recorded and reported. In gravel or sand pits, the specific location of the source of the material should be recorded and reported.

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A23.2-2A
Sieve analysis of fine and coarse aggregate

1 Scope

This Test Method specifies the procedure used to determine the particle size distribution of fine and coarse aggregate, using sieves with square openings.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-5A:19
Amount of material finer than 80 µm in aggregate

ASTM International

C136/C136M-14
Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Summary

A series of sieves with progressively smaller openings is used to separate an aggregate sample into its component size fractions. The mass of material retained on each individual sieve is used to calculate the sample grading.

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5 Significance and use

This Test Method is used to determine the grading of materials being used as concrete aggregates or proposed for use as concrete aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and concrete mixtures containing aggregates. The data might also be useful in developing relationships concerning concrete mix workability.

6 Apparatus

The following equipment shall be used:

a) a balance or scale sensitive to within 0.1% of the mass of the sample;
b) sieves that have square openings and are mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the materials to be tested. The woven wire cloth sieves shall conform to ISO 3310-1 made with the preferred wire diameter; and
c) an oven of appropriate size, capable of maintaining a uniform temperature of 110 ± 5 °C.

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Samples

8.1

Samples shall be prepared as follows:

a) Obtain a sample of the material to be tested in accordance with CSA A23.2-1A.
b) Reduce the sample for sieve analysis to the size indicated in Table 1 or 2 by the use of a sample splitter or by a suitable method of quartering.
c) Thoroughly mix the fine aggregate sampled by the quartering method in a moist condition prior to quartering.
d) Select a test sample of approximately the desired mass as the end result of the sampling method. Do not select samples of an exact predetermined mass.

8.2

Samples of fine aggregate for sieve analysis shall have a mass, after drying to constant mass, of approximately the amount indicated in Table 1. In no case, however, shall the fraction retained on any sieve at the completion of the sieving operation have a mass more than 7 kg/m^2 of the sieving surface.

Note: *The maximum mass of retained on any sieve at the completion of sieving amounts to 200 g for the typical 200 mm diameter sieve. The amount of material retained on the critical sieve may be regulated by one or both of the following:*

a) *the introduction of a sieve having larger openings than the critical sieve. Such additional sieves used to eliminate overloading the successive sieve should not be included in the gradation curve, but the material retained should be added to the successive screen; or*
b) *the proper selection of the size of the sample.*

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Table 1
Mass of samples for fine aggregate
(See Clauses 8.1 and 8.2.)

Material	Sample mass, g
Material at least 95% finer than a 2.5 mm sieve	175 ± 25
Material at least 90% finer than a 5 mm sieve and more than 5% coarser than a 2.5 mm sieve	450 ± 50

8.3

Samples of coarse aggregate for sieve analysis shall have a mass, after drying to constant mass, not less than the amount indicated in Table 2.

Table 2
Mass of samples for coarse aggregate
(See Clauses 8.1 and 8.3.)

Nominal maximum size of aggregate, mm	Minimum mass of sample, kg*
10	1
14	3
20	5
28	10
40	15
56	20
80	60

** For samples having a mass of 5 kg or more, sieves mounted in frames 400 mm in diameter or larger should be used.*

8.4

In case of mixtures of fine and coarse aggregate, the material shall be separated into two sizes on the 5 mm sieve and the samples of fine and coarse aggregate shall be prepared in accordance with Clauses 8.2 and 8.3.

8.5

When accurate determinations of the total amount passing the 80 µm sieve are required, the sample shall be washed in accordance with CSA A23.2-5A. The percentage finer than the 80 µm sieve as determined by CSA A23.2-5A shall be added to the percentage passing the 80 µm sieve by dry sieving the same sample. After the final drying operation in CSA A23.2-5A, the sample shall be dry sieved in accordance with Clause 9.4.

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9 Procedure

9.1

Samples shall be dried to constant mass at a temperature of 110 ± 5° C and cooled to ambient temperature.

9.2

Sieve sizes shall be selected as required by the specification for the material to be tested. Additional sieves may be added as desired or necessary to provide other information, such as required for calculating blended aggregate gradings or to regulate the amount of material on an individual sieve.

9.3

The quantity of material shall be limited on a given sieve so that all particles have an opportunity to reach sieve openings a number of times during sieving operations. For sieve sizes smaller than 5 mm, the quantity retained on any sieve at the completion of sieving shall not exceed 7 kg/m^2 of sieving surface area. For sieve openings of 5 mm or larger, a maximum of the product of 2.5 × (sieve opening, mm) × (effective sieving area, m^2) shall be retained. In no case shall the mass retained be so great as to cause deformation of the sieve cloth.

Notes:

1) *The limit of 7 kg/m^2 retained on any sieve at the completion of sieving amounts to about 200 g for a 200 mm diameter sieve.*
2) *The sieve area for round sieves is based on an effective diameter of 12.7 mm less than the nominal diameter. This reduction in area accounts for the area the sealer covers between the sieve cloth and the frame.*

9.4

The following procedure shall be followed:

a) Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve.
b) Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial and checked by measurement on the actual test sample, to meet the criteria for adequacy of sieving described in Item d).
c) Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action so as to keep the sample moving continuously over the surface of the sieve.
d) Continue sieving for a sufficient period and in such manner that, after completion, not more than 1% by mass of the residue retained on any individual sieve will pass that sieve during 1 min of continuous hand-sieving performed as per Item e).
e) Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand, and strike the side of the sieve sharply, with an upward motion against the heel of the other hand, at the rate of about 150 times per minute. Turn the sieve about one-sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 5 mm sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 200 mm diameter sieves to verify the sufficiency of sieving.
f) Determine the mass of each size increment to the nearest 0.1% of the mass of the sample by using a scale or balance conforming to the requirements specified in Clause 6.
g) The total mass of the sample after sieving should check closely with the original mass of the sample placed on the sieves. If the amounts differ by more than 0.3% of the original dry mass, the test results should not be used for acceptance purposes.

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10 Calculation

10.1

The percentages passing, total percentages retained, or percentages in each size fraction shall be calculated to the nearest 1% based on the dry mass of the test sample. The amount of material finer than 80 µm shall be calculated to the nearest 0.1%.

10.2

If the sample was reduced on a selected sieve to prevent overloading of the sieve screens, the mass of each size fraction of the original sample shall be calculated as follows and these masses shall be used to calculate the percentages as specified in Clause 10.1:

$A = (W_1/W_2) \times B$

where

A = mass of size fraction on a total sample basis

W_1 = mass of sample finer than the selected sieve in the total sample

W_2 = mass of reduced portion finer than the selected sieve actually sieve

B = mass of size fraction in reduced portion sieved

10.3

When required, the fineness modulus shall be calculated by adding the total percentage of material in the sample that is coarser than each of the following sieves (cumulative percentage retained) and dividing the sum by 100: 160 µm, 315 µm, 630 µm, 1.25 mm, 2.5 mm, 5 mm, 10 mm, 20 mm, 40 mm, and 80 mm.

11 Reporting

11.1 Reporting method

The results of the sieve analysis shall be reported by one of the following methods:

a) total percentages of material passing each sieve;
b) total percentages of material retained on each sieve; or
c) percentages of material retained between consecutive sieves, depending upon the form of the specifications for the use of the material under test.

11.2 Required information

The report shall include the following information, as applicable:

a) sample number or identification;
b) date of test;
c) percentages to the nearest whole number;
d) in cases of mixtures of fine and coarse aggregate, the combined percentages, which show the sieve analysis of the sample as received;
e) when required, the fineness modulus to the nearest 0.01;
f) name of the certified technician who performed the test;
g) identification of the certified laboratory that performed the test (i.e., name and address);
h) name and signature of the person responsible for the review of the test report; and
i) any deviation from the test procedure.

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11.3 Optional information

The following information may be included in the test report:

a) name of person or organization who sampled the aggregate;
b) date sample was taken or received by the test laboratory;
c) sample source or sample location, or both; and
d) material description or designation.

12 Precision and bias

12.1 Precision

The precision of this Test Method is expected to be similar to that of ASTM C136/C136M.

12.2 Bias

Since there is no accepted reference material suitable for determining bias in this Test Method, no statement on bias is made.

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A23.2-3A
Clay lumps in natural aggregate

1 Scope

This Test Method specifies the procedure used to determine the approximate amount of clay lumps and other friable particles in natural aggregate.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-5A:19
Amount of material finer than 80 µm in aggregate

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

ASTM International

C142/C142M-17
Standard Test Method for Clay Lumps and Friable Particles in Aggregates

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

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4 Summary

After washing to remove material finer than 80 µm, aggregate particles are soaked in water and then tested to identify particles that can be broken between thumb and forefinger.

5 Significance and use

This Test Method is used to identify deleterious materials for conformance with the limits specified in Table 12 of CSA A23.1.

6 Apparatus

The apparatus shall consist of the following:

a) a balance or scale sensitive to within 0.1% of the mass of the sample;
b) containers of a size and shape that will permit the spreading of the sample in a thin layer on the bottom;
c) sieves with woven wire cloth conforming to ISO 3310-1 made with the preferred wire diameter; and
d) an oven of appropriate size, capable of maintaining a uniform temperature of 110 ± 5 °C.

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Samples

8.1

Aggregate samples shall be obtained in accordance with CSA A23.2-1A. The sample size shall be reduced as required by quartering or by use of a sample splitter.

8.2

Samples shall be washed in accordance with CSA A23.2-5A and dried to constant mass at a temperature of 110 ± 5 °C.

8.3

Samples of fine aggregate shall consist of the particles coarser than a 1.25 mm sieve and shall be not less than 100 g.

8.4

The sample of coarse aggregate shall be separated into size fractions using the following sieves: 5 mm, 10 mm, 20 mm, and 40 mm. The mass of sample for each size fraction tested shall be not less than indicated in Table 1. Sizes representing less than 5% of the aggregate shall not be tested.

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Table 1
Mass of samples
(See Clause 8.4.)

Size of particles making up sample, mm	Minimum mass of sample, kg
5–10	1
10–20	2
20– 40	3
Over 40	5

8.5

In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 10 or 11 of CSA A23.1, the material shall be separated into two sizes on the 5 mm sieve and the samples of fine and coarse aggregate shall be prepared in accordance with Clauses 8.3 and 8.4.

Note: *See Clause 6.2 of CSA A23.2-30A.*

9 Procedure

The procedure shall be performed as follows:

a) Determine the mass of each test sample to the nearest 0.1%. Spread each sample in a thin layer on the bottom of a container, cover with distilled water, and allow to soak for a period of 24 ± 4 h. Roll and squeeze particles individually between the thumb and forefinger to attempt to break the particles into smaller sizes. Do not use fingernails to break up the particles or press particles against a hard surface or each other.

b) After the discernible clay lumps and/or friable particles have been broken into smaller sizes, remove the detritus from the remainder of the sample by wet sieving over the sieve prescribed in Table 2.

c) Remove the retained particles from the sieve, dry to a constant mass at a temperature of 110 ± 5 °C, allow to cool, and determine the mass of each test sample to the nearest 0.1% of the mass of the sample.

Table 2
Sieve size
(See Clause 9.)

Size of particles making up sample, mm	Size of sieve for sieving residue of clay lumps
Fine aggregate (retained on 1.25 mm sieve)	630 µm
5–10	2.5 mm
10–20	5.0 mm
20–40	5.0 mm
Over 40	5.0 mm

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10 Calculation

The percentage of clay lumps shall be calculated to the nearest 0.1% as follows:

$$L = \frac{M - R}{M} \times 100$$

where

L = clay lumps, %

M = mass of sample, g

R = mass of sample after removal of clay lumps and friable particles, g

Notes:

1) *For fine aggregate, the percentage of clay lumps is based on the sand fraction coarser than a 1.25 mm sieve.*
2) *For coarse aggregate, the percentage of clay lumps should be an average based on the percentage of clay lumps in each size fraction weighted in accordance with the grading of the original sample before separation. Should the aggregate contain less than 5% of any of the sizes specified in Table 1, that size should not be tested, but for the purpose of calculating the weighted average, it should be considered to contain the same percentage of clay lumps as the next larger or smaller size, whichever is present.*

11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) source of the sample supply;
b) sample number or identification;
c) sieve size and mass of the sample making up the test sample;
d) percentage by mass of clay lumps for each sieve size tested to the nearest 0.1%;
e) weighted average mass of clay lumps to the nearest 0.1%;
f) name of the certified technician who performed the test;
g) identification of the certified laboratory that performed the test (i.e., name and address);
h) name and signature of the person responsible for the review of the test report; and
i) any deviation from test procedure.

11.2 Optional information

The following information may be included in the test report:

a) name of person or organization who sampled the aggregate; and
b) date sample was taken or received by the test laboratory.

12 Precision and bias

12.1 Precision

The precision of this Test Method is expected to be similar to that of ASTM C142/C142M.

12.2 Bias

Since there is no accepted reference material suitable for determining bias in this Test Method, no statement on bias is made.

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A23.2-4A
Low-density granular material in aggregate

1 Scope

This Test Method specifies the procedure used to determine the approximate percentage of low-density granular material in aggregate.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-6A:19
Relative density and absorption of fine aggregate

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

ASTM International

C123/C123M-14
Standard Test Method for Lightweight Particles in Aggregate

E100-17
Standard Specification for ASTM Hydrometers

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously*

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found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.

4 Summary

Saturated surface dry aggregate is placed in a heavy liquid with a relative density of 2.0. Low density material is determined by means of sink-float separation.

5 Significance and use

This Test Method is used to determine conformance with the limits specified in Table 12 of CSA A23.1. A heavy liquid with a relative density of 2.0 is used to separate particles classified as low density granular material (e.g., coal or lignite).

6 Apparatus

The apparatus shall consist of the following:

a) for measuring the mass of fine aggregate, a balance having a capacity of not less than 500 g, sensitive to 0.1 g;
b) for measuring the mass of coarse aggregate, a balance having a capacity of not less than 5 kg, sensitive to 1 g;
c) containers for drying the aggregate sample and for holding the heavy liquid during the sink-float separation;
d) a piece of 315 µm sieve cloth, conforming to ISO 3310-1 made with the preferred wire diameter, of suitable size and shape for use as a skimmer for separating the floating pieces from the heavy liquid;
e) an oven of appropriate size, capable of maintaining a uniform temperature of 110 ± 5 °C; and
f) a hydrometer conforming to the physical requirements for individual hydrometers specified in ASTM E100, or a suitable combination of graduate glassware and balances capable of measuring the liquid relative density within ±0.01.

7 Reagents and materials

7.1

The heavy liquid shall consist of a solution of zinc chloride in water proportioned to provide a relative density of 2.0. The relative density shall be maintained within ±0.01 of the specified value at all times during the test.

Note: *The exothermic reaction when zinc chloride is mixed with water will increase liquid temperature. Heavy liquid should be prevented from contacting the skin by use of the appropriate personal protective equipment, including gloves and goggles.*

7.2

For special applications, this Test Method may be used with a heavy liquid of a different relative density. The relative density shall be maintained within ±0.01 of the selected value at all times during the test.

8 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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9 Samples

9.1

Samples shall be obtained in accordance with CSA A23.2-1A and dried to a constant mass at a temperature of 110 ± 5 °C before testing.

9.2

The minimum size of the test sample shall be as specified in Table 1.

Table 1
Mass of aggregate samples
(See Clause 9.2.)

Nominal maximum size of aggregate, mm	Minimum mass of sample, kg
5 (fine aggregate)	0.2
10	1
20	3
40	5
56	7
80	10

9.3

In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 10 or 11 of CSA A23.1, the material shall be separated into two sizes on the 5 mm sieve and the samples of fine and coarse aggregate shall be prepared and tested in accordance with Clauses 10.1 and 10.2.

Note: *See Clause 6.2 of CSA A23.2-30A.*

10 Procedure

10.1 Fine aggregate

The procedure for fine aggregate shall be as follows:

a) Cool the dried sample of fine aggregate to room temperature and then sieve over a 315 µm sieve until less than 1% of the retained material passes the sieve in 1 min of continuous sieving.
b) Measure the mass of the material coarser than the 315 µm sieve to the nearest 0.1 g, bring this material to a saturated surface-dry condition in accordance with CSA A23.2-6A, then introduce it into the heavy liquid in a suitable container (the volume of liquid being at least three times the absolute volume of the aggregate).
c) Pour the liquid off into a second container, passing it through the skimmer, and taking care that only the floating pieces are poured off with the liquid and that none of the sink is decanted onto the skimmer.
d) Return to the first container the liquid that has been collected in the second container and, after further agitation of the sample by stirring, repeat the decanting process just described until the sample is free of floating pieces.

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e) Wash the decanted pieces contained on the skimmer in water and dry to a constant mass at 110 ± 5 °C.
f) Brush the dry decanted pieces from the skimmer onto the balance pan and measure the mass to the nearest 0.1 g.

Note: *When the absorption of the fine aggregate has been determined in accordance with CSA A23.2-6A, the fine aggregate may be prepared for the test by adding the amount of absorbed water to the known amount of dry aggregate and mixing thoroughly. The mixture of aggregate and water should be allowed to stand for 30 min in a covered container.*

10.2 Coarse aggregate

The procedure for coarse aggregate shall be as follows:

a) Cool the dried sample of coarse aggregate to room temperature and sieve over a 5 mm sieve.
b) Measure the mass of the material coarser than the 5 mm sieve to the nearest 1 g and bring this material to a saturated surface-dry condition in accordance with CSA A23.2-12A, then introduce it into the heavy liquid in a suitable container (the volume of the liquid being at least three times the absolute volume of the aggregate).
c) Using the skimmer, remove the pieces that rise to the surface and save them.
d) Repeatedly agitate the remaining pieces and remove the floating pieces until no additional pieces rise to the surface.
e) Wash the decanted pieces in water and dry in an oven at 110 ± 5 °C until constant mass is attained.
f) Measure the mass of the decanted pieces to the nearest 1 g.

11 Calculation

The percentage of low-density pieces (i.e., pieces floating on the heavy liquid) shall be calculated as follows:

a) for fine aggregate:

$$L = \frac{M_1}{M_2} \times 100$$

b) for coarse aggregate:

$$L = \frac{M_1}{M_3} \times 100$$

where

L = low-density pieces, %

M_1 = dry mass of decanted pieces, g

M_2 = dry mass of portion of sample coarser than 315 µm sieve, g

M_3 = dry mass of portion of sample coarser than 5 mm sieve, g

12 Reporting

12.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification;
b) nominal maximum aggregate size;
c) mass of the test sample;
d) type and specific gravity of heavy liquid used for test;

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e) percentage of lightweight particles for each maximum nominal sieve size tested to the nearest 0.1%;
f) name of the certified technician who performed the test;
g) identification of the certified laboratory that performed the test (i.e., name and address);
h) name and signature of the person responsible for the review of the test report; and
i) any deviations from the test procedure.

12.2 Optional information

The following information may be included in the test report:
a) name of the person who sampled the aggregate;
b) date the sample was taken or received by the test laboratory; and
c) sample location or source, or both.

13 Precision and bias

Note: *The precision and bias of this Test Method are expected to be similar to that of ASTM C123/C123M.*

13.1 Precision

No interlaboratory or intralaboratory studies have been conducted to determine precision indices.

Note: *The Subcommittee is seeking pertinent data from users of this Test Method which might be used to develop meaningful statements of precision and bias.*

13.2 Bias

The bias of the Test Method may be estimated by determining relative density and absorption values for particles in the sink or float fractions, or both.

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A23.2-5A
Amount of material finer than 80 µm in aggregate

1 Scope

This Test Method specifies the procedure used to determine the total quantity of material finer than an 80 µm sieve in aggregate by washing. Clay particles and other aggregates that can be dispersed by the wash water as well as water soluble materials will be removed from the aggregate during the test.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

ASTM International

C117-17
Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Summary

A sample is oven dried to a constant mass and washed on an 80 µm sieve. The washed sample is dried to a constant mass. The amount of material passing the 80 µm sieve is expressed as a percentage by mass of the original sample.

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5 Significance and use

Increased amounts of material finer than 80 µm tends to increase the amount of mixing water required for a given slump and can negatively impact the quality of the bond between aggregate and cement paste. Separating material finer than 80 µm from larger particles by wet sieving is more efficient and complete than dry sieving. Therefore, washing is required when accurate determination of material finer than 80 µm is required or when clayey coatings resistant to dry sieving are present. This Test Method is used prior to dry sieving in accordance with CSA A23.2-2A.

The results of this Test Method are included in the calculation in CSA A23.2-2A and the total amount of material finer than 80 µm by washing plus that obtained by dry sieving the same sample is reported with the results of CSA A23.2-2A.

For fine aggregate, the limits provided in Table 12 of CSA A23.1 for material finer than 80 µm shall apply to the total amount of material finer than 80 µm determined by washing plus that determined by dry sieving the same sample.

For coarse aggregate, the limits provided in Table 12 of CSA A23.1 for material finer than 80 µm shall apply to the amount of material finer than 80 µm as determined by washing.

6 Apparatus

The apparatus shall consist of the following:

a) a balance or scale sensitive to 0.1 g or 0.1% of the mass of the sample fraction to be tested, whichever is greater, at any point within the range of use;
b) a nest of two sieves, the lower being an 80 µm sieve and the upper being an approximately 1.25 mm sieve, both made of woven wire cloth conforming to ISO 3310-1 made with the preferred wire diameter;
c) a pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without inadvertent loss of any part of the sample or water; and
d) an oven of appropriate size, capable of maintaining a uniform temperature of 110 ± 5 °C.

Note: *A mechanical apparatus may be used to perform the washing, provided the results are consistent with those obtained during operations. In some cases, the use of mechanical washing can cause sample degradation.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Test sample

The test sample shall be selected in accordance with CSA A23.2-1A from material that has been thoroughly mixed and contains sufficient moisture to prevent segregation. A representative sample shall be selected, sufficient to yield not less than the appropriate mass of dried material required by Table 1.

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Table 1
Mass of samples
(See Clause 8.)

Nominal maximum size of aggregate, mm	Minimum mass of sample, kg
5	0.5
10	1.0
20	2.5
40	5.0

9 Procedure

The test shall be performed as follows:

a) Dry the test sample to constant mass at a temperature of 110 ± 5 °C and measure the mass to the nearest 0.1%.

b) After drying and measuring the sample mass, place the test sample in the container and add sufficient water to cover it. Agitate the contents of the container vigorously and immediately pour the wash water over the nested sieves, arranged with the coarser sieve on top.

c) Agitate with sufficient vigour to effect the complete separation from the coarse particles of all particles finer than an 80 µm sieve, and to bring the fine material into suspension in order that it will be removed by decantation of the wash water. Take care to avoid, as much as possible, the decantation of the coarse particles of the sample. Repeat the operation until the wash water is clear.

d) Return all material retained on the nested sieves to the washed sample. Dry the washed aggregate to constant mass at a temperature of 110 ± 5 °C and measure the mass to the nearest 0.1%.

10 Calculation

The amount of material finer than the 80 µm sieve shall be calculated as follows:

$$A = \frac{B - C}{B} \times 100$$

where

A = material finer than 80 µm, %

B = original dry mass, g

C = dry mass after washing, g

11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification;

b) amount of material finer than the 80 µm sieve size tested to the nearest 0.1%, except if the result is 10% or more to the nearest whole number;

c) name of the certified technician who performed the test;

d) identification of the certified laboratory that performed the test (i.e., name and address);

e) name and signature of the person responsible for the review of the test report; and

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f) any deviations from the test procedure.

11.2 Optional information

The following information may be included in the test report:

a) name of the person or organization who sampled the aggregate;
b) date the sample was taken or received by the testing laboratory;
c) sample source or sample location, or both;
d) nominal maximum sieve size and mass of the sample making up the test sample; and
e) date of test.

12 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C117.

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A23.2-6A
Relative density and absorption of fine aggregate

1 Scope

This Test Method specifies the procedure to determine the bulk and apparent relative density and absorption of fine aggregate. Bulk relative density is the characteristic generally used for calculations of the volume occupied by the aggregate in concrete.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-5A:19
Amount of material finer than 80 µm in aggregate

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

ASTM International

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C702/C702M-18
Standard Practice for Reducing Samples of Aggregate to Testing Size

D854-14
Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

Other publication

Rogers, C. and Dziedziejko, T. 2008. Fine aggregate water absorption and density testing — effect of fines on results, Canadian Technical Asphalt Association, *Proceedings 53rd Annual Conference*, Saskatoon: 190-209.

3 Definitions

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Absorption — the increase in the mass of aggregate due to water in the pores of the material (but not including water adhering to the outside surface of the particles) expressed as a percentage of the dry

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mass. The aggregate is considered “dry” when it has been maintained at a temperature of 110 ± 5 °C for sufficient time to achieve constant mass.

Apparent relative density — the ratio of the mass in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the mass in air of an equal volume of water at a stated temperature.

Bulk relative density — the ratio of the mass in air of a unit volume of aggregate, including the permeable and impermeable voids in the particles but not including the voids between particles, at a stated temperature to the mass in air of an equal volume of water at a stated temperature.

Bulk relative density (SSD*) — the ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 24 h but not including the voids between particles, at a stated temperature to the mass in air of an equal volume of water at a stated temperature.

* *SSD = saturated surface-dry.*

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Significance and use

4.1

Bulk relative density (SSD) is the property used for calculation of the volume occupied by wet aggregate in hydraulic cement concrete that is proportioned on an absolute volume basis. Bulk relative density (dry) is used when the aggregate is dry or assumed to be dry.

4.2

Apparent relative density is the solid material making up the particles but does not include the pore space within the particles accessible to water. This value is not widely used with concrete aggregates.

4.3

Absorption is the mass of water absorbed into the internal pores of the aggregate particles. Aggregate that has been extracted below the water table and has not been dried will usually have a higher absorption than that of the same aggregate that has been dried and saturated for 24 h. The fine aggregate absorption is used to determine the adjustments to the amount of aggregate and water required to be added or subtracted from a concrete batch to satisfy the yield and design water content of the mix.

4.4

Periods of immersion longer than 24 h will normally result in higher absorption values since not all pores are completely filled after 24 h. This Test Method can be used for other times of soaking or means of saturating the aggregate such as boiling in water or vacuum saturation. This Test Method may be used for lightweight aggregate,but saturation should be for 72 h.

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5 Apparatus

5.1 Balance

A balance or scale shall be used having a capacity of 1 kg or more, sensitive to 0.1 g or less, and accurate to 0.1% of the test load at any point within the range of use for this test. Within any 100 g range of test load, a difference between readings shall be accurate to 0.1 g.

5.2 Pycnometer

A flask or other suitable container shall be used into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced within ±0.1 mL. The volume of the container filled to the mark shall be at least 50% greater than the space required to accommodate the test sample.

Note: *A volumetric flask of 500 mL capacity or a fruit jar fitted with a pycnometer top is sufficient for a 500 g test sample of most fine aggregates.*

5.3 Mould

The mould shall be made of a non-corroding metal, such as brass, copper, or stainless steel.

The mould shall be in the form of a frustum of a cone with dimensions as follows:

a) 40 ± 3 mm inside diameter at the top;
b) 90 ± 3 mm inside diameter at the bottom;
c) 75 ± 3 mm in height; and
d) the metal having a minimum thickness of 0.8 mm.

5.4 Tamper

The tamper shall be made of a non-corroding metal, such as brass, copper, or stainless steel. The tamper shall have a mass of 340 ± 15 g and a flat circular tamping face of 25 ± 3 mm in diameter.

5.5 Oven

The oven shall be of sufficient size and shall be capable of maintaining a uniform temperature of 110 ± 5 °C.

6 Preparation of test specimen

The test specimen shall be prepared as follows:

a) Obtain approximately 1 kg of the fine aggregate from the sample by using a sample splitter or by quartering.* In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 10 of CSA A23.1, the material shall be separated into two sizes on the 5 mm sieve and the samples of fine and coarse aggregate shall be prepared and tested in accordance with this Test Method and CSA A23.2-12A, respectively.†
b) Dry it in a suitable pan or vessel to constant mass at a temperature of 110 ± 5 °C.
c) Allow it to cool to a comfortable handling temperature, cover with water, and permit it to stand for 24 ± 4 h.‡
d) Decant excess water with care to avoid loss of fines (see Attachment A1), spread the sample on a flat surface exposed to a gently moving current of warm air, and stir frequently to secure uniform drying.
e) Continue this operation until the test specimen approaches a free-flowing condition, then place a portion of the partially dried fine aggregate loosely into the mould by filling it to overflowing and heaping additional material above the top of the mould.

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f) Hold the mould firmly on a smooth nonabsorbent surface with the large diameter down.
g) Lightly tamp the surface 25 times with the tamper. Each drop should start about 5 mm above the surface of the fine aggregate. Permit the tamper to fall freely on each drop. Do not add additional sand.
h) Remove the loose sand from the base and lift the mould vertically. If surface moisture is still present, the fine aggregate will retain the moulded shape.
i) Continue drying with constant stirring and test at frequent intervals until the tamped fine aggregate slumps slightly upon removal of the mould. This indicates that it has reached a surface-dry condition.§ If desired, mechanical aids such as tumbling or stirring may be employed to assist in achieving the saturated surface-dry condition.

* *The process of quartering and the correct use of a sample splitter are described in ASTM C702/C702M.*
† *See Clause 6.2 of CSA A23.2-30A.*
‡ *Where the absorption and relative density values are to be used in proportioning concrete mixtures with aggregates used in their naturally moist condition, the requirement for initial drying to constant mass may be waived. Values for absorption and for relative density in the saturated surface-dry condition may be significantly higher for aggregate not oven-dried before soaking than for the same aggregate treated in accordance with this Clause.*
§ *The procedure described in Clause 6 is intended to ensure that the first cone test trial will be made with some surface water in the specimen. If the fine aggregate slumps on the first trial, it has been dried past the saturated surface-dry condition. In this case, a few millilitres of water should be thoroughly mixed with the fine aggregate and the specimen should stand in a covered container for 30 min. The process of drying and testing for the free-flowing condition should then be resumed.*

Note: *For improved accuracy, duplicate samples should be tested.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Procedure

8.1

Partially fill the pycnometer with water and introduce into the pycnometer approximately 500 g* of saturated surface-dry fine aggregate, prepared as described in Clause 6, then fill with water to approximately 90% of capacity. Roll, invert, and agitate the pycnometer to eliminate all air bubbles. Adjust its temperature to 23 ± 2 °C (if necessary, by partial immersion in a water bath) and bring the water level in the pycnometer to its calibrated capacity. Measure the total mass of the pycnometer, aggregate, and water.† Record the total mass and all other determinations to the nearest 0.1 g.

* *If the mass used is less than 500 g, limits on accuracy of mass determination and measuring should be scaled down in proportion.*
† *As an alternative, the quantity of water necessary to fill the pycnometer may be determined volumetrically using a burette accurate to 0.15 mL. The total mass of the pycnometer, aggregate, and water is then calculated as follows:*

$C = 0.9976V_a + M_f + M$

where

C = mass of pycnometer filled with the aggregate plus water, g

V_a = volume of water added to pycnometer, mL

M_f = mass of saturated surface-dry fine aggregate, g

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M = mass of pycnometer empty, g

8.2

Remove the fine aggregate from the pycnometer, dry to constant mass at a temperature of 110 ± 5 °C, cool in air at room temperature for 0.5 to 1.5 h, and measure the mass.

8.3

Measure the mass of the pycnometer filled to its calibration capacity with water at 23 ± 2 °C.

Note: *If a volumetric flask is used and is calibrated to an accuracy of 0.15 mL at 23 °C, the mass of the flask filled with water may be calculated as follows:*

B = 0.9976V + M

where

B = mass of flask filled with water, g

V = volume of flask, mL

M = mass of the flask empty, g

9 Calculations

9.1 Bulk relative density

The bulk relative density 23/23 °C shall be calculated as follows:

$$\text{Bulk relative density} = \frac{A}{B + M_f - C}$$

where

A = mass of oven-dry aggregate in air, g

B = mass of pycnometer filled with water, g

M_f = mass of saturated surface-dry fine aggregate, g

C = mass of pycnometer with aggregate and water to calibration mark, g

9.2 Bulk relative density (saturated surface-dry basis)

The bulk relative density 23/23 °C shall be calculated on the basis of mass of saturated surface-dry aggregate as follows:

$$\text{Bulk relative density (saturated surface-dry basis)} = \frac{M_f}{B + M_f - C}$$

9.3 Apparent relative density

The apparent relative density 23/23 °C shall be calculated as follows:

$$\text{Apparent relative density} = \frac{A}{B + A - C}$$

9.4 Absorption

Calculate the percentage of absorption as follows:

$$\text{Absorption (\%)} = \frac{M_f - A}{A} \times 100$$

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10 Reporting

10.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification;
b) name of the certified technician performing the test;
c) mass of the test sample;
d) bulk relative density to the nearest 0.01;
e) bulk relative density (saturated surface-dry basis) to the nearest 0.01;
f) apparent relative density to the nearest 0.01;
g) absorption to the nearest 0.1%;
h) if the relative density values were determined without first drying the aggregate a notation to this effect;
i) name of the certified technician who performed the test (name and address);
j) identification of the certified laboratory that performed the test (i.e., name and address);
k) name and signature of the person responsible for the review of the test report; and
l) any deviations from the test procedures.

10.2 Optional information

The following information may be included in the test report:

a) name of the person or organization who sampled the aggregate;
b) date the sample was taken or received by the test laboratory; and
c) sample source or sample location or both.

11 Precision and bias

11.1 Precision

For fine aggregate with relative density in the approximate range 2.57 to 2.72, the single-operator standard deviation has been found to be 0.006*. Therefore, results of two properly conducted tests on samples of the same aggregate by the same operator using the same equipment are not expected to differ by more than 0.17*, 95% of the time. The multi-laboratory standard deviation has been found to be 0.012*. Therefore, results of two properly conducted tests by different laboratories on samples of the same aggregate are not expected to differ by more than 0.034*, 95% of the time.

For fine aggregate with absorption values in the approximate range 0.4% to 1.0%, the single-operator standard deviation has been found to be 0.07%*. Therefore, results of two properly conducted tests on samples of the same aggregate by the same operator using the same equipment are not expected to differ by more than 0.20%*, 95% of the time. The multi-laboratory standard deviation has been found to be 0.16%*. Therefore, results of two properly conducted tests by different laboratories on samples of the same aggregate are not expected to differ by more than 0.45%*, 95% of the time.

* *These numbers represent, respectively, the (1s) and (d2s) limits described in ASTM C670.*

11.2 Bias

Since there is no accepted reference material suitable for determining the bias of this Test Method, no statement on bias is made.

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Attachment A1 (informative)
Potential differences in bulk relative density and absorption due to presence of material finer than 80 µm

Note: *This Attachment is not a mandatory part of this Test Method.*

A1.1

It has been found that there can be significant differences in bulk relative density and absorption between fine aggregate samples tested with material finer than 80 µm present and not present in the samples (Rogers and Dziedziejko, 2008). Samples from which the material finer than 80 µm is not removed usually give a higher absorption and a lower bulk relative density compared to testing the same fine aggregate from which the material finer than 80 µm is removed following the procedures of CSA A23.2-5A. Samples with material finer than 80 µm may build up a coating around the coarser fine aggregate particles during the surface drying process. The resultant relative density and absorption that is subsequently measured is that of the agglomerated and coated particles and not that of the parent material. The difference in absorption and relative density determined between samples from which the material finer than 80 µm have not been removed and samples from which the material finer than 80 µm have been removed depends on both the amount of the material finer than 80 µm present and the nature of the material. When the material finer than 80 µm is less than about 4% by mass, the difference in relative density between washed and unwashed samples is less than 0.03. When the material finer than 80 µm is greater than about 8% by mass, the difference in density obtained between washed and unwashed samples can be as great as 0.13. It has been found that the relative density determined on fine aggregate from which the material finer than 80 µm has been removed prior to testing more closely reflects the real relative density of the material.

A1.2

The material finer than 80 µm which is removed by washing can be assumed to have a relative density that is the same of that of the fine aggregate. Alternatively, the relative density (specific gravity) of the material finer than 80 µm may be further evaluated using ASTM D854; however, this Test Method determines the apparent relative density and not the bulk relative density.

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A23.2-7A
Test for organic impurities in fine aggregates for concrete

1 Scope

This Test Method specifies the procedure used to determine approximately the presence of possibly injurious organic compounds in natural sands for use in cement mortar or concrete. The procedure uses a glass colour standard for comparison purposes.

Note: *The principal intent of the test is to furnish a warning that further tests of the fine aggregate is necessary before approved for use.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

ASTM International

D1544-04 (2018)
Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)

3 Significance and use

This Test Method is used in making a preliminary determination of the acceptability of fine aggregates with respect to the requirements of CSA A23.1 relating to organic impurities. The principal intent of this Test Method is to furnish a warning that injurious amounts of organic impurities might be present in the fine aggregate. When a sample subjected to this Test Method produces a colour darker than the standard colour, the relevant clauses in CSA A23.1 should be followed to further determine the potential acceptability of the fine aggregate.

4 Apparatus

The apparatus shall consist of the following:

a) clear glass graduated bottles approximately 300 mL capacity with a rubber or other nonreactive stopper; and
b) reference standard colour plate, which consists of the glass colour reference suitably mounted in a plastic holder.

Note: *Suitable colour plates are available from the Cement and Concrete Reference Laboratory, Institute of Standards and Technology, Washington, and from laboratory equipment suppliers.*

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5 Reagents and materials

The reagents shall consist of sodium hydroxide solution (3%): 30 g of reagent grade sodium hydroxide dissolved in water and diluted to 1 L.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Sample

7.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

7.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

7.3

A representative test sample of fine aggregate with a mass of approximately 500 g by quartering or by the use of a sample splitter shall be obtained.

8 Procedure

The test shall be performed as follows:

a) Fill a 300 mL graduated clear glass bottle to the 130 mL mark with the sample of sand to be tested.
b) Add a 3% solution of sodium hydroxide until the volume of the sand and liquid, indicated after shaking, is 200 mL.
c) Stopper the bottle, shake vigorously, and then allow to stand for 24 h.
d) At the end of the 24 h standing period, compare the colour of light transmitted through the supernatant liquid above the test sample with colour of light transmitted though the reference standard colour plate.
e) Use the glass standard colours as described in Table 1 of ASTM D1544. Make the colour comparison by holding the bottle and colour plate close together and looking through them.

9 Report

9.1 Required information

The following information shall be included in the test report, as applicable:

a) colour plate value of the test sample;
b) source of the test sample;
c) sample number or identification of the sample;
d) name of the certified technician who performed the test;
e) identification of the certified laboratory that performed the test (i.e., name and address);
f) name and signature of the person responsible for the review of the test report; and
g) any deviations from the test procedure.

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9.2 Optional information

The name of the technician who sampled the aggregate may be included in the test report.

10 Precision and bias

No information is presented about either the precision or bias of the Test Method for measuring organic properties because the test result is non-quantitative.

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A23.2-8A
Measuring mortar-strength properties of fine aggregate

1 Scope

This Test Method specifies the procedure used to measure the mortar-strength properties of fine aggregate for concrete by means of a compressive strength test on specimens made from a mortar of plastic consistency and gauged to a definite water-to-cementitious materials ratio. The Test Method is used for the determination of the effect on mortar strength of organic impurities determined in accordance with CSA A23.2-7A.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-7A:19
Test for organic impurities in fine aggregates for concrete

A3005-18
Test equipment and materials for cementitious materials for use in concrete and masonry

ASTM International

C87/C87M-17
Standard Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar

3 Summary

A portion of the fine aggregate that produced a colour darker than the standard in CSA A23.2-7A is used to prepare mortar cube specimens. A separate portion of the same fine aggregate is washed in sodium hydroxide to remove the organic impurities that caused the failing result when tested in accordance with CSA A23.2-7A, and that washed fine aggregate is used to prepare another set of mortar cube specimens.

After curing for a stated period, the compressive strengths of the two sets of cube specimens are determined and compared.

4 Significance and use

4.1

This Test Method provides a means for the acceptance of fine aggregate with respect to organic impurities.

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4.2

This Test Method is applicable to fine aggregate samples, when tested in accordance with CSA A23.2-7A, producing a supernatant liquid colour greater than standard colour plate No. 3 or colour solution.

4.3

Unless otherwise specified or permitted, compressive strengths at 7 d and 28 d of mortars prepared with a treated and untreated sample of the fine aggregate are compared. Refer to Clause 4.2.3.3.3.2 of CSA A23.1.

5 Apparatus

The apparatus shall consist of the following:

a) a flow table, flow mould, and caliper conforming to the requirements of CSA A3005;
b) a mixer, bowl, and paddle as described in CSA A3005;
c) a tamper, made of a non-absorptive, nonabrasive, non-brittle material (e.g., a rubber compound having a Shore A durometer hardness of 80 ± 10 or seasoned oak wood rendered non-absorptive by immersion for 15 min in paraffin at approximately 200 °C) having a cross-section of 13 × 25 mm and a convenient length of about 150 mm with a tamping face that is flat and at right angles to the length of the tamper;
d) a trowel with a steel blade 100 to 150 mm in length, with straight edges;
e) cube moulds 50 mm in dimension conforming to the requirements of CSA A3005; and
f) compression testing machine meeting the requirements of CSA A3005.

6 Reagents and materials

The reagents shall consist of sodium hydroxide solution (3%): 30 g of reagent grade sodium hydroxide dissolved in water and diluted to 1 L.

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Sample

The fine aggregate used in this Test Method shall be obtained from the same bulk sample used in the determination described in CSA A23.2-7A.

9 Procedure

9.1 Preparation of fine aggregate

Fine aggregate shall be prepared as follows:

a) Wash a portion of the fine aggregate in a 3% solution of sodium hydroxide.
b) Repeat the treatment a sufficient number of times to produce a washed material having a colour lighter than the standard described in CSA A23.2-7A.
c) Thoroughly rinse the fine aggregate in water.
d) Wash the aggregate so that the loss of fines is minimized and the washed aggregate has a fineness modulus within 0.10 of that of the unwashed aggregate.

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e) Check the washed and rinsed aggregate with a suitable indicator such as phenolphthalein or litmus to ensure that all sodium hydroxide has been removed prior to preparation of the mortar.
f) Condition the washed treated and untreated fine aggregate to a saturated surface dry condition.

Note: *When the absorption is known, the aggregate may be prepared for testing by adding to a known mass of dry aggregate the amount of water it will absorb, mixing thoroughly, and permitting the aggregate to stand in a covered pan for 30 min before use.*

9.2 Preparation of mortar

Mortar shall be prepared as follows:

a) Mix three batches of mortar with the aggregate treated in sodium hydroxide and three batches with the untreated aggregate on the same day.
b) Mix the mortar in a mechanical mixer in accordance with the procedure described in Items g) to m).
c) Proportion the mortar to produce a consistency of 100 ± 5% as determined by the flow test (see Clause 10).
d) Remove oversize particles by sieving on the 5.0 mm or 2.5 mm sieve if the particles are so large that the adjustment bracket cannot provide adequate clearance. Indicate the quantity of material removed if this procedure is employed.

   Note: *The clearances between the paddle and the bowl specified in CSA A3005 are suitable when using standard mortar.*

   To permit the mixer to operate freely and to avoid serious damage to the paddle and bowl when coarser aggregates are used, it might be necessary to set the clearance adjustment bracket to provide greater clearances than those specified. A clearance of approximately 5.0 mm has been found to be satisfactory for this method when used with fine aggregate from which the material retained on the 5.0 mm sieve has been removed.
e) Use water and cement in quantities that will yield a water-to-cement ratio of 0.6 by mass. It has been found that 600 g of cement and 360 mL of water will usually be adequate for a six-cube batch. Condition the water to a temperature of 23 ± 2 °C.
f) Using fine aggregate in a saturated surface-dry condition, prepare a quantity of aggregate estimated to provide slightly more than needed to produce a batch of the desired consistency.

   Note: *The quantity of fine aggregate used with this amount of cement may vary from 1200 g for fine to 2000 g or more for coarse fine aggregate.*
g) After placing all the mixing water in the bowl, add the cement to the water. Mix with the mixer at a slow speed (140 ± 5 r/min) for 30 s.
h) While still mixing at a slow speed over a 30 s period, add a measured quantity of fine aggregate estimated to provide the specified consistency. The quantity of aggregate used may be determined by subtracting from a known quantity of prepared aggregate the mass of the portion remaining after mixing.
i) Stop the mixer, change to medium speed (285 ± 10 r/min), and mix for 30 s.
j) Stop the mixer and let the mortar stand for 1-1/2 min. During the first 15 s of this interval, quickly scrape down into the batch any mortar that has collected on the sides of the bowl; for the remainder of this interval, cover the bowl with the lid.
k) Finish by mixing for 1 min at medium speed (285 ± 10 r/min). If the flow appears to be too high, additional sand may be added after the first 30 s of this mixing period. If so, stop the mixer briefly, add the sand, and then complete the additional 30 s of mixing.
l) In any case requiring a remixing interval, quickly scrape any mortar adhering to the sides of the bowl down into the batch with the scraper prior to remixing.
m) Make a determination of the flow.

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10 Flow test

10.1

The test shall be performed as follows:

a) Carefully wipe the flow-table top clean and dry, and place the flow mould at the centre.
b) Immediately after completing the mixing operation, place a layer of mortar about 25 mm in thickness in the mould and tamp 20 times with the tamper.
c) Ensure that the tamping pressure is just sufficient to produce uniform filling of the mould.
d) Fill the mould with mortar and tamp as specified for the first layer.
e) Cut off the mortar to a plane surface, flush with the top of the mould, by drawing the straight edge of the trowel (held nearly perpendicular to the mould) with a sawing motion across the top of the mould.
f) Wipe the tabletop clean and dry, being especially careful to remove any water from around the edge of the flow mould.
g) Lift the mould away from the mortar 1 min after completing the mixing operation.
h) Immediately drop the table through a height of 13 mm, ten times in 6 s. The flow is the resulting increase in average diameter of the mortar mass, measured on at least four diameters at approximately equal angles, expressed as a percentage of the original diameter.

10.2

If the flow is in excess of 105 %, the mortar shall be returned to the mixing vessel, additional sand shall be added and mixed for 30 s at medium speed, and another determination of the flow shall be made. If more than two trials are made to obtain a flow of 100 ± 5%, the mortar should be considered a trial mortar, and specimens shall be tested from a new batch and tested.

10.3

If the flow of the mortar is less than 95%, the batch shall be discarded.

10.4

The quantity of sand used shall be determined by subtracting the mass of the portion remaining after mixing from the mass of the initial sample.

11 Moulding test specimens

11.1 Making specimens

The specimens shall be made as follows:

a) Mould three 50 mm cubes from each batch of mortar with the aggregate treated in sodium hydroxide and three batches with the untreated aggregate.
b) Start moulding the specimens within a total elapsed time of not more than 2 min and 30 s after completion of the original mixing of the mortar batch. Place a layer of mortar about 25 mm (approximately one half of the depth of the mould) in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 s in four rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen, as illustrated in Figure 1. Ensure that the tamping pressure is just sufficient to produce uniform filling of the moulds.
c) Complete the four rounds of tamping (32 strokes) of the mortar in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first layer.

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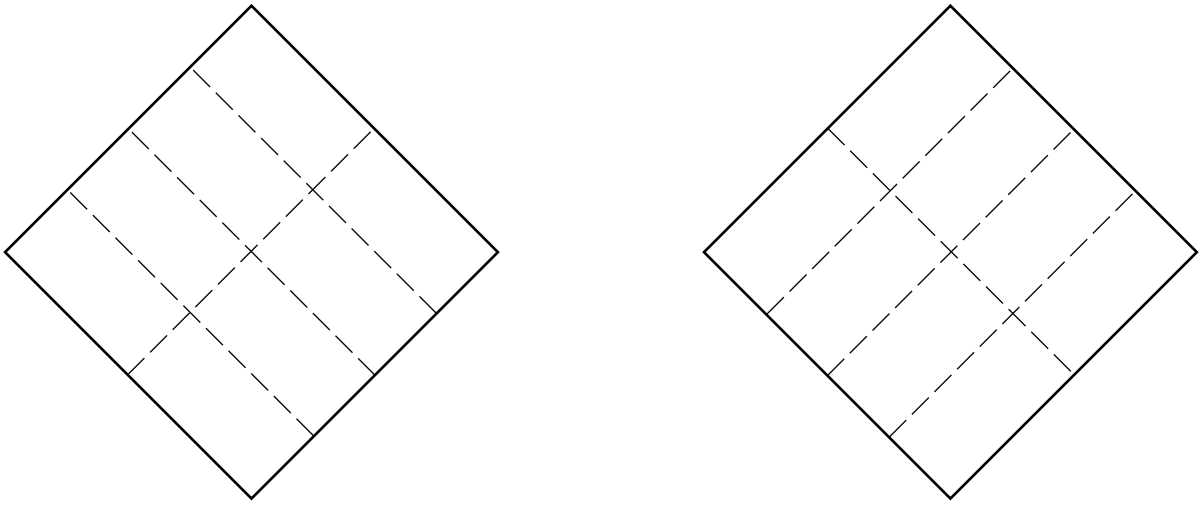
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d) During tamping of the second layer, bring in the mortar forced out onto the tops of the moulds after each round of tamping, by means of gloved fingers and the tamper, upon completion of each round and before starting the next round of tamping.

e) On completion of the tamping, the tops of all cubes will probably extend slightly above the tops of the moulds. Bring in the mortar that has been forced out onto the tops of the moulds with a trowel and smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mould. Then, for the purpose of levelling the mortar and making the mortar that protrudes above the top of the mould of more uniform thickness, draw the flat side of the trowel (with the leading edge slightly raised) lightly once along the length of the mould. Cut off the mortar to a plane surface flush with the top of the mould by drawing the straight edge of the trowel (held nearly perpendicular to the mould) with a sawing motion over the length of the mould.

Note: *When a duplicate batch is to be made immediately for additional specimens, the flow test may be omitted and the mortar allowed to stand in the mixing bowl for 90 s and then remixed for 15 s at medium speed (285 ± 10 r/min) before starting the moulding of the specimens.*

Figure 1
Tamping order
(See Clause 11.1.)



11.2 Storage of test specimens

The test specimens shall be stored as follows:

a) Immediately upon completion of moulding, place the test specimens in a moist closet or moist room. Keep all test specimens, immediately after moulding, in the moulds on the base plates in the moist closet or moist room from 20 to 24 h with their upper surfaces exposed to the moist air, but protected from dripping water.

b) If the specimens are removed from the moulds before 24 h, keep them on the shelves of the moist closet or moist room until they are 24 h old and then immerse the specimens in saturated lime water in storage tanks constructed of non-corroding materials.

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12 Determination of compressive strength

Compressive strength shall be determined as follows:

a) Test the specimens immediately after their removal from the storage water. If more than one specimen at a time is removed from the moist closet for the 24 h tests, keep these specimens covered with a damp cloth until the time of testing. If more than one specimen at a time is removed from the storage water for testing, keep these specimens in water at a temperature of 23 ± 2 °C and of sufficient depth to completely immerse each specimen until the time of testing.

b) Surface-dry each specimen and remove any loose sand grains or encrustations from the faces that will be in contact with the bearing blocks of the testing machine. Check these faces by applying a straightedge and inserting a 0.05 mm thick feeler gauge. If the bearing surface departs from the plane by more than 0.05 mm, grind the face or faces to plane surfaces or discard the specimen.

Note: *Results much lower than the true strength will be obtained by loading faces of the specimen that are not truly plane surfaces. Therefore, it is essential that specimen moulds be kept scrupulously clean, as otherwise large irregularities in the surfaces will occur. Instruments for cleaning the moulds should always be softer than the metal in the moulds to prevent wear. If grinding of specimen faces is necessary, it can be accomplished best by rubbing the specimen on a sheet of fine emery paper or cloth glued to a plane surface, using only moderate pressure. Such grinding is tedious for more than a few hundredths of a millimetre; where more grinding than this is found necessary, the specimen should be discarded.*

c) Carefully place the specimen in the testing machine below the centre of the upper bearing block. Use no cushioning or bedding materials. Apply the load continuously and without shock to plane faces of the specimen. In testing machines of the screw type, the moving head shall travel at a rate of about 1.3 mm/min when the machine is running idle. In hydraulically operated machines, apply the load at a constant rate within the range of 0.15 to 0.35 MPa/s. During the application of the first half of the maximum load, a higher rate of loading may be used. Make no adjustment in the controls of the testing machine, as the rate of loading slows down immediately before failure.

13 Calculation of results

The results shall be calculated as follows:

a) Calculate the compressive strength of each specimen by dividing the maximum load it carried during the test by the cross-sectional area.

b) Average the strengths of the three specimens from each batch.

c) Calculate three strength ratios by dividing the average strength for a batch containing untreated sand by the average strength for the corresponding (in respective order of mixing) batch containing treated fine aggregate.

d) Report the average of the three ratios, expressed as a percentage precision, as the relative strength for the sand under test.

14 Reporting

14.1 Required information

The following information shall be included in the test report, as applicable:

a) source of the sample supply;

b) sample number or identification marks;

c) name of the certified technician performing the test;

d) mix proportions for each test and control mixture produced;

e) flow test results to the nearest 0.5% for each test and control mixture produced;

f) compressive strength of each cube tested to the nearest 0.1 MPa;

g) the mean compressive strength of each set of three cubes cast each for each mixture to the nearest 0.1 MPa;

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h) identification of the certified laboratory that performed the test (i.e., name and address);
i) name and signature of the person responsible for the review of the test report; and
j) any deviations from the test procedure.

14.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate; and
b) date the sample was taken.

15 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C87/C87M.

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A23.2-9A
Soundness of fine and coarse aggregate by use of magnesium sulphate

1 Scope
This Test Method specifies the procedure used to test aggregate to determine its resistance to disintegration using a saturated solution of magnesium sulphate.

It furnishes information helpful in judging the soundness of aggregate subject to freezing and thawing. In others cases, this Test Method can be used to evaluate the potential of sulphate attack of aggregate.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1A:19
Sampling aggregates for use in concrete

ASTM International

C88-13
Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

Other reference

Keyser, J.H. and Aubin, R.M., *Évaluation des méthodes de stockage et d'essais d'agrégats*, MTQ, Project B-004-74, 1975.

3 Summary
The sample is subjected to five repeated immersions in a saturated sulphate solution followed by a drying period to permit salt accumulation and crystallization. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing.

4 Significance and use
This Test Method provides a procedure for making a preliminary estimate of the soundness of aggregates for use in concrete and other purposes. In some cases this Test Method will not be suitable for outright rejection of aggregates without confirmation from other tests more closely related to the specific service intended.

The Test Method may be used for the evaluation of coarse aggregate samples, fine aggregate samples, or a combination of coarse and fine (e.g., graded aggregate, pit run samples).

This Test Method is not suitable for coarse aggregate larger than 40 mm from sedimentary rock.

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5 Apparatus

The apparatus shall consist of the following:

a) sieves with square openings of the sizes given in Table 1 with woven wire cloth conforming to ISO 3310-1 made with the preferred wire diameter for sieving the samples in accordance with Clauses 7 and 8;

b) containers for immersing the samples of aggregate in the solution, in accordance with the procedure described in this Test Method, perforated in such a manner as to permit free access of the solution to the sample and drainage of the solution from the sample without loss of aggregate.* The volume of the solution in which samples are immersed shall be at least five times the volume of the sample immersed at any one time;

** Baskets made of suitable wire mesh or sieves with suitable openings are satisfactory containers for the samples.*

c) suitable means for regulating the temperature of the samples during immersion in the magnesium sulphate solution;

d) for fine aggregate: a balance having a capacity of not less than 500 g, sensitive to 0.1 g or less, for coarse aggregate: a balance having a capacity of not less than 5 kg, sensitive to 1 g or less; and

e) a drying oven capable of being heated continuously at 110 ± 5 °C. The rate of evaporation at this range of temperature shall be at least 25 g/h for 4 h per beaker, during which period the doors of the oven shall be kept closed. This rate shall be determined by the loss of water from 1 L Griffin low-form beakers (each initially containing 500 g of water at a temperature of 23 ± 2 °C) placed at each corner and the centre of each shelf of the oven that is to be used.

Table 1
Sieve sizes for coarse and fine aggregates
(See Clause 5.)

Material	Sieve size
Coarse aggregates	80 mm
	56 mm
	40 mm
	28 mm
	20 mm
	14 mm
	10 mm
Fine aggregates	5 mm
	2.5 mm
	1.25 mm
	630 µm
	315 µm

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. It is the responsibility of the user of this Test Method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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7 Preparation of solution

The solution shall be prepared as follows:

a) Prepare a saturated solution of magnesium sulphate by dissolving a CP, USP, or equal grade of the salt in water at 25 to 30 °C.
b) Add sufficient salt, of either the anhydrous ($MgSO_4$) or the heptahydrate ($MgSO_4 \cdot 7H_2O$, Epsom salt) form, to ensure saturation and the presence of excess crystals when the solution is ready for use in the tests.
c) Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used.
d) Cool the solution to a temperature of 23 ± 2 °C and maintain at that temperature for at least 48 h before use.
e) Prior to each use, break up the salt cake (if any), stir the solution thoroughly, and determine the relative density of the solution.
f) Ensure that, when used, the solution has a relative density not less than 1.295 or more than 1.308.
g) Discard a discoloured solution or filter it and check for relative density.

Note: *For the solution, 350 g of anhydrous salt or 1230 g/L of the heptahydrate is sufficient for saturation at 23 ± 2 °C. However, since these salts are not completely stable, with the hydrous salt being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate salt be used and in an amount of not less than 1400 g/L of water.*

8 Samples

8.1 General

Samples shall be obtained in accordance with CSA A23.2-1A and reduced to suitable test masses by quartering. Should the samples contain less than 5% of any of the sizes specified in Clause 8.2 or 8.3, that size shall not be tested. For the purpose of calculating the test results, the sample shall be considered to have the same loss in magnesium sulphate treatment as the average of the next smaller and the next larger size or, if one of these sizes is absent, it should be considered to have the same loss as either the next larger or the next smaller size, whichever is present.

8.2 Fine aggregate

Fine aggregate shall be passed through a 10 mm sieve. The sample size shall be such that it will yield not less than 100 g for each of the sizes given in Table 2 that are available in amounts of 5% or more of the total sample.

Table 2
Fine aggregate sieve sizes and quantities
(See Clause 8.2.)

Passing sieve	Retained on sieve	Minimum quantity, g	Sieve used to determine loss
10 mm	5 mm	100	5 mm
5 mm	2.5 mm	100	2.5 mm
2.5 mm	1.25 mm	100	1.25 mm
1.25 mm	630 µm	100	630 µm
630 µm	315 µm	100	315 µm

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8.3 Coarse aggregate

Coarse aggregate shall consist of material from which the sizes finer than the 5 mm sieve have been removed. The material that is finer than 5 mm shall be tested in accordance with the procedure for fine aggregate. The sample size shall be such that it will yield not less than the amounts for each of the sieve sizes given in Table 3 that are available in amounts of 5% or more.

Table 3
Coarse aggregate sieve sizes and quantities
(See Clauses 8.3 and 11.3.)

Size fraction, mm	Minimum quantity, g	Sieve used to determine loss, mm
40 to 80 consisting of 40 to 56 (50%) 56 to 80 (50%)	3000	31.5
20 to 40 consisting of 20 to 28 (50%) 28 to 40 (50%)	1500	16
10 to 20 consisting of 10 to 14 (50%) 14 to 20 (50%)	1000	8
5 to 10	300	4

9 Preparation of test sample

9.1 Fine aggregate

The sample of fine aggregate shall be thoroughly washed on a 315 µm sieve, then dried to constant mass at 110 ± 5°C, and separated into the different sizes by the following sieving procedure:

a) Make a rough separation of the graded sample by means of a nest of the standard sieves specified in Clause 5.
b) From the fractions obtained in Item a), select samples of sufficient size to yield 100 g after sieving to refusal (in general, a 110 g sample is sufficient). Do not use the fine aggregate that is embedded in the meshes of the sieves in preparing the samples.
c) Measure samples consisting of 100 g from each of the separated fractions after final sieving and place the samples in separate containers for the test.

9.2 Coarse aggregate

The sample of coarse aggregate shall be thoroughly washed until all traces of fine material are removed, then dried to constant mass at 110 ± 5 °C, and separated into the different sizes shown in Clause 8.3 by sieving to refusal. Each fraction shall be separately measured and placed in separate containers for the test. In the case of fractions coarser than the 20 mm sieve, the number of particles shall also be counted.

9.3 Ledge rock

For testing ledge rock, the sample shall be prepared by crushing it into fragments of reasonably uniform size and shape, weighing approximately 100 g each. The sample shall have a mass of 5000 g ± 2%. The

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sample shall be thoroughly washed until all traces of fine material are removed and shall be dried prior to testing as described in Clause 9.2.

10 Procedure

10.1 Storage of samples in solution

The samples shall be immersed in the prepared solution for not less than 16 h or more than 18 h in such a manner that the solution covers them to a depth of at least 10 mm. The containers shall be covered to reduce evaporation and to prevent the accidental addition of extraneous substances. The samples immersed in the solution shall be maintained at a temperature of 23 ± 2 °C for the immersion period.

Note: *Wire grids with a suitable mass placed over the sample in the containers will allow this coverage to be achieved with very low-density aggregates.*

10.2 Drying samples after immersion

After the immersion period, the aggregate sample shall be removed from the solution, drained for 15 ± 5 min, and placed in the drying oven. Within 5 min of placing the sample in the oven, the air temperature within the oven shall be at 110 ± 5 °C. Care shall be exercised to avoid loss of any of the aggregate particles or, in the case of fine aggregate, of any detritus coarser than a 160 µm sieve. The samples shall be dried to constant mass at the specified temperature. After drying, the samples shall be allowed to cool to room temperature, after which they shall again be immersed in the prepared solution as described in Clause 10.1.

Note: *In the case of coarse aggregate, the detritus should also be saved if the complete analysis suggested in the Note to Clause 11.1 is made.*

10.3 Number of cycles

The cycle of alternating between immersion and drying shall be repeated five times.

If a cycle is interrupted, the material within the containers shall remain at room temperature, after drying, until the next cycle is resumed in the magnesium sulphate solution.

11 Quantitative examination

11.1

The quantitative examination shall be made in accordance with the requirements of Clauses 11.2 to 11.4.

Note: *In addition to the evidence provided by the procedure described in Clauses 11.2 and 11.3, additional information of value can be obtained by examining each fraction visually in order to determine whether there is any evidence of excessive splitting of the grains. Additional information of value should be obtained if, after treating each separate fraction of the samples as described in Clause 11.3, all sizes, including detritus, are combined and a sieve analysis made using a complete set of sieves for the determination of the fineness modulus. The results of the sieve analysis should be recorded as cumulative percentages retained on each sieve.*

11.2

After the completion of the final cycle and after the sample has cooled, the sample shall be washed free of magnesium sulphate.

Note: *The washing procedure could be qualified as determined by the reaction of the wash water with a barium chloride solution prepared by dissolving 200 g of $BaCl_2 \cdot 2H_2O$ in 1 L of water. If present, magnesium sulphate will react with barium chloride to form a cloudy precipitate of barium sulphate.*

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11.3
After the magnesium sulphate solution has been removed, each fraction of the sample shall be dried to constant mass at 110 ± 5 °C and its mass recorded. The fine aggregate shall be sieved over the same sieve on which it was retained before the test and the coarse aggregate shall be sieved over the sieve shown in Table 3 for the appropriate size of particle. The amount retained on each sieve shall be weighed and the mass recorded.

11.4
In the case of ledge rock, the loss in mass shall be determined by subtracting the final mass of all fragments that have not broken into more than two pieces from the original mass of the sample.

Note: *A piece of aggregate is defined as any fragment that has a mass of at least 10% of that of the fragment from which it was broken.*

12 Qualitative examination

12.1
Fractions of samples coarser than 20 mm shall be examined qualitatively after each immersion and quantitatively at the completion of the test.

12.2
The qualitative examination and record shall consist of the following two parts:

a) observing the effect of the action by the magnesium sulphate solution and the nature of the action; and
b) counting the number of particles affected.

Note: *Many types of action can be expected. In general, they may be classified as disintegration, splitting, crumbling, cracking, flaking, etc. While only particles larger than 20 mm are required to be examined qualitatively, examination of the smaller sizes should be made in order to determine whether there is any evidence of excessive splitting.*

13 Reporting

13.1 Required information
The following information shall be included in the test report:

a) sample number or identification marks;
b) mass of each fraction of the sample before the test;
c) except for ledge rock, the percentage by mass of the fraction of material from each fraction of the sample finer than the sieve on which the fraction was retained before the test;
d) the weighted average calculated from the percentage of loss for each fraction, based on the grading of the material from that portion of the supply of which the sample is representative (in these calculations, size finer than the 315 µm sieve shall be assumed to have 0% loss);
e) for particles coarser than 20 mm before test:
    i) number of particles in each sieve fraction before test; and
    ii) number of particles affected, classified as to the number disintegrated, splitting, crumbling, cracking, flaking, etc.;
f) for ledge rock:
    i) percentage of loss calculated, as described in Clause 9.3; and
    ii) number of particles affected, classified as to the number disintegrated, splitting, crumbling, cracking, flaking, etc.;

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g) characteristics of the magnesium sulphate solution;
h) name of the certified technician who performed the test;
i) identification of the certified laboratory that performed the test (i.e., name and address);
j) name and signature of the person responsible for the review of the test report; and
k) any deviations from the test method.

Note: *A suggested form for recording test data is shown in Table 4.*

13.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate;
b) date sample was taken or was received; and
c) sample source or sample location or both.

Table 4
Example of form for recording test data (with illustrative test values)
(See Clause 13.1.)

Sieve size					
Passing	**Retained on**	**Grading of original sample, %**	**Mass of test fractions before test, g**	**Passing finer sieve after test, % (actual % loss)**	**Weighted average (corrected % loss)**
Soundness test of coarse aggregate					
80 mm	40 mm	20.0	3000*	4.8	0.96
40 mm	20 mm	45.0	1500*	8.0	3.60
20 mm	10 mm	23.0	1000*	9.6	2.20
10 mm	5 mm	12.0	300*	11.2	1.34
Total		**100.0**	**5800**	—	**8.10**
Soundness test of fine aggregate					
10 mm	5 mm	4.6	—	11.2†	0.52
5 mm	2.5 mm	10.8	100	11.2	1.21
2.5 mm	1.25 mm	17.0	100	8.0	1.36
1.25 mm	630 µm	25.2	100	4.8	1.21
630 µm	315 µm	26.0	100	4.2	1.09
315 µm	160 µm	11.4	—	—	—
160 µm	—	5.0	—	—	—
Total		**100.0**	**400**	—	**5.39**

* *Minimum amounts. Larger samples may be used.*
† *The percentage loss (11.2%) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5% of the original samples as received (see Clause 8.1).*

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14 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C88.

According to Keyser and Aubin (1975), for coarse aggregate with weighted average sulphate soundness losses in the ranges of 9 to 20%, the precision indexes are as follows:

	Coefficient of variation (1S%), %	Difference between two tests (D2S %), % of average
Multi-laboratory	5.6	15
Single operator	2.7	8.0

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A23.2-10A
Bulk density of aggregate

1 Scope
This Test Method defines the procedures for determining the bulk density of fine, coarse, or mixed aggregate in a compacted or loose state.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

ASTM International

C29/C29M-17a
Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition
In addition to the definitions specified in CSA A23.1, the following definition applies in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Summary
A calibrated metal measure of known volume is filled with the test aggregate using specified procedures. The bulk density of the test aggregate is determined by dividing the net mass of the aggregate in the measure by the volume of the measure.

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5 Significance and use

This Test Method provides the procedures to determine the bulk density of

a) aggregates in a loose state facilitates volume conversion of aggregates in stockpile; and
b) coarse aggregate in a compacted state facilitates preparation of theoretical concrete mix designs.

6 Apparatus and supplies

The apparatus shall consist of the following:

a) a balance or scale sensitive to 0.1% of the mass of the sample;
b) a round, straight, steel tamping rod, 16 ± 1 mm in diameter and approximately 450 to 600 mm in length, having at least one end rounded to a hemispherical tip;
c) sieves conforming to ISO 3310-1 made with the preferred wire diameter; and
d) a watertight metal measure, cylindrical in form and preferably provided with handles, with the top and bottom true and even, preferably machined to accurate dimensions on the inside, and of sufficient rigidity to retain its form under rough usage. The top rim of the metal measure shall be smooth and plane within 0.25 mm and shall be parallel to the bottom within 0.5°. The 15 L and 30 L size measures listed in Table 1 shall be reinforced around the top with a metal band to provide an overall wall thickness of not less than 5 mm in the upper 40 mm. The capacity and dimensions of the measure shall conform to the limits in Table 1.

Note: *In the event that 15 L or 30 L measures are not readily sourced, 14 L or 28 L measures in conformance with ASTM C29/C29M may be substituted.*

Table 1
Dimensional requirements for measures
(See Clause 6.)

Capacity, L	Inside dimensions, mm		Minimum thickness of metal, mm		Nominal maximum size of coarse aggregate, mm
	Diameter	Height	Base	Walls	
7	205 ± 2	210 ± 2	5.0	2.5	28 or less
15*	255 ± 2	295 ± 2	5.0	3.0 (5.0 mm in the upper 40 mm (+0 mm, –2 mm))	56 or less
30*	355 ± 2	305 ± 2	5.0	3.0 (5.0 mm in the upper 40 mm (+0 mm, –2 mm))	80 or less

** 14 L and 28 L measures, conforming to ASTM C29/C29M, may be substituted for 15 L and 30 L measures respectively based on availability. See note to Clause 6.*

7 Calibration of measure

The measure shall be calibrated as follows:

a) Fill the measure with water at room temperature and cover completely with a piece of plate glass in such a way as to eliminate bubbles and excess water.
b) Determine the mass of the water in the measure.
c) Measure the temperature of the water and determine its density of water from Table 2, interpolating as necessary.
d) Calculate the volume, *V*, of the measure by dividing the mass of the water required to fill the measure by its density. Also calculate the factor for the measure (1/*V*) by dividing the density of the water by the mass required to fill the measure.

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Table 2
Density of water
(See Clause 7.)

Temperature, °C	kg/m³
18	998.62
19	998.43
20	998.23
21	998.02
22	997.80
23	997.56
24	997.32
25	997.07
26	996.81
27	996.54
28	996.26

8 Test sample

8.1

A sample of suitable size shall be obtained in accordance with CSA A23.1-1A.

8.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

8.3

The aggregate sample to be tested shall be thoroughly mixed and oven dried at a temperature of 110 ± 5 °C to a constant mass. The moisture condition of the test aggregate sample shall be reported if it is other than oven dry.

Notes:

1) *Depending on the purpose of the test results, alternative moisture conditioning may be used (e.g., in situ moisture for volume conversions of aggregate in stockpiles).*
2) *For improved accuracy, duplicate samples should be tested.*

9 Compacted aggregate bulk density test procedures

9.1 Rodding procedure (applicable for nominal aggregate size up to 56 mm)

9.1.1

The procedure shall be performed as specified in Clauses 9.1.2 to 9.1.4.

9.1.2

Fill the measure with the test aggregate to one-third full and level the top with the fingers. Consolidate the aggregate by rodding with the tamping rod with 25 strokes, evenly distributed over the entire surface area. In rodding the first layer, do not strike the bottom of the measure with the rod. Fill the

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measure to two-thirds full and again consolidate with rod with 25 strokes as before. Overfill the measure and rod with 25 strokes as before, and strike off the surplus aggregate, using the tamping rod as a straightedge. In rodding the second and final layers, use only enough force to cause the tamping rod to penetrate the last layer of aggregate placed in the measure.

9.1.3
Level off the surface of the aggregate in the final layer with fingers or a tamping rod in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

9.1.4
Determine the net mass of the aggregate in the measure and calculate the bulk density of the aggregate by multiplying the net mass of the aggregate by the factor for the measure (1/*V*) determined by the procedure specified in Clause 7.

9.2 Jigging procedure (applicable for nominal aggregate sizes 56 mm to 80 mm)

9.2.1
The jigging procedure shall be performed as specified in Clauses 9.2.2 and 9.2.4.

9.2.2
Fill the measure in three approximately equal layers, each layer being compacted by placing the measure on a firm foundation, such as a concrete floor, and alternately raise each side of the measure about 50 mm from the foundation and allow it to drop in such a manner as to hit with a sharp, slapping blow. The aggregate particles, by this procedure, will arrange themselves in a closely compacted condition. Compact each layer by dropping the measure 50 times in the manner described, 25 times on each side.

9.2.3
Level off the surface of the aggregate with fingers or a tamping rod in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

9.2.4
Determine the net mass of the aggregate in the measure and calculate the bulk density of the aggregate by multiplying the net mass of the aggregate by the factor for the measure (1/*V*) determined by the procedure specified in Clause 7.

10 Loose aggregate bulk density test procedure (applicable for nominal aggregate sizes up to 80 mm)

10.1
The loose aggregate bulk density test procedure shall be performed as specified in Clauses 10.2 to 10.2.

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10.2
Overfill the measure with the test aggregate by means of a shovel or scoop by discharging the aggregate from a height not to exceed 50 mm above the top of the measure. Take care to prevent, so far as possible, segregation of the particle sizes of which the sample is composed.

10.3
Level off the surface of the aggregate with the fingers or a tamping rod in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

10.4
Determine the net mass of the aggregate in the measure and calculate the loose bulk density of the aggregate by multiplying the net mass of the aggregate by the factor for the measure (1/*V*) determined by the procedure described in Clause 7.

11 Reporting

11.1 Required information
The following information shall be included in the test report, as applicable:
a) sample number or identification marks;
b) bulk density to the nearest 1 kg/m^3 of the following:
   i) compacted aggregate bulk density by rodding procedure (as applicable);
   ii) compacted aggregate bulk density by jigging procedure (as applicable); or
   iii) loose aggregate bulk density (as applicable);
c) name of the certified technician who performed the test;
d) identification of the certified laboratory that performed the test (i.e., name and address);
e) name and signature of the person responsible for the review of the test report; and
f) any deviations from the test procedure.

11.2 Optional information
The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate;
b) date the sample was obtained; and
c) sample source or sample location or both.

12 Precision and bias
The precision and bias information for this Test Method is not available.

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A23.2-11A
Surface moisture in fine and coarse aggregate

1 Scope
This quantitative Test Method specifies the procedures for determining, in the field, the amount of surface moisture in fine and coarse aggregates by displacement in water. The accuracy of the method depends upon accurate information on the bulk relative density of the aggregates in a saturated surface-dry condition.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-6A:19
Relative density and absorption of fine aggregate

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

3 Summary
Test aggregate is placed in a graduated container with and without water using specified procedures. Mass or volume of the test aggregate with or without water is determined to compute the mass or volume of water displaced by the test aggregate. Surface moisture of the test aggregate is computed using the bulk relative density of the test aggregate.

4 Significance and use
This Test Method determines the surface moisture in the aggregates to facilitate proper decisions as to the amount of water required to be added to a batch of concrete mix to satisfy the design net water content of the mix.

5 Apparatus
The apparatus shall consist of the following:

a) a balance having a capacity of 2 kg or more and sensitive to 0.5 g or less; and

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b) a suitable container or flask, preferably of glass or corrosion-resistant metal. The container may be a pycnometer, a volumetric flask, a graduated volumetric flask, or another suitable measuring device with easily readable graduation markings. The capacity of the container shall be two to three times the loose volume of the test aggregate sample. The container shall be designed so that it can be filled to the mark or the volume of its contents can be read within the accuracy of 1.0 mL or less.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Samples

7.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

7.2

A representative test sample, of mass not less than 200 g of the fine aggregate to be tested or not less than 2 kg of the coarse aggregate to be tested, shall be selected.

Note: *Larger samples generally yield more accurate results.*

7.3

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

8 Test procedure

8.1 General

The surface water content of fine and coarse aggregates shall be determined either by mass or by volume. The test shall be conducted at a temperature of 23 ± 5 °C.

8.2 Determination by mass

Determination by mass shall be as follows:

a) Fill the container to the mark with water and determine the mass of the container and water accurate to within ± 0.5 g.
b) Empty the container.
c) Weigh the test sample and introduce it into the container.
d) Place enough water in the container to cover the test sample.
e) Remove the entrapped air by stirring the contents of the container.
f) Fill the container to the original mark and weigh it to within ± 0.5 g.
g) Calculate the mass of water displaced by the test sample as follows:

$M_w = M_c + M_s - M$

where

M_w = mass of water displaced by sample, g

M_c = mass of container filled to mark with water, g

M_s = mass of sample, g

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M = mass of container and sample, filled to mark with water, g

8.3 Determination by volume

Determination by volume shall be as follows:

a) Place sufficient volume of water to cover the test sample in the graduated flask container and measure the volume of water by direct reading.
b) Introduce the weighed test sample into the same container and remove the entrapped air by stirring the contents of the container.
c) Determine the combined volume of the test sample and the water by direct reading.
d) When a pycnometer or volumetric flask of known volume is used, determine the combined volume of the sample and the water by filling to the mark with a measured volume of water and subtracting this volume from the volume of the container.
e) Calculate the volume of water displaced by the sample, as follows:

$V_s = V_2 - V_1$

where

V_s = volume of water displaced by sample, mL

V_2 = combined volume of sample and water, mL

V_1 = volume of water required to cover sample, mL

The mass of water displaced by the sample in grams shall be as follows:

$M_w = V_s \times Y_w$

where

Y_w = the unit weight of water, g/mL

9 Calculation

The percentage of surface moisture compared to the mass of saturated surface-dry aggregate, shall be calculated and compared to the mass of wet aggregate as follows:

$$P_1 = \frac{M_w - M_s / G}{M_s - M_w} \times 100$$

$$P_2 = \frac{M_w - M_s / G}{M_s - M_s / G} \times 100$$

where

P_1 = surface moisture compared to the mass of the saturated surface-dry aggregate, %

M_w = mass of water displaced by the sample, g

M_s = mass of sample, g

G = bulk relative density of the aggregate in a saturated surface-dry condition determined as specified in CSA A23.2-6A or CSA A23.2-12A. In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 10 or 11 of CSA A23.1, use the weighted average bulk relative density.*

P_2 = surface moisture compared to the mass of wet aggregate, %

** See Clause 6.2 of CSA A23.2-30A.*

Note: *The formulae are readily derived from basic relationships. For convenience, use r as the ratio of the mass of surface moisture to the mass of the saturated surface-dry sample. It follows that*

$P_1 = 100r$

and

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$$P_2 = 100\left(\frac{r}{r+1}\right)$$

The mass of saturated surface-dry aggregate is

$$M_s = \left(\frac{1}{r}\right)$$

The mass of surface moisture is

$$\left(\frac{M_s}{r+1}\right)r$$

The volume of the sample, *Vs*, can be determined as the sum of two terms, the volume of the saturated surface-dry aggregate plus the volume of the surface moisture, as follows:

$$V_s = \frac{M_s}{G\gamma_w(1+r)} + \frac{M_s r}{\gamma_w(1+r)}$$

This can be easily solved to determine *r*:

$$r = \frac{V_s\gamma_w - M_s / G}{M_s - V_s\gamma_w}$$

For this test, γ_w may be taken to be 1 g/mL.

10 Alternative methods

10.1 General

For control purposes only, the test for surface moisture in fine aggregate shall be performed by the method specified in Clause 10.2 or the test for surface moisture in fine or coarse aggregate shall be performed by the method described in Clause 10.3. The accuracy of the alternative method in Clause 10.2 depends upon accurate information on the apparent relative density of the fine aggregate.

10.2 Flask method (fine aggregate only)

Note: *This method requires that the apparent relative density of the fine aggregate, determined in accordance with CSA A23.2-6A, be known.*

10.2.1 General

This quantitative method is intended for use in making approximate determinations of the percentage of surface moisture in fine aggregate. The range of use for the apparatus is between dry fine aggregate of 2.20 apparent relative density and fine aggregate of 2.85 apparent relative density containing up to 10% moisture. This method determines only surface moisture (i.e., moisture on the outside of the particles). The moisture absorbed within the particles does not add to the volume of the particles and, therefore, is not measured by this test.

10.2.2 Apparatus

The apparatus shall consist of the following:

a) a balance, preferably of the torsion type, having a capacity of 2 kg or more and sensitive to 0.5 g or less; and

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b) a special graduated flask of the type and conforming to the dimensions shown in Figure 1, or a standardized volumetric flask of 500 mL capacity.

10.2.3 Test sample

The sample shall be prepared as follows:

a) Select about 1 kg of representative fine aggregate test sample.
b) Mix the sample thoroughly avoiding the moisture loss through evaporation.
c) Weigh about 500 g of the sample within accuracy of 0.5 g.

10.2.4 Procedure

The procedure shall be as follows:

a) Fill the graduated flask to the 200 mL mark on the lower neck with water at room temperature.
b) Slowly introduce the 500 g test sample of damp aggregate into the flask and agitate or stir the contents of the flask to free any entrapped air bubbles.
c) Read the combined volume, in millilitres, of the water and test sample on the scale on the upper neck of the flask.

10.2.5 Calculations

The percentage of surface moisture in the fine aggregate (air-dry basis) shall be calculated as follows:

$$\text{Surface moisture (\%)} = \frac{V - \frac{500}{\text{(relative density)}} - 200}{200 + 500 - V} \times 100$$

where

V = the combined volume of the water and fine aggregate in the flasks, mL

relative density = approximate apparent relative density of the fine aggregate

Note: *Duplicate determinations of surface moisture determined through this method should agree within 0.5%.*

10.3 Hotplate method (fine or coarse aggregate)

10.3.1 General

This quantitative method is intended to approximately determine the surface moisture of fine and coarse aggregates.

10.3.2 Apparatus

The apparatus shall consist of the following:

a) a balance having a capacity of 2 kg and sensitive to 0.5 g or less;
b) a small shallow pan;
c) a stirring rod or spoon; and
d) a hotplate or stove.

10.3.3 Procedure

The procedure shall be as follows:

a) Weigh a representative sample of the aggregate (e.g., about 500 g for fine aggregate and 1000 g or more for coarse aggregate) and spread in a thin layer in the pan.

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b) Heat the sample slowly and stir frequently when surface moisture is to be determined on the basis of a saturated surface-dry condition. When a saturated surface-dry condition has been obtained, immediately measure its mass.
c) If the total moisture content is desired, the sample shall be dried to a constant mass, and after cooling, the mass measured to calculate the total moisture.

Note: *As the material approaches a surface-dry condition, it should be stirred continuously, using extreme care to avoid driving off more than the surface moisture.*

10.3.4 Calculations

10.3.4.1

The moisture shall be calculated using one of the following formulas:

a) saturated surface-dry condition:

$$\text{Surface moisture (\%) saturated surface-dry basis} = \frac{S - B}{B} \times 100$$

b) absorption correction method:

$$\text{Total moisture (\%) dry basis} = \frac{S - A}{A} \times 100$$

where

S = mass of wet aggregate tested, g

B = mass of saturated surface-dry aggregate tested, g

A = mass of oven-dry sample, g

10.3.4.2

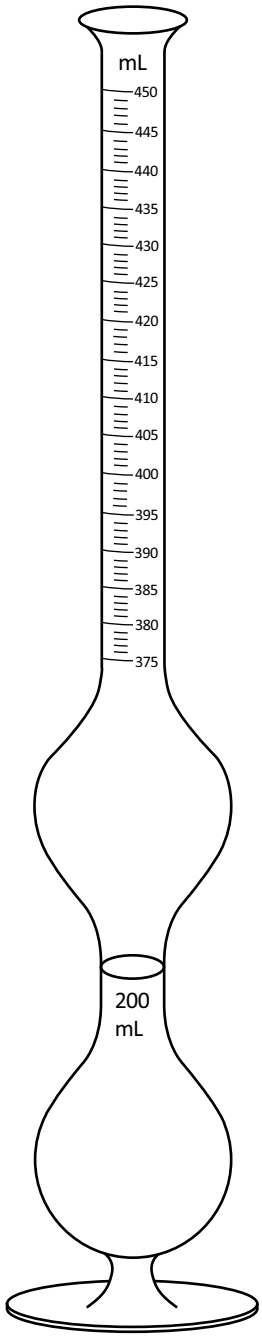
Surface moisture shall be calculated as follows:

Surface moisture (%) dry basis = total moisture (%) – absorption (%)

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Figure 1
Graduated flask for field testing of fine aggregate
(See Clause 10.2.2.)



Diameter of bore of graduated upper neck, approximately 20 mm.

Scale graduated in 1 mL divisions, from 375 mL to 450 mL.

Diameter of opening in lower neck, approximately 22 mm.

Volume of lower chamber to mark on lower neck, 200 mL.

Combined volume of lower and upper chambers to lower end of graduated scale on upper neck, 375 mL.

Range of use: from dry sand of 2.85 relative density to sand of 2.2 relative density having 10% moisture.

11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification marks;
b) percentage moisture of the test sample to the nearest 0.1%;

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c) bulk relative density value of the test aggregate in a saturated surface-dried condition used in the computation of the surface moisture content of the aggregate;
d) name of the certified technician who performed the test;
e) identification of the certified laboratory that performed the test (i.e., name and address);
f) signature of the person responsible for the review of the test report; and
g) any deviations from the test procedure.

11.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate;
b) date sample was obtained; and
c) sample source or sample location or both.

12 Precision and bias

The precision and bias information for this Test Method is not available.

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A23.2-12A
Relative density and absorption of coarse aggregate

1 Scope

This Test Method specifies the procedure for determining the average density of the solid portion of a large number of coarse aggregate particles. It provides requirements for the determination of bulk relative density (oven dry), bulk relative density (SSD*), and apparent relative density and absorption of coarse aggregate.

* *Saturated surface-dry.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto.

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-6A:19
Relative density and absorption of fine aggregate

A23.2-10A:19
Bulk density of aggregate

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

ASTM International

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

ISO (International Organization for Standardization)

3310-1:2006
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

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3 Definitions

In addition to the definitions specified in CSA A23.1, the following definitions shall apply in this Test Method:

Absorption — the increase in the mass of aggregate due to water in the pores of the material (but not including water adhering to the outside surface of the particles) expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5 °C for sufficient time to achieve constant mass.

Apparent relative density — the ratio of the oven dry mass in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the mass in air of an equal volume of water at a stated temperature.

Bulk relative density — the ratio of the oven dry mass in air of a unit volume of aggregate, including the permeable and impermeable voids in the particles but not including the voids between particles, at a stated temperature to the mass in air of an equal volume of water at a stated temperature.

Bulk relative density (SSD) — the ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 24 h but not including the voids between particles, at a stated temperature to the mass in air of an equal volume of water at a stated temperature.

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Significance and use

4.1

Bulk relative density (SSD) is the property used for calculation of the volume occupied by wet aggregate in hydraulic cement concrete that is proportioned on an absolute volume basis. Bulk relative density (dry) is used when the aggregate is dry or assumed to be dry.

4.2

Apparent relative density is the solid material making up the particles but does not include the pore space within the particles accessible to water. This value is not widely used with concrete aggregates.

4.3

Absorption is the mass of water absorbed into the internal pores of the aggregate particles. Aggregate that has been extracted below the water table and has not been dried will usually have a higher absorption than that of the same aggregate that has been dried and saturated for 24 h. The coarse aggregate absorption is used to determine the adjustments to the amount of aggregate and water required to be added or subtracted from a concrete batch to satisfy the yield and design water content of the mix.

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4.4
Coarse aggregates that have high absorption values are likely to be more susceptible to damage caused by freezing and thawing when saturated, or nearly so, compared with aggregates of lower absorption. Some organizations have developed maximum amounts of coarse aggregate absorption that are permitted for use as concrete aggregates. Coarse aggregates that are susceptible to D-cracking usually have high absorption values but not all such aggregates will be prone to such damage.

4.5
Longer periods of immersion than 24 h will normally result in higher absorption values since not all pores are completely filled after 24 h. This Test Method can be used for other times of soaking or means of saturating the aggregate such as boiling in water or vacuum saturation. This Test Method may be used for lightweight aggregate but saturation should be for 72 h.

5 Apparatus

5.1 Balance
A balance or scale shall be used having a capacity of 5 kg or more, sensitive to 0.5 g or 0.05% of the sample mass, whichever is greater and accurate to 0.1% of the test load at any point within the range of use for this Test Method. The balance shall be equipped with a suitable apparatus for suspending the sample container in water from the centre of the platform or pan of the balance.

5.2 Wire basket
A wire basket shall have 2.5 mm or finer mesh or a bucket of approximately equal breadth and height with a capacity of 4 L to 7 L for 40 mm maximum size aggregate or smaller and a larger capacity container in the range 8 L to 16 L for the testing of larger maximum size aggregate.

5.3 Sieve
A 5 mm sieve or as required (see Clause 6.3) shall be used, made of woven wire cloth conforming to ISO 3310-1 made with the preferred wire diameter.

5.4 Oven
An oven of sufficient size shall be used, capable of maintaining a uniform temperature of 110 ± 5 °C.

6 Samples

6.1
A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

6.2
Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

6.3
The sample shall be prepared as follows:

a) Thoroughly mix the sample of aggregate to be tested and reduce it to the approximate quantity needed in accordance with CSA A23.2-1A.

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b) In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 11 of CSA A23.1 or coarse aggregate with more than 15% passing the 5 mm sieve, separate the material into two sizes on the 5 mm sieve and prepare and test the samples of fine and coarse aggregate in accordance with CSA A23.2-6A and CSA A23.2-12A, respectively.
c) Reject all material passing a 5 mm sieve.
d) Use at least the minimum mass of sample given in Table 1.
e) In many instances, it will be desirable to test a coarse aggregate in several separate size fractions: if the sample contains more than 15% material retained on the 40 mm sieve, test the plus 40 mm fraction or fractions separately from the smaller size fractions.
f) When an aggregate is tested in separate size fractions, use the sample size corresponding to the nominal maximum size of each fraction as provided in Table 1.

Note: *See Clause 6.2 of CSA A23.2-30A.*

Table 1
Sample size for relative density and absorption
(See Clause 6.3.)

Nominal maximum aggregate size, mm	Minimum mass of sample, kg
14 and less	2
20	3
28	4
40	5
56	10
80	18

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Procedure

8.1

This Test Method shall be performed as specified in Clauses 8.2 to 8.5.

8.2

Thoroughly wash the sample to remove dust or other coatings from the surface of the particles. Dry the sample to constant mass at a temperature of 110 ± 5 °C. Cool the sample in air at room temperature for 1 to 3 h and then immerse in water at room temperature for a period of 24 ± 4 h.

Note: *Where the absorption and relative density are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be waived. Values for absorption and for relative density in the saturated surface-dry condition may be significantly higher for aggregate that is not oven-dried before soaking than for the same aggregate treated in accordance with this Clause. Therefore, any exceptions to the procedure of this Clause should be noted when reporting the results.*

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8.3

Remove the sample from the water and roll it in a large absorbent cloth until the visible films of water are removed. Wipe the larger particles individually. Take care to avoid evaporation of water from aggregate pores during the operation of surface-drying. Determine the mass of the sample in the saturated surface-dry condition. Record this and all subsequent determinations to the nearest 0.5 g or 0.05% of the sample mass, whichever is greater.

8.4

Immediately place the saturated surface-dry specimen in the sample container and determine its mass in water at 23 ± 2 °C. Take care to remove all entrapped air before measuring the mass by shaking the container while immersed.

Notes:

1) *The container should be immersed to a depth sufficient to cover it and the test specimen during mass determinations. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.*
2) *The density of water given in Table 2 of CSA A23.2-10A should be used.*

8.5

Dry the sample to constant mass at a temperature of 110 ± 5 °C and cool it in air at room temperature for 1 to 3 h and measure its mass.

9 Calculations

9.1 Bulk relative density

The bulk relative density (oven dry basis) shall be calculated as follows:

$$\text{Bulk realtive density} = \frac{A}{B - C}$$

where

A = mass of oven-dry specimen in air, g

B = mass of saturated surface-dry specimen in air, g

C = mass of saturated specimen in water, g

9.2 Bulk relative density (saturated surface-dry basis)

The bulk relative density on the basis of the mass of saturated surface-dry aggregate shall be calculated as follows:

$$\text{Bulk relative density, saturated surface-dry basis} = \frac{B}{B - C}$$

9.3 Apparent relative density

The apparent relative density (oven dry) shall be calculated as follows:

$$\text{Apparent relative density} = \frac{A}{A - C}$$

9.4 Absorption

The percentage of absorption shall be calculated as follows:

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$$\text{Absorption, \%} = \frac{B - A}{A} \times 100$$

9.5 Calculation of average values

9.5.1 Relative density

When the sample is tested in separate size fractions, the average value for bulk relative density, bulk relative density (saturated surface-dry basis), or apparent relative density shall be calculated as the weighted average of the values as calculated in accordance with Clause 9.1, 9.2, or 9.3 using the following equation:

$$G = \frac{1}{\frac{P_1}{100G_1} + \frac{P_2}{100G_2} + \ldots + \frac{P_n}{100G_n}}$$

where

G = average relative density (bulk-dry, saturated surface-dry, or apparent relative densities can be averaged in this manner)

$P_1, P_2, \ldots, P_n$ = mass percentages of each size fraction present in the original sample

$G_1, G_2, \ldots, G_n$ = appropriate relative density values for each size fraction, depending on the type of relative density being averaged

9.5.2 Absorption

For absorption, the average value shall be the weighted average of the values as calculated in Clause 9.4, measured in proportion to the mass percentages of the size fractions in the original sample, as follows:

$$A = \frac{P_1A_1}{100} + \frac{P_2A_2}{100} + \ldots + \frac{P_nA_n}{100}$$

where

A = average absorption, %

$P_1, P_2, \ldots, P_n$ = mass percentages of each size fraction present in the original sample

$A_1, A_2, \ldots, A_n$ = absorption percentages for each size fraction

10 Reporting

10.1 Required information

The following information shall be included in the test report as applicable:

a) sample number or identification marks;
b) nominal maximum sieve size of the test sample;
c) bulk relative density to the nearest 0.01;
d) bulk relative density (i.e., saturated surface-dry basis) to the nearest 0.01;
e) apparent relative density to the nearest 0.01;
f) absorption to the nearest 0.1%;
g) when the sample is tested in separate size fractions, the individual and the average bulk relative density, bulk relative density (saturated surface-dry basis), or apparent relative density to the nearest 0.01;
h) indication if the bulk relative density, apparent relative density, and absorption values were determined without first drying the aggregate, as permitted by Clause 8.2;

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i) if the average relative density and absorbtion values were determined without first drying the aggregate a notation to this effect;
j) name of the certified technician who performed the test;
k) identification of the certified laboratory that performed the test (i.e., name and address);
l) name and signature of the person responsible for the review of the test report; and
m) any deviations from the procedure.

10.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate;
b) date sample was taken or received by testing laboratory;
c) sample source or sample location or both; and
d) mass of the sample making up the test sample.

11 Precision and bias

11.1 Precision

For coarse aggregate with relative density in the approximate range 2.60 to 2.70, the single-operator standard deviation has been found to be 0.004*. Therefore, results of two properly conducted tests on samples of the same aggregate by the same operator using the same equipment are not expected to differ by more than 0.011*, 95% of the time. The multi-laboratory standard deviation has been found to be 0.006*. Therefore, results of two properly conducted tests by different laboratories on samples of the same aggregate are not expected to differ by more than 0.017*, 95% of the time.

* *These numbers represent, respectively, the (1s) and (d2s) limits described in ASTM C670.*

For coarse aggregate with absorption values in the approximate range 0.4% to 1.8%, the single-operator standard deviation has been found to be 0.04%*. Therefore, results of two properly conducted tests on samples of the same aggregate by the same operator using the same equipment are not expected to differ by more than 0.11%*, 95% of the time. The multi-laboratory standard deviation has been found to be 0.09%*. Therefore, results of two properly conducted tests by different laboratories on samples of the same aggregate are not expected to differ by more than 0.26%*, 95% of the time.

* *These numbers represent, respectively, the (1s) and (d2s) limits described in ASTM C670.*

11.2 Bias

Since there is no accepted reference material suitable for determining the bias of this Test Method, no statement on bias is made.

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A23.2-13A
Flat and elongated particles in coarse aggregate

1 Scope

1.1 General

This Test Method specifies two procedures (A and B) used to determine the amount of flat, elongated and flat and elongated particles in coarse aggregate using different criteria to define each category.

1.2 Summary

Procedure A uses a proportional caliper to determine the percentage of flat and elongated particles in coarse aggregate.

Procedure B uses a thickness and length gauges to measure the percentage of flat, elongated and flat and elongated particles in coarse aggregate.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definitions

3.1 Procedure A

The following definitions apply in this Test Method:

Length, *L* — the longest distance between two parallel planes, tangent to the particle.

Thickness, *E* — the shortest distance between two parallel planes, tangent to the particle.

Width, *G* — the least dimension in a plane perpendicular to the length of the particle.

3.2 Procedure B

The following definition applies in this Test Method:

Width, *G* — the mean dimension, equivalent to the mean between the smallest sieve opening through which the particle is passing and the sieve opening on which it is retained.

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4 Significance and use

The shape of aggregate particles has a significant influence on the properties of fresh and hardened concrete. Procedures A and B are intended to classify and compare aggregates according to their shape and as a basis of acceptance in accordance with the limits set in CSA A23.1, Table 12 for flat and elongated particles in coarse aggregates.

5 Apparatus

5.1 General

The apparatus shall be as specified in Clauses 5.2 (Procedure A) and 5.3 (Procedure B).

5.2 Procedure A

5.2.1

A balance sensitive to 0.1g or 0.5% of the mass of the material being measured, whichever is greater shall be used.

5.2.2

Sieves shall meet the requirements of ISO 3310-1 made with the preferred wire diameter.

5.2.3

Suitable equipment with which the ratios of length to width and width to thickness can be determined shall be used.

Note: *The proportional caliper shown in Figure 1 has been found to be satisfactory.*

5.3 Procedure B

5.3.1 Scale

A scale with the required capacity shall be used in order to weigh the quantities required in Clause 6.2.2, with a precision of 1 g.

5.3.2 Sieves

Sieves shall meet the requirements of ISO 3310-1 made with the preferred wire diameter.

5.3.3 Thickness gauge

In order to measure thickness, *E* (the smallest dimension), of particles or to verify if *E/G* is smaller than 0.6, any of the following apparatus may be used:

a) a thickness gauge (see Figure 2) made from a metal plate with a slot of a width equivalent to 3/5 of the mean dimension, G, for each fraction or aggregate size;
b) special sieves (see Figure 2), one for each fraction, made from square or rectangular metal frames with cylinder-shaped parallel bars spaced at a distance of 3/5 of G; and
c) any apparatus or instrument, such as a caliper, compass, or rule, allowing for the measurement of *E/G* with the same precision as obtained with the gauge (see Table 1).

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5.3.4 Length gauge

In order to measure length, L (the largest dimension), of particles or to verify if L/G is larger than 1.8, any of the following apparatus may be used:

a) a length gauge (see Figure 3) made from a metal plate with metal sticks firmly attached perpendicular to the base and spaced at intervals of 9/5 of G; and
b) any apparatus or instrument, such as a caliper, compass, or rule, allowing for the measurement of L/G with the same precision as obtained with the length gauge (see Table 1).

6 Procedures

6.1 Procedure A

6.1.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

6.1.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

6.1.3

A representative sample shall be obtained of each size of aggregate to be tested by sieving and reduced by quartering or splitting, or both, until approximately 100 particles of each sieve size larger than the 5 mm sieve and making up 10% or more of the sample have been procured.

6.1.4

Each of the particles in each subsample shall be tested and segregated into one of the following four categories:

a) flat — particles with a ratio of width to thickness greater than 3, 4, or 5;
b) elongated — particles with a ratio of length to width greater than 3, 4, or 5;
c) flat and elongated — particles with a ratio length to thickness greater than 3, 4, or 5; and
d) neither flat nor elongated.

Note: *The ratio of 3, 4, or 5 should be established before testing.*

6.1.5

When a device as shown in Figure 1 is used, the following procedures shall be adopted:

a) Test for elongation by setting the larger opening equal to the length of the particle. If the width of the particle is less than the smaller opening, it is elongated.
b) Test for flatness by setting the larger opening equal to the width of the particle. If the thickness of the particle is less than the smaller opening, it is flat.
c) Test for flat and elongated by setting the large opening equal to the length of the particle. If the thickness of the particle is less than the smaller opening, it is flat and elongated.

6.1.6

For each subsample, the percentages shall be calculated for flat, elongated, and flat and elongated particles based on the mass of the subsample.

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The weighted average percentages shall be calculated for flat, elongated, and flat and elongated particles from the percentage in each subsample based on the original grading of the sample, as determined by CSA A23.2-2A.

In the case of a size fraction representing less than 10% of the sample retained on the next sieve size larger than the largest sized subsample tested, its contribution shall be calculated to the weighted average based on the percentages in the largest sized subsample tested.

A sample calculation report for Procedure A is as follows:

Sample No.	Size fraction, mm		Proportion of sample in size fraction, %	Percentage by mass of sample, %			
				Flat*	Elongated†	Flat and elongated	Neither flat nor elongated
123	40	28	0.0				
	28	20	6.0	1.3	1.3	4.2	93.2
	20	14	22.0	1.3	1.3	4.2	93.2
	14	10	32.0	4.0	6.6	20.8	68.7
	10	5	40.0	6.0	8.2	25.6	60.2
Weighted average (5 mm retained):				4.0	5.8	18.1	72.2

* *Flat: Ratio of width to thickness greater than 4.*
† *Elongated: Ratio of length to width greater than 4.*

6.2 Procedure B

6.2.1 General requirements

6.2.1.1 Flat particles (plates)

A particle shall be considered flat when its smallest dimension, *E*, is smaller than 0.6 of the mean dimension, *G* (i.e., $E/G < 0.6$).

6.2.1.2 Elongated particle (needles)

A particle shall be considered elongated when its largest dimension, *L*, is larger than 1.8 of the mean dimension, *G* (i.e., $L/G > 1.8$).

6.2.1.3 Flat and elongated particles

A particle shall be considered “flat” and “elongated” when it conforms to the criteria for both flat particles and elongated particles provided in Clauses 6.2.1.1 and 6.2.1.2.

6.2.2 Sample preparation

6.2.2.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

6.2.2.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

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6.2.2.3

A representative sample shall be obtained of each size of aggregate to be tested by sieving and reduced by quartering or splitting. The following shall apply:

a) For each size fraction representing 15% or more of the sample, at least 200 particles shall be procured.
b) For each fraction representing 5 to 15% of the sample, at least 100 particles shall be procured.
c) Particles representing less than 5% of the sample shall not be accounted for.
d) The total mass of each size fraction shall be determined within 1 g and reported as a percentage of the mass of the total sample.

Note: *When flat and elongated particles need to be separated, samples used to establish the percentage of flat particles for a size fraction can be reused to establish the percentage of elongated particles. A double sampling can also be used.*

For a size fraction, if the total initial mass of the particles is not used, an *f* factor shall be used for the evaluation of the mass of flat, elongated, and flat and elongated particles in that fraction as follows:

$f = tim/mp$

where

tim = total initial mass, g

mp = sample mass, g

6.2.3 Procedure

6.2.3.1 Flat particles

On each sample, using the appropriate gauge, each particle shall be classified as flat when passing through the appropriate opening or when their thickness is less than 3/5 of *G*.

The mass of particles classified as flat shall be evaluated within 0.1% of the sample mass.

Note: *If the thickness is measured with a special sieve, all particles may be separated by sieving at the same time. All particles passing through this special sieve or those verified individually by the operator may be considered to be flat.*

6.2.3.2 Elongated particles

On each sample, using the appropriate gauge, each particle shall be classified as elongated when the longest dimension is larger than the space between the pins in the gauge.

The mass of particles classified as elongated shall be evaluated within 0.1% of the sample mass.

6.2.3.3 Flat and elongated particles

On each sample, using the appropriate gauge, classify each particle as flat and elongated when the largest dimension of particles classified previously as flat is larger than the space between the pins in the gauge or when the length exceeds 9/5 of *G*.

The mass of particles classified as flat and elongated shall be evaluated within 0.1% of the sample mass.

6.2.4 Calculations

6.2.4.1

When the total initial mass of a size fraction is used, the total mass of flat, elongated, and flat and elongated particles shall be recorded.

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6.2.4.2

When a fraction of the total initial mass is used, the mass of flat, elongated, and flat and elongated particles shall be calculated as the product of the *f* factor (Clause 6.2.2.3) and the mass of particles in that fraction.

6.2.4.3

The percentage of flat, elongated, and flat and elongated particles shall be calculated as the percent fraction between the total of the masses calculated in Clauses 6.2.3.1, 6.2.3.2, or 6.2.3.3 over the total initial masses of each size fraction. A sample calculation report for Procedure B is shown in Table 2.

7 Reporting

7.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification marks;
b) date of testing;
c) test procedure used (A or B);
d) length-to-width ratio used in Procedure A;
e) percentage of flat, elongated, and flat and elongated particles to the nearest 0.1%;
f) if required, the individual percentages of each size fraction;
g) name of the certified technician who performed the test;
h) identification of the certified laboratory that performed the test (i.e., name and address);
i) name and signature of the person responsible for the review of the test report; and
j) any deviations from the test procedure.

7.2 Optional information

The following information may be included in the test report if applicable:

a) name of the person or organization who sampled the aggregate;
b) date the sample was obtained or received by test laboratory; and
c) sample source or sample location, or both.

8 Precision and bias

8.1 Procedure A

Precision based on the results of testing in multi-laboratory proficiency sample testing programs involving between 34 and 146 laboratories is given below:

Coarse aggregate properties	Coefficient of variation, %	Acceptable range of two results (D2S), %*
Between 8% and 16% flat and elongated particles at a ratio of 4:1	39.6	112

** Figures given for D2S are the limits of the difference between the results of two properly conducted tests, in different laboratories, on samples of the same material that should only be exceeded 1 time in 20.*

8.2 Procedure B

No precision statement is available for this Test Method.

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Table 1
Size fractions — Mean dimensions and gauges (thickness and length)
(See Clauses 5.3.3 and 5.3.4.)

Fractions		Dimension, mm		
Sieve size passing, mm	**Sieve size retained, mm**	**Mean dimension, G**	**Thickness gauge (0.6 × G), E**	**Length gauge (1.8 × G), L**
63.0	50.0	56.50	33.9 ± 0.3	—
50.0	37.5	43.75	26.3 ± 0.3	78.8 ± 0.3
37.5	28.0	32.75	19.7 ± 0.3	59.0 ± 0.3
28.0	20.0	24.00	14.4 ± 0.15	43.2 ± 0.3
20.0	14.0	17.00	10.2 ± 0.15	30.6 ± 0.3
14.0	10.0	12.00	7.2 ± 0.1	21.6 ± 0.2
10.0	6.3	8.15	4.9 ± 0.1	14.7 ± 0.2

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Table 2
Sample calculation report for Procedure B
(See Clause 6.2.4.3.)

Elongated particles									
Size fractions		**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Passing, mm	**Retained, mm**	**Mass of fraction, g**	**Fraction percentage, %**	**Subsample mass, g**	***f* factor**	**Length gauge (1.8 × *G*) = *L***	**Mass of elongated particles, g**	**Total mass of elongated particles, g**	**Elongated particles, %**
50	37.5	—	—	—	—	78.8 ± 0.3	—		
37.5	28	—	—	—	—	59.0 ± 0.3	—		
28	20	—	—	—	—	43.2 ± 0.3	—		
20	14	3570	59	1785	2.0	30.6 ± 0.3	339	678	—
14	10	2239	37	1120	2.0	21.6 ± 0.2	235	470	—
10	6.3	241	4*	—	—	14.7 ± 0.2	—	—	—
Total		A = 6050A* = 5809						B = 1148	19.8(100 × B) A*
Flat particles passing, mm	**Retained, mm**	**Mass of fraction, g**	**Fraction percentage, %**	**Subsample mass, g**	***f* factor**	**Thickness gauge (0.6 × G), E**	**Mass of flat particles, g**	**Total mass of flat particles, g**	**Flat particles, %**
50	37.5	—	—	—	—	26.3 ± 0.3	—	—	—
37.5	28	—	—	—	—	19.7 ± 0.3	—	—	—
28	20	—	—	—	—	14.4 ± 0.15	—	—	—
20	14	3570	59	1785	2.0	10.2 ± 0.15	268	536	—
14	10	2239	37	1120	2.0	7.2 ± 0.1	201	402	—
10	6.3	241	4*	—	—	4.9 ± 0.1	—	—	—
Total		A = 6050 A* = 5809						B = 938	16.1(100 × B) A*

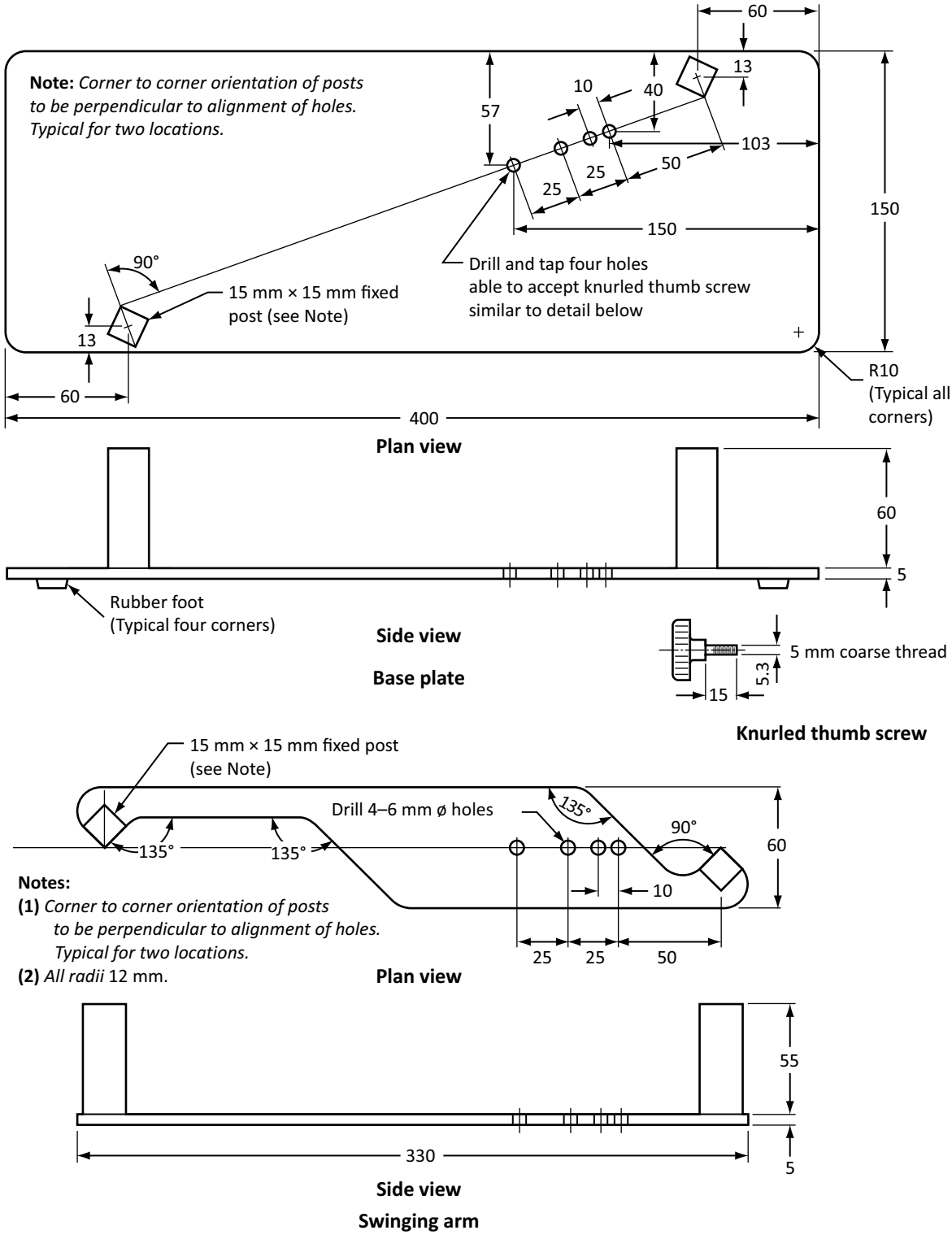
* *The size fraction (< 5%) which has not been analyzed is not included for the calculation of "flat, elongated, or flat and elongated" particles.*

Note: *The calculations are the same for flat and elongated particles.*

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13A
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Figure 1
Proportional caliper
(See Clauses 5.2.3 and 6.1.5.)



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Figure 2
Thickness gauge
(See Clause 5.3.3.)

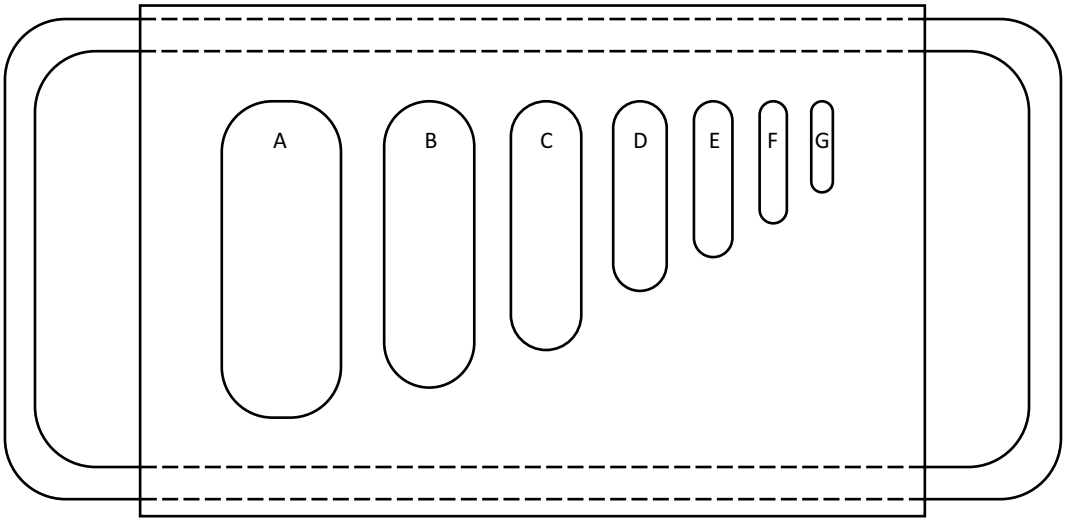
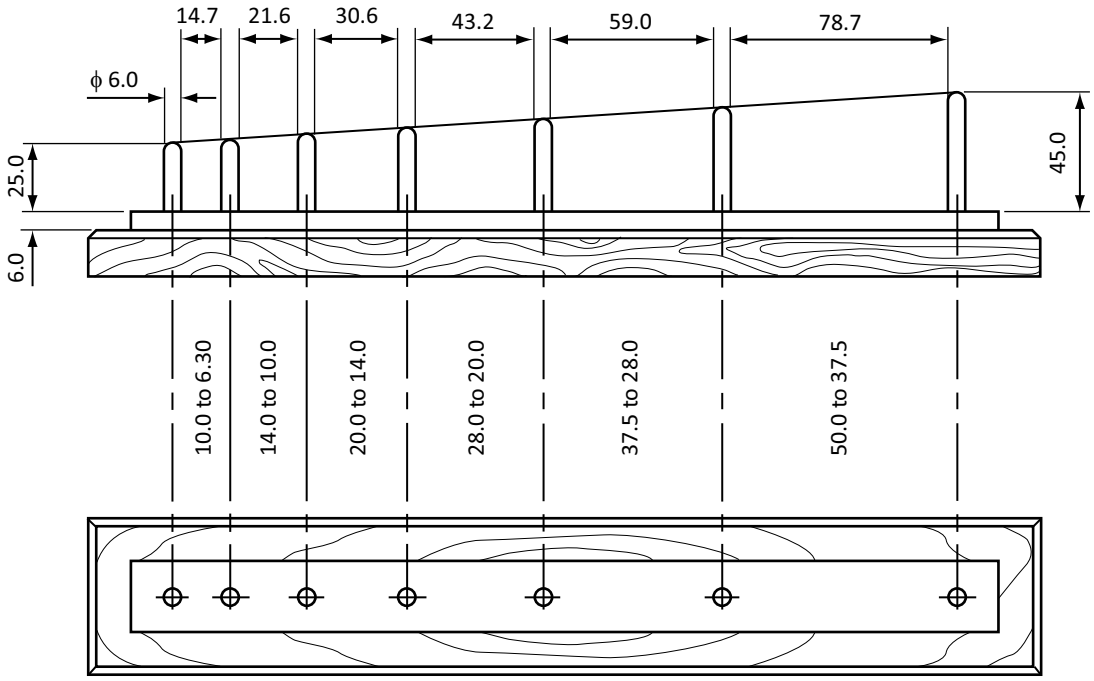


Figure 3
Length gauge
(See Clause 5.3.4.)



Note: *Dimensions are in millimetres.*

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A23.2-14A
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

1 Scope

1.1
This Test Method specifies the procedure for measuring the length change of concrete prisms, due to alkali-aggregate reaction, stored under moist conditions at a temperature of 38 °C, for a minimum of 365 d.

1.2
This Test Method is intended for the evaluation of the potential expansivity (related to alkali-aggregate reaction) of coarse or fine aggregates, or a combination of fine and coarse aggregates.

1.3
This Test Method may be used to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete in accordance with CSA A23.2-28A.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-25A:19
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-27A:19
Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

A23.2-28A:19
Standard practice for laboratory testing to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete

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A23.2-2C:19
Making concrete mixes in the laboratory

A3001-18
Cementitious materials for use in concrete

ASTM International

C490/C490M-17
Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

C494/C494M-17
Standard Specification for Chemical Admixtures for Concrete

C856-18a
Standard Practice for Petrographic Examination and Hardened Concrete

Other publications

Coté, T. 2009. *Gestion des ouvrages en béton affectés de réactivité alcalis-silice: contribution à la détermination de l'expansion atteinte à ce jour et de l'expansion résiduelle à venir.* Mémoire de maîtrise, Faculté des Sciences et de Génies, Université Laval.

Fournier, B. and Malhotra, 1996. V.M. Inter-laboratory Study on the CSA A23.2-14A Concrete Prism Test for Alkali-Silica Reactivity in Concrete. *Proceedings of the 10th International Conference on Alkali-Reaction in Concrete,* Melbourne (Australia), 302–309.

Fournier, B. and Rogers, C.A. 2008. Multi-laboratory study of accelerated mortar bar test and concrete prism expansion tests at 38° and 60 °C. *Proceedings of the 13th International Conference on Alkali-Aggregate Reaction in Concrete (ICAAR)*, June 16–20, Trondheim (Norway) (electronic).

Fournier, B., Rogers, C.A. and MacDonald, C.A. 2012. Multilaboratory study of the concrete prism and accelerated mortar bar expansion tests with Spratt aggregate. *Proceedings of the 14th International Conference on Alkali-Aggregate Reaction in Concrete*, May 20–25th 2012, Austin (Texas) (electronic).

Rogers, C.A. 1987. Interlaboratory Study of the Concrete Prism Expansion Test for the Alkali-Carbonate Reaction.*Proceedings of the 7th International Conference on Alkali-Aggregate Reaction in Concrete, August 18–22th 1987, Ottawa (Canada). Noyes Publication (New York), 270–274.*

Smaoui, N., Bérubé, M.A., Fournier, B. and Bissonnette, B. (2004). Influence of Specimen Geometry, Direction of Casting, and Mode of Concrete Consolidation on Expansion due to ASR. *Cement, Concrete and Aggregates*, 26: 58–70.

3 Definitions

In addition to the definitions in Clause 3 of CSA A23.1, the definitions of CSA A3001 apply in this Test Method.

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4 Significance and use

4.1

The data correlating results of this Test Method, with observations of the performance of concrete in service (where possible) and results of petrographic examination, should form the basis for drawing conclusions or making recommendations concerning the use of the aggregate in concrete.

4.2

The results of tests performed using this Test Method provide information on the potential of aggregates to produce deleterious expansions in concrete as a consequence of either alkali-silica or alkali-carbonate reactions. Valuable information that can be used to determine the potential deleterious expansions measured in this test is provided in CSA A23.2-27A.

4.3

Although rare, significant expansions might occur due to reasons other than alkali-aggregate reaction. Such expansions can be due to the following:

a) the presence in the aggregate of sulphides (e.g., pyrite, pyrrhotite, and marcasite) that can oxidize and hydrate with expansion and/or the release of sulphate, which produces a sulphate attack upon the cement paste;
b) the presence in the aggregate of sulphates, such as gypsum, resulting in sulphate attack on the cement paste; or
c) the presence of free lime (CaO) or free magnesia (MgO) in the cement or aggregate that can progressively hydrate and carbonate with consequent expansion, which leads to disruption of the cement paste and hence the concrete. CaO and MgO are found in steel slags and can also occur in other aggregates.

This Test Method has not been shown to be suitable for evaluating these kinds of reactions.

4.4

When the expansions in this Test Method are greater than the limit given in CSA A23.2-27A, it is a strong indication that the aggregate is potentially alkali-aggregate reactive. Supplementary information should be developed to confirm that the expansion is actually due to alkali-aggregate reactivity. Sources of supplementary information include petrographic examination of the concrete prisms, after the test, to determine if known reactive constituents are present and to identify the products of alkali reactivity.

4.5

When it has been concluded from the test results, and from supplementary information as outlined, that a given aggregate is potentially deleteriously reactive, additional studies might be appropriate to develop information on preventive measures to be taken.

4.6

This Test Method can be used for evaluating the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete. The use of the Test Method for that purpose is covered in CSA A23.2-28A.

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4.7

Because of problems related to alkali leaching, this Test Method cannot be used for evaluating the beneficial effect of low-alkali cement, lower cement contents on alkali-aggregate reaction, or actual or proposed job concrete mixes.

Note: *Work is in progress to develop an appropriate test for evaluating job mixtures.*

5 Apparatus

5.1

Prisms shall be cast in moulds. The prisms shall have a dimension of not less than 75 mm × 75 mm × 275 mm and not more than 75 mm × 75 mm × 405 mm. The cross-sectional dimensions of the mould shall not vary by more than ± 1.0 mm. All prisms in any test shall be of the same size. A suitable design for the moulds is shown in Figure 1.

5.2

Stainless steel studs or bolts 5 to 7 mm in diameter and 25 ± 1.0 mm in length shall be cast in the test prism at the centre of each end. Stainless steel bolts with the ends machined round have been found to be most suitable.

5.3

The comparator for the determination of the length change shall be used in conjunction with a reference bar and a dial gauge or micrometer. A suitable design for a length measuring device is shown in Figure 2. The dial gauge or micrometer shall be graduated to read in 0.002 mm units, accurate within 0.002 mm in any 0.02 mm range, and within 0.005 mm in any 0.25 mm range, with sufficient range (at least 8 mm) to allow for variations in the gauge length of various specimens. The reference bar shall be of a steel alloy (invar) having a coefficient of thermal expansion not greater than two-millionths per °C. Each end shall be machined to the same shape as the contact end of the gauge stud. The central 100 mm length of the reference bar shall be covered by a rubber tube with a wall at least 3 mm thick to minimize the effect of temperature change during handling. The reference bar shall have a length that is equal to the distance between the exterior ends of the stainless steel studs of the prisms, with a variation of ±1.5 mm. The bar shall be provided, near one end, with a positioning mark and shall be placed in the instrument in the same position each time a length measurement is taken. The dial gauge setting of the measuring device shall be checked by use of the reference bar, at least at the beginning and end of the readings made within a half-day when the apparatus is kept in a room maintained at constant temperature. It should be checked more often if there is any doubt about the control of the temperature in the room.

5.4

Storage containers shall be approximately 22 to 25 L plastic pails with airtight lids. Approximate dimensions should be 250 to 270 mm diameter at bottom, 290 to 310 mm at top, and 450 to 480 mm high.* The seal of the lid shall be sufficient to prevent loss of water by evaporation. A perforated rack shall be placed in the bottom of the storage container, so that the prisms shall be 30 to 40 mm above the bottom. The container shall have water, in the bottom, to a depth of 20 ± 5 mm. A wick of absorbent material (terry cloth, filter paper, or equivalent) shall be placed around the inside wall of the container from the top, so that the bottom extends into the water.

* *Storage containers other than those specified may be used, provided the efficiency of the storage container is calibrated with a standard alkali-reactive aggregate. The expansion at one year obtained using the alternative container should be within 10% of that obtained using the specified container. If an alternative container is used, it*

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should be noted in reporting the results, together with documentation proving compliance with the calibration requirements of this Clause.

5.5

The storage environment shall be a sealed space insulated so as to minimize heat loss and to provide even heat distribution.* There shall be a fan that provides adequate air circulation so that the maximum variation in temperature measured within 250 mm of the top and bottom of the space does not exceed 2.0 °C. The entry door to the space shall be insulated and provided with adequate seals so as to minimize heat loss. Racks for storing containers within the space shall not be closer than 30 mm to the sides and shall be perforated so as to provide an adequate flow of air. There shall be a source of heat and a means of automatically controlling the heat so that the temperature is maintained at 38 ± 2 °C.† There shall be a means of automatically recording the ambient temperature and its variation within the spaces.

* *Alternative storage environments, such as the AFNOR reactor may be used. In these cases, the efficiency of the storage container in its storage environment should be calibrated with a standard alkali-reactive aggregate. The expansion at one year obtained using the alternative container and storage environment should be within 10% of that obtained using the specified container and storage environment. If an alternative container and/or environment is used, it should be noted in reporting the results, together with documentation showing compliance with this Clause.*

† *The efficiency of the storage environment should be monitored by placing thermocouples inside dummy concrete specimens that are placed inside a dummy container within the storage area.*

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Sampling, test specimens

7.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A. Samples for alkali-aggregate reaction testing shall, if possible, be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production.

7.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

7.3

The test specimens shall be concrete prisms cast in the moulds specified in Clause 5.1. Three prisms shall constitute a test.

Note: *It has been found useful to cast an additional (fourth) prism that can be removed from the test and sectioned for petrographic examination at any time. However, recent research has shown that the number of test prisms in the storage container can affect the amount of expansion measured because of variations in the humid air-to-concrete volume ratio that influence the leaching process of alkalis from the test prisms; Coté (2009) found that reducing the number of test specimens in the storage container from three to one can result in expansion reduction of about 60%.*

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8 Materials

8.1 Cement

The cement shall meet the requirements of general use Portland cement (type GU) as specified in CSA A3001. The total (acid-soluble) alkali content of the cement shall be 0.90% ± 0.10%, calculated as $Na_2O + 0.658\ K_2O$ (i.e., the Na_2O equivalent)*. Reagent grade NaOH shall be added to the concrete mix water so as to increase the alkali content of the mixture, expressed as Na_2O equivalent, to 1.25% by mass of Portland cement.† The alkali content of the cement shall be determined either by a chemist or by obtaining the chemical analysis of the cement used, from the manufacturer.

* *When CSA A23.2-14A is used to evaluate the effectiveness of a supplementary cementitious material or combination of supplementary cementitious materials to control expansion due to alkali-silica reaction, the use of cements with an alkali content greater than 1.00% is permissible (see Clause 7.2.1.1 of CSA A23.2-28A).*

† *The value of 1.25% Na_2O equivalent by mass of cement has been chosen to accelerate the process of expansion rather than to reproduce field conditions.*

8.2 Aggregates

8.2.1

A non-reactive fine aggregate shall be used if the test is being done to evaluate the reactivity of coarse aggregate. The fine aggregate shall have an expansion when tested in accordance with CSA A23.2-25A, of less than 0.10% at 14 d or an expansion of less than 0.015% at one year when tested in concrete with an innocuous coarse aggregate as specified in this Test Method. The fine aggregate shall meet the requirements of CSA A23.1 and shall have a fineness modulus of 2.7 ± 0.2.

8.2.2

If the test is being used to evaluate the reactivity of fine aggregate, a non-reactive coarse aggregate prepared in accordance with Clause 8.2.3 shall be used. The coarse aggregate shall have an expansion, when tested in accordance with CSA A23.2-25A, of less than 0.10% at 14 d or an expansion of less than 0.015% at one year when tested in concrete with an innocuous fine aggregate as specified in this Test Method. Fine aggregate under test shall be tested in the grading delivered to the laboratory unless otherwise specified.

8.2.3

The coarse aggregate under test shall be composed of three equal parts consisting of material between the 20 mm to 14 mm, 14 mm to 10 mm, and 10 mm to 5 mm sieves. If the coarse aggregate contains more than 15% retained on the 20 mm sieve, the oversize material shall be crushed down to pass the 20 mm sieve and then recombined. To test aggregate with a nominal size of 14 mm, the aggregates shall contain equal parts of the 14 mm to 10 mm and 10 mm to 5 mm size fractions. If necessary, the material shall be washed to meet the 80 µm requirements of Table 12 of CSA A23.1.

8.2.4

A combination of fine and coarse aggregates for a specific concrete application may be tested.

9 Concrete mixture proportions

The concrete mixture shall be proportioned to the following requirements:

a) cement content of 420 ± 10 kg/m^3 of concrete;

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b) coarse to fine aggregate ratio of 60:40 by mass, except when using high-density or low-density aggregates. When using high- or low-density aggregates, the volume of dry-rodded coarse aggregate per unit volume of concrete shall be 70 ± 2%;
c) Maintain *w/cm* in the range of 0.42 to 0.45 by mass. Adjust the *w/cm* within this range to give sufficient workability to permit satisfactory compaction of the concrete in the moulds without segregation. If necessary to obtain sufficient workability within the specified *w/cm* range, water-reducing admixture meeting the requirements of ASTM C494/C494M may be used. If, within the specified *w/cm* range, specimens representative of the concrete mixture cannot be fabricated due to excessive bleeding or segregation, a viscosity modifying admixture (VMA) may be used. Report the *w/cm* ratio used and the amount and type of admixture used, if any;
d) NaOH (reagent grade), dissolved in water, added as required, to bring the alkali content of the concrete mixture, expressed as Na_2O equivalent, up to 1.25% by mass of cement; and
e) No other admixture shall be used.

Notes:

1) *A sample calculation for determining the amount of NaOH to be added to the mix water to increase the alkali content of the cement from 0.90 to 1.25% is as follows:*
Cement content of 1 m³ concrete = 420 kg
Amount of alkali in the concrete = 420 × 0.90% = 3.78 kg
Specified amount of alkali in concrete = 420 × 1.25% = 5.25 kg
The difference (1.47 kg) is the amount of alkali expressed as Na_2O equivalent to be added to the mix water.
Factor to convert Na_2O to NaOH: ($Na_2O + H_2O - 2$ NaOH)
Formula weight: Na_2O = 61.98
NaOH = 39.997
Conversion factor: 2 × 39.997/61.98 = 1.291
Amount of NaOH required:1.47 × 1.291 = 1.898 kg/m³
2) *When supplementary cementitious materials are used in combination with the Portland cement, as described in Test Method CSA A23.2-28A, the alkali content of the concrete mixture should be raised to 1.25% by mass of only the Portland cement content, expressed as Na_2O equivalent. In the case of a blended cement, then the 1.25% by mass alkali content should be based only on the reported Portland cement component (or clinker plus gypsum component in an interground blended cement).*

10 Preparation of concrete prisms

10.1 Mixing

The aggregates shall be measured out and the mixture made using the procedures specified in CSA A23.2-2C.

10.2 Casting prisms

Prisms shall be cast, consolidated, and finished using the procedure specified in CSA A23.2-3C, except that the method of consolidation shall be by rodding (see Note). The rod diameter shall be 10 mm and each layer shall be rodded once for every 7 cm² of surface area. The following precautions shall be taken:

a) The prism mould, with the measuring studs in place, shall be filled with concrete and consolidated with a tamping tool to ensure that no large air voids occur and that proper compaction is achieved.
b) After moulding and consolidating, any excess concrete shall be struck off and the surface of the prisms brought to a smooth finish. Excessive finishing should be avoided.
c) Immediately after finishing, the prisms shall be covered with a polyethylene sheet and placed in the moist room at 23 ± 2.0 °C and 100% humidity. Alternatively, the prisms shall be covered with wet burlap and maintained at 23 ± 2.0 °C. The burlap shall be saturated but not dripping and shall cover the top and sides of the samples without being in direct contact with the concrete surface.

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The burlap shall be completely covered with a polyethylene sheet in such a manner as to prevent drying of the burlap.

Note: *Research has shown that the use of a vibrating table can influence the results of the test (Smaoui et al. 2004).*

11 Demoulding and storage of concrete prisms

11.1

The prisms shall be demoulded 24 ± 4 h after casting. During this procedure, special care shall be taken to avoid damaging or disturbing the measuring studs. Immediately after demoulding, each prism shall be covered by a damp cloth to prevent drying before the initial length measurement. The temperature of the room used for demoulding and subsequent measurement of the length of the prisms shall be maintained at 23 ± 2 °C. The prisms shall be measured for length following the procedure in Clause 13.3 within 4 h of demoulding.

11.2

Following length measurement, the prisms shall be placed in a vertical position inside the storage container specified in Clause 5.4. The storage container shall be placed in the storage environment specified in Clause 5.5. At no time shall the container be in contact with the walls or floor of the storage area and there shall be an adequate flow of air around the container.

12 Qualification of laboratories

12.1

When testing is conducted, the laboratory shall demonstrate its ability to conduct the test. At the time of testing or at least every 6 months, testing with a known reactive aggregate shall be conducted.

12.2

As a means of qualifying the testing laboratory and validating the testing process, Spratt aggregate shall be tested. After one year of testing, the expansion of concrete made with Spratt aggregate shall be between 0.12% and 0.23%. When testing to satisfy the requirements of CSA A23.2-28A, the expansion shall be between 0.15% and 0.29% after two years of testing. When expansion data fall outside these limits, the concrete that was cast with aggregates from the start of testing of the Spratt aggregate until the start of the next test with Spratt aggregate shall be retested.

Note: *Spratt coarse aggregate is available in 25 kg bags from the Soils and Aggregates Section, Materials Research and Engineering Office, Ontario Ministry of Transportation (Soils-Aggregates@ontario.ca).*

13 Length change measurements

13.1

All length measurements and calculations shall be made in accordance with ASTM C490/C490M.

13.2

The containers holding the prisms shall be removed from the 38 °C temperature storage and maintained at a temperature of 23 ± 2.0 °C for 16 ± 4 h before measurement.

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13.3
The prisms shall be measured for length change at least after 1, 2, 4, 8, 13, 18, 26, 39, and 52 weeks to satisfy the requirements of CSA A23.2-27A. When testing to satisfy the requirements of CSA A23.2-28A, readings shall continue to be taken every 3 months until 2 years have elapsed. For research and other purposes, readings shall be taken approximately every 6 months thereafter.

13.4
After each length change measurement and after the final length change measurement, the concrete prisms shall be visually examined for cracks or other surface changes, such as the deposition of alkali-silica gel. The use of a stereobinocular microscope will facilitate the detection of fine cracks. Care shall be taken to prevent undue moisture loss during examination.

Note: *Interpretation of test results is generally facilitated by a petrographic examination of the interior of the concrete prisms at the end of the test. For a procedure for petrographic examination of hardened concrete, see ASTM C856. The presence of gel-filled pores, reaction rims surrounding aggregate particles, and fractures, both in the cement paste and in the coarse aggregate, are indicators of alkali-aggregate reaction. The type of rock or rocks involved in the reaction may also be identified.*

14 Calculation of length change

14.1
The change in length of each prism shall be based on the initial measurement.

14.2
The difference between the initial and each succeeding measurement shall be calculated and expressed as a percentage of the initial effective length, adjusted to reflect the fact that the effective length is the distance between the inner ends of the steel measuring studs and not the overall length. Length change values for each prism shall be calculated to the nearest 0.001%.

15 Reporting

15.1 Required information
The following information shall be included in the test report, if applicable:

a) sample number or identification marks;
b) type and source of coarse and fine aggregates;
c) location within the source (e.g., bench level, area in the pit);
d) type and source of Portland cement;
e) the alkali content (Na_2O and K_2O) of the cement;
f) concrete mixture proportions based on SSD aggregates;
g) amount of alkali (NaOH) added to the mix, expressed as percentage equivalent Na_2O by mass of the cement;
h) effective water-to-cementitious materials ratio (*w/cm*) based on SSD aggregates;
i) cast date;
j) the average length change percentage at each reading of the prisms, with the individual values for each prism;
k) any significant features revealed by examination of the concrete prisms, either during the test or at the end of the test (e.g., cracks, gel formation, pop-outs or reaction rims surrounding aggregate particles);
l) type of container used to store the concrete prisms, if it differs from that specified in Clause 5.4;

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m) expansion of concrete prisms made with the Spratt aggregate;
n) name of the certified technician who performed the test;
o) identification of the certified laboratory that performed the test (i.e., name and address);
p) name and signature of the person responsible for the review of the test report; and
q) any deviations from this Test Method.

15.2 Optional information

The following information may be included in the test report:
a) name of the person who sampled the aggregate; and
b) date the sample was taken.

16 Precision

16.1 Multi-laboratory precision

The precision estimates presented below are based on studies reported by Rogers (1987), Fournier and Malhotra (1996), and Fournier *et al*. (2008, 2012).

16.2 Average expansion less than 0.014%

The multi-laboratory standard deviation of a single test result (mean of measurements on three prisms) for average expansion less than 0.014% has been found to be 0.0032%. Therefore, results of two properly conducted tests in different laboratories on the same aggregate should not differ by more than 0.009%, 19 times in 20.

16.3 Average expansion greater than 0.014%

The multi-laboratory coefficient of variation of a single test result (mean of measurements on three prisms) for average expansion greater than 0.014% has been found to be 23%. Therefore, results of two properly conducted tests in different laboratories on the same aggregate should not differ from each other by more than 65% of their average, 19 times in 20.

16.4 Range for three prisms

16.4.1 Average expansion less than 0.02%

For average expansions (mean expansion of three prisms) of less than 0.02%, the multi-specimen, single-operator standard deviation has been found to be 0.0025%. Therefore, the range (difference between highest and lowest) of the three individual prism measurements used in calculating a test result should not exceed 0.008%, 19 times in 20.

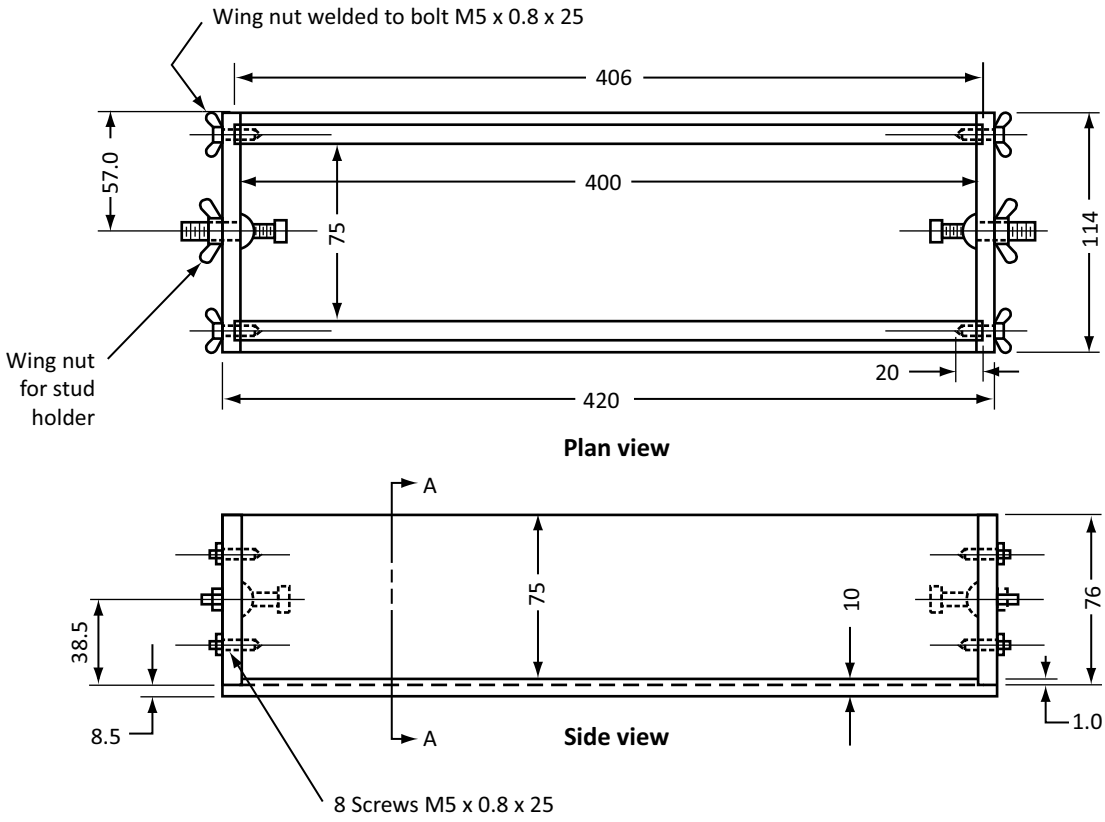
16.4.2 Average expansion greater than 0.02%

For average expansions (mean expansion of three prisms) of more than 0.02%, the multi-specimen, single-operator coefficient of variation has been found to be 12%. Therefore, the range (difference between highest and lowest) of the three individual prism measurements used in calculating a test result should not exceed 40% of the average of the three, 19 times in 20.

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Figure 1
Drawing of a mould suitable for casting concrete prisms
(See Clause 5.1.)



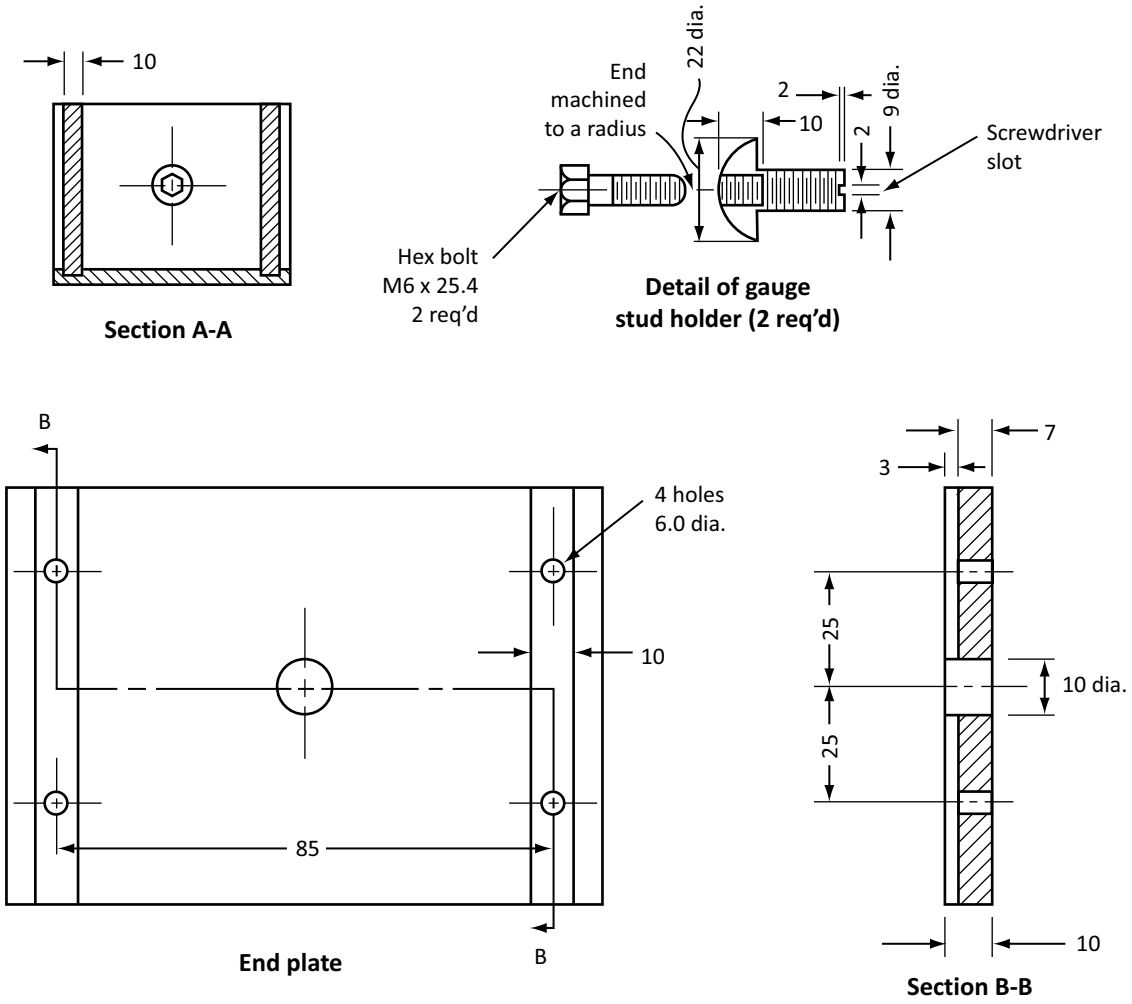
a)

Note: *Dimensions are in millimetres.*

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Figure 1 (Concluded)



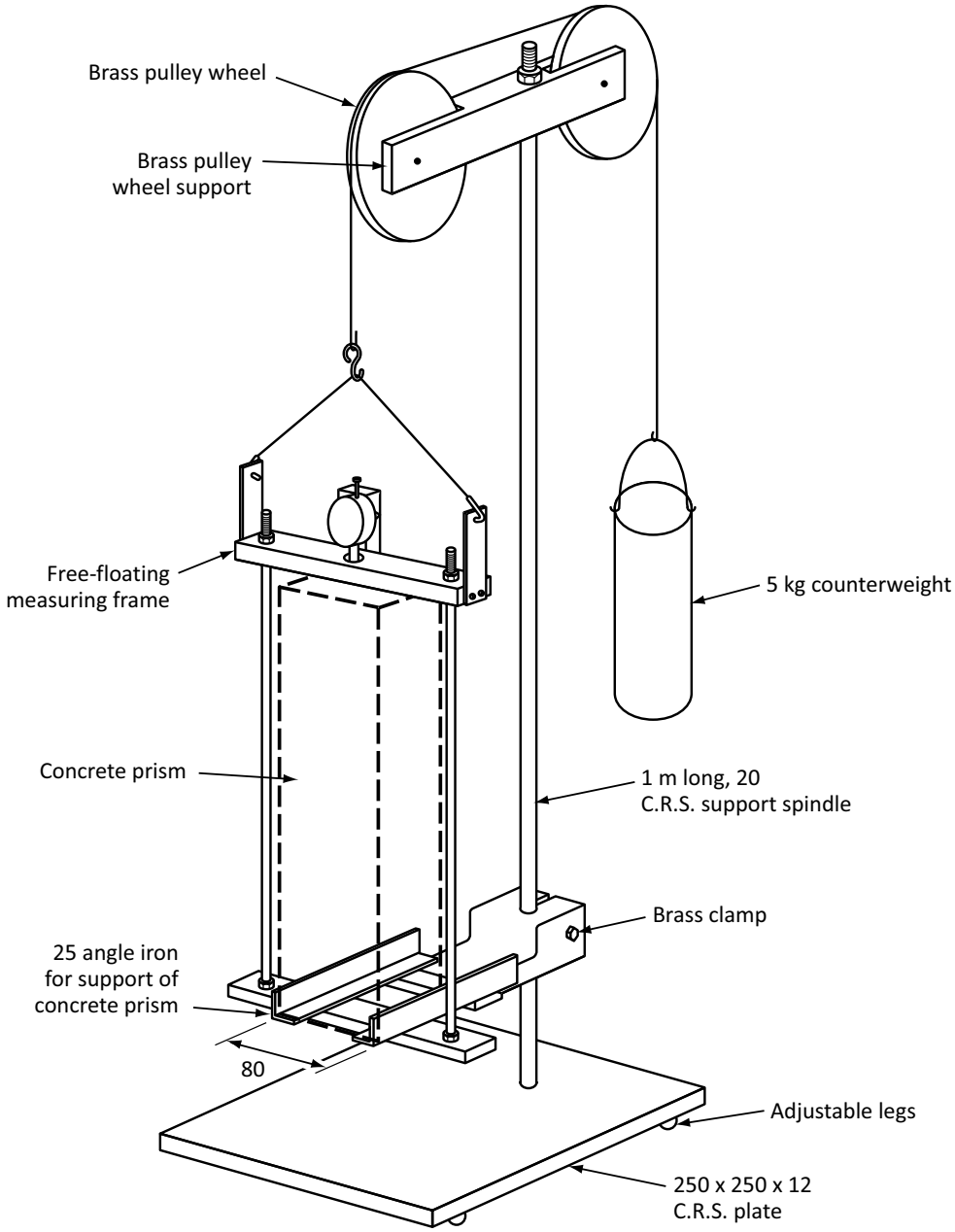
b)

Note: *Dimensions are in millimetres.*

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Figure 2
Type of suitable comparator for length change measurements of concrete prisms
(See Clause 5.3.)

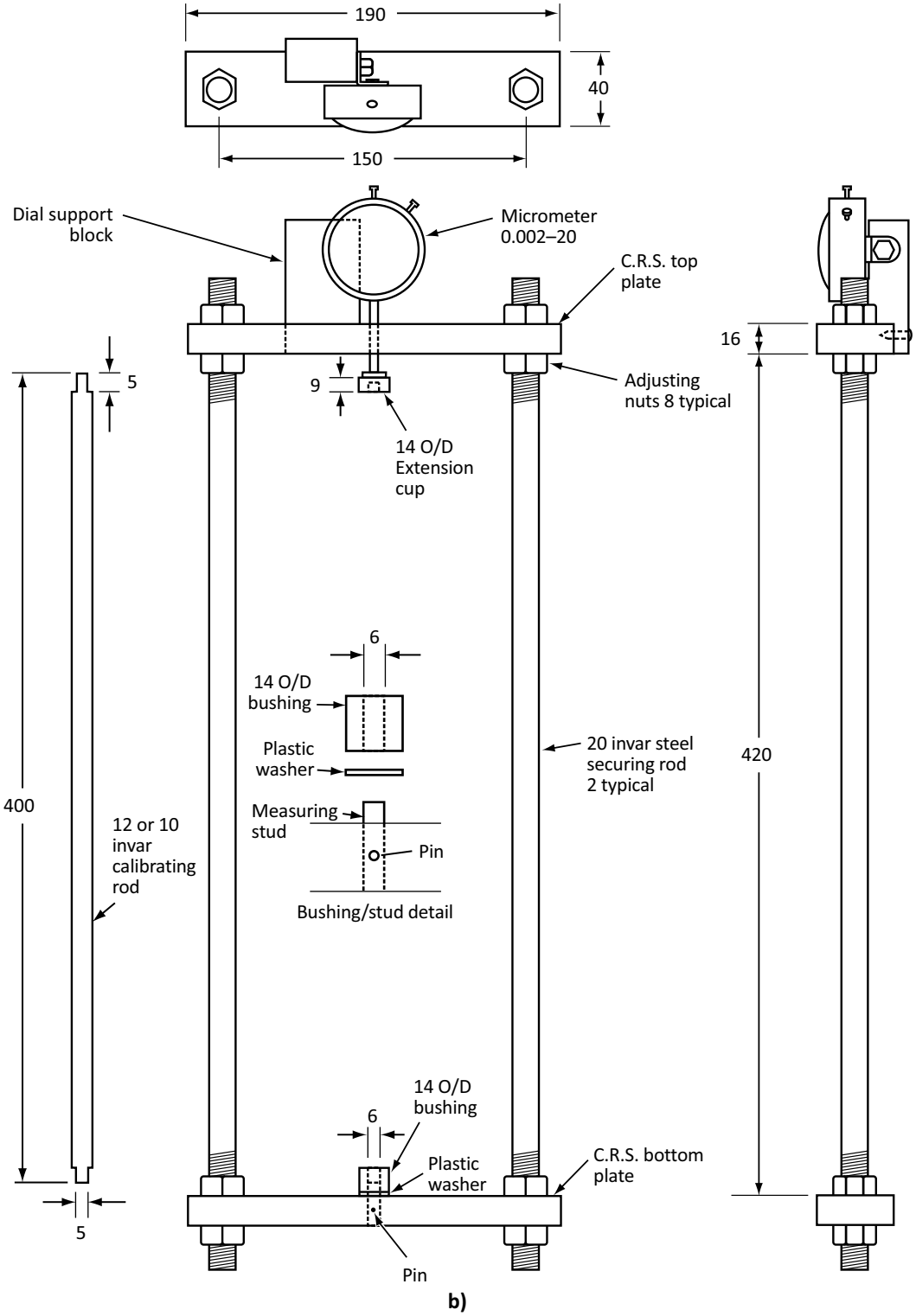


a)

Note: *Dimensions are in millimetres.*

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Figure 2 (Concluded)



Note: *Dimensions are in millimetres.*

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A23.2-15A
Petrographic examination of aggregates

1 Scope

1.1
This Test Method specifies the procedures used for petrographic examination of representative samples of materials proposed for or in use as aggregates in construction.

1.2
This Test Method outlines the extent to which petrographic techniques should be used, the manner in which such techniques should be employed, and the selection of properties that should be determined.

1.3
This Test Method does not attempt to describe petrographic techniques, since it is intended for use by persons who are qualified by education and experience to employ such techniques to recognize the characteristic properties of rocks and minerals, to describe and classify the constituents of an aggregate sample, and to assess not only the utility but also the potential problems that may be associated with their use in construction.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

Note: *See Attachment A3 for other relevant publications.*

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-13A:19
Flat and elongated particles in coarse aggregate

ASTM International

Volume 04.02-18
Concrete and Aggregates

Canadian Geotechnical Society

Canadian Foundation Engineering Manual, fourth edition, 2006

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3 Significance and use

3.1

Petrographic examinations may be used for materials to be used as fine or coarse aggregate. This procedure may also be applied to examination of bedrock and drill core.

The procedure outlined in this Test Method is designed principally for the evaluation of aggregate considered for use in hydraulic cement concrete. It may also be used for the evaluation of hot mix asphalt aggregate, common fill, structural fill, road-building aggregate, railroad ballast, rip-rap and/or shoreline protection stone, building stone, and other construction materials.

Petrographic examinations outline the extent to which petrographic techniques should be used, the manner in which such techniques should be employed, and the selection of properties to be assessed. This procedure does not attempt to describe the petrographic techniques since it is intended for use by persons who are qualified by both education and experience.

The contracting organization should inform the petrographer, in as much detail as necessary, of the purposes and objectives of the examination and the kind of information required. Pertinent background information, including results of prior testing, should be made available. The petrographer's advice and judgment should be sought regarding the extent of the examination and the method (see Method A or B in Clause 6) to be used.

Petrographic examinations provide identification of rock types present in aggregates. For many purposes, grouping of similar rock types into broad classifications might be adequate. In other instances, however, it might be necessary to classify certain rock types on a more detailed basis. The petrographer conducting the examination should make these judgments and note them in the report.

3.2

Petrographic examinations may be used to calculate a numeric index, called a "petrographic number" (PN), to provide an appraisal of the physical-mechanical quality of coarse aggregate. Determination of PNs applies solely to coarse aggregates and should not be used for fine aggregates.

The PN may be used for the following purposes:

a) monitoring the quality of aggregate produced during different production periods;
b) providing a preliminary assessment of the quality of aggregates from new or previously untested sources (e.g., in the exploration phase of a potential aggregate supply);
c) determining the quality of different aggregate products (from the same source or different sources);
d) determining the quality of aggregates produced from different formations, lifts, or strata in a quarry or pit; and
e) comparing the quality of aggregate produced from different parts of the same property or from neighbouring properties.

3.3

Petrographic examinations are made for the following purposes:

a) determining the physical and chemical characteristics of the aggregate that can have a bearing on the performance of the material in its intended use;
b) describing, classifying, and determining the relative amounts of constituents of the aggregate;
c) comparing samples of aggregates from new or proposed sources with samples of aggregate from other sources for which test data or performance records are available; and

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d) identifying harmful characteristics or undesirable components of aggregates specific to their intended use.

3.4

Petrographic examinations should establish whether the aggregate contains deleterious substances, such as swelling clays, soluble sulphates, and unstable sulphides that can form sulphuric acid and further contribute to concrete distress.

Petrographic examinations should identify the portion of a coarse aggregate that is composed of weathered or otherwise altered particles, the extent of that weathering or alteration (i.e., severe, moderate, or slight), and the proportion of each rock type in each condition. The degree and type of alteration present in the aggregate can have a significant effect on the intended use of the material.

Petrographic examinations may be used to determine the proportions of cubic, spherical, ellipsoidal, pyramidal, tabular, flat, and elongated particles in an aggregate sample.

Petrographic examinations should identify and call attention to potentially alkali-silica reactive and alkali-carbonate reactive constituents, determine such constituents quantitatively, and recommend additional tests to confirm or refute the presence in significant amounts of aggregate constituents capable of alkali reaction in concrete.

Petrographic examinations should provide information on potentially chemically unstable components of aggregate materials such as sulphide minerals (pyrrhotite, marcasite, pyrite, chalcopyrite), gypsum, selenite, anhydrite, zeolites, or others that are reported to have been associated with deleterious reactions. Particular care should be used when these minerals, singly or in combination, are present in aggregates. Refer to the supplemental information provided in Clause A1.6 for a recommended practice for identification of sulphide minerals in polished thin-section.

Petrographic examinations may be directed specifically at the possible presence of contaminants in aggregates. Contaminants include synthetic glass, cinders, clinker, coal ash, magnesium oxide, calcium oxide, soil hydrocarbons, chemicals that can affect the setting of concrete or the properties of the aggregate, animal excrement, plants or rotten vegetation, and any other contaminant that is undesirable.

4 Equipment and materials

Items necessary for the identification of rocks and minerals may be selected by the petrographer and may include the following:

a) binocular microscope with magnification ranging from 8x to 60x, with illuminator;
b) petrographic (polarizing) microscope; optionally, such equipment may be fitted with reflected light viewing arrangement that enables examination and identification of metallic minerals including sulphide minerals;
c) hammer;
d) knife with a steel blade;
e) magnet;
f) hardness points or other suitable means of estimating scratch hardness;
g) balance capable of measuring to 0.1 g accuracy, with a capacity appropriate to the recommended sample sizes (see Table 1);
h) point counter;
i) immersion fluids, for the determination of refractive indices of minerals; and
j) diluted (10%) solution of HCl.

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5 Sampling

All materials should be sampled in accordance with CSA A23.2-1A. Whenever possible, the sampling should be undertaken or directed by the petrographer. This is especially recommended for assessments of new, proposed, or previously untested sources of aggregate, whether the property is developed or in exploration phases.

6 Procedure

6.1 General

6.1.1

Petrographers shall have the ability to recognize minerals and rocks and also have knowledge of construction materials, including properties of fresh and hardened concrete, deleterious reactions, and physical effects such as freezing and thawing, so that the beneficial and negative effects of aggregate composition and texture on concrete performance are considered.

Note: *Petrographers who do not have such knowledge of construction materials will be capable of recognizing various rock types and mineral constituents but might not be able to classify the quality of the aggregate particles and to predict the likely performance of the material in service based on the results of the examination. In such cases, the results of examination should be interpreted by a person with such knowledge.*

6.1.2

Two procedures are specified in Clauses 6.2 and 6.3:

a) Method A, which is a comprehensive and detailed petrographic examination. It is intended for aggregate that has not been previously evaluated for engineering applications and for which there might be no service or testing records. This method consists of comprehensive identification of rock and mineral types and may be supplemented by any of the following:
   i) study of thin sections and/or scanning electron microscopy;
   ii) x-ray analysis; and
   iii) analytical chemistry methods.
   This method may also be used in instances where the geology of the production material is different from that of previously produced material.
b) Method B is a quality control level of petrographic analysis and is intended for use with production-run aggregates with a prior history of testing and service record. It is typically conducted to monitor overall aggregate quality in the context of ongoing quality assessment of a specific aggregate supply.

The determination of a PN is included in both Methods A and B.

6.1.3

Because of the potential for high multi-operator variability, the PN shall not be used as the sole acceptance or rejection criterion. In cases where the PN is used as a specification parameter for aggregate quality, other physical testing shall supplement the PN.

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6.2 Method A

6.2.1 Petrographic examination of coarse aggregate

6.2.1.1 Sample

The minimum size of the sample to be examined shall be determined by either the minimum particle count or minimum mass as indicated in Table 1.

If the sample contains multiple sieve fractions, the petrographer may elect to examine each sieve fraction individually, or may examine a graded, whole sample. If examined on an individual-sieve size basis, only fractions containing at least 5% by mass of the sample should be examined. The choice of method should be agreed upon following discussion between the petrographer and the individual requesting the petrographic examination.*

The sample should be observed in "as received" condition, with any noteworthy features recorded. Such features might include the presence of weak or friable material (e.g., clay lumps, organic material, and weathered rock fragments) that might be removed by washing or sample preparation and the type and extent of coatings (e.g., clay, silt, sand, limonite, calcite, opal, or gypsum).

It is helpful to wash the sample prior to examination in order to promote adequate observation of the mineralogy and textures of the aggregate particles.

* *For natural gravel, significant variability of geological composition for various sieve fractions can occur, due to the depositional history of the deposit. These variations can be of importance in the correct assessment of the suitability of the material produced from the deposit. Thus, petrographic examination on the basis of individual sieve fractions can be preferred on at least an occasional basis (e.g., every fourth time an examination is conducted).*

Table 1
Particle count and mass of coarse aggregate sample
(See Clauses 4, 6.2.1.1, 6.3.1, and 6.3.3.)

Particle size, mm	Minimum particle count	Minimum mass, g
5–10	300	200
10–14	250	750
14–20	200	1800
20–28	150	2500
28–40	100	4000

6.2.1.2 Examination

An initial examination of the sample should be done to assess the presence of coatings or very weak materials in the aggregate. If these are noted, weak or brittle particles should be separated from the test sample prior to examination as these components can be readily broken down during washing of the sample. Following this initial separation, observations regarding the coatings on particle surfaces should be made and recorded. Upon completion of these observations, the test sample should be soaked for an extended period of time prior to classification of the particles into individual rock types and determination of their quality. It has been found that for certain rock types (e.g., argillaceous carbonates), a prolonged soaking period of 24 h can be useful in the identification of weaker quality components.

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Following the soaking period, each particle in the sample shall be examined separately and the rock type shall be identified. Cases in which this is not possible should be noted and samples of the unidentified rock types should be submitted for thin section analysis.

A guide providing suggested lithologies and a framework for geological classification is included as Attachment A1. If rock types that are not found in Attachment A1 are present in the sample, the petrographer shall provide rock type names and descriptions.

Table 2 lists physical characteristics that should be considered in the petrographic examination.

Table 3 lists mechanical characteristics that should be considered in the petrographic examination.

Based upon the determinations made in accordance with Tables 2 and 3, the aggregate particles shall be sorted into categories that reflect both physical quality and geologic composition. Categories such as the following may be utilized:

a) granite, fresh, strong;
b) quartzite, ferruginous, slightly weathered, medium strong;
c) basalt, porphyritic, fresh, strong; or
d) mica schist, highly weathered (iron-oxides), weak.

In some cases, subtypes of a single general rock type should be distinguished based on coincident engineering quality with distinct lithology (e.g., micritic limestone, light to dark grey, strong, fresh; argillaceous limestone, buff-grey, medium strength; sandy limestone, brown/light grey, slightly weathered, medium strong to weak).

Following sorting, the mass of each category shall be determined to the nearest 0.1 g and its relative abundance in the sample calculated to the nearest 0.1%.

Table 2
Physical characteristics of rocks
(See Clauses 6.2.1.2 and 6.3.2.)

Characteristic	Examples and considerations
Structures	Pore space, particle produces “crackling or whistling” sound as water is absorbed, packing of grains, cementation of grains, crystal structure, micro-fractures
Crystallinity	Aphanitic, porphyritic, pegmatitic, etc.
Grain size	Fine, medium, coarse
Mineralogy	Quartz, biotite, calcite, etc.
Colour	Medium grey, pale brown, etc.
Particle shape	Sphericity, roundness
Particle surface texture	Smoothness or roughness, presence or absence of fractured faces
Significant heterogeneities	Veining, joint filling, alteration zones
Coatings/encrustations	Calcite, limonite, clay, sand, etc.

(Continued)

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Table 2 (Concluded)

Characteristic	Examples and considerations
Degree of weathering and alteration	Slight, moderate, severe
Type of weathering and alteration	Mechanical, chemical, biological

Table 3
Mechanical characteristics of rocks
(See Clauses 6.2.1.2 and 6.3.2.)

Characteristics	Considerations
Strength	Low, medium, high (when particle is struck with hammer, note sharp ring or dull sound, ease of fracturing, type of fragmentation when fractured)
Hardness	1 to 10 on Mohs' hardness scale

6.2.1.3 Assessment

The aggregate particles, when sorted into individual categories as shown in the examples of Clause 6.2.1.2, shall then be classified as to overall physical quality into one of four petrographic classes: Good, Fair, Poor, and Deleterious. The determination of a PN for the sample shall be achieved through the multiplication of the percentage of each of the four quality classifications by the petrographic quality multipliers listed below:

a) Good — 1;
b) Fair — 3;
c) Poor — 6; and
d) Deleterious — 10.

Multipliers intermediate to those listed above (i.e., 2, 4, 5) may be used if the experience of the petrographer, combined with local service records for the aggregate under investigation, warrants their use. In these cases, reasons for their use shall be provided. The explanations should clearly explain the basis for the different multipliers and preferably be accompanied by the assessment criteria (e.g., results of other testing or evidence from field performance records) that assisted in the analysis so that verification can be done.

6.2.1.4 Calculation

A PN shall be calculated as outlined in Clause 6.2.1.3. If individual PNs are calculated for each sieve fraction, these shall be individually tallied; however, a weighted PN for the whole sample shall be determined using sieve analysis data, weighted to 100% for the sample. Individual PNs and weighted PNs should be rounded and reported to the nearest whole number (e.g., 105 not 105.4).

6.2.1.5 Reporting

A two-part report shall be produced, consisting of a textual discussion of the results and a table presenting the relative proportions of rock types in the sample and the physical-mechanical categories into which the sample was sorted. Figures A2.1 and A2.2 provide examples of such a format. The discussion shall present detailed information on the rock types, the physical and mechanical characteristics, the PN, the overall rating of the aggregate for engineering quality, and potential effects of deleterious materials identified in the sample during the examination.

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Specific attention shall be directed to discussion of any components of the sample that could have potential for chemical instability, if identified. Properties or constituents known to have specific unfavourable effects in concrete should be described qualitatively and, to the extent practicable, quantitatively. When appropriate, it should be stated that a given sample was not found to contain any undesirable features.

If considered appropriate, recommendations regarding any additional petrographic, chemical, physical, or geological investigations that might be required to evaluate adverse properties shall be included.

The results of the examination should be provided in such a way that recipients of the report would be able to form an opinion on the utility of the material.

6.2.2 Petrographic examination of fine aggregate

6.2.2.1 Sample

The procedure for the examination of fine aggregate (i.e., natural and manufactured sand) is similar to that for the examination of gravel or crushed stone from bedrock, with the modifications necessitated by the difference in grain size. Sand samples shall be examined in individual sieve size fractions.

All size fractions that comprise at least 5% by mass of the sample shall be included in the examination. Material that passes the 80 µm screen shall not be included in the examination. In preparation for the examination, the sample shall be sieved in accordance with CSA A23.2-2A. A sample size of 450 ± 50 g has been found to provide a sufficient mass of material for petrographic examination.

6.2.2.2 Examination

The examination shall be conducted using a stereoscopic microscope with a minimum magnification range of 8x to 60x. In some cases, a higher magnification will be warranted.

A representative portion of each sieve fraction to be examined shall be placed on the microscope stage. Methods that are suitable for the examination of sand include the following:

a) using epoxy to affix sand grains from individual size fractions on a microscope slide, a stiff paper mount, or equivalent. Inscribing of a grid on the paper or slide might be convenient for methodical examination of the epoxy sample;
b) sprinkling sand grains from individual size fractions onto the microscope stage and manipulation with forceps or tweezers; and
c) using a grooved holder into which sand grains are placed.

The minimum number of particles to be examined in any sieve fraction shall be 300. Individual grains shall be manipulated under the microscope and identified as to rock/mineral type, and shall be assessed for competence. Individual grains found to be of low competence shall be classified separately. As each grain is identified as to lithology and physical quality, it shall be recorded. The determination of the proportions of the individual components in each of the size fractions shall be conducted by point counting.

Note: *Some examinations will require the preparation of thin sections or grain mounts of individual sieve fractions, so as to make identifications of minerals via conventional petrography. For the coarsest sand fractions (i.e., 2.50 mm and 1.25 mm retained), several thin sections or grain mounts might be necessary in order to provide a sufficient number of sand particles for a representative sample.*

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6.2.2.3 Calculation

The percentage of each rock/mineral type in each sieve fraction shall be determined to the nearest 0.1%. Weighted percentages for individual sieve fractions may be calculated by adding together the weighted percentages for individual sieve fractions of each constituent.

6.2.2.4 Reporting

For fine aggregate, a report shall comprise of a textual narrative that summarizes the essential data on composition and properties of the material. The report shall record the test procedure employed and provide a description of the nature and features of each constituent of the sample, accompanied by relevant tables and photographs, as well as presenting recommendations for additional assessment or testing. Comments on potentially alkali-reactive rocks and minerals and other deleterious substances should be included in the report, along with details of the supporting observations, accompanied by a table indicating the relative amounts of the various rock and mineral types. An example of such a table is provided in Figure A2.3.

As appropriate, recommendations should be made regarding any additional petrographic, chemical, physical, or geological investigations required to evaluate adverse properties that are indicated by the petrographic examination. Attention should be drawn to any potentially adverse characteristics of constituents that were identified in the sample. The results of the examination should be provided in such a way that recipients of the report would be able to form an opinion on the utility of the material.

6.2.3 Petrographic examination of bedrock samples and drilled core

6.2.3.1

This procedure can be used for assessing bedrock proposed for use as

a) quarried aggregate;
b) building stone;
c) rip rap;
d) armour stone;
e) railroad ballast; and
f) granular base material.

6.2.3.2

The following methods may be used to assist in the petrographic examination of bedrock samples and drilled core:

a) visual core logging;
b) determination of the rock quality designation RQD (see the Canadian Geotechnical Society's Canadian Foundation Engineering Manual, Section 3.2.5);
c) stereomicroscopic examination;
d) thin section analysis; and
e) whole rock chemical analysis.

6.2.3.3

If sufficient core is available, it may be crushed to a coarse aggregate grading (e.g., 20 or 28 mm), and then a sample may be screened to a 5 to 20 mm grading for examination.

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6.2.3.4

The examination should focus on the identification of the following characteristics:

a) type, location, and spacing of fractures and parting planes;
b) lithology;
c) alteration;
d) strength, hardness, and coherence;
e) porosity;
f) grain size;
g) texture; and
h) constituents capable of deleterious reaction in concrete.

For calculation of the PN, see Clause 6.2.1.3.

A report for bedrock or core samples shall summarize the petrographic data in a manner similar to that used for coarse aggregate samples (see Clause 6.2.1.5). A description of both chemical and physical-mechanical characteristics of the sample shall be provided.

6.3 Method B — Rapid (quality control) petrographic examination of coarse aggregate

6.3.1 Sample

The sample size shall be in accordance with Table 1. The sample shall be spread on a flat working surface and examined visually for angularity and shape characteristics. An estimate of the percentage of crushed, as well as flat and elongated particles, should be made. CSA A23.2-13A outlines two procedures (A and B) for the determination of flat and elongated particles in coarse aggregate.

The aggregate shall be examined for coatings (such as clay), cementations, and encrustations that might affect the bond with Portland cement paste or asphalt cement. If clay balls or other particles that can break down in water or with normal handling are present, these particles shall be separately classified. The sample shall be washed to remove clay and dust coatings.

If the material being tested is suspected of being susceptible to weakening when wetted, the sample shall be soaked for a period of at least 1 h prior to testing. This can cause clay, shale, or argillaceous particles to soften, making their recognition easier.

6.3.2 Assessment

Each particle in the sample shall be classified into a rock or mineral type. The physical and mechanical characteristics listed in Tables 2 and 3 should be considered in the petrographic examination. A guide providing suggested lithologies and a framework for geological classification is included as Attachment A1. If any rock types that are not found in Attachment A1 are present in the sample, the petrographer shall provide rock type names and descriptions.

Following classification, the mass of each category shall be determined to the nearest 0.1 g and its relative abundance in the sample calculated to the nearest 0.1%.

The aggregate particles, when sorted into individual categories, may then be classified as to overall physical quality, into one of four petrographic classes: Good, Fair, Poor, and Deleterious.

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The determination of a PN for the sample shall be achieved through the multiplication of the percentage of each of the four quality classifications by an appropriate petrographic quality multiplier, as follows:

a) Good — 1;
b) Fair — 3;
c) Poor — 6; and
d) Deleterious — 10.

Intermediate multipliers (i.e., 2, 4, and 5) may be used if the experience of petrographer, combined with local service records for the aggregate under investigation, warrants their use. In these cases, reasons for their use shall be provided. The explanations should clearly illustrate the basis for the different multipliers and preferably be accompanied by the assessment criteria that assisted in the analysis so that verification can be done.

6.3.3 Calculation

A PN shall be calculated as specified in Clause 6.3.2. When the test is performed on more than one size fraction, a weighted average PN shall be calculated by multiplying the percentage (based on the "as received" coarse aggregate sample grading) of each sieve fraction by the PN for that fraction, adding these products, and dividing by 100.

The calculation may also be made on the basis of particle count, rather than mass. Between 100 and 300 (see Table 1) randomly picked particles from the sample shall be separated into each rock type, whose relative abundance in the sample should be calculated to the nearest 1%. An example of the calculation is shown in Figure A2.4.

6.3.4 Reporting

The report shall include the following information, as applicable:

a) sample identification;
b) source name and location, if known;
   Note: *The sample might not be an aggregate, but could be a pile of rock cores, cobbles, or such.*
c) sample identification/type;
d) date of sampling;
e) name of sampler;
f) date of examination;
g) fractions examined;
h) percentages (to the nearest 0.1%) of each rock type and of good, fair, poor, and deleterious particles;
i) PN for individual sieve fractions and/or for the whole sample on the basis of a weighted value;
j) name of the petrographer;
k) identification of the certified laboratory (i.e., name and address); and
l) applicable comments.

An example table is shown in Figure A2.4.

7 Precision

The petrographic methods described in this Test Method are inherently dependent upon the skill and experience of the petrographer and the results might therefore be subjective to a certain degree. While the geological identification of various rock types has an inherent variability, the use of thin section

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examination, X-ray diffraction analysis, chemistry, and scanning electron microscopy can be used to refine the rock identification.

Additionally, other physical tests, such as those described in CSA A23.2 or in ASTM Volume 04.02, may supplement the petrographic examination.

In Ontario, round-robin testing prior to 2003 has found that the PN determined by experienced analysts can vary by up to ±20 units of the mean for samples of coarse aggregate from a single reference stockpile, 19 times out of 20. Results of yearly correlation testing between 2013 and 2016 in Ontario has shown that for less qualified and less experienced operators, the PN value can vary by ±54 units from the median.

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Attachment A1 (informative)
Rock and quality type descriptions

Note: *This Attachment is not a mandatory part of this Test Method.*

A1.1 Discussion

In the PN determination of aggregates, individual aggregate particles are initially subjected to geological classification. This should be done in accordance with generally accepted geological practices and terminology and on the basis of visual and basic physical index tests. After the aggregate particles have been identified as to rock type, they are then categorized into quality types, using descriptors such as “hard”, “soft”, “strong”, ‘”weak”, “friable”, “fresh (unweathered)”, “surface weathered”, “deeply weathered”, “decomposed”, etc. For the purposes of standardization, descriptions of the various types are presented in this Attachment.

Characterization methods related to the strength and competence of the aggregate particles, such as scratching, scraping, peeling and plucking using a knife blade, fracture with a geologic hammer, or similar means, are employed in this classification. Scratching, scraping, and peeling determine the application of hardness descriptors, striking with a hammer determines the resulting mode of fracture, and plucking determines the application of descriptors such as ”strong”, “medium strength”, “low strength”, “weak”, and “friable”. Each rock group, such as plutonic rock, volcanic rock, sandstone, and conglomerate, carbonate, etc., is described separately so as to highlight the decreasing quality of the group through categories “good” to “deleterious”. This enables an aggregate to be classified on a systematic basis.

Due to the subjective nature of this Test Method, descriptions of rock types contained in this Attachment should be considered only as a guideline. The petrographic examination is largely dependent on the experience of the analyst and, where possible, should be complemented by routine tests or performance data, or both. In specific cases (especially those of rocks whose performance is unfamiliar to the analyst), additional testing might be necessary, including study of thin sections, scanning electron microscopy, X-ray diffraction analysis, and chemical analysis. For example, a freeze-thaw test conducted on medium hard and slightly shaley carbonate can be used to determine if the shale seams are planes of weakness and therefore whether or not the particles are classified correctly.

Note: *The material should be immersed in a 3% sodium chloride solution in a pan and subjected to 5 cycles, each cycle consisting of approximately 16 h of freezing followed by approximately 8 h of thawing at room temperature.*

A1.2 Rock and quality type list

The list of rock and quality types in Clauses A1.3 to A1.7 is intended to provide a reasonably comprehensive rock classification compatible with all or nearly all of the particles that comprise aggregate samples submitted for PN determination. The intention is that a petrographer would be able to identify an aggregate particle as to rock type and then assign it to a quality category.

General terms such as “sandstone”, “carbonates”, and “granite” are considered to be appropriate rock type names for PN determinations. However, more specific rock type names may be employed. For example, Table A1.1 provides two sets of three specific rock type names for each of the three general terms referred to in this Clause. Some users of the petrographic examination might not be conversant with technical geological terminology. When more specific names are used, the petrographer should provide explanatory notes as appropriate.

The nomenclature of rock types in Clauses A1.3 to A1.7 is neither comprehensive nor exhaustive; consequently, rock type names that are more descriptive or detailed may be used at the discretion of the petrographer.

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Special attention should be given to the identification of potentially chemically unstable components in aggregate materials, such as sulphide minerals (pyrrhotite, marcasite, pyrite, chalcopyrite — see Annex PP of CSA A23.1), gypsum, selenite, anhydrite, zeolites or others that are reported to have been associated with deleterious reactions. These types of deleterious minerals could be present in a variety of rock types.

Table A1.1
General and specific rock type names
(See Clause A1.2.)

General rock type name	Rock type name	Specific rock type name
Sandstone	Calcareous fine-grained sandstone	Lithic arenite
	Thin bedded silty sandstone	Arkose
	Conglomeratic cherty sandstone	Orthoquartzite
Carbonate	Limestone	Micrite
	Sandy limestone	Argillaceous limestone
	Dolomite (“Dolostone”)	Calcitic dolomite (“Dolostone”)
Granite	Biotite granite	Altered chloritic granodiorite
	Quartz diorite	Slightly weathered monzonite
	Gabbro	Fine-grained syenite

A1.3 Igneous rocks

A1.3.1 Plutonic rock

A1.3.1.1 Rock-type names

The following plutonic rock-type names are commonly used in Canada:

a) syenite;
b) granite;
c) monzonite;
d) granodiorite;
e) diorite;
f) gabbro;
g) dunite;
h) diabase; and
i) trap or trap rocks, which are collective terms for dark-coloured medium to fine-grained igneous rocks, especially diabase or basalt.

Note: *The term “trap” is typically used as a field mapping term.*

A1.3.1.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good (hard, strong):
   i) mainly very high strength;
   ii) generally cannot be scratched;

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iii) particle requires strong blow to fracture with hammer and breaks cleanly (produces little fines);
iv) minor medium strength (e.g., micaceous and chloritic) zones which can be scratched and scraped with some difficulty;
v) can have partial thin surface weathering; and
vi) particle can be altered but is strong.

b) Fair (brittle, medium strong):
i) mainly medium to high strength;
ii) particle requires medium-energy blow to fracture with hammer and might produce some fines in addition to larger pieces when broken;
iii) generally cannot be scratched;
iv) brittle (edges and corners can be plucked);
v) minor medium- to low-strength zones that can be plucked with ease; can have partial to total thin surface weathering; and
vi) can exhibit partial alteration (e.g., feldspar, ferromagnesian minerals to chlorite, clay; sulphides to iron oxides).

c) Poor (low strength/weak or friable):
i) low strength;
ii) friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles when plucked); and
iii) could be extensively altered (e.g., feldspar, ferromagnesian minerals to chlorite, clay; sulphides to iron oxides).

A1.3.2 Volcanic rock

A1.3.2.1 Rock-type names

The following volcanic rock-type names are commonly used in Canada:

a) rhyolite;
b) trachyte;
c) dacite;
d) andesite;
e) basalt;
f) volcaniclastic rock;
g) tuff;
h) scoria;
i) pumice; and
j) trap or trap rocks, which are collective terms for dark-coloured medium to fine-grained igneous rocks, especially diabase or basalt.

Note: *The term "trap" is typically used as a field mapping term.*

A1.3.2.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good (hard to medium hard, strong):
i) mainly very high strength;
ii) generally cannot be scratched;
iii) requires strong blow with hammer to fracture and typically breaks cleanly into a few smaller particles;

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iv) minor medium to high strength zones which can be scratched and scraped with some difficulty; and
v) can have partial, thin, surface weathering.

b) Fair:
i) Soft, medium strength:
1) medium strength;
2) can be scratched with moderate ease and scraped with some difficulty;
3) moderate effort to fracture with hammer and breaks into some smaller particles accompanied by modest amount of fines; and
4) can contain minor low-strength zones that can be gouged.
ii) Glassy:
1) cannot be scratched;
2) conchoidal to semi-conchoidal fracture; and
3) includes obsidian.
iii) Ochreous: contains between 25% and 50% ochreous material.

c) Poor:
i) Very soft, weak:
1) low strength;
2) can be scraped with ease and peeled with some difficulty;
3) moderate or strong blow with hammer crumbles sample; and
4) some can contain up to 75% ochre.
ii) Porous:
1) low strength;
2) can be scratched and scraped with ease; and
3) can contain up to 75% ochre.

d) Deleterious or decomposed:
i) very low strength; and
ii) can be peeled with ease and crumbled with fingers.

A1.4 Sedimentary rocks

A1.4.1 General

A1.4.1.1 Sandstone and conglomerate

A1.4.1.1.1 Rock-type names

The following sandstone and conglomerate rock-type names are commonly used in Canada (siltstone is included in Clause A1.4.1.3 as a type of mudrock, but should be included in this category when the existence of a sandstone-siltstone series is evident):

a) orthoquartzite;
b) quartz arenite;
c) lithic arenite;
d) arkose;
e) greywacke;
f) conglomeratic sandstone; and
g) conglomerate.

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A1.4.1.1.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good:
   i) Hard:
      1) high strength;
      2) cannot be scratched;
      3) intact (edges and corners cannot be plucked); and
      4) strong blow of hammer necessary to fracture particle, and produces only a few pieces and little fines when broken.
   ii) Medium hard:
      1) high strength;
      2) generally cannot be scratched, although cementitious material can be scratched with some difficulty; and
      3) some edges and corners can be plucked with difficulty, particle requires strong blow of hammer to break and produces only a few particles with little fines when broken.
b) Fair (brittle):
   i) medium to high strength;
   ii) generally cannot be scratched, although cementitious material can be scratched with moderate ease;
   iii) when struck with hammer, fractures with moderate effort, producing some smaller pieces, possibly with accompanying fines; and
   iv) brittle (edges and corners can be plucked).
c) Poor (friable):
   i) low strength;
   ii) generally poorly indurated/cemented;
   iii) particle breaks with low energy from hammer, and will fracture into several smaller pieces or crumbles mostly into constituent grains;
   iv) friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles totally when plucked); and
   v) can be broken by hand.

A1.4.1.2 Carbonate (excluding cherty carbonate) rock

A1.4.1.2.1 Rock type names

The intention in this Clause is to provide a higher level of detail in identification, reflecting the importance of quarried carbonate rock in central Canada (Québec, Ontario, and Manitoba) and regional aggregate supplies.

The following carbonate rock-type names are commonly used in Canada:

a) limestone;
b) sandy limestone;
c) argillaceous (shaley) limestone;
d) dolomite (“dolostone”);
e) arenaceous dolomite (“dolostone”); and
f) argillaceous dolomite (“dolostone”).

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A1.4.1.2.2 Rock quality categories

The following guidelines may be used to assist in making an engineering quality judgment:

a) Good:
   i) Hard:
      1) high strength;
      2) can be scratched (a relatively thin scratch);
      3) strong blow of hammer necessary to fracture; and
      4) typically unweathered.
   ii) Hard, silty:
      1) high strength;
      2) can be scratched (a relatively thin scratch);
      3) raspy sound when scratched;
      4) commonly greenish grey;
      5) strong blow of hammer necessary to fracture particle and produces only a few pieces and little fines when broken; and
      6) typically unweathered.
   iii) Medium hard:
      1) high strength;
      2) can be scratched (a relatively thick scratch); and
      3) fractures under hammer with moderate effort producing a few subparticles, and little fines.
   iv) Silty, medium hard:
      1) high strength;
      2) can be scratched (a relatively thick scratch);
      3) raspy sound when scratched; and
      4) commonly greenish grey.
   v) Surface weathered:
      1) mainly high strength;
      2) can be scratched; and
      3) no more than a third of particle consists of medium- to low-strength weathered material.
   vi) Silty, surface weathered:
      1) mainly high strength;
      2) can be scratched;
      3) raspy sound when scratched;
      4) commonly greenish grey; and
      5) no more than a third of particle consists of medium- to low-strength weathered material.

b) Fair:
   i) Soft:
      1) medium strength;
      2) uniform consistency;
      3) can be scratched and scraped with ease;
      4) cannot be peeled; and
      5) breaks with relatively moderate energy under hammer.
   ii) Silty, soft:
      1) medium strength;
      2) can be scratched with ease and scraped with some difficulty;
      3) can contain minor low-strength zones that can be scraped with ease;
      4) raspy sound when scratched;
      5) breaks with relative ease when struck with hammer; and

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6) commonly greenish grey.

iii) Soft, pitted:
1) medium strength;
2) can be scratched with ease and scraped with some difficulty;
3) breaks with relative ease when struck with hammer; and
4) moderately pitted.

iv) Deeply weathered:
1) more than 33% of particle consists of medium- to low-strength weathered material; and
2) breaks with relative ease when struck with hammer.

v) Silty, deeply weathered:
1) more than 33% of particle consists of medium- to low-strength weathered material;
2) raspy sound when scratched; and
3) commonly greenish grey.

vi) Porous, medium strength:
1) pitted from dissolution, can contain fossil material, sometimes partly siliceous, can be partially ferruginous;
2) often variegated in colour (buff/tan/orange/rust), giving a patchy appearance;
3) uneven scratch response (harder and softer zones);
4) can require moderate effort to fracture with hammer; and
5) treatment with dilute HCl often reveals porous structure.

c) Poor:

i) Clayey (argillaceous):
1) contains between 33% and 75% very low strength material; and
2) can be scraped and peeled with ease.

ii) Silty, clayey (argillaceous):
1) contains between 33% and 75% very low-strength material;
2) can be scraped and peeled with ease; and
3) raspy sound when scratched.

iii) Ochreous: contains between 33% and 75% ochreous material.

iv) Fissile:
1) tends to separate readily along thin bedding planes on which mica flakes can commonly be seen;
2) medium to low strength;
3) poorly cemented; and
4) friable (many pieces can be plucked easily from particle).

v) Porous, low strength:
1) heavily pitted (from dissolution), can contain fossil material, sometimes partly siliceous, can be partially ferruginous;
2) typically variegated in colour (buff/tan/orange/rust), with patchy appearance;
3) uneven scratch response (harder and softer zones);
4) requires low effort to fracture with hammer; and
5) treatment with dilute HCl often reveals porous structure.

d) Deleterious (clay):

i) greater than 75% of particle consists of very low-strength material;

ii) can be peeled with ease and, at times, can be broken with the fingers or cut completely through; and

iii) includes kaolin.

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A1.4.1.2.3 Sandy carbonate

The following guidelines may be used in making an engineering quality judgment for sandy carbonates:

a) Good (sandy, hard, or medium hard):
   i) high strength (matrix material can be slightly weaker than quartz grains);
   ii) can be scratched with some difficulty;
   iii) raspy sound when scratched;
   iv) strong blow with hammer necessary to fracture;
   v) ranges from no weathering to thin surface weathering; and
   vi) contains 5% to 49% sand-sized quartz grains.
b) Fair (sandy, soft):
   i) medium strength;
   ii) can be scratched with ease and scraped with some difficulty;
   iii) can contain minor low-strength zones that can be scraped with ease;
   iv) medium blow with hammer necessary to fracture;
   v) raspy sound when scratched; and
   vi) contains 5% to 49% sand-sized quartz grains.
c) Poor (sandy, ochreous):
   i) contains between 33% and 75% ochreous material; and
   ii) contains 5% to 49% sand-sized quartz grains.

A1.4.1.3 Mudrock

A1.4.1.3.1 Rock type names

The naming of fine-grained sedimentary rocks is an inexact process due to inherent difficulties in determination of their texture and mineralogy and in the application of field terminology to small aggregate particles. Some latitude might, therefore, be needed in identification of mudrock.

The following mudrock type names are commonly used in Canada:

a) Shale:
   i) very fine-grained;
   ii) laminated;
   iii) wavy/undulating bedding commonly results in ovoid particles; and
   iv) can slake or swell, depending upon type and amount of clay mineral present.
b) Claystone:
   i) variety of shale; and
   ii) bedding planar (not undulating).
c) Siltstone:
   i) grain size between that of claystone/shale and sandstone;
   ii) can contain some clay or sand (sandy siltstone typically feels gritty); and
   iii) its quality depends on strength, scratchability, and porosity, which depend on degree of induration, cementing agent, and composition.
d) Mudstone:
   i) typically, a rock that incorporates both silt-size grains and clay-size grains/matrix, and might also include sand-sized material;
   ii) tends to be less fissile than shale, and can be vaguely laminated, well laminated, or massive; and
   iii) is frequently a host for pyrite (including framboidal forms), marcasite, and pyrrhotite.

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A1.4.1.3.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good:
   i) Strong:
      1) high or moderately high strength;
      2) typically not flatter than 1:2 (thickness-to-width);
      3) can be scratched;
      4) moderately intact (edges and corners can be plucked but with difficulty);
      5) strong blow with hammer necessary to fracture particle;
      6) when fractured, does not produce primarily flat particles from breaking along bedding planes;
      7) particle can exhibit slight metamorphism;
      8) often, unmetamorphosed mudstones tend to exhibit properties that are inconsistent with a classification of "Good"; and
      9) commonly host fine-grained pyrite/pyrrhotite/marcasite, which can alter rapidly upon exposure to ambient conditions and produce sulphuric acid. This can lead to environmental damage as well as pyrite-gypsum heave.
   ii) Medium strong:
      1) medium strength;
      2) generally cannot be scratched;
      3) some edges and corners can be plucked; and
      4) particle requires moderate effort of hammer to break.
b) Fair (medium strength, brittle):
   i) medium strength;
   ii) generally can be scratched;
   iii) when struck with hammer, fractures readily with moderate effort, producing some smaller pieces, many of which are flatter than 1:2 (thickness-to-width); and
   iv) brittle (edges and corners can be plucked).
c) Poor(low strength, fissile):
   i) low strength;
   ii) generally poorly indurated/cemented;
   iii) can be slaking rock (swells when wetted);
   iv) likely softens when wetted;
   v) particle breaks with low energy from hammer; and
   vi) often assumes flat particle geometry (flatter than 1:3 thickness-to-width).
d) Deleterious (friable):
   i) typically can be broken by hand, very flat, easily scratched; and
   ii) can disaggregate after soaking.

A1.4.1.4 Chert and cherty carbonate

A1.4.1.4.1 Rock type names

Chert is hard, compact cryptocrystalline quartz. The following names are commonly used in Canada:

a) agate;
b) banded chert;
c) chalcedony (often occurs in mafic volcanic rocks, as amygdules occupying vugs, but can occur with opal as particle coatings);
d) jasper;

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e) leached chert:
   i) can be very pitted and weathered;
   ii) reactivity; and
   iii) absorptive (can generally stick to the tongue);
f) semi-leached chert (can be classified as leached chert or unleached chert based on the rate of absorption);
g) opal:
   i) typically fractures with conchoidal pattern;
   ii) aphanitic, lightweight and light-coloured;
   iii) tends to be highly reactive with alkalies; and
   iv) found occasionally in western Canadian gravels; and
h) iron formation (typically banded, consisting of cryptocrystalline quartz and iron minerals such as hematite).

A1.4.1.4.2 Rock quality categories — Iron formation

Iron formation commonly forms dense strong particles, but is generally reactive in concrete. It occurs in the Lake Superior/Mesabi Range area of Ontario, Michigan, and Wisconsin and is similar to Australian BIFs. It has high strength, cannot be scratched, and is unweathered. The following guidelines may be used in making an engineering quality judgment:

a) Good (slightly weathered):
   i) mainly high strength;
   ii) can be scratched with difficulty;
   iii) less than 5% of particle consists of penetrating zones of low- to medium-strength weathered material that can be scraped or gouged; and
   iv) can have partial to total thin surface weathering (rusty stains).
b) Fair (moderately weathered):
   i) mainly medium to high strength;
   ii) can be scratched with difficulty;
   iii) outer crust can be scraped and plucked with difficulty; and
   iv) contains between 5% and 25% penetrating zones of low- to medium-strength weathered material that can be scraped or gouged.
c) Poor (highly weathered):
   i) contains between 25% and 75% low-strength weathered material that can be scraped or gouged with ease;
   ii) outer crust containing medium- to low-strength zones can be scraped and plucked with moderate ease; and
   iii) inner core can have appearance of ochre or pumice.
d) Deleterious (decomposed):
   i) low to very low strength; and
   ii) greater than 75% of particle consists of low-strength weathered material that can be scraped, peeled, or gouged with ease.

A1.4.1.4.3 Rock quality categories — Chert and cherty carbonate

The following guidelines may be used in making an engineering quality judgment for chert and cherty carbonate:

a) Good carbonate (slightly cherty less than 5% chert):
   i) high strength;
   ii) hard and/or slightly weathered carbonate;
   iii) particle contains less than 5% chert;

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iv) dense, fine-grained, or aphanitic, hard, strong chert;
v) can include jasper, banded chert, or agate;
vi) when pebble in fluvial gravels, can be very smooth to polished; and
vii) not scratched by knife.

b) Fair cherty carbonate (less than 20% leached chert):
i) high strength;
ii) hard and/or slightly weathered carbonate;
iii) particle contains 5% or more chert but less than 20% of the particle is leached (i.e., absorptive) chert which can generally stick to the tongue;
iv) mostly dense chert, but with some vugs/voids or eroded (weathered) veins; and
v) can have slightly lower strength than hard, dense, fresh chert.

c) Poor cherty carbonate (20% leached chert):
i) high to medium strength; and
ii) particle contains 20% or more leached (i.e., absorptive) chert that can generally stick to the tongue.

Note: *The classification of semi-leached chert as leached chert or unleached chert should be based on the rate of absorption.*

A1.4.2 Other sedimentary rocks, concretions, encrustations, cementations, and silt/clay/till lumps

A1.4.2.1 Rock type names

The following occur in some regions of Canada:

a) coal: very weak;
b) gypsum:
i) very soft; and
ii) breaks along cleavage planes;
c) phosphatic rock:
i) medium strong to very week; and
ii) porous;
d) ironstone:
i) sedimentary rock/nodule occurring in Mesozoic and Cenozoic sedimentary formations (common in prairie provinces and eastern BC);
ii) concretionary arrangement of indurated clay and silt with iron minerals (e.g., goethite, siderite, and hematite);
iii) typically rusty brown but can range from light buff to very dark brown;
iv) often has a dull to shiny lustre and a bluish to purplish sheen on exterior surfaces;
v) often forms round-shaped particles;
vi) often brittle and fractures into concretionary layers when broken; and
vii) propensity for popouts in pavements and concrete flatwork;
e) glauconitic rock;
f) salt rock:
i) contains sodium and/or potassium chloride;
ii) water-soluble; and
iii) breaks along cleavage planes;
g) concretion:
i) medium strong to very weak; and
ii) often porous;
h) encrustation: 33% or more of particle is covered by a coating (25% in the case of a thick coating);

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i) cementation (partial):
   i) a group of particles cemented together, usually by calcium carbonate; and
   ii) one dominant host particle;
j) cementation (total):
   i) a group of particles cemented together, usually by calcium carbonate; and
   ii) no dominant host particle; and
k) silt/clay/till lump.

A1.4.2.2 Rock quality categories

The engineering quality of the materials listed in Clause A1.4.2.1 is as follows:

a) fair: encrustation;
b) fair to deleterious:
   i) phosphatic rock;
   ii) glauconitic rock; and
   iii) concretion;
c) poor: cementation;
d) poor to deleterious:
   i) gypsum; and
   ii) salt rock; and
e) deleterious:
   i) coal;
   ii) ironstone; and
   iii) silt/clay/till lump.

A1.5 Metamorphic rocks

A1.5.1 General

A1.5.1.1 Low-grade metamorphic rock

A1.5.1.1.1 Rock type names

The following low-grade metamorphic rock type names are commonly used in Canada:

a) argillite;
b) slate; and
c) phyllite.

A1.5.1.1.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good:
   i) Slate/phyllite (hard or medium hard):
      1) high strength;
      2) can be scratched with difficulty; and
      3) some edges and corners can be plucked with difficulty.
   ii) Argillite (hard or medium hard):
      1) high to very high strength; and
      2) can be scratched with difficulty.

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b) Fair:
   i) Slate/phyllite (brittle):
      1) medium to high strength;
      2) can be scratched with moderate ease and scraped with some difficulty; and
      3) brittle (edges and corners can be plucked).
   ii) Argillite (medium soft):
      1) medium strength; and
      2) can be scratched with moderate ease and scraped with some difficulty.
c) Poor:
   i) Slate/phyllite (friable):
      1) low strength; and
      2) friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles when plucked).
   ii) Argillite-slate (soft):
      1) low to medium strength;
      2) can be scratched and scraped with ease;
      3) fissile (particle breaks along closely spaced fractures, and shatters when struck by a hammer); and
      4) generally characterized by length-to-thickness ratio less than 4 to 1.
d) Deleterious:argillite-slate (very soft)
   i) low to very low strength;
   ii) can be scraped and peeled with ease;
   iii) very fissile (particle breaks readily along very closely spaced fractures and shatters easily when struck by a hammer);
   iv) rusty weathering stains penetrate into the particle; and
   v) generally characterized by length-to-thickness ratio greater than 4 to 1.

A1.5.1.2 Medium- to high-grade metamorphic rock

A1.5.1.2.1 Rock type names

Rock types in this group tend to exhibit layering and lineation of minerals but are generally stronger than low-grade metamorphic rocks. The following medium- to high-grade metamorphic rock type names are commonly used in Canada:

a) schist: mica contents typically high, resulting in low strength and high scratchability;
b) gneiss:
   i) quartz and feldspar contents are typically high;
   ii) low strength and high absorption can result from a high biotite mica content or the presence of weathered biotite; and
   iii) due to layer, aggregate particles can be difficult to identify; and
c) amphibolite: high content of aligned amphibole minerals.

A1.5.1.2.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good: gneiss-amphibolite(hard/strong):
   i) mainly very high strength;
   ii) generally cannot be scratched;
   iii) minor medium- to high-strength (e.g., micaceous and chloritic) zones that can be scratched and scraped with some difficult, requires effort to fracture with hammer; and

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iv) can have partial thin surface weathering.

b) Fair:
   i) Gneiss (brittle/medium strength):
      1) mainly medium to high strength;
      2) generally cannot be scratched;
      3) brittle (edges and corners can be plucked);
      4) moderate effort to fracture with hammer;
      5) some fines produced along with some or several larger pieces;
      6) minor medium- to low-strength zones that can be plucked with ease; and
      7) can have partial to total, thin, surface weathering.
   ii) Schist (brittle):
      1) medium strength;
      2) can be scratched with moderate ease;
      3) brittle (edges and corners can be plucked); and
      4) can contain minor more friable zones that can be plucked and scraped with ease, moderate effort to fracture, and produces flattish particles.

c) Poor:
   i) Gneiss-amphibolite (friable):
      1) low strength; and
      2) friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles when plucked).
   ii) Schist (soft/weak):
      1) low strength;
      2) can be scraped and plucked with ease; and
      3) can contain chloritic and/or micaceous zones that can be peeled with ease.

d) Deleterious: schist or gneiss (decomposed):
   i) very low strength;
   ii) can be crumbled with fingers;
   iii) high mica or chlorite content; and
   iv) low quartz and feldspar content.

A1.5.2 Other metamorphic rocks

A1.5.2.1 Rock type names

The following metamorphic rock type names are used in some regions of Canada:

a) granulite:
   i) even-grained metamorphic rock with well-interlocking crystals; and
   ii) strong to weak;
b) hornfels: a term more applicable in field evaluations, but that can be used for aggregate particles;
c) migmatite: a term more applicable in field evaluations, but that can be used for aggregate particles from stone source identified as migmatites;
d) skarn: contact metamorphic rocks, often resulting from reaction of carbonate rocks with intrusions;
e) quartzite:
   i) interpenetrating quartz grains;
   ii) can contain mica, garnet, feldspar, etc.;
   iii) generally fractures through, rather than around, quartz grains; and
   iv) ranges from non-ferruginous (strong) to ferruginous (medium strong, up to 10% iron oxides resulting from weathering of pyrite, magnetite, hematite, etc.) to highly ferruginous (weak, more than 10% iron oxides, can be deeply pitted/incised); and

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f) marble: ranges from strong to medium strong (can be scraped with difficulty, edges and corners can be plucked) to weak (friable, can be scraped and plucked with ease).

A1.5.2.2 Rock quality categories

The following guidelines may be used in making an engineering quality judgment:

a) Good (hard or medium hard):
   i) high strength;
   ii) can be scratched; and
   iii) intact (edges and corners cannot be plucked).
b) Fair (brittle):
   i) medium strength;
   ii) can be scratched with ease and scraped with some difficulty;
   iii) brittle (edges and corners can be plucked); and
   iv) can have partial to total thin surface weathering.
c) Poor (friable):
   i) low strength;
   ii) friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles totally when plucked); and
   iii) includes cleavable calcite.

A1.6 Recognition of sulphide minerals

Concerns regarding the presence of sulphide minerals in aggregate are discussed in further detail in Annex P of CSA A23.1. The identification of sulphide minerals, their relative abundance, their form, and their mode of occurrence can be determined on the basis of a combination of optical petrography and chemical analyses.

The first step in the identification of sulphide minerals can be achieved in the petrographic examination of aggregates. When rock particles that contain sulphide minerals are observed, these can be separately classified and described in terms of the estimated amount of the sulphides, species (if known), crystallinity and crystal size (if applicable), and the relative abundance of the rocks that contain the sulphides.

Not all sulphide minerals will necessarily produce a problem; much crystalline pyrite, for example, is seen after decades in service embedded in aggregate in concrete, and can be in a completely unaltered and sound condition. However, disordered, poorly crystalline, fine-grained, and framboidal varieties of pyrite, in addition to pyrrhotite, chalcopyrite, and marcasite, are considered to be far more susceptible to unstable behaviour. Rocks that contain sulphides should be carefully examined for these undesirable sulphides.

The recommended optical method for distinguishing metallic minerals is by use of polished, uncovered thin-sections, viewed in reflected light using a polarizing microscope of sufficient magnification to enable viewing and identification of these minerals (see Figure A1.1).

When sulphide minerals are identified in samples of aggregate, it is important that

- the proportion of the sulphide-bearing rocks is determined within the sample;
- the relative proportion of the sulphides within that rock type is estimated or determined (if possible); and
- distinction be made between varieties of rock in which sulphide minerals were identified.

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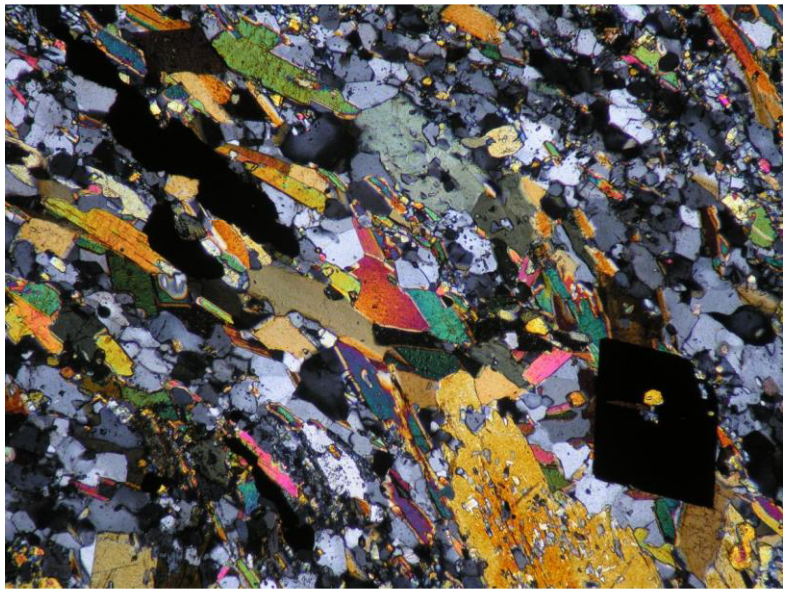
This would enable an estimate of the total sulphides in the sample on the basis of rock type. If the subject rock type changes in proportion during different periods of extraction and production, quality control testing and analyses can be conducted to delineate these changes.

A polished, uncovered thin-section specimen should be prepared from sufficient rock particles to provide a representative selection for each rock type that bears sulphide minerals. In reflected light, a petrographer who is experienced in the recognition of metallic minerals should examine the samples using variable magnifications and identify the sulphide minerals with respect to

- species;
- grain size;
- crystalline form;
- oxidation/alteration, if applicable; and
- relative proportion using point counting or visual estimation.

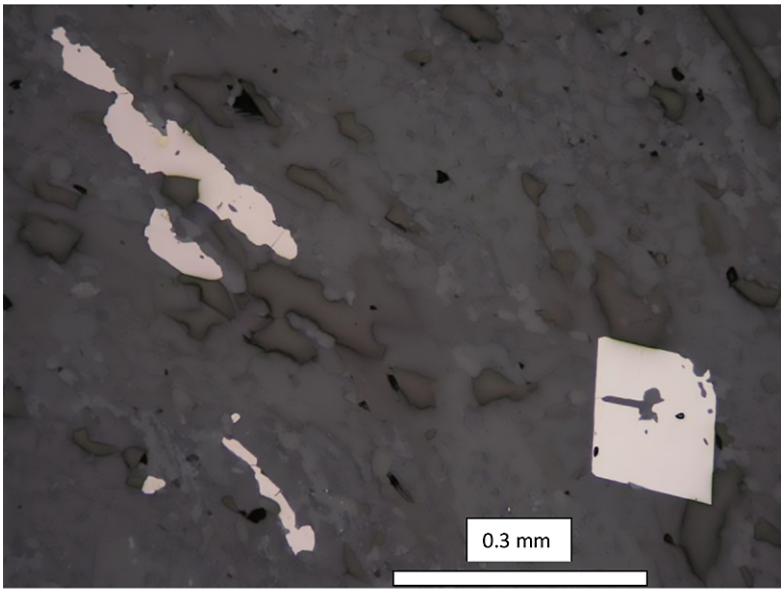
It is important that the microscope used for this purpose is equipped to provide adequate magnification, since in some cases recognition of sulphide minerals might require examination of grains in the order of only a few microns. The intergrowth of various sulphides and other metallic minerals is common, with some species being difficult to discern at lower magnifications.

Figure A1.1
Views of a portion of a polished thin-section
(See Clause A1.6.)



a) crossed-polarized light

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b) reflected light

Note: *In these views of a portion of a thin section, pyrrhotite is the main opaque mineral but contains inclusions of chalcopyrite (upper left grain). Scale applies to both micrographs.*

A1.7 Miscellaneous natural materials

A1.7.1 Names

The following can be found in Canadian aggregates:

a) breccia;
b) serpentinite;
c) psammite;
d) pelite;
e) quartz: vein or pegmatitic, ranges from strong to weak as for quartzite;
f) sulphide: particle contains at least 75% sulphide minerals such as pyrite, marcasite, and chalcopyrite; and
g) talc: sectile, greasy to touch.

A1.7.2 Quality categories

The engineering quality of the materials listed in Clause A1.7.1 is as follows:

a) good to poor: quartz;
b) good to deleterious:
   i) breccia; and
   ii) serpentinite;
c) fair: sulphide; and
d) deleterious: talc.

A1.8 Synthetic materials

The following synthetic materials can be found in Canadian aggregates:

a) slag;

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b) glass;
c) recycled concrete; and
d) recycled asphalt.

The engineering quality of synthetic materials is variable (e.g., glass can be deleterious in concrete due to reactivity).

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Attachment A2 (informative)
Examples of report formats

Note: *This Attachment is not a mandatory part of this Test Method.*

The following sample reports are provided for reference purposes.

Figure A2.1
Petrographic examination of coarse aggregate — Example of discussion
(See Clause 6.2.1.5.)

Detailed petrographic examination of coarse aggregate	
Source name: —	**Sieve fraction: 5 mm–14 mm**
Sample number: —	**Date sampled: —**
Petrographer: —	**Date tested: —**

General

The aggregate sample consists of natural gravel, crushed in part. Coatings on the aggregate consisted of silt/clay, much of which was removed by washing. A fine residual coating of very fine weathered material remained on many of the particles following washing. The coating may affect the bond strength between the cement and the aggregate particles.

All identifications were made using standard visual and basic geological diagnostic techniques. No thin section or X-ray analyses were utilized in these identifications. Hence, some descriptions should be regarded as tentative.

Geology of the aggregate

The aggregate consists of a mixture of volcanic rocks; granitic rocks, including some mafic varieties; several different metamorphic rock types, including ultramafic greenstone, “soapstone” (i.e., talc schist), and quartzite; sandstone; limestone; chert; and minor quartz.

Many of these rocks exhibited variability in terms of texture, mineralogy, and alteration. Some volcanic rocks were affected by metamorphism, for example, but in cases where the original fabric was discernible, the rock was classified as “volcanic”. In cases where the texture and mineralogy appeared to be more highly affected by metamorphism, the rock was classified as “metamorphic”.

Similarly, quartzite and sandstone included several distinct varieties, and could be subdivided further on the basis of detailed mineralogical analysis.

Petrographic quality

In accordance with methods in use in the aggregate engineering industry, the sample was classified on the basis of the PN method. Using standard petrographic quality multipliers for the various quality classifications of each rock type, a PN of 121 was calculated for the sample, equivalent to a “Good” rating.

The accompanying table provides a detailed listing of rock types that were classified as “Good”, “Fair”, or “Poor”.

(Continued)

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Figure A2.1 (Concluded)

Alkali-aggregate reactivity

Many of the rock types in this sample have a potential for reaction with the alkali compounds in portland cement. If the aggregate has not been previously evaluated for alkali-aggregate reaction (AAR) in accordance with test methods and criteria given in CSA A23.1, it is recommended that such assessment be carried out. It is noted that CSA A23.1 recommends that this type of assessment be done at least annually.

The aggregate deposit occurs in an area that has been identified as containing alkali-reactive aggregates, based on testing of other aggregate sources. In these tests, some aggregates gave expansion results that were more than three times the CSA recommended expansion limit.

Additionally, several concrete structures located within this area have been identified as being affected by AAR.

On the basis of both AAR testing of aggregates and AAR characterization of aged concrete, the rock types implicated as being associated with AAR include chert, volcanic rocks, metamorphic rocks (including quartzite), and sandstone.

Summary

The 5 mm to 14 mm coarse aggregate is composed of a variety of igneous, metamorphic, and sedimentary rocks, and its PN of 121 is judged to be “Good” in its physical-mechanical quality for concrete production.

Concerning chemical stability, the aggregate is indicated to be potentially alkali-reactive, and it is, therefore, strongly recommended that the AAR potential of the aggregate be assessed.

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Figure A2.2
Petrographic examination of coarse aggregate — Example table showing proportions of rock types
(See Clause 6.2.1.5.)

Detailed petrographic examination of coarse aggregate

Source name: — **Sieve fraction: 5 mm–14 mm**

Sample number: — **Date sampled: —**

Petrographer: — **Date tested: —**

Detailed petrographic examination of coarse aggregate

Petrographic description and quality	Per cent by mass	Petrographic number contribution
Good (PN Multiplier: 1)		
Basalt — Andesite	21.7	21.7
Rhyolite — Dacite	9.5	9.5
Granite — Diorite	13.1	13.1
Metamorphic (undifferentiated)	18.9	18.9
Quartzite	11.9	11.9
Sandstone	3.0	3.0
Limestone	1.8	1.8
Chert	9.2	9.2
Quartz	0.7	0.7
Subtotal	89.8	89.8
Fair (PN Multiplier: 3)		
Volcanic (undifferentiated)	2.3	6.9
Granite — Diorite	1.5	4.5
Metamorphic (undifferentiated)	3.1	9.3
Quartzite	2.3	6.9
Sandstone	0.7	2.1
Subtotal	9.9	29.7
Poor (PN Multiplier: 6)		
Volcanic (undifferentiated)	0.3	1.8
Total	100.0%	121.3

Notes:

1) *The PN is not related to the potential for alkali-aggregate reactivity (AAR) of this aggregate when used in portland cement concrete. AAR potential must be separately assessed.*

2) *Rock types indicated by * may have potential for alkali-aggregate reaction (AAR). See CSA A23.1 and CSA A23.2 for information on the assessment of AAR in new concrete construction.*

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Figure A2.3
Petrographic examination of fine aggregate — Sample table showing proportions of rock and mineral types
(See Clause 6.2.2.4.)

Rock/mineral type	Total per sieve fraction					Weighted content (%)
	5.00–2.50 mm (14.2%)	2.50–1.25 mm (19.4%)	1.25–0.630 mm (21.8%)	0.630–0.315 mm (22.6%)	0.315–0.160 mm (22.0%)	
Volcanic (undifferentiated)	8.7	2.3	3.1	3.1	—	3.0
Granite	60.5	58.6	49.5	2.3	—	31.2
Diorite-gabbro	24.3	17.1	10.0	—	—	8.9
Quartzite	0.5	—	—	—	—	0.1
Metamorphic (undifferentiated)	4.9	4.5	1.8	1.8	—	2.4
Quartz	—	8.6	15.0	65.2	70.1	35.0
Hornblende	—	—0	0.5	6.9	4.8	2.8
Feldspar	—	7.6	18.4	15.5	19.2	13.2
Mica	—	0.4	0.3	3.4	4.8	2.1
Weathered particles	—	—	0.3	0.8	1.1	0.5
Friable particles	1.1	0.9	1.1	1.0	—	0.8
Totals	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

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Figure A2.4
Rapid petrographic examination of coarse aggregate — Example of particle count table
(See Clauses 6.3.3 and 6.3.4.)

Detailed petrographic examination of coarse aggregate

Source name: — **Sieve fraction: 5 mm–14 mm**

Sample number: — **Date sampled: —**

Petrographer: — **Date tested: —**

Rock type	Number of particles	Per cent of sample	Petrographic multiplier	Petrographic factor	Classification
Granite	90	30	1.0	30	Good
Gabbro	60	20	1.0	20	Good
Sandstone	30	10	2.0	20	Fair
Gneiss	87	29	1.0	29	Good
Schist	15	5	3.0	15	Poor
Limestone	18	6	1.0	6	Good
Total	300	100	—	120	Good

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Attachment A3 (informative)
Interpretation of petrographic number

Note: *This Attachment is not a mandatory part of this Test Method.*

A3.1

Table A3.1 provides an example of PN limits for coarse aggregates used in various applications.

Individual specifiers and agencies may choose to develop PN limits that reflect local or regional experience and that can be correlated with performance and service records within regions.

It is not appropriate to reject a coarse aggregate for use based solely on its PN value. Such decisions should only be made after review of other physical test data obtained in the context of a comprehensive test program or based on field performance history.

It should be noted that the PN provides an indication of a coarse aggregate's projected physical-mechanical qualities; chemical characteristics are to be considered separately from the PN. In some cases, materials proposed for use as aggregate might be suitable for some applications, but might be unsuited for other uses due to chemical regimes that are specific to those uses.

Table A3.1
Suggested PN limits for aggregate quality classifications
(See Clause A3.1.)

Product type	PN limits, max
Concrete class C1, C2, F1, C-XL A-XL, A-1, A-2	125
Other concrete classes	140
Shotcrete	125
Railroad ballast	125
Granular base	150
Select granular sub base	160

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Attachment A4 (informative)
Bibliography

Note: *This Attachment is not a mandatory part of this Test Method.*

CSA Group

A23.2-15A-86
Petrographic examination of aggregates for concrete, Supplement No. 2-1986 to CAN3-A23.1-M77/ CAN3-A23.2-M77 (withdrawn)

Alberta Transportation and Utilities

TLT-107/94
Determination of Detrimental Matter Content in Coarse Aggregate, Abbreviated Petrographic Analysis

ASTM International

C294-12(2017)
Descriptive Nomenclature of Constituents of Natural and Mineral Aggregates

C295/C295M-18
Standard Guide for Petrographic Examination of Aggregates for Concrete

C702/C702M-18
Standard Practice for Reducing Field Samples of Aggregates to Testing Size

STP 169D-06
Significance of Tests and Properties of Concrete and Concrete-Making Materials

STP 1061-90
Petrography Applied to Concrete and Concrete Aggregates

British Columbia Ministry of Highways

BCH I-17-1995
Petrographic Analysis, Specifications for Highway Construction, Test Methods for Aggregates

BNQ (Bureau de normalisation du Québec)

2560 – 900-1974
Granulats — Détermination du nombre pétrographique

Ministry of Transportation of Ontario

LS-609
Procedure for the Petrographic Analysis of Coarse Aggregate, MTO Laboratory Testing Manual

LS-616
Procedure for the Petrographic Examination of Fine Aggregate, MTO Laboratory Testing Manual

Nova Scotia Department of Transportation and Infrastructure Renewal

TM-2
Test Method for the Petrographic Analysis of Coarse Aggregate

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Other publications

Bragg, D.J. 1995. Petrographic Examination of Construction Aggregates of Newfoundland. *Newfoundland Department of Natural Resources, Geological Survey*, Current Research, Report 95-1, pp.77–104.

Dolar-Mantuani, L. 1983. *Handbook of Concrete Aggregates:A Petrographic and Technological Evaluation.* Park Ridge NJ: Noyes Publications.

RILEM. 2001. *Petrographic Method, AAR 1, Final Draft*. RILEM/TC-ARP/01/ 03.

Rogers, C.A. 1990. Petrographic Examination of Aggregate and Concrete in Ontario. *Petrography Applied to Concrete and Concrete Aggregates* (ASTM STP 1061): 5–31.

Soles, J.A. 1982. Thermally Destructive Particles in Sound Dolostone Aggregate from an Ontario Quarry. *Cement, Concrete and Aggregates*, Vol. 4, No. 2: 99-102.

Wong, S. G. 2006. Petrographic Evaluation of Concrete Aggregates. In: *Significance of Tests and Properties of Concrete and Concrete-Making Materials* (ASTM STP 169D): 377–400.

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A23.2-16A
Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine

1 Scope

This Test Method specifies the procedure for testing sizes of coarse aggregate smaller than 40 mm for resistance to degradation using the Los Angeles testing machine.

Note: *A procedure for testing coarse aggregate larger than 40 mm is covered in CSA A23.2-17A.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-17A:19
Resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine

ASTM International

C131/C131M-14
Standard Test Method for Resistance to Degradation of Small-Size Aggregate by Abrasion and Impact in the Los Angeles Machine

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

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4 Summary

The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions, including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres, the number depending upon the grading of the test sample. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss.

5 Significance and use

The Los Angeles test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions. The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Specification limits based on this Test Method should be assigned with extreme care in consideration of available aggregate types and their performance history in specific end uses.

6 Apparatus

6.1 Los Angeles machine

6.1.1

A Los Angeles testing machine, which conforms in all its essential characteristics to the design shown in Figure 1, shall be used. The machine shall consist of a hollow steel cylinder, closed at both ends, with an inside diameter of 711 ± 5 mm and an inside length of 508 ± 5 mm. The cylinder shall be mounted on stub shafts attached to the ends of the cylinder, but not entering it, and shall be mounted so that it can be rotated with the axis in a horizontal position within a tolerance in slope of 1 in 100. An opening in the cylinder shall be provided for the introduction of the test sample. A suitable, dust-tight cover shall be provided for the opening with means for bolting the cover in place. The cover shall be so designed as to maintain the cylindrical contour of the interior surface, unless the shelf is so located that the charge will not fall on the cover or come in contact with it during the test. A removable steel shelf extending the full length of the cylinder and projecting inward 89 ± 2 mm shall be mounted on the interior cylindrical surface of the cylinder in such a way that a plane centred between the large faces coincides with an axial plane. The shelf shall be of such thickness and so mounted, by bolts or other suitable means, as to be firm and rigid. The position of the shelf shall be such that the distance from the shelf to the opening, measured along the outside circumference of the cylinder in the direction of rotation, shall be not less than 1.27 m.

Notes:

1) *The position of the shelf shown in Figure 1 is such that during operation, steel balls might fall on or near the opening cover. This can result in damage to and distortion of the cover, leading to loss of aggregate. In such a case, the position of the shelf may be varied from that shown in the drawing and specified in this Clause.*
2) *The use of a shelf of wear-resistant steel, rectangular in cross-section and mounted independently of the cover, is preferred. However, a shelf consisting of a section of rolled angle, properly mounted on the inside of the cover plate, may be used provided that the direction of rotation is such that the charge will be caught on the outside face of the angle. If the shelf becomes distorted from its original shape to such an extent that the requirements given in Attachment A1 are not met, the shelf is either to be repaired or replaced before additional tests are made.*
3) *For maintenance of the shelf of the Los Angeles machine, see Attachment A1.*

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6.1.2

The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed.

Note: *Backlash or slip in the driving mechanism is very likely to furnish test results that are not duplicated by other Los Angeles machines producing constant peripheral speed.*

6.2 Sieves

Sieves shall conform to the requirements of ISO 3310-1 made with the preferred wire diameter.

6.3 Balance

Balance or scale shall be accurate to within 0.1% of test load over the range required for this test.

6.4 Charge

6.4.1 Steel spheres

Steel spheres averaging approximately 47 mm in diameter and each having a mass of 390 to 445 g shall be used.

6.4.2 Required charge

Depending upon the grading of the test sample, as described in Clause 8.2, the number of steel spheres listed in Table 1 shall be used.

Table 1
Required charge
(See Clause 6.4.2.)

Grading	Number of spheres	Mass of charge, g
A	12	5000 ± 25
B	11	4584 ± 25
C	9	3750 ± 25
D	8	3330 ± 20
E	6	2500 ± 15

Note: *Steel ball bearings 46.0 mm and 47.6 mm in diameter, with masses of approximately 400 g and 440 g respectively, are readily available. Steel spheres 46.8 mm in diameter with a mass of approximately 420 g can also be obtained. The charge may consist of a mixture of these sizes conforming to the tolerances on mass in Clauses 6.4.1 and 6.4.2.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Test sample

8.1 Sampling

The field sample shall be obtained and reduced in accordance with CSA A23.2-1A.

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8.2 Sample

The sample and shall be washed and oven-dried to constant mass at 110 ± 5 °C. The sample shall be separated into individual size fractions and recombined to the grading specified in Table 2 that most nearly corresponds to the range of sizes in the aggregate as furnished for the work. The mass of the sample shall be recorded prior to test to the nearest 1 g.

Table 2
Gradings of test samples
(See Clauses 8.2 and 11.1.)

Sieve size (square openings)		Mass of indicated sizes, g				
		Grading				
Passing, mm	Retained on, mm	A	B	C	D	E
40	28	1250 ± 25	—	—	—	—
28	20	1250 ± 25	—	—	—	—
20	14	1250 ± 10	2500 ± 10	—	—	—
14	10	1250 ± 10	2500 ± 10	2500 ± 10	—	—
10	5	—	—	2500 ± 10	5000 ± 10	—
5	2.5	—	—	—	—	5000 ± 10
Total		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

9 Procedure

The test sample and the charge shall be placed in the Los Angeles testing machine. The machine shall rotate at a speed of 30 revolutions/minute to 33 revolutions/minute for 500 revolutions. After the prescribed number of revolutions, the material shall be discharged from the machine and a preliminary separation of the sample shall be made on a sieve coarser than the 1.8 mm size. The finer portion of the sample shall be sieved on a 1.8 mm sieve in a manner conforming to Clause 9 of CSA A23.2-2A. The material coarser than the 1.8 mm sieve shall be washed and then oven-dried at 110 ± 5 °C to constant mass, determined to the nearest 1 g.

Notes:

1) *If the aggregate is essentially free of adherent coatings and dust, the requirement for washing before and after the test may be waived. Elimination of washing after test will seldom reduce the measured loss by more than about 0.2% of the original sample mass.*
2) *Valuable information concerning the uniformity of the sample under test may be obtained by determining the loss after 100 revolutions. This loss should be determined without washing the material that is coarser than the 1.8 mm sieve. The ratio of the loss after 100 revolutions to the loss after 500 revolutions should not greatly exceed 0.20 for material of uniform hardness. When this determination is made, care should be taken to avoid losing any part of the sample; the entire sample, including the dust of fracture, should be returned to the testing machine for the final 400 revolutions required to complete the test.*

10 Calculation

The loss (i.e., the difference between the original mass and the final mass of the test sample) shall be expressed as a percentage of the original mass of the test sample. This value shall be reported as the percent loss.

Note: *The percent loss determined by this Test Method has no known consistent relationship to the percent loss for the same material when tested in accordance with CSA A23.2-17A.*

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11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification marks;
b) nominal maximum aggregate size;
c) test grading designation from Table 2;
d) loss in mass by abrasion and impact of the sample expressed to the nearest 1.0% by mass of sample;
e) date tested;
f) name of the certified technician who performed the test;
g) identification of the certified laboratory (i.e., name and address) that performed the test;
h) name and signature of the person responsible for the review of the test report; and
i) any deviation from the test procedure.

11.2 Optional information

The following information may be included in the test report:

a) name of the person or organization who sampled the aggregate;
b) date the sample was taken or received by the testing laboratory; and
c) sample source or sample location, or both.

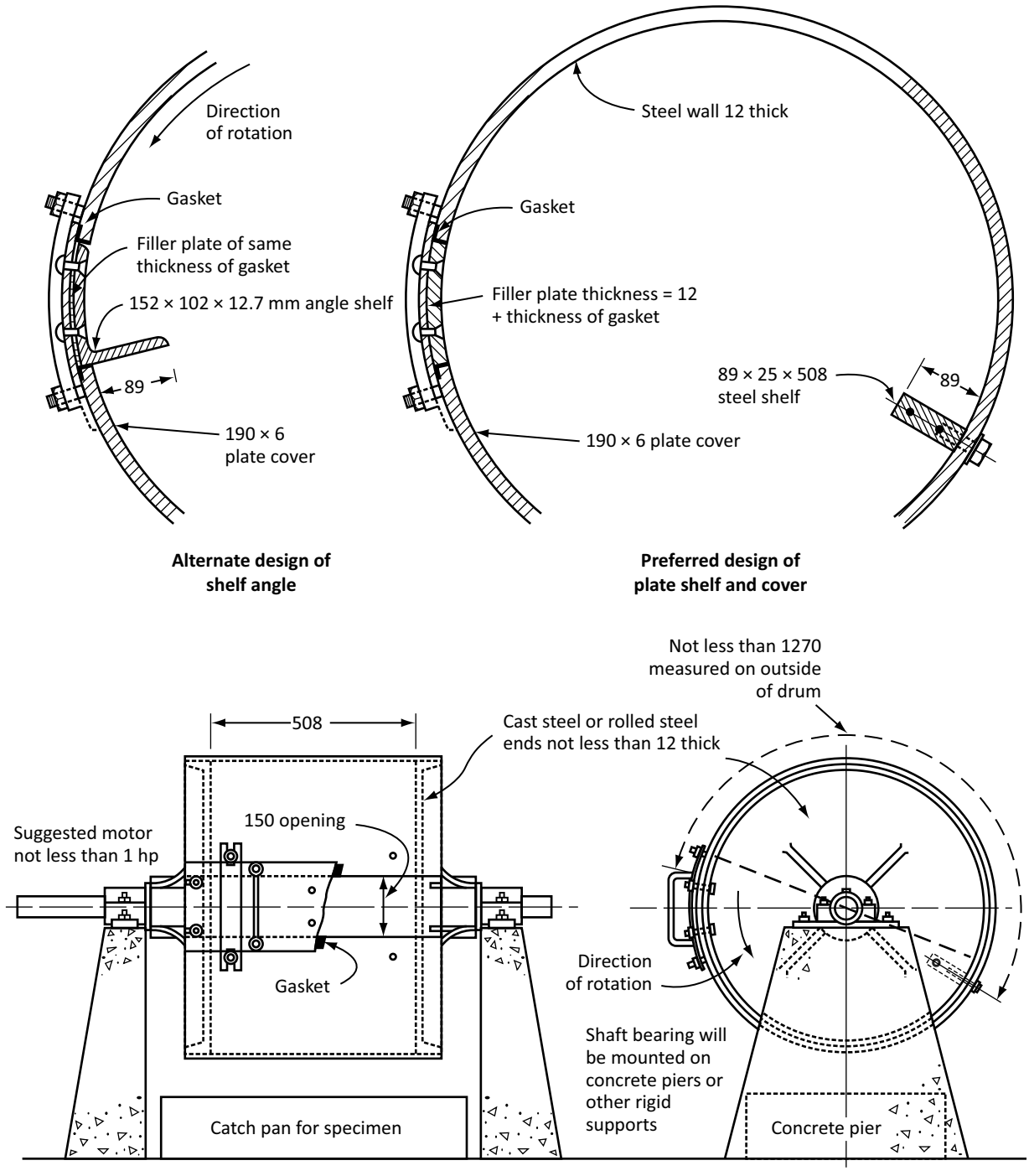
12 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C131/C131M.

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Figure 1
Los Angeles testing machine
(See Clause 6.1.1.)



Note: *Dimensions are in millimetres.*

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Attachment A1 (informative)
Maintenance of shelf

Note: *This Attachment is not a mandatory part of this Test Method.*

A1.1

The shelf of the Los Angeles machine is subject to severe surface wear and impact. With use, the working surface of the shelf is peened by the balls and tends to develop a ridge of metal parallel to and about 32 mm from the junction of the shelf and the inner surface of the cylinder. If the shelf is made from a section of rolled angle, not only might this ridge develop but the shelf itself might be bent longitudinally or transversely from its proper position.

A1.2

The shelf should be inspected periodically to determine that it is not bent either lengthwise or from its normal radial position with respect to the cylinder. If either condition is found, the shelf should be repaired or replaced before further tests are made. The influence on the test result of the ridge developed by peening of the working face of the shelf is not known. However, for uniform test conditions, the ridge should be ground off if its height exceeds 2 mm.

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A23.2-17A
Resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine

1 Scope

This Test Method specifies the procedures for testing sizes of coarse aggregate larger than 40 mm for resistance to degradation using the Los Angeles testing machine.

Note: *A procedure for testing coarse aggregate smaller than 40 mm is covered in CSA A23.2-16A.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-16A:19
Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine

ASTM International

C535-16
Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

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4 Summary

The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions, including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres, the number depending upon the grading of the test sample. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss.

5 Significance and use

The Los Angeles test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions. The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Specification limits based on this Test Method should be assigned with extreme care in consideration of available aggregate types and their performance history in specific end uses.

6 Apparatus

6.1 Los Angeles machine

6.1.1

A Los Angeles machine conforming to the requirements of CSA A23.2-16A shall be used.

6.1.2

The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed.

Note: *Backlash or slip in the driving mechanism is very likely to furnish test results that are not duplicated by other Los Angeles machines producing constant peripheral speed.*

6.2 Sieves

Sieves shall conform to the requirements of ISO 3310-1 made with the preferred wire diameter.

6.3 Balance

A balance or scale accurate to within 0.1% of test load over the range required for this test shall be used.

6.4 Charge

A charge consisting of 12 steel spheres averaging approximately 47 mm in diameter, each with a mass of from 390 to 445 g and having a total mass of 5000 ± 25 g shall be used.

Note: *Steel ball bearings 46.0 mm and 47.6 mm in diameter, with masses of approximately 400 g and 440 g, respectively, are readily available. Steel spheres 46.8 mm in diameter with a mass of approximately 420 g can also be obtained. The charge may consist of a mixture of these sizes.*

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7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Test sample

8.1 Sampling

The sample shall be obtained and reduced in accordance with CSA A23.2-1A.

8.2 Sample

The test sample shall be washed and then oven-dried to constant mass at 110 ± 5 °C. The sample shall be separated into individual size fractions and recombined to the grading specified in Table 1 that most nearly corresponds to the range of sizes in the aggregate as furnished for the work. The mass of the sample shall be recorded prior to test to the nearest 1 g.

Note: *If the aggregate is essentially free of adherent coatings and dust, the requirement for washing before and after the test may be waived. Elimination of washing after the test will seldom reduce the measured loss by more than about 0.2% of the original sample mass.*

Table 1
Gradings of test samples
(See Clauses 8.2 and 11.1.)

		Mass of indicated sizes, g		
Sieve size, mm (square openings)		Grading		
Passing	Retained on	1	2	3
80	63	2500 ± 50	—	—
63	50	2500 ± 50	—	—
50	40	5000 ± 50	5000 ± 50	—
40	28	—	5000 ± 25	5000 ± 25
28	20	—	—	5000 ± 25
Total		10 000 ±150	10 000 ± 75	10 000 ± 50

9 Procedure

The test sample and charge shall be placed in the Los Angeles testing machine. The machine shall rotate at 30 revolutions/minute to 33 revolutions/minute for 1000 revolutions. After the prescribed number of revolutions, the material shall be discharged from the machine. A preliminary separation of the sample shall be made on a sieve coarser than the 1.8 mm sieve. The finer portion of the sample shall be sieved on a 1.8 mm sieve in a manner conforming to Clause 9 of CSA A23.2-2A. Material coarser than the 1.8 mm sieve shall be washed and then oven-dried to a constant mass at 110 ± 5 °C, determined to the nearest 1 g.

Note: *Valuable information concerning the uniformity of the sample under test may be obtained by determining the loss after 200 revolutions. This loss should be determined without washing the material coarser than the 1.8 mm sieve. The ratio of the loss after 200 revolutions to the loss after 1000 revolutions should not greatly exceed 0.20 for material of uniform hardness. When this determination is made, care should be taken to avoid losing any*

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part of the sample; the entire sample, including the dust of fracture, should be returned to the testing machine for the final 800 revolutions required to complete the test.

10 Calculation

The loss (i.e., the difference between the original mass and the final mass of the test sample) shall be expressed as a percentage of the original mass of the test sample. This value shall be reported to the nearest whole number as the percent loss.

Note: *The percent loss determined by this Test Method has no known consistent relationship to the percent loss for the same material when tested in accordance with CSA A23.2-16A.*

11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification marks;
b) date tested;
c) nominal maximum aggregate size;
d) test grading designation from Table 1;
e) loss in mass by abrasion and impact of the sample expressed to the nearest 1.0 % by mass of sample;
f) name of the certified technician who performed the test;
g) identification of the certified laboratory that performed the test (i.e., name and address);
h) name and signature of the person responsible for the review of the test report; and
i) any deviations from the test procedure.

11.2 Optional information

The following information may be included in the test report:

a) name of the person or organization who sampled the aggregate;
b) date the sample was taken and/or received by the test laboratory; and
c) sample source or sample location or both.

12 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C535.

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A23.2-23A
Test method for the resistance of fine aggregate to degradation by abrasion in the Micro-Deval apparatus

1 Scope

This Test Method specifies the procedure for testing fine aggregate for resistance to abrasion using the Micro-Deval apparatus. It furnishes information helpful in judging the suitability of fine aggregate subject to weathering and abrasive action when adequate information is not available from service records.

Note: *For further information, see Roger et al. (1991).*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-5A:19
Amount of material finer than 80 µm in aggregate

A23.2-29A:19
Test method for the resistance of coarse aggregate to degradation by abrasion in the Micro-Deval apparatus

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

ASTM International

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

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Other publication

Rogers, C.A., Bailey, M., and Price, B. 1991. *Micro-Deval Test for Evaluating the Quality of Fine Aggregate for Concrete and Asphalt.* Transportation Research Board Record 1301, 68–76. Washington, DC.

3 Definition

In addition to the definitions in CSA A23.1, the following definition applies in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Summary

The Micro-Deval abrasion test is a measure of abrasion resistance and durability of mineral aggregates resulting from a combination of actions, including abrasion and grinding with steel balls in the presence of water. A sample with standard grading is initially soaked in water for not less than 1 h. The sample is then placed in a jar mill with 750 mL of water and an abrasive charge consisting of 1250 g of 9.5 mm diameter steel balls. The jar, aggregate, water, and charge are revolved at 100 r/min for 15 min. The sample is then washed and oven-dried. The loss is the amount of material passing the 80 µm sieve expressed as a percentage by mass of the original sample.

5 Significance and use

5.1

The Micro-Deval abrasion test is a test of fine aggregates to determine their abrasion loss in the presence of water and an abrasive charge. Many aggregates are weaker or more susceptible to abrasion when wet than when dry and the use of water in this test measures this reduction in resistance to degradation, in contrast to other tests conducted on dry aggregate. When adequate information is not available from service records, this test furnishes information helpful in judging the toughness, abrasion resistance, durability, and soundness of fine aggregate subject to abrasion and weathering action. It is capable of detecting aggregates that can degrade during handling and mixing.

5.2

The Micro-Deval abrasion test is a useful test for detecting changes in properties of aggregate produced from a source as part of a quality control or quality assurance process.

5.3

The Micro-Deval abrasion test on fine aggregate, in contrast to the version on coarse aggregate, has a significant correlation with the magnesium sulphate soundness loss of fine aggregate. The Micro-Deval test on fine aggregate has better precision than the sulphate soundness test, is quicker, and may be used in place of that test.

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6 Apparatus and supplies

6.1 Rolling mill

A jar rolling mill shall be used that shall be capable of rotating Micro-Deval abrasion jars at 100 ± 5 r/min. It shall be of the general configuration shown in Figure 1.

6.2 Abrasion jars

Stainless steel Micro-Deval abrasion jars shall be used. These jars shall have a 5 L capacity and shall be fitted with a watertight rubber gasket in the rotary locking cover. The jars shall have an external diameter of 194 to 202 mm and an internal height of 170 mm to 178 mm (see Note to Clause 6.3). The inside and outside surfaces of the jars shall be smooth and have no observable ridges or indentations.

6.3 Steel balls

Magnetic stainless steel balls shall be used. These balls shall have a diameter of 9.5 ± 0.5 mm. Each jar shall have a charge of 1250 ± 5 g of balls.

Note: *Prior to use, new containers and new steel balls should be conditioned. Conditioning is accomplished by running the equipment with a charge of 500 g silica sand with 750 mL of water for a period of 4 h. At the end of the 4 h period, this procedure should be repeated with a new sand sample. From time to time, it might be necessary to recondition the containers and steel balls. The need for reconditioning will be indicated by significant change in loss with the control calibration material. It has been found that reconditioning is usually needed when the equipment has been used for testing carbonate coarse aggregate in CSA A23.2-29A, which can lead to polishing of the container and ball surfaces.*

6.4 Sieves

Square hole, 200 mm diameter, woven wire cloth sieves, which conform to ISO 3310-1 made with the preferred wire diameter shall be used, and shall be of the following sizes: 5 mm, 2.5 mm, 1.25 mm, 630 µm, 315 µm, 160 µm, and 80 µm. An 80 µm sieve that is 300 mm diameter or larger shall be used for washing the aggregate.

Note: *A 6 mm or larger sieve that is 300 mm diameter or larger can be used for separating the steel balls from the aggregate at the conclusion of the test.*

6.5 Oven

An oven capable of maintaining a temperature of 110 ± 5 °C shall be used.

6.6 Balance

A balance or scale with a capacity of 1 kg, accurate to 0.1 g shall be used.

6.7 Reference material

6.7.1

A supply of the reference standard Sutherland Micro-Deval fine aggregate shall be prepared as shown in Table 1 (see Clause 11).

Note: *This is available from the Soils and Aggregates Section, Materials Engineering and Research Office, Ontario Ministry of Transportation (Soils-Aggregates@ontario.ca).*

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Table 1
Gradation
(See Clause 6.7.)

Sieve fraction	Mass, g
5–2.5 mm	40
2.5–1.25 mm	115
1.25 mm–630 µm	180
630–315 µm	120
315–160 µm	38
160–80 µm	7

6.7.2
The mean loss of the laboratory reference aggregate (see Clause 11.2) in multi-laboratory study of the Micro-Deval test is 16.8%. For continued acceptance of data, individual test data shall fall within the range 15.2% to 18.4% loss, 95% of the time.

6.8 Calibration material
An adequate supply of calibration aggregate, established by the laboratory, shall be used for calibration of this Test Method (see Clause 11).

7 Hazards
This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Samples

8.1
A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

8.2
Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

8.3
In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 10 of CSA A23.1, the material shall be separated into two sizes on the 5 mm sieve. Aggregate for the test shall consist of material passing the 5 mm sieve. A representative sample of at least 725 ± 25 g shall be obtained by use of a sample splitter or by a suitable method of quartering and be placed in a sealed container.

Note: *See Clause 6.2 of CSA A23.2-30A.*

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9 Procedure

9.1

The sample shall be washed over an 80 µm sieve until the wash water is clear, in accordance with CSA A23.2-5A.

9.2

The sample shall be oven-dried to constant mass at a temperature of 110 ± 5 °C.

9.3

A representative 500 ± 5 g sample shall be prepared from the washed sample (see Note). The mass A shall be recorded to the nearest 0.1 g.

Note: *In cases of dispute, the sample should be sieved into separate sizes and each size fraction thoroughly washed and dried to constant mass. The sample should be prepared to a fineness modulus (FM) of 2.8 using the gradation shown in Table 2.*

Table 2
Gradation
(See Clause 9.3.)

Sieve fraction	Mass, g
5–2.5 mm	50
2.5–1.25 mm	125
1.25 mm–630 µm	125
630–315 µm	100
315–160 µm	75
160–80 µm	25

9.4

The sample shall be saturated in tap water at a temperature of 20 ± 5 °C for 24 ± 4 h.

9.5

Any excess water shall be poured off and the sample shall be placed in the Micro-Deval abrasion container with 1250 ± 5 g of steel balls and 750 mL of tap water at room temperature. The Micro-Deval jar shall be placed on the machine. The machine shall run so that the jar rotates at 100 ± 5 r/min for 15 min ± 10 s.

9.6

The balls shall be removed from the sample by passing the sample and water through a 300 mm or larger diameter, 6.7 mm sieve. The aggregate shall be washed over the 300 mm or larger diameter, 80 µm sieve, in accordance with CSA A23.2-5A, until the wash water is clear, being careful not to lose any retained 80 µm sieve material.

9.7

The sample shall be oven-dried to a constant mass at a temperature of 110 ± 5 °C.

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9.8
The mass of the sample shall be determined to the nearest 0.1 g and recorded as mass B.

10 Calculation
Using the values for A and B (see Clauses 9.3 and 9.8), the Micro-Deval abrasion loss shall be calculated as follows to the nearest 0.1%:

$$\text{Loss, \%} = \frac{A - B}{A} = 100$$

11 Use of reference and calibration materials

11.1
See Attachment A for guidance concerning reference aggregates for the calibration of this Test Method.

11.2
When test data of the calibration aggregate is outside the limits, an investigation as to the probable cause shall be conducted. The equipment shall be re-calibrated and the testing technique re-examined to detect non-conformance with the test procedure.

11.3
For every 10 samples, but at least every week in which a sample is tested, a sample of the calibration aggregate shall also be tested. The material shall be taken from a stock supply and prepared in accordance with Clause 6.7. When 20 samples of calibration material have been tested and the results show satisfactory variation, the frequency of testing may be changed to a minimum of one sample every month.

11.4
The percentage loss of the last 20 samples of calibration material shall be plotted on a trend chart in order to monitor the variation of results (see Figure 2).

12 Reporting

12.1 Required information
The following information shall be included in the test report, as applicable:

a) sample number or identification;
b) any relevant information concerning the preparation of the aggregate;
c) percentage loss of the test sample to one decimal place;
d) percentage loss of the control aggregate, tested closest to the time at which the aggregate sample was tested, to one decimal place;
e) percentage loss of the previous 20 samples of calibration aggregate shown on a control chart (see Figure 2);
f) name of the certified technician who performed the test;
g) identification of the certified laboratory that performed the test (i.e., name and address);
h) signature of the person responsible for the laboratory performing the test; and
i) any deviations from the test procedure.

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12.2 Optional Information

The following information may be included in the test report:

a) name of the person or organization who sampled the aggregate;
b) date the sample was taken and/or received by the test laboratory;
c) type of aggregate; and
d) sample source or sample location or both.

13 Precision and bias

13.1 Precision

For fine aggregate with abrasion losses in the range from 7% to 30%, the single-operator coefficient of variation has been found to be 3.4%*. Therefore, results of two properly conducted tests on samples of the same aggregate by the same operator using the same equipment are not expected to differ by more than 9.6%* of their average, 95% of the time. The multi-laboratory coefficient of variation has been found to be 8.7%*. Therefore, the results of two properly conducted tests by different laboratories on samples of the same aggregate are not expected to differ by more than 24.6%* of their average, 95% of the time.

* *These numbers represent, respectively, the (1s %) and (d2s %) limits as described in ASTM C670.*

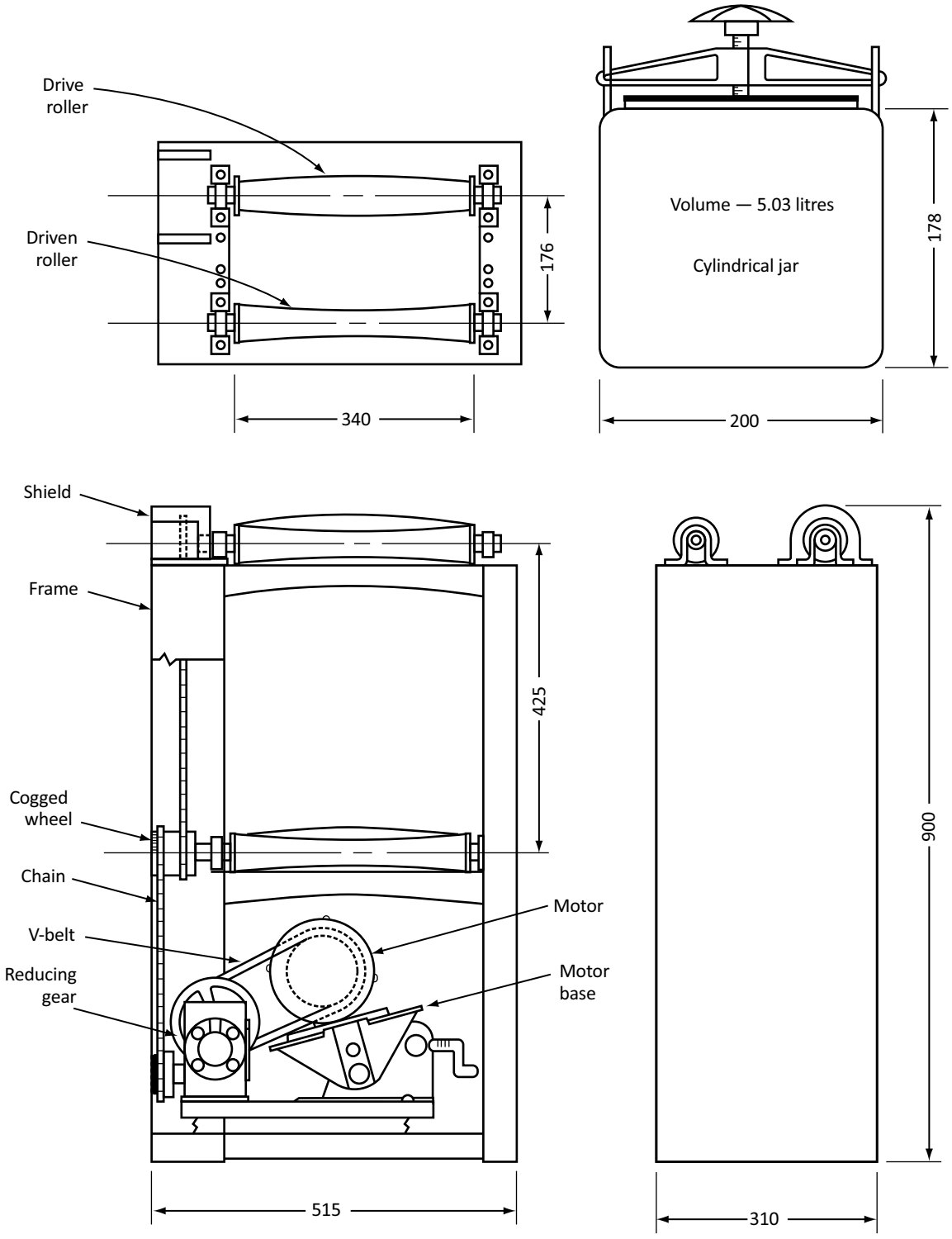
13.2 Bias

The procedure in this Test Method for measuring resistance to abrasion has no bias because the resistance to abrasion can only be defined in terms of the Test Method.

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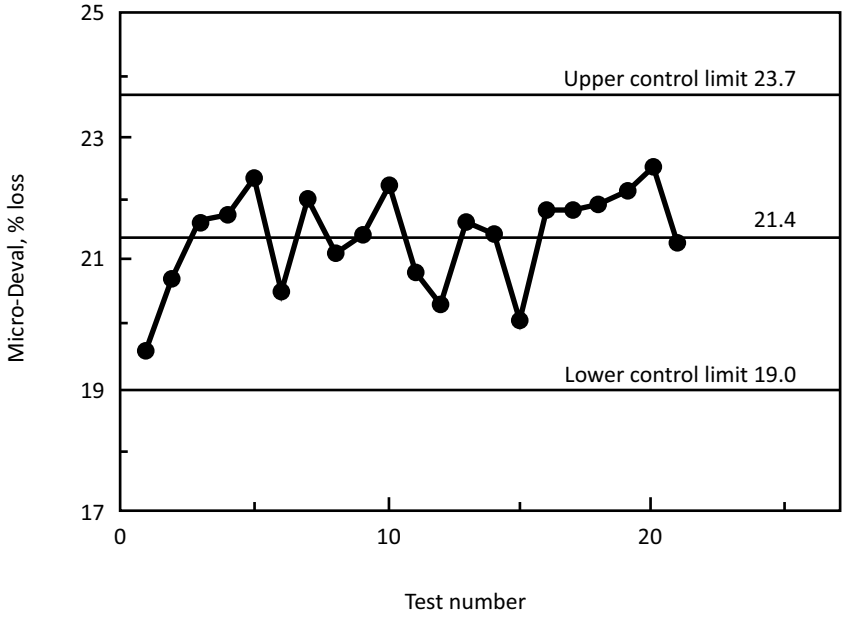
Figure 1
Micro-Deval abrasion machine and jar
(See Clause 6.1.)



Note: *Dimensions are in millimetres.*

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Figure 2
Example of a control chart showing average Micro-Deval loss and variation in results of a laboratory calibration aggregate
(See Clause 11.4 and 12.1.)



23A

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Attachment A1 (informative)
Material for calibration of Test Method

Note: *This Attachment is not a mandatory part of this Test Method.*

The laboratory should establish an adequate supply of material to use for calibration of this Test Method, having a loss of between 10 and 25%. From this material, 10 samples should be taken randomly and tested. At the same time 10 samples of the reference aggregate (see Clause 6.7) should also be tested. Provided that the mean loss and variation of the reference Micro-Deval fine aggregate is within the allowed tolerance given in Clause 6.7.1, the mean value and range obtained with the supply of the in house calibration aggregate should be used thereafter. At any time a new supply is required, the calibration procedure should be conducted.

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A23.2-24A
Test method for the resistance of unconfined coarse aggregate to freezing and thawing

1 Scope

This Test Method specifies the procedure for testing coarse aggregates to determine their resistance to disintegration by repeated freezing and thawing in a sodium chloride solution.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

ASTM International

E1-14
Standard Specification for ASTM Liquid-in-Glass Thermometers

E220-13
Standard Test Method for Calibration of Thermocouples by Comparison Techniques

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

Other publication

Rogers, C.A. Senior, S.A., and Boothe, D. 1989. *Development of an Unconfined Freeze-thaw Test for Coarse Aggregates*. Ontario Ministry of Transportation Engineering Materials Report EM-87.

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% after 2 h of drying.

Note: *Such a condition of dryness may be verified by weighing the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the constant mass condition under equal or heavier loading conditions of the oven.*

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4 Summary

This Test Method subjects a prepared sample of saturated coarse aggregate of known gradation to five cycles of freezing and thawing. Each freeze thaw cycle is performed over a 24 h period. The percent loss is calculated from the gradation analysis performed on the aggregate sample at the completion of the five freeze thaw cycles.

5 Significance and use

This Test Method is used in making a preliminary determination of the soundness of coarse aggregates subject to freezing and thawing action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions.

Note: *For further information, see Rogers et al. (1989).*

6 Apparatus

The apparatus shall consist of the following:

a) Freezing equipment: a freezer (i.e., chest, standup/reach-in, or walk-in type) capable of maintaining a temperature of –18 ± 2.0 °C and providing adequate air circulation with a fan so that the maximum variation within 25 cm of the top and the bottom of the space does not exceed 2.0 °C. The temperature of the freezer shall be continually monitored at minimum two different points within the freezer chamber, either by thermometer or thermocouple. The bulb of the thermometer, if used, shall be protected with a metal sleeve to avoid sudden temperature changes when the freezer door or freezer lid is opened;

b) Sieves: sieves measuring 300 mm in diameter or larger with square openings, conforming to the requirements of ISO 3310-1 made with the preferred wire diameter, of the following sizes: 40 mm, 28 mm, 20 mm, 14 mm, 10 mm, and 5 mm;

c) Thermometers: mercury or alcohol thermometers conforming to the requirements of ASTM E1 with a range of –25 to +30 °C, marked in 1° increments readable to 0.5 °C. Alternatively, thermocouples calibrated in accordance with ASTM E220 may be acceptable;

d) Sample containers: autoclavable plastic containers with airtight screw-on caps that can withstand a continuous temperature of 110 °C:
   i) 1 L containers shall be used for fractions coarser than 10 mm; and
   ii) 500 mL containers shall be used for fractions passing 10 mm and retained on 5 mm;

   Note: *Autoclavable plastic mason jars are available from laboratory testing equipment suppliers.*

e) Sample baskets: plastic or metal mesh baskets or similarly perforated trays capable of holding four 500 mL containers or two 1 L containers and one 500 mL container. Suitable wooden or plastic spacers shall be placed between them to keep the containers from coming in contact with each other and the walls of the freezer;

   Note: *The baskets should be stackable, with sufficient clearance for the larger containers.*

f) Balance: a balance or scale accurate to within 0.1% of the sample mass or 1 g, whichever is greater, over the range required for the test; and

g) Oven: a mechanical convection oven capable of maintaining a temperature of 110 ± 5 °C.

7 Reagents and materials

7.1 Sodium chloride solution (3%)

Thirty grams of sodium chloride shall be dissolved in water and diluted to 1 L. The solution shall be

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thoroughly mixed while adding the water and until the salt is dissolved. Prior to using the solution, the solution shall be thoroughly stirred.

Notes:

1) *Domestic table salt may be used to prepare the solution.*
2) *Studies have shown that a concentration of 3% caused the most severe freeze-thaw damage. See Rogers et al. (1989).*

7.2 Laboratory reference aggregate

7.2.1

Standard Drain Brothers' Stoney Lake Quarry coarse aggregate shall be tested using the grading shown in Table 1.

Note: *A supply of standard Drain Brothers' Stoney Lake Quarry coarse aggregate is available from the Soils and Aggregates Section, Materials Engineering and Research Office, Ontario Ministry of Transportation (Soils-Aggregates@ontario.ca).*

Table 1
Grading of reference aggregate
(See Clause 7.2.1.)

Sieve fraction, mm	Retained, %
20–14	45
14–10	35
10–5	20

7.2.2

For continued acceptance of data, individual reference material test data shall fall within the range 8.5 to 15.3% loss, 95% of the time.

Note: *The mean loss of the Drain Brothers' Stoney Lake Quarry reference aggregate in multi-laboratory study of the freeze-thaw test is 11.9%.*

7.3 Calibration aggregate

The laboratory shall establish an adequate supply of material to use for calibration of this Test Method (see Clause 10.2).

8 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

9 Sample

9.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

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9.2
Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

9.3
Oven-dried coarse aggregate retained on the 5 mm sieve shall be used.

9.4
The sample shall be separated into fractions, using the sieve sizes indicated in Table 2, by sieving as specified in CSA A23.2-2A. The quantities of the different sizes present in the sample, as indicated in Table 2, shall be weighed. If any fraction constitutes less than 5% of the original sample, it shall not be tested but considered to have the same loss in the test as the average of the next smaller and the next larger size or, if one of these sizes is absent, as the next larger or the next smaller size, whichever is present.

Table 2
Minimum mass of test samples
(See Clause 9.4.)

Passing, mm	Retained, mm	Mass, g
40	28	5000
28	20	2500
20	14	1250
14	10	1000
10	5	500

10 Use of reference and calibration materials

10.1
The Laboratory shall establish an adequate supply of material to use for calibration of this Test Method. A suitable material with a loss of between 5 and 25 % shall be established. From this material ten samples shall be taken randomly and tested. At the same time ten samples of reference aggregate from Drain Brothers Stoney Lake Quarry (see Clause 7.2) shall also be tested. Provided the mean loss and variation of the Drain Brothers Stoney Lake Quarry aggregate is within the allowed tolerance of Clause 7.2.2, the mean value and range obtained with the supply of the in-house calibration aggregate shall be used thereafter. At any time a new supply of the in-house calibration aggregate is required, the calibration procedure shall be conducted.

10.2
When test data of the calibration aggregate is outside the limits, an investigation as to the probable cause shall be conducted. The equipment shall be re-calibrated and the testing technique re-examined to detect non-conformance with the test procedure.

10.3
Every ten samples, or at least every week in which a sample is tested, a sample of the calibration aggregate shall also be tested. The material shall be taken from a stock supply and prepared in accordance with Clause 9.4. When twenty samples of calibration material have been tested, and the

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results show satisfactory variation, the frequency of testing may be changed to a minimum of one sample every month.

10.4 Trend chart use

The percent loss of the last twenty samples of calibration material shall be plotted on a trend chart in order to monitor the variation in results (Figure 1).

11 Procedure

11.1

The procedure shall be as specified in Clauses 11.2 to 11.10.

11.2

Place each aggregate fraction in appropriate size containers. Place an aggregate coarser than 20 mm in two or more containers so that all of the required samples are tested.

11.3

Fill sample containers with the prepared 3% sodium chloride solution so as to completely immerse all aggregate particles. Seal the containers with lids to prevent evaporation and keep at room temperature for 24 ± 2 h.

11.4

Rapidly drain off the solution by inverting each container over a screen smaller than 5 mm mesh for about 5 s (do not remove the aggregate from the container).* Seal the containers to maintain a 100% humidity condition. Place the containers on their sides in baskets with spacers between the containers so as to prevent contact.

* *A screen of about 1 mm mesh may be cut to fit inside a modified container lid to facilitate draining and washing.*

11.5

Freeze the samples by placing the baskets in the freezer at –18 ± 2.0 °C for 16 ± 2 h. Remove the containers from the freezer and allow to thaw approximately 8 ± 1 h at room temperature. Rotate the jars one quarter turn after each thaw period and return to the freezer.

11.6

Subject the samples to five cycles of freezing and thawing. If for any reason the sequence of freezing and thawing is interrupted, keep the aggregates frozen inside the container until the cycle can be resumed.

11.7

Wash aggregates at the end of the fifth period of thawing by filling the container with tap water and invert the container over a sink using a lid fitted with a screen, as described in the Note to Clause 11.4, or by other suitable means. Repeat this washing five times without removing the aggregate from the container.

11.8

Remove the lid from the container and oven-dry the sample to constant mass at 110 ± 5 °C.

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11.9

Place each aggregate fraction on the same sieve used in the preparation of the sample and shake in the same sieve shaker for the appropriate time*. Perform sieving for each size separately.†

** The appropriate time is determined following the procedure given in Attachment A1. Sieving beyond this time can lead to excessive mechanical breakdown. Judgment should be exercised to ensure that further sieving does not induce additional breakdown.*

† The order of the sieves may be inverted before the samples are sieved (i.e., 5 mm sieve at the top and 14 mm sieve at the bottom of the nest). Any material that passes through the 5 mm sieve will naturally fall through the larger sieves below into the pan.

11.10

Weigh the fraction retained on each sieve following sieving and record the mass.

12 Calculation

12.1

The percentage of mass loss shall be calculated on each sieve to the nearest 0.1%.

12.2

The weighted average mass loss shall be calculated as follows:

Multiply the retained percentage of each fraction, based on the total mass of material retained on the 5 mm sieve, with the percentage loss for that fraction. The sum of these products, divided by 100, is the weighted average percentage freeze-thaw mass loss for the sample. An example is shown in Table 3.

Table 3
Example of calculation of weighted mass loss
(See Clause 12.2.)

Sieve sizes		Retained grading original sample %	Mass of test fraction before test, g	Passing after test % actual loss	Weighted average corrected % loss
Passing	Retained				
28	20	3.0	—	15.0*	0.45
20	14	17.0	1250.0	15.0	2.55
14	10	30.0	1000.0	18.0	5.40
10	5	50.0	500.0	16.0	8.00
Total	—	100.0	2750.0	—	16.40

** The percentage loss (15.0%) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5% of the original samples as received (see Clause 9.4).*

13 Reporting

13.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification marks;
b) freeze-thaw loss of each sieve fraction that was tested, to 0.1%;
c) weighted freeze-thaw loss to the nearest whole number;

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d) weighted loss, to 0.1%, of the previous twenty samples of calibration aggregate shown on a control chart;
e) name of the certified technician who performed the test;
f) identification of the certified laboratory that performed the test (i.e., name and address);
g) name and signature of the person responsible for the review of the test report; and
h) any deviations from the test procedure.

13.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate;
b) date the sample was taken and/or received by the test laboratory; and
c) sample source or sample location, or both.

14 Precision and bias

Preliminary data indicate that for 20 mm to 5 mm aggregates having a weighted freeze-thaw loss between 1% and 25%, the variability is as shown in Table 4.

Table 4
Variability of weighted freeze-thaw loss
(See Clause 14.)

20 mm to 5 mm weighted % average loss	Standard deviation	Acceptable range for two results (D2S)*
Single-operator precision		
25	1.5	4.3
19	1.6	4.5
6	0.9	2.6
5	0.8	2.3
1	0.3	0.9
Multi-operator precision		
25	2.2	6.2
19	1.7	4.9
6	1.2	3.5
5	1.1	3.1
1	0.5	1.4

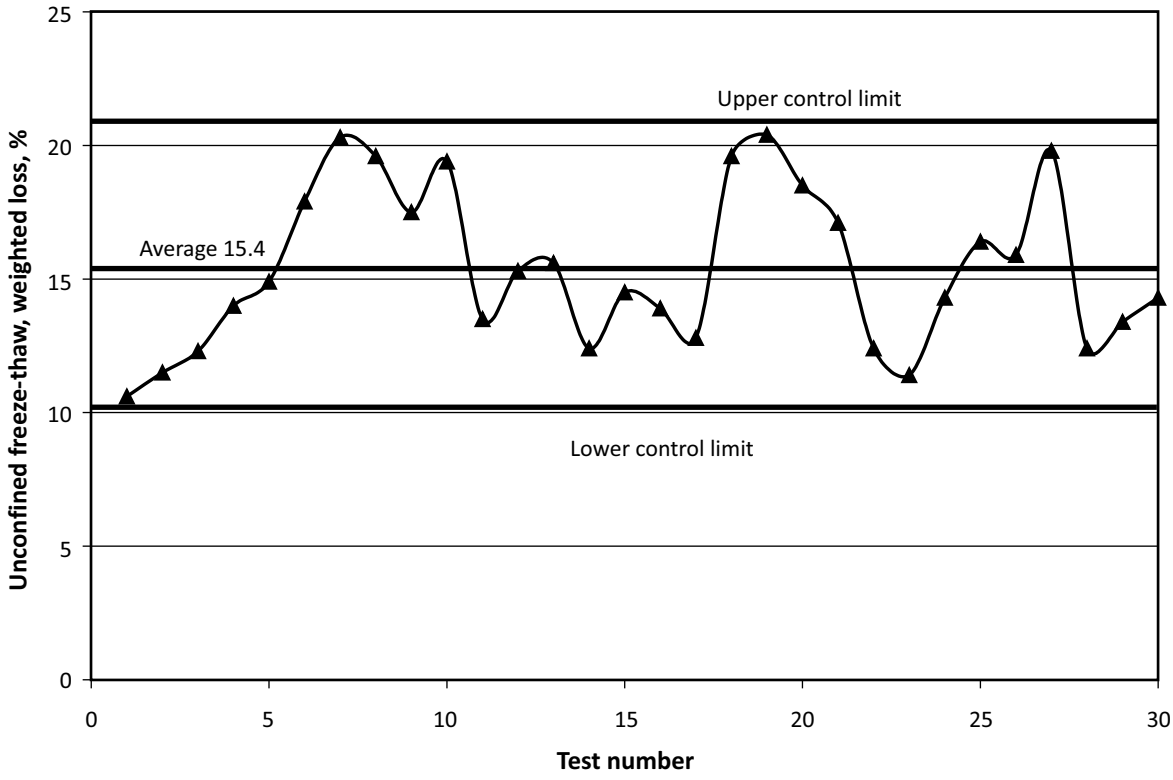
** Figures given for D2S are the limits of the difference between the results of two properly conducted tests on samples of the same material that should only be exceeded one time in 20.*

Note: *See Rogers et al. (1989).*

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Figure 1
Example of a trend chart showing weighted loss and variation in results of a laboratory calibration aggregate
(See Clauses 10.4.)



24A

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Attachment A1 (normative)
Determination of sieving time for quantitative analysis

Note: *This Attachment is a mandatory part of this Test Method.*

A1.1 General

The procedure in Clause A1.2 has been established to reduce inter-laboratory variation of the weighted percentage loss of an individual sample due to differences that can arise from the use of different types of laboratory equipment (e.g., mechanical shaker, diameter of sieves). The amount of time required for quantitative sieving is established through incremental timed-testing of the control aggregate. Sieving time is interpolated from the mean weighted freeze-thaw loss of the calibration aggregate as given in Clause 10. This time is then used for testing all other samples.

A1.2 Procedure

The following steps shall be taken:

a) Prepare and test a minimum of three calibration aggregate samples.
b) For each sample, after drying, place the aggregate on the same sieves and shake in the same sieve shaker used for the sample preparation for 1 min. Following removal from the sieve shaker, gently shake all the aggregates on each sieve for a maximum of 5 s to ensure thorough sieving has taken place (see Clause 11.9).
c) Weigh each individual sieve fraction separately and record the mass to the nearest 0.1 g. Return each fraction to the corresponding sieve and continue shaking in the sieve shaker for one additional minute.
d) Repeat Item c) for a cumulative total of 5 min.
e) Repeat Items b) to d) for the remaining control aggregate samples (see example in Table A1.1).
f) Calculate the cumulative percent loss for each individual sieve for all the control aggregate samples (see example in Table A1.1).
g) Calculate the cumulative weighted freeze-thaw loss for each control aggregate sample at each incremental test time (see example in Table A1.2).
h) Calculate the average weighted freeze-thaw loss of each sample at each incremental test time (see example in Table A1.2).
i) Plot the average weighted freeze-thaw loss against sieving time (see example in Figure A1.1).
j) For the freeze-thaw loss of the control aggregate given in Clause 10, interpolate the required sieving time from the plot (see example in Figure A1.1).
k) Use the sieving time determined in this Clause in the quantitative examination of samples as given in Clause 11.9.
l) Repeat this procedure to establish a quantitative sieving time for each individual sieve set, shaker, or combination thereof every 12 months or whenever changes in equipment or control aggregate occur.

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Table A1.1
Mass of individual sieves as a function of time
(See Clause A1.2.)

Sample	Sieve size (mm)	Initial mass (g)	1 min (g)	2 min (g)	3 min (g)	4 min (g)	5 min (g)
1	14	1250.6	1190.8	1178.3	1157.1	1145.2	1135.8
	10	1000.8	903.1	890.7	884.1	876.1	870.0
	5	500.5	415.1	409.8	406.8	404.5	402.6
2	14	1250.5	1173.0	1157.5	1141.6	1136.8	1121.9
	10	1000.8	889.3	882.3	878.2	872.9	865.1
	5	500.7	421.6	412.5	406.8	403.9	401.2
3	14	1251.0	1182.5	1173.7	1144.4	1133.4	1132.5
	10	1000.1	888.6	877.1	870.8	860.9	853.6
	5	500.9	418.7	413.6	407.5	403.4	401.5

Note: *The following are examples:*

a) *sieve set: set A, 300 mm dia., 14 mm, 10 mm, 5 mm, pan; and*

b) *shaker: shaker X, makers name and type, 300 mm.*

Table A1.2
Cumulative percent loss for individual sieves
(See Clause A1.2.)

Sample	Sieve size (mm)	1 min (%)	2 min (%)	3 min (%)	4 min (%)	5 min (%)
1	14	4.78	5.78	7.48	8.43	9.18
	10	9.76	11.00	11.66	12.46	13.07
	5	17.06	18.12	18.72	19.18	19.56
2	14	6.20	7.44	8.71	9.09	10.28
	10	11.14	11.84	12.25	12.78	13.56
	5	15.80	17.62	18.75	19.33	19.87
3	14	5.48	6.18	8.52	9.40	9.47
	10	11.15	12.30	12.93	13.92	14.65
	5	16.41	17.43	18.65	19.46	19.84

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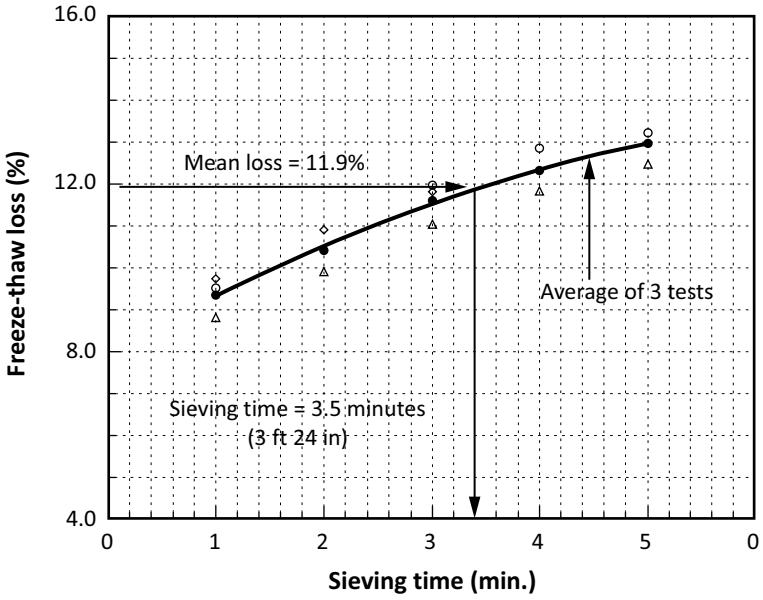
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Table A1.3
Average weighted freeze-thaw loss
(See Clause A1.2.)

	Sample			
Time (min)	1 (%)	2 (%)	3 (%)	Average (%)
1	8.98	9.85	9.65	9.49
2	10.07	11.01	10.58	10.55
3	11.19	11.96	12.09	11.75
4	11.99	12.43	12.99	12.47
5	12.61	13.35	13.36	13.11

Note: *Plot of average weighted freeze-thaw loss of control aggregate against sieving time. The time of 1 min, 52 s is established for quantitative sieving of samples when prepared, tested, and evaluated using sieve set A and shaker X.*

Figure A1.1
Determination of time of sieving to obtain required loss with the reference aggregate for a specific set of sieves and sieve shaker
(See Clause A1.2.)



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A23.2-25A
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

1 Scope

This Test Method specifies the procedure for detecting within 16 d of the potential for deleterious expansion of concrete aggregates due to alkali-silica reaction, by means of mortar bars subjected to accelerated test conditions.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-14A:19
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-15A:19
Petrographic examination of aggregates

A23.2-27A:19
Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

A23.2-28A:19
Standard practice for laboratory testing to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete

A3001-18
Cementitious materials for use in concrete

ASTM International

C109/C109M-16a
Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens)

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C151/C151M-18
Standard Test Method for Autoclave Expansion of Hydraulic Cement

C305-14
Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars for Plastic Consistency

C490/C490M-17
Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

C511-13
Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction

C856-18a
Standard Practice for Petrographic Examination of Hardened Concrete

D1193-06 (2018)
Standard Specification for Reagent Water

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

Other publications

Davies, G., and Oberholster, R.E. 1987a. *An Interlaboratory Test Programme on the NBRI Accelerated Test to Determine the Alkali-Reactivity of Aggregates.* National Building Research Institute Special Report BOU 92–1987. Pretoria: CSIRO.

Davies, G., and Oberholster, R.E. 1987b. Use of the NBRI Accelerated Test to Evaluate the Effectiveness of Mineral Admixtures in Preventing the Alkali-Silica Reaction. *Cement and Concrete Research* 17: 97–107.

Fournier, B. and Bérubé, M.A. 2000. Alkali-Aggregate Reaction in Concrete: A Review of Basic Concepts and Engineering Implications. *Canadian Journal of Civil Engineering*, 27(2): 167–191.

Grattan-Bellew, P.E. 1990. Canadian Experience with the Mortar Bar Accelerated Test for Alkali-Aggregate Reactivity. *Canadian Developments in Testing Concrete Aggregates for Alkali-Aggregate Reactivity,* 17–34. Ontario Ministry of Transportation Engineering Materials Report 92.

Oberholster, R.E., and Davies, G. 1986. An Accelerated Method for Testing the Potential Alkali-Reactivity of Siliceous Aggregates. *Cement and Concrete Research* 16: 181–189.

3 Definitions

In addition to the definitions in Clause 3 of CSA A23.1, the definitions of CSA A3001 shall apply in this Test Method.

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4 Significance and use

4.1

This Test Method provides a means of screening aggregates for their potential reactivity. It is based on the NBRI Accelerated Test Method.

Note: *For additional information, see Oberholster and Davies (1986), Davies and Oberholster (1987a) and (1987b), Grattan-Bellew (1990), and Fournier and Bérubé (2000).*

4.2

Criteria to determine the potential deleteriousness of expansions measured in this Test Method are given in CSA A23.2-27A. When excessive expansions are developed, supplementary information should be developed to confirm that the expansion is actually due to alkali reactivity. Sources of such supplementary information include

a) petrographic examination of the aggregate (see CSA A23.2-15A) to determine whether known reactive constituents are present; and
b) examination of the specimens after tests (see ASTM C856) to identify the products of alkali reactivity.

4.3

When it has been concluded from the results of tests performed, using this Test Method and supplementary information, that a given aggregate might be considered potentially deleteriously reactive, additional studies using alternative methods (see CSA A23.2-14A) may be appropriate to develop further information on the potential reactivity.

4.4

This Test Method is not intended for evaluating the potential reactivity of combinations of coarse and fine aggregates.

4.5

This Test Method may be used to demonstrate the effectiveness of supplementary cementitious materials to prevent alkali-silica reaction in concrete in accordance with CSA A23.2-28A.

5 Apparatus

The apparatus shall conform to the requirements of ASTM C490/C490M, except as follows:

a) Square hole, woven-wire cloth sieves shall conform to the requirements of ISO 3310-1 made with the preferred wire diameter.
b) The mixer, paddle, and mixing bowl shall conform to the requirements of ASTM C305, except that the clearance between the lower end of the paddle and the bottom of the bowl shall be 5.1 ± 0.3 mm.
c) The tamper and trowel shall conform to the requirements of ASTM C109/C109M.
d) The containers shall be of such a design that the bars can be totally immersed in either the water or 1 N NaOH solution. The containers shall be made of material that can withstand prolonged exposure to 80 °C and shall be inert to a 1 N NaOH solution.* The containers shall be so constructed that, when used for storing specimens, the loss of moisture is prevented by tight-fitting covers, by sealing, or both. The bars in the solution shall be placed and supported so that the solution has access to the whole of the bars; therefore, it shall be ensured that the specimens do not touch the sides of the container or each other. The specimens, if stood upright in the solution, shall not be supported by the metal gauge stud.

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e) The convection oven shall have temperature control maintaining 80 ± 2.0 °C.

* *The NaOH solution will corrode glass or metal containers.*

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Reagents and materials

7.1 Sodium hydroxide

USP or technical grade sodium hydroxide may be used, provided that the Na+ and OH^- concentrations of the storage solution in Clause 6.3 are shown by chemical analysis to lie between 0.99 N and 1.01 N.

Note: *Sodium hydroxide should be kept in sealed containers until use, as it will absorb moisture and carbon dioxide if exposed to air.*

7.2 Water

Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Type IV of ASTM D1193.

7.3 Storage solution

Each 1.0 L of sodium hydroxide solution shall contain 40.0 g of NaOH dissolved in 900 mL of water and shall be diluted with additional distilled or deionized water to obtain 1.0 L of solution.* The volume proportion of sodium hydroxide solution to mortar bars in a storage container shall be 4 ± 0.5 volumes of solution to 1 volume of mortar bars.†

* *Precaution: before using NaOH, review*

a) the safety precautions for using NaOH;

b) first aid for burns; and

c) the emergency response to spills as described in the manufacturer's Materials Safety Data Sheet or other reliable safety literature. NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pin holes.

† *The volume of a mortar bar may be taken as 184 mL.*

7.4 Cement

A supply of cement meeting the requirement of general use Portland cement (Type GU) as specified in CSA A3001 shall be used. The total alkali content of the cement shall be 0.90% ± 0.10%, calculated as $Na_2O + 0.658\ K_2O$ (i.e., the Na_2O equivalent). In addition, the autoclave expansion determined as per ASTM C151/C151M shall be less than 0.20 %.

7.5 Control aggregate

A supply of Spratt alkali-silica reactive control aggregate shall be prepared as described in Clause 9.2.

Note: *This aggregate is available from the Materials Engineering and Research Office, Ontario Ministry of Transportation.*

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8 Conditioning

8.1

The temperature of the moulding room, apparatus, and dry materials shall be determined at not less than 20 °C and not more than 26 °C. The temperature of the mixing water and of the moist closet or moist room shall be 23 ± 2.0 °C.

8.2

The relative humidity of the moulding room shall be maintained at not less than 50%. The moist closet or room, if used, shall conform to ASTM C511.

8.3

The storage oven in which the specimens are stored in the containers shall be maintained at a temperature of 80 ± 2.0 °C.

9 Sampling and preparation of test specimens

9.1 General

9.1.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A. Samples for alkali-aggregate reaction testing shall, if possible, be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production.

9.1.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

9.1.3

Materials proposed for use as fine aggregate in concrete shall be processed as described in Clause 9.2 with a minimum of crushing. Materials proposed for use as coarse aggregates in concrete shall be processed by crushing to produce, as nearly as practicable, a graded product from which a sample can be obtained. The sample shall have the grading specified in Table 1 and be representative of the composition of the coarse aggregate as proposed for use.

9.1.4

When a given quarried material is proposed for use both as coarse and as fine aggregate, each aggregate shall be tested.

9.2 Grading

All aggregates to which this Test Method is applied shall be graded in accordance with the requirements in Table 1. Aggregates in which sufficient quantities of the sizes specified in Table 1 do not exist shall be crushed until the required material has been produced. If aggregates contain insufficient amounts of one or more of the larger sizes listed in Table 1, and if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size as determined from the grading specified in Table 1. When such procedures are required, a special note shall be made to that effect in the test report. After the aggregate has been

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separated into the various sieve sizes, each size shall be washed with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. The portions retained on the various sieves shall be dried and, unless used immediately, stored individually in a clean container provided with a tight-fitting cover.

Note: *In order to produce a graded aggregate sample that is representative of the original coarse aggregate material, the following procedure may be used:*

a) *Start with a representative 6 kg (including 2 kg of each fraction 5 to 20 mm) subsample prepared by quartering or other suitable means to ensure a representative portion of the original sample collected following CSA A23.2-1A.*
b) *Using a small jaw crusher (or other appropriate equipment), crush the coarse aggregate particles by multiple passes.*
c) *Sieve the material over a 5 mm sieve between each pass until all material passes the sieve. Care should be exercised not to close the opening between the jaws or the disks too rapidly because this can produce significant amounts of fine dust.*
d) *Separate the material into the various size fractions required for the test.*
e) *If insufficient quantities of some of the fractions are produced, ground the particles using a disk pulverizer by progressive passes. The material can be sieved over a suitable sieve between each pass until all material passes the sieve. The material is then separated into the smaller size fractions and blended with the previously produced material.*

Table 1
Grading requirements
(See Clauses 9.1.1, 9.2, and 9.4.3.)

Sieve size		
Passing	**Retained**	**Mass, %**
5 mm	2.5 mm	10
2.5 mm	1.25 mm	25
1.25 mm	630 µm	25
630 µm	315 µm	25
315 µm	160 µm	15

9.3 Cement

Portland cement meeting the requirements of Clause 7.4 shall be used. Cement for use in this test shall be passed through a 710 µm sieve to remove lumps before use.

9.4 Preparation of test specimens

9.4.1

At least three test specimens shall be made for each aggregate.

9.4.2

The specimen moulds shall be prepared in accordance with the requirements of ASTM C490/C490M, except that the interior surfaces of the mould shall be covered with a release agent.* A release agent shall be suitable if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen.

* *TFE-Fluorocarbon (Teflon) tape complies with the requirements for a mould release agent.*

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9.4.3

The dry materials for the test mortar shall be proportioned using 1 part cement to 2.25 parts graded aggregate by mass. The quantities of dry materials to be mixed at one time in the batch of mortar for making three specimens shall be 440 g of cement and 990 g of aggregate made up by recombining the portions retained on the various sieves (see Clause 9.2) in the grading prescribed in Table 1. For natural fine aggregates, a water-to-cement ratio equal to 0.44 by mass shall be used. For crushed coarse aggregates or manufactured sands, a water-to-cement ratio equal to 0.50 by mass shall be used.

Notes:

1) *Ruggedness tests indicate that mortar bar expansions were less variable at a fixed water-to-cement ratio than when gauged to a constant flow.*
2) *The water-to-cement ratios selected should give acceptable workability in most cases.*

9.4.4

The mortar shall be mixed in accordance with the requirements of ASTM C305.

9.4.5

Test specimens shall be moulded with a total elapsed time of not more than 2 min and 15 s after completion of the original mixing of the mortar batch. The moulds shall be filled with two approximately equal layers, each layer being compacted with the tamper. The mortar shall be worked into the corners, around the gauge studs, and along the surfaces of the mould with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, the mortar shall be cut off flush with the top of the mould and shall be smoothed with a few strokes of the trowel.

10 Procedure

10.1

The procedure shall be performed as specified in Clauses 10.2 and 10.3.

10.2

Place each mould in the moist cabinet or room immediately after moulds have been filled. Alternatively, the mortar bar moulds may be covered with wet burlap or placed over water in a sealed container, and maintained at 23 ± 2.0 °C. When burlap is used, it shall be saturated but not dripping and shall cover the top and sides of the samples without being in direct contact with the mortar surface. The burlap shall be completely covered with a polyethylene sheet in such a manner as to prevent drying of the burlap.

Leave the specimens in the moulds for 24 ± 2 h. Remove the specimens from the moulds and, while they are being protected from loss of moisture, properly identify and measure for initial length. Make and record the initial and all subsequent measurements to the nearest 0.002 mm. Place the specimens made with each aggregate sample in a storage container with sufficient tap water, at room temperature, to totally immerse them. Seal and place the containers in an oven at 80 ± 2.0 °C for a period of 24 h.

Remove the containers from the oven one at a time. Remove other containers only after the bars in the first container have been measured and returned to the oven. Remove the bars one at a time from the water and dry their surfaces with a towel, paying particular attention to the two metal gauge measuring studs. Take the zero measurement of each bar immediately after drying, and read as soon as the bar is in position.* Complete the process of drying and measuring within 15 ± 5 s of removing the specimen from the water. Ensure that the elapsed time between removal of the container from the oven and completion of the measurements is no more than 5 min. After measurement, leave the specimen on a

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towel until the remainder of the bars have been measured. Place all three specimens in a container with the 1 N NaOH, preheated at 80 ± 2.0 °C. Totally immerse the samples. Seal the container and return it to the oven.

* *The comparator bar should be measured prior to each set of specimens since the heat from the mortar bars might cause the length of the comparator to change. The lower measuring stud of the comparator should be wiped dry after each measurement to prevent corrosion.*

10.3

Undertake subsequent measurements of the specimens periodically, with at least three intermediate readings for 14 d after the zero reading, at approximately the same time each day. In some cases, if measurements are continued beyond the 14 d period, take at least one reading per week. Follow the measuring procedure described in Clause 10.2, but return the specimens to their containers after measurement.

11 Calculation

The difference between the zero length of the specimen and the length at each period of measurement shall be calculated to the nearest 0.001% of the effective length and recorded as the expansion of the specimen for that period. The average expansion of the three specimens shall be reported to the nearest 0.01% as the expansion for a given period.

12 Use of a control material

12.1

When testing is conducted, the laboratory shall demonstrate its ability to conduct the test. At the time of testing or at least every six months, testing with a known reactive aggregate shall be conducted.

12.2

As a means of validating the testing laboratory and validating the testing process, Spratt aggregate shall be tested. After 14 d in solution, the expansion of mortar bars made with Spratt aggregate shall be between 0.30% and 0.55%. After 28 d of testing, the expansion shall be between 0.47% and 0.98%. When expansion data are obtained that fall outside these limits, mortar cast with aggregates from the beginning of the first test of the Spratt aggregate until the beginning of the next test with Spratt aggregate shall be retested.

Note: *Spratt coarse aggregate is available in 25 kg bags from the Soils and Aggregates Section, Materials Engineering and Research Office, Ontario Ministry of Transportation (Soils-Aggregates@ontario.ca).*

13 Reporting

13.1 Required information

The following information shall be included in the test report, as applicable:

a) sample number or identification marks;
b) type and source of aggregate, location of aggregate within the source (e.g., bench level, area within a pit, etc.);
c) type and source of Portland cement;
d) alkali content of cement as percentage potassium oxide (K_2O), sodium oxide (Na_2O), and calculated sodium oxide (Na_2O) equivalent;
e) average length change percentage at each reading of the specimens;

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f) any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in Clause 8.2;
g) any significant features revealed by examination of the specimens and the sodium hydroxide solution during and after the test;*
h) amount of mixing water expressed as water-to-cement ratio;
i) a graph of the length change data from the time of the zero reading to the end of the period of testing;
j) a graph of the length change data from the time of the zero reading to the end of the 14 d period of the control aggregate;
k) expansion of mortar bars made with the Spratt aggregate tested closest in time to that of the results of the sample being reported;
l) name of the certified technician who performed the test;
m) identification of the certified laboratory that performed the test (i.e., name and address);
n) name and signature of the person responsible for the review and approval of the test report; and
o) any deviations from the test procedure.

* *In some cases, the solution might become cloudy due to the presence of alkali-silica gel.*

13.2 Optional information

The following information may be included in the test report:
a) name of the person or organization who sampled the aggregate; and
b) date the sample was taken or received by testing laboratory.

14 Precision

14.1 Single-laboratory precision

It has been found that the average single-laboratory coefficient of variation for materials with an average expansion greater than 0.1% at 14 d is 2.94%.* Therefore, the results of two properly conducted tests within the same laboratory on specimens of a sample of aggregate should not differ by more than 8.3%* of the mean expansion, 19 times out of 20.

* *These numbers represent, respectively, the 1S% and D2S% limits as described in ASTM C670.*

14.2 Multi-laboratory precision

It has been found that the average multi-laboratory coefficient of variation for materials with an average expansion greater than 0.1% at 14 d is 15.2%.* Therefore, the results of two properly conducted tests in different laboratories on specimens of a sample of aggregate should not differ by more than 43%* of the mean expansion, 19 times out of 20.

* *These numbers represent, respectively, the 1S% and D2S% limits as described in ASTM C670.*

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A23.2-26A
Determination of potential alkali-carbonate reactivity of quarried carbonate rocks by chemical composition

1 Scope

This Test Method specifies the laboratory procedure for testing quarried carbonate aggregates by chemical analysis to determine whether they are potentially alkali-carbonate expansive.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1A:19
Sampling aggregates for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-14A:19
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

ASTM International

C25-17
Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction

C702/C702M-18
Standard Practice for Reducing Samples of Aggregate to Testing Size

Other publications

Norrish, K., and Chappell, B.W. 1977. X-ray Fluorescence Spectrometry. *Physical Methods in Determinative Mineralogy*, 201–272. Ed. J. Zussman. London: Academic Press.

Rogers, C.A. 1986. Evaluation of the Potential for Expansion and Cracking of Concrete Caused by the Alkali-Carbonate Reaction. *Cement, Concrete and Aggregates*, ASTM, Summer: 13–23.

Shapiro, L. 1975. *Rapid Analysis of Silicate, Carbonate and Phosphate Rocks (Revised Edition).* United States Geological Survey Bulletin 1401.

Shehata, M. H., Jagdat, S., Rogers, C., and Lachemi, M. 2017. Long-term effects of different cementing blends on alkali-carbonate reaction. *ACI Materials Journal,* 114(4): 661–672.

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3 Significance and use

3.1

Deleteriously expansive alkali-carbonate reactive (ACR) aggregates in Ontario are dolomitic limestones with a high clay or acid insoluble residue content. Dolomitic limestone can be recognized by determining the CaO:MgO ratio. Clay content can be determined by measuring alumina (Al_2O_3) content (Rogers, 1986). This Test Method has been found to be a useful screening procedure for expansive carbonate rock in Ontario; it might not have similar application elsewhere. Users of this Test Method in other geographic locations should establish the usefulness of this Test Method with suspect alkali-carbonate reactive rocks in their area.

3.2

Carbonate rocks that are not alkali-carbonate reactive might be alkali-silica reactive. This Test Method does not determine the potential for alkali-silica reactivity.

3.3

Recent work using laboratory blends of known Ontario ACR highly expansive dolomitic limestone with known non-expansive dolostone have shown that the test did not predict the expansivity in all cases. Aggregate blends containing expansive aggregate contents of 15 and 20% fell in the lower “non-expansive” field of Figure 1, but showed expansions in excess of 0.040% (0.047 and 0.076%) at one year in the concrete prism test (Shehata *et al.*, 2017).

4 Apparatus

The apparatus shall consist of a small jaw crusher or other suitable equipment capable of crushing aggregate to pass a 2.5 mm sieve and a shatter box or other suitable equipment capable of grinding approximately 30 g of aggregate finer than 2.5 mm to pass a 160 µm sieve.

5 Sample selection

5.1

The procedures specified in CSA A23.2-1A shall be followed to obtain a representative sample of the aggregate to be tested. The sample, if possible, shall be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production.

5.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

6 Test specimen preparation

6.1

The procedures specified in ASTM C702/C702M shall be followed to obtain representative test specimens of the aggregate sample. The mass of test specimens shall be determined by the particle size of the aggregate as given in Table 1. No attempt shall be made to obtain the required test specimen mass by adding or subtracting individual pieces.

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Table 1
Test specimen size
(See Clause 6.1.)

Nominal maximum aggregate size, mm	Minimum mass of sample, kg
14 and less	2
20	3
28	4
40	5
56	10
80	18

6.2
The test specimen shall be crushed using a small jaw crusher or other suitable means so that the entire sample passes a 2.5 mm sieve. The jaw crusher shall be clean and no material shall be lost.

6.3
The crushed test specimen shall be mixed thoroughly and a representative specimen of 30 ± 5 g shall be prepared using a sample splitter or other suitable means. The test specimen shall be pulverized using suitable equipment so that it passes a 160 µm sieve. Any material retained on the 160 µm sieve shall be further treated until it is able to pass the sieve. Care shall be taken so that no material is lost.

6.4
The material passing the 160 µm sieve shall be mixed thoroughly. Specimens of a suitable size shall be obtained for chemical analysis.

7 Hazards
This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Test procedures

8.1 General

8.1.1
Where analytical data obtained in accordance with this Test Method are required, any method may be used that meets the requirements of Table 2. A method shall be considered to consist of the specific procedures, reagents, supplies, equipment, instruments, etc., selected and used in a consistent manner by a specific laboratory.

Note: *Examples of methods used successfully for analysis of carbonate rocks are given in Shapiro (1975), Norrish and Chappell (1977), and ASTM C25.*

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8.1.2
If two or more instruments, even if they are substantially identical, are used in a specific laboratory for the sample analyses, use of each instrument shall constitute a separate method and each shall be qualified separately.

8.2 Qualification of a method

8.2.1
Prior to use for analysis of aggregate, the method chosen shall be qualified for such analysis.

8.2.2
Using the method chosen, duplicate determinations shall be made for each oxide on the standard reference materials.

Note: *The standard reference materials are available from the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, Reference Materials ID, 88B.*

8.2.3
The differences between duplicates shall not exceed the limits specified in Column 3 of Table 2.

8.2.4
The average for each component shall not differ from the qualified concentrations by more than the value specified in Column 4 of Table 2.

Table 2
Maximum permissible variation in results
(See Clauses 8.1.1, 8.2.3, 8.2.4, and 9.)

Standard reference material (SRM)	Component	Maximum difference between duplicates, %	Maximum difference of the average of duplicates from the SRM certificate values, %
NIST 1D	CaO	0.6	±0.5
	MgO	0.1	±0.1
	Al_2O_3	0.1	±0.2
NIST 88B	CaO	0.7	±0.6
	MgO	0.4	±0.5
	Al_2O_3	0.1	±0.1

8.3
The aggregate specimen shall be tested using the chosen analytical method.

9 Reporting

9.1 Required information
The following information shall be included in the test report, if applicable:

a) sample number or identification marks;
b) type and source of aggregate;

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c) a description of the elevations and the location of the quarry face that was sampled, or if the sample was taken from a stockpile, this shall be reported;
d) maximum nominal size of the aggregate;
e) percentage mass of the various oxides in the sample to the nearest 0.1%;
f) a description of the type of analytical method used, together with data to show that the method used meets the precision and accuracy limits shown in Table 2;
g) name of the technician who performed the test;
h) identification of the certified laboratory that performed the test (i.e., name and address);
i) name and signature of the person responsible for the review and approval of the test report; and
j) any deviation from the test procedure.

9.2 Optional information

The following information may be included in the test report:
a) name of the technician who sampled the aggregate; and
b) date the sample was taken.

10 Interpretation of results

Correlations among data obtained by this Test Method, expansion of concrete prisms and rock cylinders, and performance of aggregates in concrete structures have been published.* On the basis of these data, an area on the graph in Figure 1 has been established where potentially expansive alkali-carbonate reactive rocks are found. Aggregates whose results of analysis fall in this area shall be considered to be potentially deleterious until the innocuous character of the aggregate is demonstrated by service records or by a supplementary tests in accordance with CSA A23.2-14A.

* *For further information see Rogers (1986).*

11 Precision

Preliminary data indicate that the multi-laboratory coefficient of variation (for experienced laboratories) is dependent upon the element being analyzed. Multi-laboratory coefficient of variation for an alkali-carbonate reactive rock, obtained in a study with 12 participants, is given in Table 3. The D2S values are the limits that should not be exceeded by the difference between the results of two properly conducted tests, in different laboratories, expressed as a percentage of their mean. These values are only applicable to a carbonate rock with a chemical composition similar to that specified in Table 3.

Table 3
Multi-laboratory variation
(See Clause 11.)

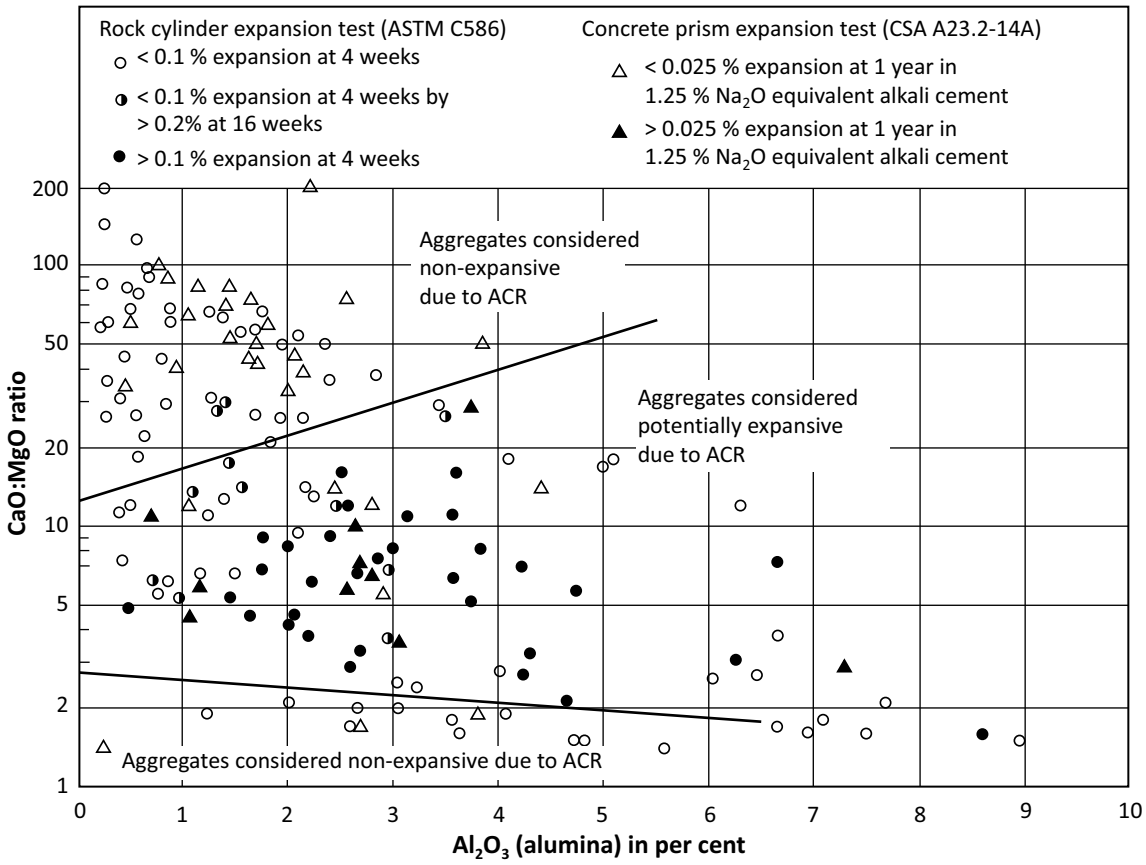
	CaO	MgO	CaO:MgO	Al_2O_3
Value	43	6	7	2
C of V*	1.5%	6.9%	7.6%	13%
D2S†	4.3%	20%	22%	37%

* *Coefficient of variation.*
† *D2S = acceptable maximum difference between two results; see ASTM C670.*

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Figure 1
Illustration of the division between non-expansive and potentially expansive alkali-carbonate reactive rock on the basis of chemical composition
(See Clauses 3.3 and 10.)



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A23.2-27A
Standard Practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

1 Scope

1.1
This Standard Practice specifies the procedure for the determination of the potential alkali-reactivity of concrete aggregates and the selection of preventive measures to control ASR in concrete based on a prescriptive approach. The latter involves the determination of the degree of alkali-silica reactivity of aggregates, the risk level associated with structure size and environment, the level of prevention related to service life requirements, and the determination of the appropriate preventive measures.

1.2
This Standard Practice describes the determination of the potential for deleterious alkali-carbonate reaction and provides advice on appropriate preventive measures.

1.3
This Standard Practice applies to virgin aggregates and does not apply to recycled concrete used as aggregate for new concrete [see Clause B.6 of Annex B of CSA A23.1 for more information on the potential alkali-reactivity of reclaimed concrete aggregate (RCA)].

1.4
The levels of prevention determined following the procedure described in Clause 6 are applicable for concrete incorporating either Portland cement or Portland-limestone cement.

2 Reference publications
This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregate for use in concrete

A23.2-14A:19
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-15A:19
Petrographic examination of aggregates

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A23.2-25A:19
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-26A:19
Determination of potential alkali-carbonate reactivity of quarried carbonate rocks by chemical composition

A23.2-28A:19
Standard practice for laboratory testing to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete

A3001-18
Cementitious materials for use in concrete

AASHTO (American Association of State Highway and Transportation Officials)

T 105-14
Standard Method of Test for Chemical Analysis of Hydraulic Cement

ASTM International

C586-11
Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock Cylinder Method)

C856-18a
Standard Practice for Petrographic Examination of Hardened Concrete

C1084-10 (withdrawn)
Standard Test Method for Portland-Cement Content of Hardened Hydraulic-Cement Concrete

RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures)

Recommended Specification AAR-7.1
International specification to minimize damage from alkali reactions in concrete — Part I : alkali-silica reaction and Part 2: alkali-carbonate reaction

Other publications

de la Barona, O.F. 1951. Alkali-Aggregate Expansion Corrected with Portland-Slag Cement. *Journal of the American Concrete Institute* 22: 545–552.

Bérubé, M.A., Durand, B., Vezina, D., and Fournier, B. 2000. Alkali-Aggregate Reactivity in Québec (Canada). *Canadian Journal of Civil Engineering* 27: 226–245.

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3 Definitions

In addition to the definitions in Clause 3 of CSA A23.1, the definitions of CSA A3001 apply in this Standard Practice.

4 Significance and use

CSA A23.1 requires that the aggregates used in concrete not contain any materials that are deleteriously reactive with the alkalis contained within the concrete in an amount sufficient to cause excessive expansion, except that if such materials are present in injurious amounts, aggregate may be used if certain precautions are taken. This Standard Practice provides information on determining the potential for deleterious expansion due to alkali reactivity of aggregates, and the measures that are suitable for preventing deleterious expansion. The identification of the need for preventive measures depends on the potential alkali-reactivity of the aggregate, the composition of the concrete, the environment to which the concrete will be exposed, and the service life of the structure.

Note: *Background information is provided by Hooton (1991) and Fournier and Bérubé (1992). See Attachment A1 for a brief survey of related research.*

5 Determination of the potential alkali-reactivity of aggregates

5.1 Process

The process for determining the potential alkali-reactivity of aggregates to be used in concrete shall be as shown in Figure 1.

5.2 Alkali-carbonate reactivity (ACR)

CSA A23.2-26A and CSA A23.2-14A may be used for evaluating the potential alkali-carbonate reactivity of quarried carbonate rocks. CSA A23.2-25A shall not be used to determine potential ACR of aggregates.

Note: *The petrographic characteristics of quarried carbonate rocks susceptible to ACR are illustrated in Figure B.1 of CSA A23.1.*

Aggregates that fall into the “potentially expansive zone” of Figure 1 of CSA A23.2-26A shall be tested using CSA A23.2-14A; if such aggregates then induce concrete prism expansion exceeding 0.040% at one year, they shall be identified as potentially alkali-carbonate reactive. This shall be confirmed by petrographic examination of the test prisms, at the completion of the expansion test, following ASTM C856.

5.3 Alkali-silica reaction (ASR)

Petrographic examination alone is not sufficient to assess the potential for deleterious expansion due to alkali-silica reaction. CSA A23.2-25A and CSA A23.2-14A may be used for evaluating the potential alkali-silica reactivity of aggregates.

Note: *Minerals and rocks susceptible to deleterious alkali-silica reaction in concrete are listed in Table B.1 of CSA A23.1.*

Aggregates that induce accelerated mortar bar or concrete prism expansions in excess of the limits listed in Table 1 shall be identified as potentially alkali-silica reactive.

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Table 1
Expansion values for identifying potentially alkali-silica reactive aggregates
(See Clause 5.3 and Table 2.)

Concrete prism expansion test	Mortar bar accelerated expansion test
CSA A23.2-14A	CSA A23.2-25A*
(See CSA A23.1, Clause B3.4)	(See CSA A23.1, Clause B3.3)
≥ 0.040% at one year†	Greater than 0.150% at 14 d‡

* *This method is not appropriate for testing aggregates for alkali-carbonate reactivity.*
† *In critical structures such as those used for nuclear containment or large dams, a lower expansion limit might be required.*
‡ *Several aggregates that expand more than 0.150% after 14 d have not caused deleterious expansion in field structures and expanded less than 0.040% in CSA A23.2-14A. Therefore, expansion in excess of the recommended limit calls for further testing of concrete specimens.*

A number of quarried siliceous limestone aggregates from the St. Lawrence Lowlands, which expand less than 0.150% after 14 d, have caused deleterious expansion in field structures and have expanded more than 0.040% in concrete prism tests. Therefore, a lower limit of 0.100% should be considered for this type of aggregate (Fournier and Bérubé,1991b).

Some dolostones from the Beekmantown Group expand significantly in CSA A23.2-14A (i.e., greater than 0.040% after one year), while expanding between 0.10% and 0.15% after 14 d in CSA A23.2-25A. Deleterious expansion in field structures has not been confirmed (Bérubé et al., 2000).

There are reports of deterioration of field concretes made with quarried bedrock aggregates of Grenville Age in Ontario containing granites, gneisses, and granodiorites and also some horizons of the Potsdam sandstone, which exhibit less than 0.100% expansion at 14 d in CSA A23.2-25A. Therefore, such aggregates shall be tested in accordance with CSA A23.2-14A.

6 Identification of preventive measures

6.1 Use of long-term field performance data

Long-term field performance may be used to determine if aggregates are non-deleteriously reactive. Field performance shall not be used to determine degree of alkali-silica reactivity of aggregates. When field performance is to be assessed,

a) the cement content and the alkali content of the cement shall be the same or higher in the field concrete as that proposed in the new structure;
b) the concrete examined shall be at least 10 years old;
c) the exposure conditions of the field concrete shall be at least as severe as those in the proposed structure;
d) a petrographic study shall be conducted to demonstrate that the aggregate in the structure is identical to that under investigation in the absence of conclusive documentation;
e) the possibility of supplementary cementitious materials having been used shall be considered; and
f) consideration shall be given to the fact that the water-to-cementitious materials ratio of the concrete can affect performance.

Such a field performance review shall be conducted by a professional who is experienced in the assessment of AAR in structures.

Note: *Guidelines for evaluating the field performance of aggregates, including field and laboratory testing, are provided in Attachment A2.*

6.2 Preventive measures for alkali-carbonate reactivity

6.2.1

The best and most practical preventive measure is to avoid the use of these aggregates.

Notes:

1) *Low alkali-cement (lower than 0.60 Na_2O_e) does not prevent deleterious expansion (Swenson and Gillott, 1964). Blast-furnace slag cement and other SCMs have not been found to be effective (Rogers and Hooton, 1992; Shehata et al., 2009; Fecteau et al., 2016).*

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Lithium hydroxide and lithium carbonate have been found to increase expansion of alkali-carbonate reactive rock (Wang et al., 1994). In the horizontally bedded carbonate bedrock quarries, where these aggregates have been found, the use of a specific level or bench of non-reactive rock for concrete aggregate supply has been done (Ryell et al., 1974).

2) *The determination of the extent to which alkali-carbonate reaction has contributed to the expansion of concrete prisms tested in accordance with CSA A23.2-14A should be conducted by someone with experience with this type of reaction. Further testing might include petrographic examination of the concrete prisms (following ASTM C856), rock cylinder testing (ASTM C586) of samples of the rock from the quarry, and/or accelerated concrete microbar tests performed on the concrete aggregate (Lu et al. 2004, 2008).*
3) *Within the replacement levels commonly used in construction, the three types of fly ash (F, CI, and CH), silica fume, metakaolin, ternary blends of silica fume and fly ash, and silica fume and blast-furnace slag were found ineffective in mitigating expansion in concrete containing highly-reactive carbonate aggregate from Kingston, Ontario (Shehata et. al., 2009; Fecteau et al. 2016). See Clause B.5.1 of CSA A23.1.*

6.2.2

In cases where an aggregate is suspected to be susceptible to both alkali-carbonate and alkali-silica reactivity, CSA A23.2-28A may be used to demonstrate, based on concrete prism testing, the effectiveness of selected mitigation measures.

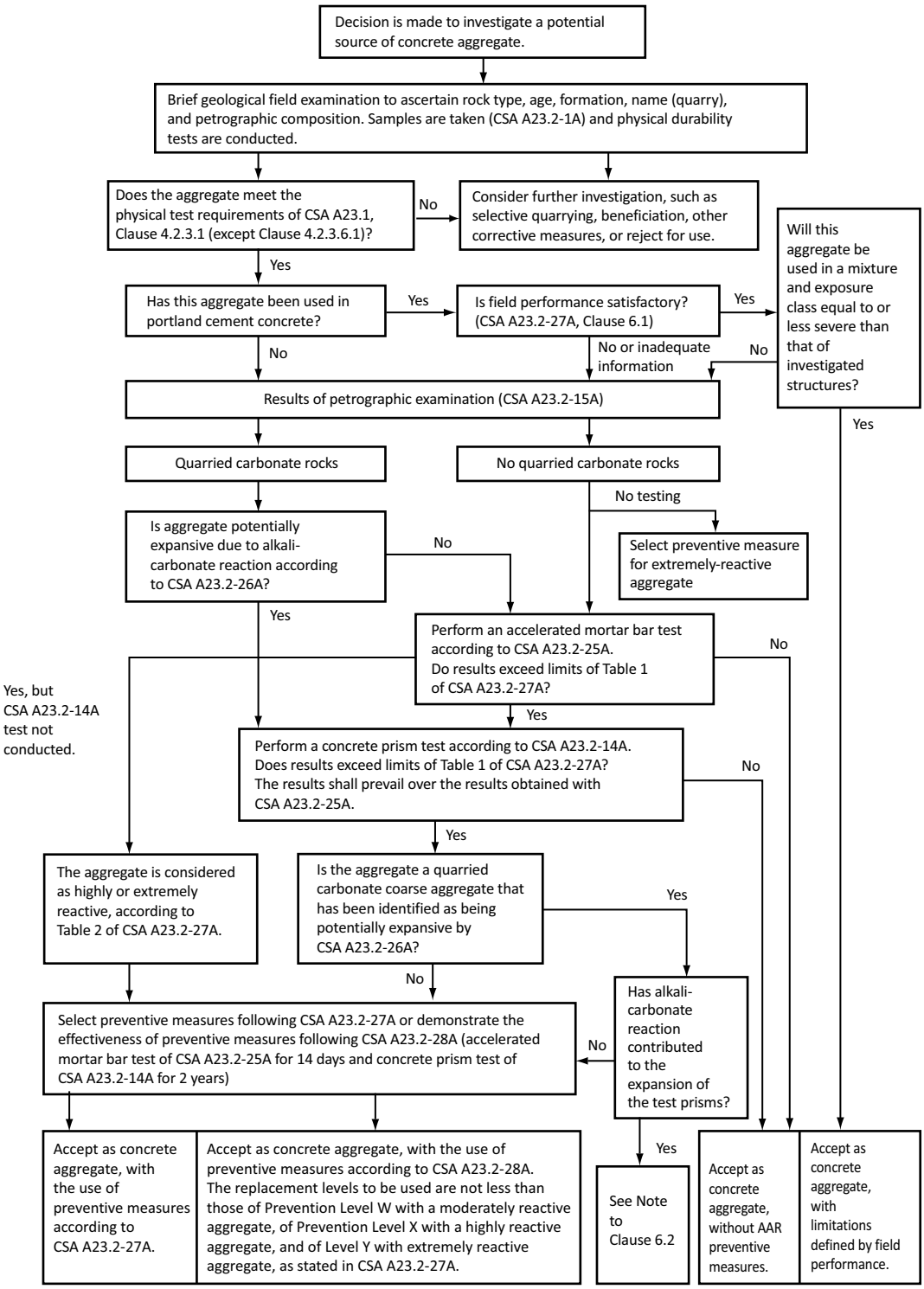
Note: *The accelerated mortar bar test is not appropriate for aggregates susceptible to alkali-carbonate reaction.*

27A

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Figure 1
Process for determining the potential alkali-aggregate reactivity of concrete aggregate and use of preventive measures
(See Clause 5.1.)



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6.3 Preventive measures for alkali-silica reactivity

6.3.1 Determination of the degree of alkali-silica reactivity

The degree of alkali-silica reactivity of aggregates shall be determined using the expansion values in Table 2. When concrete prism expansion test data are not available, the expansion of mortar in the accelerated mortar bar test may be used. For the purpose of selecting preventive measures, in the absence of test data or a record of satisfactory long-term field performance, it shall be assumed that the aggregate is extremely reactive.

Table 2
Degree of alkali-silica reactivity of aggregates
(See Clause 6.3.1 and Table 3.)

Classification of the degree of alkali-silica reactivity	One-year expansion (%) from CSA A23.2-14A*†	14 d expansion (%) from CSA A23.2-25A†‡
Non-reactive	< 0.040	< 0.150% (see Table 1)
Moderately reactive	≥ 0.040 – < 0.120	§
Highly reactive	≥ 0.120 – < 0.260	≥ 0.150 – < 0.440% (see Table 1)
Extremely reactive	≥ 0.260	≥ 0.440%

** The degree of alkali-silica reactivity obtained in CSA A23.2-14A is that of a combination of the fine and coarse aggregates intended for use in concrete. If the results of the combination are not available, then the degree of alkali-silica reactivity to be used in this Table shall be that of the most expansive of the aggregates to be used.*
† When data obtained in accordance with CSA A23.2-25A conflict with those obtained with the same aggregate in accordance with CSA A23.2-14A, the results of the latter shall prevail.
‡ When the accelerated mortar bar test is used, each aggregate to be used shall be tested and the degree of alkali-silica reactivity based on the highest test value shall be obtained.
§ The accelerated mortar bar test is not considered to be suitable for distinguishing between moderately and highly reactive aggregates. Consequently, in the absence of concrete prism test data, aggregates that produce expansion greater than or equal to 0.150% but smaller than 0.440% at 14 d in the test are classified as highly reactive. Aggregates that produce expansion greater than or equal to 0.440% at 14 d in the test are classified as extremely reactive.

6.3.2 Determination of the level of risk of alkali-silica reaction

The risk of poor performance of concrete shall be determined in accordance with Table 3. Three parameters shall be considered:

a) the size of the concrete element;
b) the humidity of the environment; and
c) the degree of reactivity of the aggregates.

Level 1 corresponds with no risk of deleterious alkali-silica reaction whereas Level 5 corresponds to extreme risk of deleterious reaction.

Note: *Potentially reactive aggregate should not be used in concrete that is intended to be exposed in service to alkali acetates, formates, or hydroxides unless it can be demonstrated by testing or field performance that an appropriate or effective preventative measure can be implemented (Diamond et al., 2006).*

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Table 3
Determination of the level of risk of ASR
(See Clauses 6.3.2 and 6.3.3 and Table 4.)

Size and concrete environment	Degree of reactivity of the aggregate (from Table 2)			
	Non reactive	Moderately	Highly	Extremely
Non-massive and dry*†	Level 1	Level 1	Level 2	Level 3
Massive and dry†‡	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried, or immersed§	Level 1	Level 3	Level 4	Level 5

* *A massive element has a least dimension of 1 m or more.*
† *A dry environment corresponds to an ambient average relative humidity condition lower than 60%, normally only found in buildings.*
‡ *A risk of alkali-silica reaction exists for massive concrete elements in a dry environment because the internal concrete has a high relative humidity.*
§ *A non-massive concrete element constantly immersed in sea water does not present a higher risk of ASR than a similar element exposed to humid air, buried in the ground, or immersed in pure water because the alkali concentration of sea water (30 g/L NaCl 0.51 M NaCl or Na) is lower than the alkali concentration of the pore solution of most concretes, while the penetration of Cl ions is usually limited to a few centimetres.*

6.3.3 Determination of the need for preventive measures

The need for preventive measures shall be determined from Table 4 by considering the risk of ASR from Table 3 together with the class of structure from Table 5. In Table 5, structures are classified on the basis of the severity of the consequences should ASR occur. For example, the consequences of ASR are far more severe for a reinforced concrete bridge element than they are for a sidewalk. As such, more onerous measures shall be used to prevent damaging ASR in a bridge.

Table 4
Level of prevention
(See Clause 6.3.3.)

Level of ASR risk (from Table 3)	Classification of the structures (from Table 5)			
	St1	St2	St3	St4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ

Note: *The level of prevention V, W, X, Y, Z, and ZZ are used in Tables 6 and 7.*

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Table 5
Structures classified on the basis of the severity of the consequences should ASR occur* (Modified from highway structures from RILEM AAR-7.1)
(See Clause 6.3.3.)

Class	Consequences of ASR	Acceptability of ASR	Examples†
St1	Safety, economic, or environmental consequences small or negligible	Some deterioration from ASR may be tolerated, without affecting serviceability	• Non-load-bearing elements inside buildings or sheltered from weather • Temporary structures (e.g., < 5 years)
St2	Some safety, economic, or environmental consequences if major deterioration	Moderate risk of ASR is acceptable. Periodic repair or maintenance might be required to maintain structural capacity and serviceability.	• Sidewalks, curbs, and gutters • Service-life < 40 years • Most low-rise domestic structures
St3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR is acceptable. More frequent and/or more extensive repair or maintenance might be required to maintain structural capacity and serviceability.	• Highway pavements, retaining walls • Culverts • Highway barriers • Low-volume bridges • Large numbers of precast elements where economic costs of replacement are severe • Parking structures • Service life normally 40 to 74 years
St4	Serious safety, economic, or environmental consequences if minor damage	ASR is not acceptable. Frequent and extensive repair or maintenance will probably be required to maintain structural capacity and serviceability	• Major bridges and harbour works • Tunnels, dams • Critical elements that are very difficult to inspect or repair • Airfield pavement • Nuclear installations • Structures retaining or encapsulating hazardous materials • Service life normally equal to or greater than 75 years

** This Table does not consider the consequences of damage due to ACR. This practice does not permit the use of alkali-carbonate reactive aggregates.*
† The types of structures listed under each class are meant to serve as examples. Some owners may decide to use their own classification system. For example, sidewalks or curbs and gutters may be placed in the Class S3.

6.3.4 Identification of preventive measures

The possible measures for the required level of prevention shall be identified using Table 6. The risk of damage due to ASR may be reduced by adopting one or more of the following approaches:

a) use a non-reactive aggregate but periodically confirm the non-reactive character of the aggregate (V);
b) reject the proposed aggregate (i.e., prevention levels W3, X3, Y3, Z4, ZZ2 in Table 6);
c) limit the alkali contributed by the Portland cement to the concrete under a specified level (in kg/m^3) (i.e., prevention levels W1, X1, Y1, Z1 in Table 6);
d) use a sufficient amount of effective SCM or combination of effective SCMs (i.e., prevention levels W2, X2, Y2, Z2 in Table 6); and
e) use the options in Items c) and d) (i.e., prevention levels Z3, ZZ1).

When supplementary cementitious materials are to be used, the specific type of constituents and the minimum proportions needed shall be identified using Table 7. Alternatively, CSA A23.2-28A may be used.

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Table 6
Preventive measures
(See Clause 6.3.4 and Tables 4 and 6.)

Prevention level		Possible measures to prevent deleterious alkali-silica reaction
V		Accept the proposed aggregate without any preventive measure but periodically ensure that the reactivity of the aggregate extracted has not changed.
W		Mild preventive action is required; use one of the following techniques:
	W1	• Limit the alkali contributed by the Portland cement to the concrete to < 3.0 kg/m³ Na_2O equivalent.*
	W2	• Use a sufficient amount of effective SCM or combination of effective SCMs (see Table 7).
	W3	• Reject the proposed aggregate or use option W1 or W2.
X		Moderate preventive action is required; use one of the following techniques:
	X1	• Limit the alkali contributed by the Portland cement to the concrete to < 2.4 kg/m³ Na_2O equivalent.*
	X2	• Use a sufficient amount of effective SCM or combination of effective SCMs (see Table 7).
	X3	• Reject the proposed aggregate or use option X1 or X2.
Y		Strong preventive action is required; use one of the following techniques:
	Y1	• Limit the alkali contributed by the Portland cement to the concrete to < 1.8 kg/m³ Na_2O equivalent.*
	Y2	• Use a sufficient amount of effective SCM or combination of effective SCMs (see Table 7).
	Y3	• Reject the proposed aggregate or use option Y1 or Y2.
Z		Very strong preventive action is required; use one of the following techniques:
	Z1	• Limit the alkali contributed by the Portland cement to the concrete to < 1.2 kg/m³ Na_2O equivalent.*
	Z2	• Use a sufficient amount of effective SCM or combination of effective SCMs (see Table 7).
	Z3	• Use option Y1 and Y2.
	Z4	• Reject the proposed aggregate.
ZZ		Exceptional preventive action is required; use one of the following techniques:
	ZZ1	• Use both options Z1 and Z2.
	ZZ2	• Reject the proposed aggregate for use in concrete.

** In order to calculate the alkali content of the concrete, multiply the maximum acid soluble alkali content [total sodium oxide equivalent, which is $Na_2O + (0.658 \times K_2O)$] of the Portland cement by the cement content of the mixture in kg/m³. Example (Cement with total sodium oxide equivalent of 0.90%): Multiply by the cement dosage of 300 kg/m³ to calculate 2.70 kg/m³of total alkali loading in concrete. Allowance shall be made for likely variations that will occur in the alkali content of the cement and for variations that will occur in the cement content of the concrete. When data are available from the cement manufacturer, use a cement alkali content of 1.4 standard deviation greater than the average alkali value provided. Typically, a series of the most recent mill certificate represents an average and can be used for that purpose. When such data on standard deviation and average are not available, add a value of 0.05% to the measured alkali content of the cement.*

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Table 7
Use of supplementary cementitious materials for counteracting alkali-silica reaction
(See Clause 6.3.4 and Table 5.)

Type of SCM	Total alkali content of SCM % Na_2O equivalent[a]	Chemical composition requirement (% oxides)	Minimum level of SCMs (% by mass of total cementitious materials)[b]			
			Prevention level W	Prevention level X	Prevention level Y	Prevention level Z
Fly ash	< 3.0	CaO ≤ 15%	15	20	25	35
		CaO >15% to ≤ 20%	20	25	30	40
		CaO > 20%	[c]	[c]	[c]	[c]
	3.0–4.5	CaO ≤ 15%	20	25	30	40
		CaO > 15% to ≤ 20%	25	30	35	45
		CaO > 20%	[c]	[c]	[c]	[c]
	> 4.5	[c]	[c]	[c]	[c]	[c]
Blast-furnace slag	< 1.0[c]	None	25	35	50	60
Silica fume	< 1.0[c, d, e]	None	2.0 × alkali content	2.5 × alkali content	3.0 × alkali content	[f]
Natural pozzolans	Natural pozzolans that meet the requirements of CSA A3001 may be used provided that their effectiveness in controlling expansion due to ASR is demonstrated in accordance with CSA A23.2-28A.					
Combinations of SCMs	When two or more types of SCMs are used together to control ASR, the minimum replacement levels given in this Table for the individual SCMs may be reduced provided that the sum of the parts of each SCM is greater than or equal to one. For example, when silica fume and slag are combined, the silica fume level may be reduced to one-third of the minimum silica fume level given in this Table, provided that the slag level is at least two-thirds of the minimum slag level given in this Table. The effectiveness of other ternary blend combinations, using fly ashes, slag, silica fume, or natural pozzolans shall be demonstrated in accordance with CSA A23.2-28A.					

[a] *Na_2O equivalent = sodium oxide equivalent = Na_2O + (0.658 × K_2O).*

[b] *In order to control the total alkali content of concrete mixtures incorporating any supplementary cementitious materials, the following options may be used:*

a) *For moderately-reactive aggregates, the levels of SCMs in Table 7 shall be used with a Portland cement of not greater than 1.15% Na_2O equivalent. For Portland cements with an alkali content between 1.15% and 1.25% Na_2O equivalent, the level of SCMs shall be increased by one prevention level. Alternatively, the level of SCM required can be determined by conducting concrete prism tests in accordance with CSA A23.2-28A.*

b) *For highly- and extremely-reactive aggregates, the levels of SCMs in Table 7 shall be used with a Portland cement of not greater than 1.00% Na_2O equivalent. For Portland cements with an alkali content between 1.00% and 1.25% Na_2O equivalent, the level of SCMs shall be increased by one prevention level. Alternatively, the level of SCM required can be determined by conducting concrete prism tests in accordance with CSA A23.2-28A.*

c) *For Portland cements with an alkali content greater than 1.25% Na_2O equivalent, the level of SCM required shall be determined by conducting concrete prism tests in accordance with CSA A23.2-28A.*

d) *For Portland cements with an alkali content of less than 0.70%, the level of SCM shall be decreased by one prevention level.*

[c] *In the presence of alkali-silica reactive or potentially reactive aggregates, blast-furnace slag and silica fume with alkali contents greater than 1.0% Na_2O equivalent, and also fly ashes with alkali contents greater than 4.5% Na_2O*

(Continued)

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Table 7 (Concluded)

equivalent and/or with CaO contents greater than 20%, may be used when their effectiveness in reducing expansion due to ASR is demonstrated in accordance with CSA A23.2-28A.

[d]*The minimum level of silica fume (as a percentage of the cementitious material content) is calculated on the basis of the alkali content corresponding to the Portland cement portion of the concrete (expressed as kg/m³ Na_2O equivalent), but in cases where silica fume is the only supplementary cementitious material to be used, the silica fume content shall not be less than 7.0% by mass. See example calculation.*
When using silica fume with highly-reactive aggregates, consideration should be given to using it in combination with fly ash and/or slag.
Example calculation: In a situation for which the requirement is prevention level Y, the following equation can be used: The proportion (%) of silica fume = 3 × alkali content in the concrete. To use a concrete with 375 kg/m³ of total binders, the following should be used:
The cementitious materials are

- *Cement at 0.80% Na_2Oeq; and*
- *Silica fume at 0.63% Na_2Oeq (meet requirements of Table 7 since Na_2Oeq is < 1%)*
  Let proportion of silica fume = SF%
  SF ≥ 3 × alkalis from Portland cement
  SF ≥ 3 × 375(100-SF)/100 × 0.80/100
  SF ≥ 3 × 375 × 100/100 x0.80/100 – 3 × 375 × SF/100 × 0.80/100
  SF ≥ 9 – 0.09 SF
  SF ≥ 9/1.09
  SF ≥ 8.26%, i.e. 8.3%

[e]*When using silica fume with highly-reactive aggregates, consideration should be given to using it in combination with fly ash and/or slag.*

[f]*For Prevention Level Z, silica fume may be used as the sole SCM when its effectiveness in reducing expansion due to ASR is demonstrated in accordance with the procedures and limits of CSA A23.2-28A.*

Notes:

1) *All SCMs shall be in compliance with CSA A3001.*
2) *Blended cements may be used provided that the proportions of the supplementary cementitious materials in the blend meet the requirements of Tables 6 and 7.*

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Attachment A1 (informative)
Sources of information

Note: *This Attachment is not a mandatory part of this Standard Practice.*

A1.1

It has been known for the past sixty years that expansion due to alkali-silica reaction could be reduced by the use of appropriate supplementary cementitious materials and slag (Stanton, 1940; Cox *et al.*, 1950; de la Barona, 1951; Buck *et al.*, 1953; Pepper and Mather, 1959). Many laboratory studies have confirmed this effect. Unfortunately, because laboratory studies usually accelerate the process and do not accurately represent actual conditions, there has been uncertainty as to the efficacy of the use of supplementary cementitious materials in preventing deleterious expansion in actual construction. There are few documented cases in which supplementary cementitious materials have been knowingly used to prevent excessive expansion of a reactive aggregate with high-alkali cement (Mather, 1993; Thomas *et al.*, 2012).

A1.2

The amounts of supplementary cementitious materials necessary to safely prevent deleterious expansion with alkali-silica reactive aggregates given in this Standard Practice are based on laboratory investigations, on field experience in Canada, the United Kingdom, and the United States, and on outdoor exposure studies using known reactive aggregates in Canada and the United Kingdom (Bleszynski *et al.*, 2000; Duchesne and Bérubé, 2001; Fournier *et al.*, 1999; Fournier *et al.*, 1996; Rogers *et al.*, 2000; Thomas, 1996a and 1996b; Shehata and Thomas, 2000 and 2002; Hooton *et al.*, 2013; Fournier *et al.*, 2016). Many other published and unpublished studies have also been used in compiling this Standard Practice. Additional information can be found in Clauses B.5.2.4 and B.5.2.5 of CSA A23.1.

A1.3

The development of this Standard Practice is described in Fournier *et al.*, 1999.

A1.4

The use of materials which are known only in laboratory studies to be effective at preventing deleterious expansion is not covered by this Standard Practice because such materials have not been proven by field performance demonstration and associated published studies to be effective in actual practice.

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Attachment A2 (informative)
Guidelines for evaluating the field performance of aggregates: Field and laboratory testing

Note: *This informative Attachment has been written in normative language to facilitate adoption where users of the Standard or regulatory authorities wish to adopt it formally as additional requirements to this Standard Practice.*

A2.1

A representative sample of the aggregate shall be supplied from the aggregate source. The aggregate shall be subjected to a complete petrographic examination in accordance with CSA A23.2-15A.

A2.2

A minimum of four structures shall be made available of inspection, where possible. When selecting these structures, consideration shall be given to the

a) age of the structure (in some cases the effects of AAR do not become visually apparent for several decades);
b) type of structure;
c) exposure condition; and
d) availability of construction records and material data (e.g., concrete mix design, source of cement and aggregate, and use of SCM).

A2.3

Where possible, the structures shall be selected on the basis of offering the worse-case condition for ASR (i.e., older structures exposed to moisture, with high cement contents, high-alkali cement, and no SCM).

A2.4

Following the visual inspection of the various structures, two of the structures shall be selected for sampling and subsequent laboratory testing. When selecting these structures, consideration shall be given to the issues discussed above, in addition to the results of the visual inspection. If one or more of the structures is obviously exhibiting signs of distress, these structures shall be selected for sampling, unless it is clear that the distress is due to some other mechanism (e.g., structural cracking, de-icer salt scaling, etc.). If symptoms typical of ASR are detected in more than two of the structures, then consideration shall be given to increasing the number of structures for detailed testing.

A2.5

A minimum of two cores (100 mm diameter × minimum 200 mm length) shall be taken from each of the structures selected for testing. Samples shall be prepared from each of the cores for the following tests:

a) petrographic examination of polished (lapped) and thin sections (in accordance with ASTM C856) to
   i) compare concrete aggregate with aggregate under investigation;
   ii) identify presence and extent of alkali-aggregate reaction; and
   iii) determine approximate cement content (including presence of fly ash or slag) and approximate w/cm;
b) cement content determination (ASTM C1084); and
c) alkali content: water-soluble (AASHTO T 105) and acid-soluble.

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A2.6

The overall planning, collection, analysis, and interpretation of information shall be conducted by a engineer or geologist who is experienced in assessing ASR in concrete structures.

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A23.2-28A
Standard Practice for laboratory testing to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete

1 Scope
This Standard Practice specifies the procedures for demonstrating the effectiveness of supplementary cementitious materials and lithium-based admixtures or combination thereof, in preventing excessive expansion caused by alkali-silica reaction. The supplementary cementitious materials are as defined in CSA A3001.

2 Reference publications
This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregate for use in concrete

A23.2-14A:19
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-25A:19
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-27A:19
Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

A3001-18
Cementitious materials for use in concrete

A3004-18
Test methods for cementitious materials for use in concrete and masonry

ASTM International

C494/C494M-17
Standard Specification for Chemical Admixtures for Concrete

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Other publication

Einarsdottir, S.U., and Hooton, R.D. 2018. Modifications to ASTM C1293 That Allow Testing of Low-Alkali Binder Systems for Mitigation, *ACI Materials Journal,* Vol. 115, No. 5, Sept., 739–747.

3 Definitions

In addition to the definitions in Clause 3 of CSA A23.1, the definitions of CSA A3001 apply in this Standard Practice.

4 Significance and use

4.1

Specifications for concrete require that the aggregates used in the concrete should not react with alkali hydroxides contained within the concrete to an extent that results in excessive or deleterious expansion of the concrete. This Standard Practice describes the procedures to be followed to demonstrate the effectiveness of supplementary cementitious materials or chemical admixtures in preventing excessive expansion caused by alkali-silica reaction. CSA A23.2-27A provides information to determine when such measures are necessary and identifies measures that may be taken without the need for confirmatory laboratory testing.

4.2

It has been found that when the steps provided in this Standard Practice are followed, an indication of the likely effectiveness of supplementary cementitious materials under investigation can be found. This is based on correlations of long-term performance of structures in service with laboratory testing of the materials used. Because of the inherent difficulties in obtaining representative samples of aggregates, hydraulic cements, supplementary cementitious materials, and cementitious hydraulic slag and because of the inherent variability of laboratory testing, there will always be some uncertainty as to the effectiveness of a specific supplementary cementitious material in a specific structure and environment. The proportion of supplementary cementitious materials to be used should always be selected so as to safely prevent damage due to alkali-silica reaction in a specific structure.

4.3

When the results obtained following this practice are used as an alternative to the requirements specified in CSA A23.2-27A, the supplementary cementitious material replacement levels should not be less than those of level W of Table 7 of CSA A23.2-27A in the presence of a moderately reactive aggregate, level X of Table 7 with a highly reactive aggregate and of level Y with extremely reactive aggregate.

5 Sampling

5.1

Samples of aggregates shall be taken in accordance with CSA A23.2-1A.

5.2

Samples of cement and supplementary cementitious materials to be evaluated shall be taken following the general principles of CSA A3004-A1.

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6 Materials

6.1

When the evaluation of the effectiveness of proposed measures are to be investigated for use with specific aggregates, the aggregates of concern shall be tested individually (fine or coarse) or in combination (fine and coarse). When a single aggregate is tested, the accompanying fine or coarse fraction shall be non-reactive (as defined in CSA A23.2-14A). Combinations of coarse and fine aggregate shall not be tested in CSA A23.2-25A. When the procedure described in this Standard Practice is used, each aggregate shall be tested separately in CSA A23.2-25A.

6.2

When the effectiveness of a supplementary cementitious material or combination of supplementary cementitious materials for general use is to be evaluated with various aggregates (or combinations of aggregates), the aggregate to be used shall be Spratt reactive limestone. Alternatively, another reactive aggregate with a demonstrated expansion level of at least 0.12% at 1 year, when tested in accordance with CSA A23.2-14A, and not less than 0.30% expansion at 14 d when tested in accordance with CSA A23.2-25A, may be substituted for the Spratt aggregate. When the effectiveness of the proposed preventive measures is to be assessed for aggregates that give greater expansion than the Spratt aggregate, the more expansive aggregate shall be tested. When individual coarse or fine aggregates are to be evaluated, an accompanying non-reactive (fine or coarse) aggregate meeting the requirements of CSA A23.2-14A shall be used.

6.3

When CSA A23.2-14A is used to evaluate the effectiveness of a supplementary cementitious material or combination of supplementary cementitious materials, cements with an alkali content greater than 1.00% Na_2O equivalent may be used (see Clause 7.2.1.1).

6.4

When CSA A23.2-14A is used to evaluate the effectiveness of using either a lower alkali loading, or a combination of supplementary cementitious materials with a cement having an alkali content of less than 0.80%, the alkali loading of the concrete shall be increased by 40% above that provided by the cement (see Clause 7.2.1.1.3).

Note: *The 40% increase in alkali content is approximately equivalent to that of a 0.9% alkali cement increased to 1.25% and has been shown to adequately compensate for alkali leaching during the period of expansion measurements.*

6.5

When evaluating the effectiveness of lithium-based admixtures, the general qualification of the material and dose using Spratt aggregate or other known reactive aggregate shall not be permitted. The effectiveness of such admixtures shall be evaluated on the specific coarse and fine aggregates intended for use in the work.

7 Testing

7.1 Test methods

The materials to be evaluated shall be tested for two years in accordance with CSA A23.2-14A or, if sufficient time is not available, for 14 d in accordance with CSA A23.2-25A. When decisions are based on the results obtained from CSA A23.2-25A, a program of testing using CSA A23.2-14A shall be started at

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the same time to validate those results. The evaluation of any material intended for use in controlling alkali-aggregate reaction that does not meet the requirements of CSA A3001 shall be carried out using CSA A23.2-14A.

When evaluating the effectiveness of a fly ash with total alkalis content greater than 4.5% or a lithium-based admixture, CSA A23.2-14A shall be used.

7.2 Mixture design

7.2.1 Concrete mixtures

7.2.1.1 Mixtures incorporating supplementary cementitious materials

7.2.1.1.1 General

In designing concrete mixtures for evaluation, the mixture proportions specified in Clause 9 of CSA A23.2-14A shall be used, except for the modifications indicated hereafter. In summary,

a) The nominal total cementitious materials content shall be 420 kg/m^3 (as per CSA A23.2-14A) and supplementary cementitious materials are used as partial substitution, by mass, for the cement. For example, a 20% fly ash concrete mixture will include 84 kg/m^3 of fly ash and 336 kg/m^3 of cement. The cement used in combination with the SCMs shall be type GU Portland cement, unless the purpose of testing is to evaluate a specific combination of other types of hydraulic cements and SCMs.
b) The *w/cm* shall be maintained in the range of 0.42 to 0.45 by mass. The *w/cm* shall be adjusted within this range to give sufficient workability to permit satisfactory compaction of the concrete in the moulds without segregation. If, within the specified *w/cm* range, specimens representative of the concrete mixture cannot be fabricated due to excessive bleeding or segregation, a viscosity modifying admixture (VMA) may be used. The *w/cm* ratio used and the amount and type of admixture used, if any, shall be reported.
c) When it is proposed to evaluate the effectiveness of mixtures that contain silica fume or metakaolin in accordance with CSA A23.2-14A, a high-range water-reducing admixture meeting the requirements of specification ASTM C494/C494M Type F shall be added to achieve proper dispersion of the silica fume or metakaolin.
d) The alkali content of the mixture shall be adjusted by the addition of NaOH to the mixture water as detailed below. The amount of alkalis to be added shall be determined based on the mass of Portland cement in the mixture. In the case of evaluating the effectiveness, in preventing ASR expansion, of blended hydraulic cements composed of one or more SCMs, information shall be obtained from the producer about the clinker content and its alkali content in the blended cement in order to calculate alkali additions.

7.2.1.1.2 Adjusting alkali content in mixtures incorporating SCMs combined with cements of 0.80–1.00% alkali

For cements with an alkali content up to 1.00% Na_2Oeq, the alkali content of the mixture shall be adjusted to 1.25% based on the mass of Portland cement used in the mixture, but not for supplementary cementitious material that is substituting for Portland cement.

Note: *A sample calculation for determining the amount of NaOH to be added to the mix water to increase the alkalis content of the cement from 0.90% to 1.25% for concrete containing 25% fly ash is as follows:*

a) *Portland cement content of 1 m^3 of concrete = 315 kg/m^3 (i.e., 75% of 420 kg/m^3);*
b) *amount of Portland cement alkali in the concrete = 315 × 0.90% = 2.84 kg Na_2Oe;*
c) *specified amount of Portland cement alkali in concrete = 315 × 1.25% = 3.94 kg Na_2Oe;*

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d) *the difference (1.1025 kg) is the amount of alkali expressed as Na_2O equivalent to be added to the mix water;*
e) *factor to convert Na_2O to NaOH: ($Na_2O + H_2O$ to 2NaOH);*
f) *molecular weight: Na_2O = 61.98, NaOH = 39.997;*
g) *conversion factor: 2 × 39.997/61.98 = 1.291; and*
h) *amount of NaOH required: 1.1025 × 1.291 = 1.423 kg/m³.*

7.2.1.1.3 Adjusting alkali content in mixtures incorporating SCMs combined with cements of greater than 1.00% alkali

When evaluating cementitious combinations for ASR mitigation where the specific cement proposed for use on the project (the project cement) has an alkali content greater than 1.00% Na_2Oeq, the project cement shall be used in the test and the alkali content corresponding to the Portland cement component of the mixture shall be adjusted by the addition of NaOH to the mixture water to obtain an alkali content of 0.25% above that of the cement alkali content.

Note: *A sample calculation for determining the amount of NaOH to be added to the mix water to increase the alkalis content of the cement from 1.15% to 1.40% for concrete containing 25% fly ash is as follows:*

a) *Portland cement content of 1 m³ of concrete = 315 kg/m³ (i.e., 75% of 420 kg/m³);*
b) *amount of Portland cement alkali in the concrete = 315 × 1.15% = 3.623 kg Na_2Oe;*
c) *specified amount of Portland cement alkali in concrete = 315 × 1.40% = 4.410 kg Na_2Oe;*
d) *the difference (0.787 kg) is the amount of alkali expressed as Na_2O equivalent to be added to the mix water;*
e) *factor to convert Na_2O to NaOH: ($Na_2O + H_2O$ to 2NaOH);*
f) *molecular weight: Na_2O = 61.98, NaOH = 39.997;*
g) *conversion factor: 2 × 39.997/61.98 = 1.291; and*
h) *amount of NaOH required: 0.787 × 1.291 = 1.016 kg/m³.*

7.2.1.1.4 Adjusting alkali content in mixtures with Portland cements of less than 0.80% alkali with or without SCMs or concretes with a low alkali loading

When evaluating cements or cementitious combinations for ASR mitigation where the project cement has an alkali content lower than 0.80% Na_2Oeq, or when concrete is to be made with a cementitious materials content of less than 420 kg/m³, the project cement shall be used in the test and the alkali content corresponding to the Portland cement component of the mixture shall be adjusted by the addition of NaOH to the mixture water to obtain an alkali content of 40% above that of the cement alkali content.

Note: *A sample calculation for determining the amount of NaOH to be added to the mix water to increase the alkalis content of the cement by 40% for concrete using a cement with 0.70% alkali content, containing 25% fly ash is as follows:*

a) *Portland cement content of 1 m³ of concrete = 315 kg/m³ (i.e., 75% of 420 kg/m³);*
b) *amount of Portland cement alkali in the concrete = 315 × 0.70% = 2.205 kg Na_2Oe;*
c) *specified amount of Portland cement alkali in concrete = 315 × (1.40 × 0.70%) = 3.087 kg Na_2Oe;*
d) *the difference (0.882 kg) is the amount of alkali expressed as Na_2O equivalent to be added to the mix water;*
e) *factor to convert Na_2O to NaOH: ($Na_2O + H_2O$ to 2NaOH);*
f) *molecular weight: Na_2O = 61.98, NaOH = 39.997;*
g) *conversion factor: 2 × 39.997/61.98 = 1.291; and*
h) *amount of NaOH required: 0.883 × 1.291 = 1.140 kg/m³.*

More information can be found in Einarsdottir and Hooton (2018).

7.2.1.2 Mixtures incorporating lithium-based admixtures

When designing concrete mixtures for evaluation, the alkali content of the mixture shall be adjusted by the addition of NaOH to the mixture water as described in Clause 9 of CSA A23.2-14A. The cement used in combination with the lithium-based admixture (with or without SCMs) shall be type GU Portland cement, unless the purpose of testing is to evaluate a specific combination of lithium-based admixtures

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and other types of hydraulic cements and SCMs. Water-to-cementitious materials ratios should be adjusted within the range of 0.35 to 0.42 to achieve a slump within the range of 50 mm to 80 mm. Where the admixture is in the form of a lithium salt in solution with water (e.g., a 30% solution of lithium nitrate, which is the most common form of lithium currently available), the free water content of the admixture shall be considered as part of the mixture water and included in the calculation of the water-to-cementitious materials ratio. When testing a lithium-based admixture in combination with supplementary cementitious materials, the water-to-cementitious materials ratios given in Clause 7.2.1.1 shall be used, as appropriate.

Note: *As mentioned in the Clause B.5.2.6 of CSA A23.1, a lithium-to-alkali molar ratio of 0.74 is often referred as the standard molar ratio. A sample calculation for determining the amount of a 30% solution of $LiNO_3$ to be added to the mix water to achieve a lithium to equivalent alkali molar ratio of 0.74 is given as follows:*

a) *Portland cement content of 1 m³ of concrete = 420 kg/m³;*
b) *amount of Portland cement alkali in the concrete = 420 × 1.25% = 5.25 kg Na_2Oe;*
c) *molecular weight: Na_2O = 61.98, $LiNO_3$ = 68.94;*
d) *conversion factor: 2 × 68.94/61.98 = 2.225 (to provide 1 mole Li for each mole Na);*
e) *amount of $LiNO_3$ required (for Li/Na = 0.74 molar ratio) = 5.25 × 0.74 × 2.225 = 8.64 kg/m³;*
f) *amount of 30.0% $LiNO_3$ solution required = 8.64/0.30 = 28.8 kg/m³; and*
g) *amount of water in 28.83 kg of 30% $LiNO_3$ solution = 28.81 × 70% = 20.17 kg/m³ (this amount of water needs to be subtracted from the mix water).*

7.2.2 Mortar mixtures

7.2.2.1 Mixtures incorporating supplementary cementitious materials

In designing mortar mixtures for evaluation, the mixture proportions of CSA A23.2-25A shall be used. The quantities of dry materials to be mixed at one time in the batch of mortar for making three specimens shall be 1 part of cementitious materials (hydraulic cement plus SCMs for a total of 440 g) to 2.25 parts of graded aggregate by mass (total of 990 g). The supplementary cementitious materials are used as partial substitution, by mass, of the cement. For example, a 20% fly ash concrete mixture will include 88 g of fly ash and 352 g of cement. The cement used in combination with the SCMs shall be type GU Portland cement, unless the purpose of testing is to evaluate a specific combination of other types of hydraulic cements and SCMs.

For natural fine aggregates, a water-to-cementitious materials ratio equal to 0.44 by mass shall be used. For crushed coarse aggregates or manufactured sands, a water-to-cementitious materials ratio equal to 0.50 by mass shall be used. When evaluating the effectiveness of mixtures that contain silica fume or metakaolin in accordance with CSA A23.2-25A, the water-to-cementitious materials ratio given in CSA A23.2-25A shall be used and, if required, sufficient high-range water-reducing admixture meeting the requirements of ASTM C494/C494M Type F shall be added to provide proper dispersion and workability of the mixture to enable compaction and consolidation without segregation.

7.2.2.2 Mixtures incorporating lithium-based admixtures

CSA A23.2-25A is not suitable, in its current form, for evaluating the effectiveness of lithium-based admixtures against ASR [see Clause B.5.2.6 of CSA A23.1 (Annex B)].

7.3 Production and testing of concrete and mortar specimens

7.3.1 Concrete specimens

The preparation and storage of test specimens, as well as the measurements and calculations of length changes, shall be made in accordance with Clauses 9 to 13 of CSA A23.2-14A.

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7.3.2 Mortar specimens

The preparation and storage of test specimens, as well as the measurements and calculations of length changes, shall be made in accordance with Clauses 9.4, 10, and 12 of CSA A23.2-25A.

8 Reporting requirements

Data shall be reported as specified in CSA A23.2-14A and CSA A23.2-25A and any deviations from the test methods shall also be reported. The expansion data obtained using Spratt aggregate (or an alternative material) as a control shall be reported at the same time as data reported for the proposed preventive measure(s).

When reporting the results from tests for evaluating lithium-based admixtures in accordance with CSA A23.2-14A, both the dose and the composition of the admixture shall be reported. Any addition of water reducing admixtures and the dosage shall be reported.

9 Evaluation

In evaluating the effectiveness of a proposed measure, the following criteria shall be used: an expansion of less than 0.040% at two years when tested in accordance with CSA A23.2-14A or, if that result is not available, an expansion less than 0.10% at 14 d when tested in accordance with CSA A23.2-25A shall be deemed to show that the proposed material in that combination is effective. In cases of disagreement between the two tests, the results obtained using CSA A23.2-14A shall govern.

10 Quality control process

10.1

Effectiveness of any measure can change because of changes in the nature of the aggregate being produced or changes in the physical or chemical properties of the specific supplementary cementitious material, natural pozzolan, or admixture intended for use in controlling alkali-aggregate reaction. In order to ensure the continued effectiveness of any proposed measure, periodic testing shall be conducted. This testing shall, as a minimum, be done every 6 months and at any time that it is known that the aggregate or the specific material being used to control deleterious alkali-aggregate reaction has changed.

10.2

For the purpose of determining if significant change has taken place, the following criteria may be used:

a) Fly ash is deemed to have changed if the CaO increases by more than 2% or the alkali content increases by more than 0.5% above that of the fly ash tested.
b) Slag is deemed to have changed if the alkali content increases by more than 0.5% above that of the slag tested.
c) Silica fume is deemed to have changed if the SiO_2 content decreases by more than 5% below that of the silica fume tested or the alkali content increases by more than 0.5% above that of the silica fume tested.
d) Changes in aggregate can be detected by significant changes in petrographic composition, chemistry, or physical properties. These changes can be caused by changes in processing or changes in the location or elevation of the extraction of the aggregate. Increases in expansivity when tested in accordance with CSA A23.2-14A greater than 0.03%, or greater than 0.05% when tested in accordance with CSA A23.2-25A, represent a significant change.

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10.3

Provided that CSA A23.2-14A has been used and has shown the efficacy of the measure, CSA A23.2-25A shall be used to show that the measure continues to be effective. The expansion obtained with CSA A23.2-25A at 14 d shall not be greater than 125% of the expansion measured at the time CSA A23.2-14A was conducted. Expansion greater than this amount shall require that the proposed measure be revalidated using this Test Method. The expansion obtained with CSA A23.2-25A at 14 d shall not be greater than 0.10%. Expansion greater than this amount shall require that the proposed measure be revalidated using CSA A23.2-14A.

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A23.2-29A
Test method for the resistance of coarse aggregate to degradation by abrasion in the Micro-Deval apparatus

1 Scope
This Test Method specifies the procedure for testing coarse aggregate for resistance to abrasion using the Micro-Deval apparatus.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-23A:19
Test method for the resistance of fine aggregate to degradation by abrasion in the Micro-Deval apparatus

A23.2-30A:19
Standard Practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

ASTM International

C670-15
Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

D6928-17
Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

Other publication

Vasavithasan, M., and Rogers, C.A. 2006. Precision of Aggregate Test methods; does Laboratory Inspection Reduce Multilaboratory Variation? *Annual Symposium of International Center for Aggregate Research,* Austin, Texas.

3 Summary
The Micro-Deval abrasion test is a measure of abrasion resistance and durability of mineral aggregates resulting from a combination of actions, including abrasion and grinding with steel balls in the presence

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of water. A sample with standard grading is initially soaked in water for not less than 1 h. The sample is then placed in a jar mill with 2.0 L of water and an abrasive charge consisting of 5000 g of 9.5 mm diameter steel balls. The jar, aggregate, water, and charge are revolved at 100 revolutions/minute for 2 h. The sample is then washed and oven-dried. The loss is the amount of material passing the 1.25 mm sieve expressed as a percentage by mass of the original sample.

4 Definition

In addition to the definitions specified in CSA A23.1, the following definition applies in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

5 Significance and use

5.1

The Micro-Deval abrasion test is used for coarse aggregates to determine their abrasion loss in the presence of water and an abrasive charge. Many aggregates are weaker and less resistant to abrasion when wet than when dry and the use of water in this test measures this reduction in resistance to degradation, in contrast to other tests conducted on dry aggregate. This Test Method furnishes information helpful in judging the toughness, abrasion resistance, durability, and soundness of coarse aggregate subject to abrasion and weathering action when adequate information is not available from service records. It is capable of detecting aggregates that can degrade during handling and mixing.

5.2

The Micro-Deval abrasion test is useful for detecting changes in properties of aggregate produced from a source as part of a quality control or quality assurance process.

6 Apparatus and supplies

6.1

The apparatus shall consist of the following:

a) a jar rolling mill capable of rotating Micro-Deval abrasion jars at 100 ± 5 r/min, as described in CSA A23.2-23A shall be used.

   Note: *Micro-Deval abrasion machine fitted with a counter may be used if the test is conducted on the basis of number of revolutions (Clause 8).*

b) stainless steel Micro-Deval abrasion jars, as described in CSA A23.2-23A;

c) magnetic stainless steel balls with a diameter of 9.5 ± 0.5 mm (each jar shall have a charge of 5000 ± 5 g of balls);

d) sieves with square openings of the following sizes conforming to ISO 3310-1 made with the preferred wire diameter: 20 mm, 14 mm, 10 mm, 5 mm, and 1.25 mm;

e) an oven, capable of maintaining a temperature of 110 ± 5 °C; and

f) a balance or scale accurate to 1 g.

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6.2 Reference aggregate

6.2.1

Standard Drain Brothers' Stoney Lake Quarry coarse aggregate shall be tested using the grading shown in Table 1 running the machine in accordance with Clause 9 d) i) or e) i).

Note: *A supply of standard Drain Brothers' Stoney Lake Quarry coarse aggregate is available from the Soils and Aggregates Section, Materials Engineering and Research Office, Ministry of Transportation (Soils-Aggregates@ontario.ca).*

Table 1
Grading of reference aggregate
(See Clause 6.2.1.)

Sieve fraction, mm	Retained, %
20–14	45
14–10	35
10–5	20

6.2.2

For continued acceptance of data, individual reference material test data shall fall within the range 11.4% to 14.8% loss, 95% of the time.

Note: *The mean loss of the Drain Brothers' Stoney Lake Quarry reference aggregate (see Clause 11.1) prepared to the grading shown in Clause 6.2.1 in multi-laboratory study of the Micro-Deval test is 13.1%.*

6.3 Calibration aggregate

There shall be an adequate supply of aggregate, established by the laboratory to use for calibration of the Test Method (see Clause 11.1).

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Test sample

8.1

A sample of the aggregate to be tested shall be obtained in accordance with CSA A23.2-1A.

8.2

Bulk samples shall be reduced to test specimen size in accordance with the procedures of CSA A23.2-2A, omitting where relevant the requirement about not preparing samples of an exact predetermined mass.

8.3

The test sample shall be washed and oven-dried at 110 ± 5 °C to substantially constant mass. In the case of a mixture of fine and coarse aggregate not meeting the individual requirements of Table 11 of CSA A23.1 or coarse aggregate with more than 15% passing the 5 mm sieve, the material shall be

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separated into two sizes on the 5 mm sieve. The coarse fraction shall be separated into individual size fractions following CSA A23.2-2A, and recombined to the grading as shown in Clause 8.4.

Note: *See Clause 6.2 of CSA A23.2-30A.*

8.4

Aggregate for the test shall normally consist of material passing the 20 mm sieve, retained on the 10 mm sieve. An oven-dried sample of 1500 ± 5 g shall be prepared as follows:

Passing, mm	Retained, mm	Mass, g
20	14	750
14	10	750

8.5

In a case where the nominal maximum size of the coarse aggregate is less than 20 mm, a sample of 1500 ± 5 g shall be prepared as follows:

Passing, mm	Retained, mm	Mass, g
14	10	750
10	5	750

8.6

In a case where the nominal maximum size of the coarse aggregate is less than 14 mm, a sample of 1500 ± 5 g shall be prepared as follows:

Passing, mm	Retained, mm	Mass, g
10	5	1500

9 Test procedure

The procedure shall be as follows:

a) Prepare a representative 1500 ± 5 g sample. Record the mass A to the nearest 1 g.

b) Saturate the sample in 2.0 ± 0.05 L of tap water (temperature 20 ± 5 °C) for a minimum of 1 h either in the Micro-Deval container or some other suitable container.

c) Place the sample in the Micro-Deval abrasion container with 5000 ± 5 g of steel balls and the water. Place the Micro-Deval container on the machine.

d) Run the machine at 100 ± 5 r/min for
   i) 120 ± 1 min for the grading shown in Clause 8.4;
   ii) 105 ± 1 min for the grading shown in Clause 8.5; or
   iii) 95 ± 1 min for the grading shown in Clause 8.6.

   Note: *The different times of testing for different gradings have been selected so as to normalize the results.*

e) When a revolution counter is available, run the machine for
   i) 12 000 ± 100 revolutions for the grading shown in Clause 8.4;
   ii) 10 500 ± 100 revolutions for the grading shown in Clause 8.5; or
   iii) 9500 ± 100 revolutions for the grading shown in Clause 8.6.

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f) Carefully pour the sample over two superimposed sieves: 5 mm and 1.25 mm. Take care to remove the entire sample from the stainless steel jar. Wash and manipulate the retained material with water using a hand-held water hose until the washings are clear and all material smaller than 1.25 mm passes the sieve. Remove the stainless steel balls using a magnet or other suitable means. Discard material smaller than 1.25 mm.
g) Combine the material retained on the 5 mm and 1.25 mm sieves, being careful not to lose any material.
h) Oven-dry the sample to constant mass at 110 ± 5 °C.
i) Weigh the sample to the nearest 1 g. Record the mass B.

10 Calculations

The Micro-Deval abrasion loss shall be calculated to the nearest 0.1%, as follows:

$$\text{Loss, \%} = \frac{A - B}{A} \times 100$$

11 Use of reference and calibration aggregates

Note: *See Attachment A for guidance concerning reference aggregates for the calibration of this Test Method.*

11.1

The laboratory shall establish an adequate supply of material to use for calibration of this Test Method. A suitable material with a loss of between 10 and 25% shall be established. From this material, ten samples shall be taken randomly and tested. At the same time, ten samples of reference aggregate from Drain Brothers' Stoney Lake Quarry (see Clause 6.2) shall also be tested. Provided the mean loss and variation of the Drain Brothers' Stoney Lake Quarry aggregate is within allowed tolerance specified in Clause 6.2.2, the mean value obtained with the supply of the in-house calibration aggregate shall be used thereafter. At any time a new supply is required, the calibration procedure shall be conducted.

11.2

When test data of the calibration aggregate is outside the limits, an investigation as to the probable cause shall be conducted. The equipment shall be re-calibrated and the testing technique re-examined to detect non-conformance with the test procedure.

11.3

For every ten samples, but at least every week in which a sample is tested, a sample of the calibration aggregate shall be tested. The material shall be taken from a stock supply and prepared in accordance with Clause 8.4. When twenty samples of calibration material have been tested and the results show satisfactory variation, the frequency of testing may be changed to a minimum of one sample every month.

11.4

The percentage of loss of the last 20 samples of calibration aggregate shall be plotted on a trend chart in order to monitor the variation in results (see Figure 1).

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12 Reporting

12.1 Required information

The following information shall be included in the test report, as applicable:

a) maximum size of the aggregate tested and the grading used;
b) percentage of loss of the test sample, to 0.1%;
c) percentage of loss of the calibration aggregate, tested closest to the time at which the aggregate was tested, to 0.1%;
d) percentage of loss of the last twenty samples of calibration aggregate on a trend chart (see Figure 1);
e) name of the certified technician who performed the test;
f) identification of the certified laboratory that performed the test (i.e., name and address);
g) signature of the person responsible for the laboratory performing the test; and
h) any deviations from the test procedure.

12.2 Optional information

The following information may be included in the test report:

a) name of person or organization who sampled the aggregate; and
b) date the sample was taken;

13 Precision and bias

13.1 Precision

For 20 mm maximum size aggregate with abrasion losses in the range from 5% to 23%, the single operator coefficient of variation has been found to be 3.4*. Therefore, results of two properly conducted tests on samples of the same aggregate by the same operator using the same equipment are not expected to differ by more than 9.5%* of their average, 95% of the time. The multi-laboratory coefficient of variation has been found to be 5.5%*. Therefore, the results of two properly conducted tests by different laboratories on samples of the same aggregate are not expected to differ by more than 15.4%* of their average, 95% of the time.

* *These numbers represent, respectively, the (1s %) and (d2s %) limits as described in ASTM C670.*

Note: *The source of the data to prepare this statement is Vasavithasan and Rogers, 2006. In addition, more recent data from the Ontario Ministry of Transportation has been incorporated to revise the multi-laboratory precision statement.*

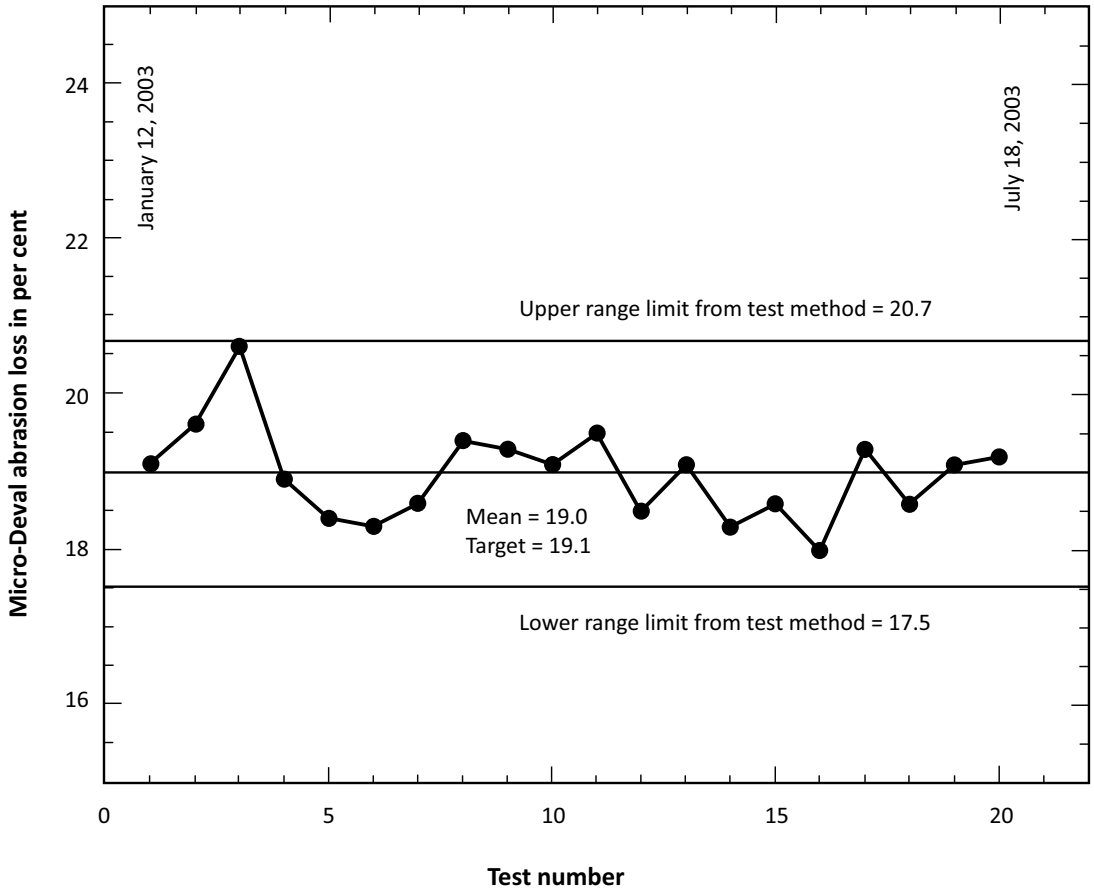
13.2 Bias

The procedures in this Test Method for measuring resistance to abrasion have no bias because the resistance to abrasion can only be defined in terms of this Test Method.

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Figure 1
Micro-Deval abrasion trend chart for calibration aggregate samples
(See Clauses 11.4 and 12.1.)



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Attachment A
Material for calibration of Test Method

Note: *This Attachment is not a mandatory part of this Test Method.*

The laboratory should establish an adequate supply of material to use for calibration of this Test Method, having a loss of between 10% and 25 %. From this material, 10 samples should be taken randomly and tested. At the same time 10 samples of the reference aggregate (see Clause 6.2) should also be tested. Provided that the mean loss and variation of the reference Micro-Deval fine aggregate is within the allowed tolerance given in Clause 6.2.2, the mean value and range obtained with the supply of the in house calibration aggregate should be used thereafter. At any time a new supply is required, the calibration procedure should be conducted.

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A23.2-30A
Standard Practice for sampling, testing, and inspection of aggregate products for use in concrete for qualification and acceptance purposes

1 Scope

This Standard Practice specifies the procedures for sampling, testing, and inspection of aggregates for use in concrete for purposes of assessing compliance with this Standard or for qualification and acceptance by the owner.

2 Reference publications

This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1A:19
Sampling aggregate for use in concrete

A23.2-2A:19
Sieve analysis of fine and coarse aggregate

A23.2-3A:19
Clay lumps in natural aggregate

A23.2-5A:19
Amount of material finer than 80 µm in aggregate

A23.2-6A:19
Relative density and absorption of fine aggregate

A23.2-7A:19
Test for organic impurities in fine aggregates for concrete

A23.2-9A:19
Soundness of fine and coarse aggregate by use of magnesium sulphate

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-13A:19
Flat and elongated particles in coarse aggregate

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A23.2-14A:19
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-15A:19
Petrographic examination of aggregates

A23.2-16A:19
Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine

A23.2-17A:19
Resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine

A23.2-23A:19
Test method for the resistance of fine aggregate to degradation by abrasion in the Micro-Deval apparatus

A23.2-24A:19
Test method for the resistance of unconfined coarse aggregate to freezing and thawing

A23.2-25A:19
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-27A:19
Standard Practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

A23.2-28A:19
Standard Practice for laboratory testing to demonstrate the effectiveness of supplementary cementitious materials and lithium-based admixtures to prevent alkali-silica reaction in concrete

A23.2-29A:19
Test method for the resistance of coarse aggregate to degradation by abrasion in the Micro-Deval apparatus

A23.2-24C:19
Standard practice for sampling, testing, and inspection of concrete for qualification purposes

A23.2-25C:19
Standard practice for sampling, testing, and inspection of concrete for acceptance purposes

ASTM International

C666/C666M-15
Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C1646/C1646M-16
Standard Practice for Making and Curing Test Specimens for Evaluating Resistance of Coarse Aggregate to Freezing and Thawing in Air-entrained Concrete

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BNQ (Bureau de normalisation du Québec)

2621-905/2018

Béton prêt à l'emploi — Programme de certification (élaboré à partir des exigences des chapitres 4, 5, 8 et 9 de la norme CSA A23.1-F14/A23.2-F14)

Other publication

Stark, D. 1976. Characteristics and Utilization of Coarse Aggregates Associated with D-cracking. PCA RD47.01p. Skokie, IL: Portland Cement Association. Reprinted in ASTM 597, 41–58.

3 Summary

The sampling procedures described are intended for use in the procurement of samples of aggregate products after they have been manufactured and are ready for use in concrete. The sampling procedures are not intended for quality control purposes during manufacture. These procedures specify the amount of testing to be done and the requirements for reporting on the conformance or non-conformance of products complying with specifications. See Clause 10.

This Standard Practice comprises both qualification testing and testing during construction. Qualification testing is intended to assess the properties and characteristics of an aggregate product in advance of its use on a project, for the purpose of determining whether the proposed product complies with the requirements of this Standard, and whether it is acceptable to the owner. Testing during construction is intended to assess the properties and characteristics of an aggregate product as incorporated into the project, for the purpose of determining compliance with the requirements of this Standard and its acceptability to the owner.

4 Aggregate test procedures

4.1

Laboratory test procedures undertaken to assess concrete aggregate quality shall be carried out by a testing laboratory meeting the requirements of Clause 4.4.1.6 of CSA A23.1.

Note: *Depending on the nature and scope of the project, the owner may accept internal test results from the aggregate supplier for qualification purposes if personnel are certified in accordance with Clause 4.4.1.6 of CSA A23.1 and testing is carried out in accordance with the applicable procedures in CSA A23.2.*

4.2

Field sampling and test procedures undertaken to assess aggregate quality shall be carried out in accordance with the requirements of the applicable procedures in CSA A23.2 by a laboratory and personnel certified to the requirements of Clauses 4.4.1.6 and 4.4.1.7 of CSA A23.1.

5 Equipment and materials

The equipment and materials for sampling and testing shall meet the requirements of the applicable test methods of CSA A23.2, unless otherwise specified in this Standard Practice.

6 Samples

6.1 General

Tests of aggregate products manufactured for use in concrete shall be conducted on single or composite samples taken, identified, and prepared in accordance with this Standard Practice and CSA A23.2-1A.

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6.2 Combined aggregate gradation

Clause 4.2.3.5.3 of CSA A23.1 allows for the use of a combined aggregate grading. For the purposes of sample preparation, testing, and establishing compliance with the applicable requirements of CSA A23.1, a combined aggregate not meeting the individual requirements of Table 10 or 11 of CSA A23.1 shall be separated into its fine and coarse components using the 5 mm size as the boundary between coarse and fine fractions. The fine component of any coarse aggregate containing more than 15% by dry mass passing the 5 mm sieve shall be tested as a fine aggregate to show compliance with the requirements of Table 12 and other aggregate requirements of CSA A23.1, including those for alkali-aggregate reactivity detailed in A23.2-27A.

Each of the coarse and fine fractions of the combined-aggregate shall be handled and weighed separately to maintain uniformity. In order to establish the complete aggregate gradation a full set of standard coarse and fine aggregate sieves shall be utilized for testing of all aggregates to be incorporated into the final mix.

Material from all aggregate sources passing the 5 mm sieve shall be tested individually, or combined in the proportions to be used in the concrete mixture, and the blend tested as a fine aggregate to show compliance with the requirements of Table 12 and other aggregate requirements of CSA A23.1, including those for alkali-aggregate reactivity as detailed in CSA A23.2-27A.

Material from all aggregate sources retained on or above the 5 mm sieve shall be tested individually, or combined in the proportions to be used in the concrete mixture, and the blend tested as a coarse aggregate to show compliance with the requirements of Table 12 and other aggregate requirements of CSA A23.1, including those for alkali-aggregate reactivity detailed in CSA A23.2-27A.

Where the combined aggregate is used for the purpose of demonstrating compliance with this Clause or with the physical requirements of Table 12 of CSA A23.1, the producer shall develop data that show conformance over the range of aggregate proportions to be used.

The concrete producer shall provide the owner with test data in accordance with this Standard Practice and CSA A23.2-24C to demonstrate that the aggregate will produce concrete of acceptable quality that meets all the applicable requirements of this Standard. Assessment of performance should include, but not be limited to, compressive strength, durability, and other properties applicable to the specified exposure class in accordance with Clause 4.1.1.1.1 of CSA A23.1.

6.3 Uniformity

The aggregate manufacturer shall have in place a system of production control to maintain uniformity. The records held by the aggregate producer shall indicate what quality control procedures are in operation during the production of the aggregate.

To control the grading of the aggregate combined at mix design proportions, every sieve analysis result shall meet the two following criteria:

a) the fineness modulus of the combined aggregate proportioned as intended to be used in the concrete mix shall not vary more than ± 0.30 from the initially established value; and
b) the permissible variation of the amount passing on each sieve size in the total gradation shall be as follows:
   i) ± 10 percentage points for sieve sizes greater than 5 mm;
   ii) ± 6 percentage points for sieve sizes 5 mm to 0.315 mm; and
   iii) ± 2 percentage points for sieve sizes < 0.315 mm.

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7 Testing for quality control during production

7.1

The aggregate manufacturer shall ensure that the aggregate product meets the requirements of Clause 4.2.3 of CSA A23.1.

7.2

Where quality control at the production facilities is done by test methods other than those specified in CSA A23.1 and CSA A23.2 (e.g., ASTM or others), tests shall be conducted in accordance with the methods stipulated in those test methods as applicable. The tests shall be performed at the intervals required to confirm the adequacy of these other methods and to furnish the typical test data or certificate, or both, as defined in the appropriate product specification.

8 Testing for qualification and acceptance

8.1 Inspection, sampling, and testing — General

The aggregate product shall be subject to inspection, sampling, and testing by the owner at the place of manufacture, at the point of shipment, or on delivery. Reasonable access to the premises for purposes of inspection and for the selection of samples shall be available to the owner.

8.2 Sampling, identification, and transportation of samples

Sampling, identification, and transportation of samples shall be conducted in accordance with CSA A23.2-1A.

Where the owner requires testing of the product for compliance to CSA A23.1 for qualification or acceptance purposes, the tests shall be made on samples of lots of bulk or bagged products that are individually identifiable.

8.3 Testing

Testing for qualification or acceptance purposes shall be done in accordance with this Standard Practice and the applicable test procedures and standard practices of CSA A23.2.

8.4 Laboratory certification

Tests used for purposes of assessing compliance with this standard or for acceptance of aggregate products shall be conducted by a laboratory certified to the requirements of Clause 4.4.1.6 of A23.1. Laboratory and field personnel shall meet the requirements of Clauses 4.4.1.6 and 4.4.1.7 of A23.1, respectively.

8.5 Frequency of testing

8.5.1

As a minimum, testing to verify compliance with the requirements of Clauses 4.2.3.3, 4.2.3.4, 4.2.3.6, 4.2.3.7, and 4.2.3.8 and Tables 10 to 12 of CSA A23.1 shall be conducted on a yearly basis and the test results shall be made available to the owner upon request. In the case of aggregate stored in stockpiles or similar distinct and identifiable lots, test results older than one year may be accepted by the owner when the supplier provides affirmation that the results submitted pertain to the identified lot and are representative of current supply.

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8.5.2

For new sources of aggregate, all testing to verify compliance shall be completed and be shown to meet the applicable requirements prior to use in concrete.

Notes:

1) *For guidance on frequency of testing to demonstrate compliance with Clause 4.2.3.6.1 of CSA A23.1, see Clause B.7.2, Items f) and g).*
2) *The frequency of testing will vary depending on the nature of the source of the aggregate and type of construction. In some cases (e.g., sieve analysis and washing for material finer than 80 µm), testing on a daily basis might be necessary.*
3) *The period of time for which test results are valid and the time required to conduct each type of test are shown in Table 1.*

Table 1
Testing requirements
(See Clause 8.5.2.)

Property	Test required	Test validity[a]	Requirements		Time required to conduct test[b]
		Qualification	Coarse aggregate	Fine aggregate	
Gradation	A23.2-2A	One year	Table 11	Table 10	One day
Material finer than 80 µm	A23.2-5A	One year	Table 12	Tables 10 and 12	One day
Organic impurities	A23.2-7A	One year	N/A	CSA A23.1, Clause 4.2.3.3.3	One day
Flat and elongated particles[g]	A23.2-13A Procedure A or B	One year	Table 12	N/A	One day
Relative density and absorption	A23.2-6A A23.2-12A	One year	N/A	N/A	Three days
Alkali aggregate reactivity	A23.2-25A	One year	Clause 4.2.3.6 A23.2-27A	Clause 4.2.3.6 A23.2-27A	Sixteen days
Alkali aggregate reactivity[c]	A23.2-14A A23.2-27A	One year	Clause 4.2.3.6 A23.2-27A	Clause 4.2.3.6 A23.2-27A	A23.2-14A Concrete prism test: one year A23.2-14A Mitigated test: two years
Petrographic analysis	A23.2-15A	One year	Clause 4.2.3.8 A23.2-15A	Clause 4.2.3.8, A23.2-15A, Table 12	One day
Clay lumps[e, f]	A23.2-3A	One year	Table 12	Table 12	One day

(Continued)

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Table 1 (Concluded)

Property	Test required	Test validity[a]	Requirements		Time required to conduct test[b]
		Qualification	Coarse aggregate	Fine aggregate	
Low density materials[e, f]	A23.2-4A	One year	Table 12	Table 12	One day
Micro-Deval abrasion	A23.2-23A, A23.2-29A	One year	Table 12	Table 12	One day
Unconfined freeze-thaw	A23.2-24A	One year	Table 12	N/A	Six days
$MgSO_4$ Soundness[d]	A23.2-9A	One year	Table 12	Table 12	Seven days
Los Angeles abrasion and impact[h]	A23.2-16A, A23.2-17A	One year	Table 12	N/A	One day

[a]*Maximum time from the date of the test report for which the test may be used for qualification purposes.*

[b]*Time required for a laboratory to conduct the test from the time it is started; does not include sample shipping and laboratory preparation time.*

[c]*CSA A23.2-14A takes one year to run. If aggregate requires mitigative measures such as use of supplementary cementitious materials, the test requires a minimum of two years (see CSA A23.2-28A). Test validity refers to time from completion of the tests, subject to verification that the sample tested is representative of production proposed for qualification or acceptance.*

[d]*The freeze-thaw requirements for coarse aggregate shall be waived provided the material meets the alternative requirements for $MgSO_4$ soundness loss as detailed in Table 12 of CSA A23.1.*

[e]*If the coarse aggregate when subject to petrographic examination (CSA A23.2-15A) does not show the presence of either clay lumps or low-density granular materials, the requirements for testing in accordance with CSA A23.2-3A and CSA A23.2-4A may be waived.*

[f]*If the Micro-Deval limits for fine aggregate in Table 12 of CSA A23.1. are met, then the tests for clay lumps and low-density granular materials may be waived.*

[g]*The aggregate producer or concrete producer shall specify Procedure A or Procedure B for determination of particle shape of coarse aggregate unless otherwise specified in the project documents.*

[h]*The Micro-Deval abrasion requirements for coarse aggregate shall be waived provided the material meets the alternative requirements for abrasion and impact loss requirements as detailed in Table 12 of CSA A23.1.*

9 Provision of test data and certificates

9.1 General

The aggregate manufacturer shall provide, when requested, a certificate providing the required test results in accordance with Clause 8.5, and stating that the product meets the requirements of this Standard at the time of sampling and testing.

Notwithstanding the reporting requirements of the individual test methods used to evaluate the source(s), the certificate shall also contain the following information:

a) the identity of the pit or quarry from which the material is obtained;

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b) the location of the plant or storage facility at which the material is processed into its final form; and
c) a description of the lot, stockpile or production run to which the certificate and test reports apply.

9.2 Test reports

9.2.1
The testing laboratory shall furnish a report of the results of all tests conducted. The report shall reference the sample tested to the identification provided with the submitted sample.

9.2.2
The test report shall certify that all tests were conducted in accordance with the requirements of this Standard or shall state any departures from the requirements.

9.2.3
The test report shall include all reporting requirements detailed in each of the test methods used to evaluate the source(s).

10 Aggregate acceptance

10.1 General requirements
Aggregates may be accepted if the requirements of Clause 4.2.3 and Tables 10 to 12 of CSA A23.1 are met. Aggregates shall be assessed for potentially deleterious expansion due to AAR and appropriate mitigation shall be implemented per CSA A23.2-27A. Aggregates shall also be free of substances in amounts that can cause deleterious expansion or other damage detailed in Clause 4.2.3.6.2 of CSA A23.1.

Note: *In some specific applications, further testing of the aggregate in concrete can be required or demonstration of satisfactory field performance can be sought. These optional owner-specified requirements are given in Clause 10.2.*

10.2 Special performance requirements
The owner may accept or reject aggregates that conform to the requirements in Clauses 4.2.3.3 to 4.2.3.7 of CSA A23.1 based on the performance of concrete in meeting job requirements when tested in accordance with one or more of the following test methods:

a) ASTM C666/C666M;
b) ASTM C1646/C1646M;
c) CSA A23.2-22C; or
d) BNQ 2621-905, Annex B.

Notes:

1) *The test methods listed in this Clause evaluate the resistance of aggregates to freezing and thawing only and not their potential for reacting deleteriously with cement alkalis.*
2) *Concrete deterioration classified as D-cracking and caused by certain absorptive limestone aggregates has been identified in parts of Manitoba, Ontario, and Québec, as well as several Midwestern states in the US. The distress is caused by delamination of the aggregate within the concrete and can occur in sidewalks, roads, highways, runways, etc., which are subjected to freezing and thawing with moisture constantly available to one side. Absorption tests and other tests on the unconfined aggregates have not proven to be reliable indicators of the problem. However, it has proven more successful to test the aggregates in concrete with a modified version of ASTM C666/C666M, using only two cycles of freezing and thawing per day and*

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length change measurements as the criteria for failure (maximum expansion of 0.035% after 350 cycles). Change in dynamic modulus has not correlated well with D-cracking deterioration (Stark, 1976).

10.3 Historical field performance

Independent of the aggregate's conformance to any of the test requirements of Clause 4.2.3 of CSA A23.1, the owner may accept or reject aggregate on the basis of the performance of similar aggregates in concrete from the same source with comparable materials and properties that have been exposed to similar conditions for at least ten years. If the owner accepts the aggregate on this basis, the aggregate shall be used in conditions similar to those of the aggregate used for comparison.

Note: *Acceptance on the basis of field performance should take into account the potential reactivity of aggregates with alkalis, as discussed in Clauses B.3.1.2 and P.7.3 of CSA A23.1, Clause 6.1 of CSA A23.2-27A, and Attachment A2 of CSA A23.2-27A.*

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A23.2-1B
Testing for properties of flowable grout

1 Scope
These Test Methods specify the procedures for determining viscosity, bleeding, expansion, and compressive strength of flowable grout.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-17C:19
Temperature of freshly mixed hydraulic cement concrete

A3005-18
Test equipment and materials for cementitious materials for use in concrete and masonry

ASTM International

C939/C939M-16a
Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)

3 Definitions
In addition to the definitions specified in CSA A23.1, the following definitions shall apply in these Test Methods:

Grout — a cementitious mixture, with and without admixtures, that is used primarily to fill voids.

Viscosity — a measure of the resistance of grout by measuring the time of efflux of a specified volume of grout from a standardized flow cone.

4 Summary

4.1 Viscosity of grout
A grout sample is introduced into a flow cone until the grout surface rises into contact with the point gauge, and the time of efflux of the grout is measured by a stopwatch.

4.2 Bleeding and expansion of grout

4.2.1
A glass or clear plastic cylinder, graduated to 250 mL in 2 mL or finer increments is filled with grout to the 200 ± 5 mL graduation. The levels of the grout and bleed water are recorded at 15 min intervals for the first hour and then at 30 min intervals until the successive readings show no further expansion or bleeding.

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4.2.2 Compressive strength of grout

The compressive strength is calculated for three grout cubes, 50 mm in dimension, at each specified age.

5 Significance and use

These Test Methods are intended to provide standard requirements and procedures to determine viscosity, bleeding, expansion, and compressive strength of flowable grout. These tests are commonly employed for the grouting of bonded tendons in post tensioned concrete construction.

6 Sampling

A sample of grout shall be obtained from the grout mixer discharge. The temperature of the grout shall be measured upon sampling in accordance with the Test Method in CSA A23.2-17C.

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Test for viscosity

8.1 General

Clauses 8.2 to 8.7 specify the procedure for determining the viscosity of grout by measuring the time of efflux of a specified volume of grout from a standardized flow cone. It is intended to be used for grouts with a flow of less than 35 s. A sand grout shall pass through a 2.5 mm sieve.

Notes:

1) *This viscosity test is in substantial agreement with ASTM C939/C939M.*
2) *This viscosity test, in some cases, will not be applicable to grouts containing a thixotropic admixture.*

8.2 Apparatus

The apparatus shall consist of the following:

a) a flow cone conforming to the dimensions and requirements indicated in Figure 1; and
b) a stopwatch having a least reading of not more than 0.2 s.

8.3 Calibration of apparatus

The flow cone shall be mounted firmly in such a manner that the top is level and the cone free from vibration. The discharge tube shall be closed by placing a finger over the lower end. A quantity of water equal to 1700 ± 10 mL shall be introduced into the cone. The point gauge shall be adjusted to indicate the level of the water surface.

8.4 Sample

The test sample shall consist of 1700 ± 10 mL of grout.

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8.5 Test procedure

8.5.1

The procedure shall be performed as follows:

a) Moisten the inside surface of the flow cone by filling the cone with water and allow the water to drain from the cone 1 min before introducing the grout sample.
b) Place a finger over the outlet of the discharge tube. Introduce the grout into the cone until the grout surface rises into contact with the point gauge.
c) Start the stopwatch and remove the finger simultaneously.
d) Stop the stopwatch at the first break in the continuous flow of grout from the discharge tube.
e) Look into the cone. If light is visible, the time indicated by the stopwatch is the time of efflux of the grout. If light is not visible, the flow cone test is not applicable for grout of this consistency.

At least two tests having times of efflux within ± 5% of the average time shall be made for any grout mixture.

8.5.2

The test time of efflux shall be made within 1 min after drawing the grout from the mixer or transmission line.

8.5.3

When grout is being placed over a significant period of time, the time of efflux may be determined at selected intervals to demonstrate that the consistency is suitable for the work.

8.6 Reporting

The following information shall be included in the test report:

a) identification of the certified laboratory that performed the test (i.e., name and address);
b) identification of the sample (i.e., location and time at which the sample was taken);
c) mix proportions of the grout sample;
d) specified time of efflux;
e) average time of efflux to the nearest 0.2 s;
f) temperature of the grout sample at time of test;
g) ambient temperature at time of test;
h) name of the certified technician who performed the test;
i) name and signature of the person responsible for the review and approval of the test report; and
j) any deviation from the test procedure.

8.7 Precision and Bias

No precision and bias statement has been established for this Test Procedure.

9 Test for bleeding and expansion

9.1 General

Clauses 9.2 to 9.5 describe the procedure for measuring the bleeding and unrestrained expansion of grout where the total expansion is more than 3%.

Note: *This procedure is not suitable for measuring the expansion of grout where the total expansion is less than 3%.*

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9.2 Apparatus

A glass or clear plastic cylinder, graduated to 250 mL in 2 mL or finer increments, shall be used.

9.3 Test procedure

9.3.1 Placing the grout

The cylinder shall be filled with grout to the 200 ± 5 mL graduation. The top of the cylinder shall be sealed to prevent evaporation. The level of the grout shall be recorded. At least two tests shall be made on every sample.

Note: *Aluminum foil has been found satisfactory for sealing the cylinder.*

9.3.2 Measurement of bleeding and expansion

The levels of the grout and bleed water shall be recorded at 15 min intervals for the first hour and then at 30 min intervals until the successive readings show no further expansion or bleeding.

9.3.3 Calculations

The bleeding and expansion after each time interval shall be expressed as a percentage, as follows:

$$\text{Bleeding} = \frac{V_3 - V_2}{V_1} \times 100$$

$$\text{Expansion} = \frac{V_3 - V_1}{V_1} \times 100$$

where

V_3 = volume to top of bleed water level, mL

V_2 = volume to bottom of bleed water level, mL

V_1 = original volume of grout, mL

9.4 Reporting

The report shall include the following information, as applicable:

a) identification of the certified laboratory that performed the test (i.e., name and address);
b) identification of the sample (i.e., location and time at which the sample was taken);
c) mix proportions of the grout sample;
d) specified bleeding and expansion;
e) average bleeding and expansion after each time interval to the nearest 0.1%;
f) temperature of the grout sample at time of test;
g) ambient temperature at time of test;
h) name of the certified technician who performed the test;
i) name and signature of the person responsible for the review and approval of the test report; and
j) any deviations from the test procedure.

9.5 Precision and bias

No precision and bias statement has been established for this Test Method.

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10 Test for compressive strength

10.1 General

Clauses 10.2 to 10.6 describe the procedure for determining the compressive strength of grouts using 50 mm cube specimens.

10.2 Apparatus

10.2.1 Moulds

Cube moulds shall be 50 mm in dimension conforming to the requirements of CSA A3005. Each cube mould shall be provided with a metal cover plate not less than 6 mm thick, and a clamping device capable of rigidly holding the cover plate in position over the mould.

Note: *The cover plate is not necessary for grouts that do not contain an expanding agent.*

10.2.2 Testing machine

The testing machine shall meet the requirements of CSA A3005.

10.3 Test procedure

10.3.1 Moulding the test specimens

The test specimens shall be moulded as follows:

a) Make cubes from each sample of grout.
b) Place the grout into each mould until it is half-full and tamp with a rubber-gloved finger.
c) Fill the remaining half of the mould, tamp again, and finish by bringing the excess grout to the centre, leaving excess grout piled slightly high.
d) Place the cover plate over the mould, clamp securely in position, and seal the edges with a suitable material such as wax or grease.

10.3.2 Storage of test specimens

The test specimens shall be stored at 23 ± 2 °C and shall be demoulded after 24 ± 0.5 h and stored in lime-saturated water at 23 ± 2 °C until the time of test.

10.3.3 Determination of compressive strength

Compressive strength shall be determined as follows:

a) Perform a test, consisting of three cubes, at each specified age.
b) Keep specimens in lime saturated water until immediately prior to test.
c) Wipe each specimen to a surface-dry condition and remove all incrustations from the faces that will be in contact with the bearing blocks of the testing machine.

Note: *The area of the individual cubes should be determined based on measurements accurate to ±0.5 mm.*

10.3.4 Placing the specimen

The specimen shall be placed as follows:

a) Apply the load to the specimen perpendicular to the direction of casting.
b) Place the specimen in the testing machine below the centre of the upper bearing block.
c) Prior to testing each cube, ascertain that the spherically seated block is free to tilt.

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10.3.5 Rate of loading

Loading shall be rated as follows:

a) Apply an initial loading of up to one-half of the expected maximum load for specimens, having an expected maximum load greater than 15 kN, at any convenient rate.
b) Adjust the rate of loading so that the remainder of the load is applied, to failure, without interruption, and at such a rate that the maximum load will be reached not less than 20 s nor more than 80 s after the start of loading.
c) Do not adjust the controls of the testing machine while the specimen is yielding before failure.

10.4 Calculation

The compressive strength of the specimen shall be calculated by dividing the maximum load in newtons carried by the specimen during the test by the cross-sectional area in square millimetres and express the result to the nearest 0.1 MPa.

10.5 Reporting

The test report shall include the following information, as applicable:

a) identification of the certified laboratory that performed the test (i.e., name and address);
b) identification of the grout sample (i.e., location and time at which the sample was taken);
c) mix proportions of the grout sample;
d) specified minimum compressive strength and test age requirements;
e) the individual and average compressive strength for each set of three cube specimens tested to the nearest 0.1 MPa;
f) age at the time strength tests were performed;
g) temperature of the grout sample at time of sampling;
h) ambient temperature at time of sampling;
i) name of the certified technician who performed the test;
j) name and signature of the person responsible for the review and approval of the test report; and
k) any deviations from the test procedure.

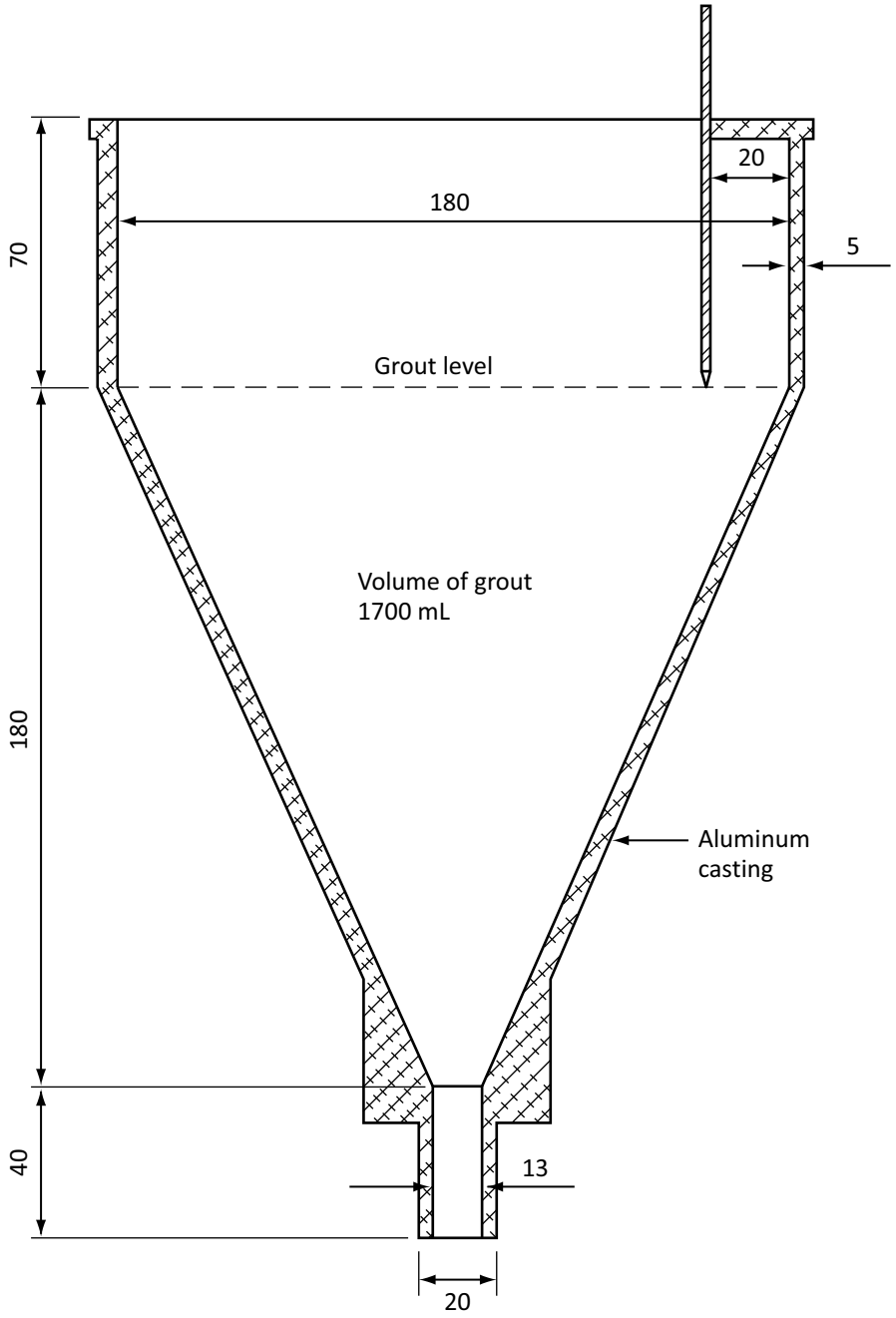
10.6 Precision and bias

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Figure 1
Cross-section of flow cone
(See Clause 8.2.)



Note: *Unless otherwise stated dimensions are in millimetres.*

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A23.2-2B
Determination of sulphate ion content in groundwater

1 Scope
This Test Method specifies the procedures for the quantitative determination of the sulphate ion content in groundwater.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

ASTM International

D1129-13
Standard Terminology Relating to Water

D1193-06 (2018)
Standard Specification for Reagent Water

3 Summary
The sulphate ion is precipitated and its mass measured as barium sulphate after the removal of silica and other soluble material. Other substances might be occluded or absorbed by the barium sulphate but this will not significantly affect the accuracy of the results.

4 Significance and use
This Test Method is intended to measure the sulphate ion content in groundwater in contact with concrete in order to evaluate the class of exposure to sulphate attack as described in Table 3 of CSA A23.1.

5 Definitions
The terms used in this Standard shall be as defined in ASTM D1129.

6 Hazards
This Test Method does not purport to include all safety issues associated with its use. The user of this Test Method shall establish appropriate safety and health practices.

7 Reagents
Reagent grade chemicals shall be used in all tests. Where the term “water” is used, it refers to any one of the grades of reagent water conforming to ASTM D1193, Type 1.

The following reagents shall be required:
a) ammonium hydroxide (relative density 0.90);
b) barium chloride solution (100 g/L of $BaCl_2$): dissolve 118 g of $BaCl_2 \bullet 2H_2O$ in water and dilute to 1L;

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c) hydrochloric acid: mix one volume of HCl (relative density 1.19) with nine volumes of water;
d) hydrofluoric acid: 48% to 51%;
e) methyl orange indicator: dissolve 1 g of methyl orange in 1 L of water;
f) silver nitrate solution: dissolve 10 g of $AgNO_3$ in water and dilute to 100 mL with water; and
g) sulphuric acid (relative density 1.84).

8 Procedure

The procedure shall be as follows:

a) If the sample is turbid, filter by using a fine ashless filter paper.
b) Measure into a beaker a quantity of the clarified sample containing the sulphate ion equivalent to 10 mg to 50 mg of $BaSO_4$. Adjust the volume by dilution or evaporation to approximately 200 mL. Adjust the acidity of the sample to the methyl orange end point by the addition of hydrochloric acid or ammonium hydroxide as required and then add 10 mL more of hydrochloric acid.
c) Heat the acidified solution to boiling and slowly add to it 5 mL of hot barium chloride solution while stirring the sample vigorously. Keep the temperature just below the boiling point for at least 2 h or until the solution has settled out completely.
d) Filter the suspension of $BaSO_4$ on a fine ashless filter paper and wash the precipitate with hot water until the washings are substantially chloride-free. Test a portion of the wash water with $AgNO_3$ solution. If an excess white precipitate is observed, continue washing until the test indicates a very faint opalescence.
e) Place the filter paper and contents in a platinum crucible, and char and consume the paper without flaming. Ignite the residue at approximately 800 °C for 1 h or until it is apparent that all carbon has been consumed.
f) Add a drop of sulphuric acid and a few drops of hydrofluoric acid and evaporate under a hood to expel silica (as silicon fluoride). Reignite at about 800 °C, cool in a desiccator, and determine the mass of barium sulphate.

9 Calculations

The sulphate ion content shall be calculated in milligrams per litre, as follows:

$$\text{Sulphate ion content} = \frac{M \times 411\,600}{S}$$

where

M = mass of barium sulphate, g

S = sample volume, mL

10 Reporting

The following information shall be included in the test report:

a) identification of the certified laboratory that performed the test (i.e., name and address);
b) water sample identification;
c) source of the water sample;
d) date of sampling;
e) date of testing;
f) percentage of water-soluble sulphate ions measured, expressed to the nearest 0.01%;
g) name and signature of the person responsible for the review of the test report; and
h) any deviations from the Test Method.

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11 Precision and bias

11.1

No precision statement has been established for the procedure in this Test Method.

11.2

Since there is no accepted reference material for determining the bias for the procedure in this Test Method, no statement on bias is made.

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A23.2-3B
Determination of total or water-soluble sulphate ion content of soil

1 Scope
This Test Method specifies the procedure for the quantitative determination of the total or water-soluble sulphate ion content of soil samples.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-2B:19
Determination of sulphate ion content in groundwater

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Summary
The soil sample is air dried and crushed to produce a sample for chemical analysis using barium chloride titration. Chemical analysis of the filtrate by alternative methods suitable for the analysis of potable water may be used, provided the test results are within 10% of the values obtained by the standard test procedure.

4 Significance and use
This Test Method is intended to measure the water-soluble sulphate ion content of soil in contact with concrete in order to evaluate the class of exposure to sulphate attack as described in Table 3 of CSA A23.1.

5 Apparatus
The apparatus for testing shall include:

a) a 315 µm sieve conforming to ISO 3310-1 made with the preferred wire diameter;
b) a hotplate;
c) a magnetic stirrer and TFE fluorocarbon-coated stirring bar;
d) Whatman Nos. 40 and 41 filter paper or equivalent;
e) a balance or scale sensitive to within 0.1% of the mass of the sample; and
f) an agate mortar and pestle.

6 Reagents
Reagents as specified in CSA A23.2-2B shall be used.

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7 Hazards

This Test Method does not purport to include all safety issues associated with its use. The user shall establish appropriate safety and health practices.

8 Sample

8.1 General

A representative sample of approximately 800 g of the soil shall be obtained for the test.

8.2 Sample preparation

The sample shall be prepared as follows:

a) Air-dry the representative sample at room temperature and humidity until friable.
b) Quarter the sample to provide a test sample with a mass of approximately 100 g.
c) Continue air-drying the sample until it can be easily sieved.
d) Separate the sample on a 315 µm sieve and crush the coarser fraction using a mortar and pestle to pass the 315 µm sieve.
e) Thoroughly mix and quarter or split the crushed and sieved sample to obtain a sample of about 10 g for final testing.

9 Procedure

9.1 Evaluation of total sulphate content

9.1.1

The test shall be performed as follows:

a) Split the 10 g sample prepared as specified in Clause 8.2 to produce a 1 g sample of soil.
b) Disperse 1 g of soil in a beaker with 25 mL of distilled water, using a swirling motion.
c) While the dispersion is still being agitated, add 5 mL of hydrochloric acid all at once.
d) Immediately dilute to 50 mL total and digest, just short of boiling, for 15 min.
e) Filter the residue filtered and wash thoroughly with hot distilled water.
f) Dilute (or evaporate) the filtrate to about 200 mL.

9.1.2

The filtrate obtained as specified in Clause 9.1.1 shall be tested in accordance with the procedure specified in CSA A23.2-2B.

9.1.3

The percentage of total SO_4 in the soil shall be calculated as follows:

$P = B \times 41.16$

where

P = total sulphate ion content, %

B = mass of barium sulphate, g

9.1.4

If the total sulphate ion content determined is 0.2% or less, it may be reported directly. If it exceeds 0.2%, the total sulphate ion content shall be determined on the basis of a water extract (see Clause 9.2).

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9.2 Evaluation of water-soluble sulphate content

9.2.1

The ratio of water to soil to be used shall be determined as follows:

$r = 9P$

where

r = water-to-soil ratio, mL/g

P = percent SO_4 as determined in Clause 9.1.3

9.2.2

The remainder of the sample prepared in accordance with Clause 8.2 (about 9 g) shall be added to the water quantity calculated in Clause 9.2.1 and agitated continuously for 6 h. After agitation, an aliquot of the clear (filtered if necessary) leach water shall be transferred to a beaker and diluted to approximately 200 mL. The acidity of the sample shall be adjusted to the methyl orange end point by the addition of hydrochloric acid or ammonium hydroxide as required and then 10 mL more of hydrochloric acid shall be added.

9.2.3

The sulphate content shall be determined by the procedure specified in CSA A23.2-2B.

Note: *Chemical analysis of the filtrate by alternative methods suitable for the analysis of potable water may be used, provided the test results are within 10% of the values obtained by the standard test procedure.*

9.2.4

The water-soluble sulphate ion content shall be calculated as follows:

$$P = \frac{41.16Br}{V}$$

where

P = water-soluble sulphate ion content, %

B = barium sulphate, g

r = ratio of water to soil, mL/g

V = volume of aliquot, mL

10 Reporting

10.1 Required information

The following information shall be included in the test report:

a) identification of the certified laboratory that performed the test (i.e., name and address);
b) specimen identification;
c) date of testing;
d) percentage of total sulphate content or water-soluble sulphate ions measured expressed to the nearest 0.01%;
e) name and signature of the person responsible for the review and approval of the test report; and
f) any deviations from the test procedure.

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10.2 Optional information

The following information may be included in the test report:

a) date sample was taken or received by test laboratory;
b) sample source or sample location, or both; and
c) name of the technician who sampled the soil.

11 Precision and bias

No precision and bias statement has been established for this Test Method.

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A23.2-4B
Sampling and determination of water-soluble chloride ion content in hardened grout or concrete

1 Scope

This Test Method specifies the procedure for the sampling and determination of the water-soluble chloride ion content of hardened concrete or grout, including the chloride ions in the aggregate that might not be free to move to the cement paste.

Notes:

1) *This Test Method is similar to Section 19 of ASTM C114, except that a boiling water extraction procedure is used instead of a nitric acid extraction.*
2) *In cases where it is suspected that the chloride ions in the aggregate are not free to move to the cement paste, the soluble chloride ion should be separately determined in each of the materials.*
3) *Concrete containing slag or slag cement can have sufficient quantities of sulphide to interfere with the ion selective electrode used in Clause 10. Sulphides can be oxidized by pretreating the sample with hydrogen peroxide, as discussed in ASTM C114.*
4) *Additional information can be found in FHWA-RS-77-85, US Department of Transportation.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1B:19
Testing for properties of flowable grout

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

ASTM International

C114-18
Standard Test Methods for Chemical Analysis of Hydraulic Cement

C1218/C1218-17
Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

US Department of Transportation, Federal Highway Administration

FHWA-RS-77-85
Sampling and Testing for Chloride Ion in Concrete, Interim Report

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3 Definition

In addition to the definitions specified in CSA A23.1, the following definition applies in this Test Method:

Constant mass — the condition of a test sample dried at a temperature of 110 ± 5 °C such that the sample will not lose more than 0.1% moisture after 2 h of drying.

Note: *Such a condition of dryness may be verified by determining the mass of the sample before and after successive 2 h drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5 °C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.*

4 Significance and use

Water soluble chloride, when present in sufficient amount, is capable of leading to the initiation or acceleration of corrosion of ferrous metals, embedded in or contacting a cement based mortar, grout, or concrete. Determination of the chloride ion content or profile with depth may form part of an investigation to determine the cause of corrosion and/or potential for future corrosion. However, it must be recognized that water soluble chloride determined at some particular time in the life of a concrete element can be substantially different than at another time.

Clause 4.1.1.2 of CSA A23.1 provides limits on chloride ion content.

5 Apparatus

5.1 Sampling

The apparatus for sampling shall include the following:

a) a rotary-impact-type drill with pulverizing bits of sufficient diameter to provide a representative sample of sufficient size for testing or a concrete coring drill with a bit of sufficient size to provide a concrete core, which can be sliced by saw cutting, to represent a range of depths from the concrete surface (the volume of the slices to be sufficient to produce samples suitable for pulverizing). In the latter instance, a suitably sized cut off saw fitted with a diamond segmented saw blade shall be provided.
b) a spoon or other suitable means to remove pulverized sample material from the drill hole without contamination;
c) a syringe or other suitable means to clean any remaining material from the drill hole without contamination; and
d) sample containers capable of maintaining samples in an uncontaminated state.

5.2 Testing

The apparatus for testing shall include the following:

a) silver, chloride/sulphide ion selective electrode or a silver billet electrode coated with silver chloride with an appropriate reference electrode;

   Note: *Suitable electrodes are available from Orion, Beckman Instruments, Fisher Scientific, and Leeds and Northrup. The manufacturer's instructions should be followed.*
b) a potentiometer with a millivolt scale readable to 1 mV or better. A digital readout is preferred, but not required;
c) a buret, Class A, 10 mL capacity with 0.05 mL divisions. A buret of the potentiometric type with a displaced delivery tip is convenient, but not required;
d) a magnetic stirrer and TFE fluorocarbon-coated stirring bar;
e) a hotplate;

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f) disposable weighing boats;
g) 315 µm and 160 µm sieves conforming to ISO 3310-1 made with the preferred wire diameter;
h) an agate mortar and pestle;
i) various glassware, consisting of 250 mL beakers, filter funnels, stirring rods, watch glasses, droppers, and wash bottles;
j) Whatman Nos. 40 and 41 filter paper or equivalent; and
k) a balance sensitive to 100 µg with a minimum capacity of 100 g.

6 Hazards

This Test Method does not purport to include all safety issues associated with its use. The user shall establish appropriate safety and health practices.

7 Reagents

The following reagents shall be used for testing:
a) sodium chloride (NaCl), primary standard grade;
b) silver nitrate ($AgNO_3$), reagent grade;
c) potassium chloride (KCl), reagent grade (required for silver billet electrode only);
d) reagent water conforming to the requirements of ASTM D1193 for Type III reagent water; and
e) ethyl alcohol, technical grade.

8 Preparation of solutions

8.1

For sodium chloride, standard solution (0.05 N NaCl), the solution shall be prepared as follows:
a) dry sodium chloride (NaCl) at 110 ± 5 °C to a constant mass;
b) measure 2.922 g of dried reagent; and
c) dissolve in water and dilute to exactly 1 L in a volumetric flask and mix thoroughly.

This solution is the standard and requires no further standardization.

8.2

For silver nitrate, standard solution (0.05 N $AgNO_3$), the solution shall be prepared as follows:
a) dissolve 8.494 g of silver nitrate ($AgNO_3$) in water;
b) dilute to 1 L in a volumetric flask and mix thoroughly;
c) standardize against 5.00 mL of standard 0.05 N sodium chloride solution diluted to 150 mL with water following the titration method given in Clause 10 g) beginning with the second sentence; and
d) calculate the exact normality from the average of three determinations, as follows:

$$N = \frac{0.25}{V}$$

where
N = normality of $AgNO_3$ solution
0.25 = milliequivalents NaCl (5.0 mL × 0.05 N)
V = volume of $AgNO_3$ solution, mL

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8.3

For methyl orange indicator, a solution containing 2 g of methyl orange per litre of 95% ethyl alcohol shall be prepared.

Note: *Commercially available standard solutions may be used provided that the normality is verified according to the standardization procedure.*

9 Sampling

9.1 Sampling method from test sample

The sampling shall be performed as follows:

a) Cast grout columns (or 50 mm cubes) or, in the case of concrete, test cylinders, directly from the mix to be tested in accordance with the applicable requirements of CSA A23.2-1B or CSA A23.2-3C, respectively. Seal specimens immediately after casting and consolidation and allow to cure for a minimum 28 d period before sampling.

   Note: *The 28 d curing period is required to minimize the variations in water-soluble chloride that can occur with insufficiently cured specimens.*

b) Using the rotary impact drill, drill parallel to the axis of the specimen to a depth sufficient to obtain a representative sample of at least 30 g of pulverized material finer than a 315 µm sieve or saw-cut a slice of concrete of sufficient volume to produce a sample of at least 30 g after pulverizing the material finer than a 315 µm sieve.

   Note: *To prevent sample contamination, contact between the sample and hands should be avoided. All sampling tools should be cleaned with ethyl alcohol and dried prior to each sampling operation. No lubricants should be used during drilling or sawing.*

c) Transfer the pulverized sample into sample container using a spoon or other suitable means.

9.2 Sampling method from structures

9.2.1

The sample may be obtained using a rotary impact drill perpendicular to the surface of the concrete under test.

When the sample represents a certain depth of concrete, the concrete shall be removed above this layer and the area shall be cleaned of any residue to prevent contamination of the subsequent layers.

Note: *Several holes from the impact drill can be required to avoid the influence of coarse aggregate particles and to obtain a representative sample of at least 30 g of pulverized material.*

9.2.2

The following alternative method may be used:

a) Drill a sufficiently large core, suitable for slicing by saw-cutting to represent a range of depths from the concrete surface.

b) Pulverize each concrete slice to obtain a representative sample of at least 30 g of material finer than a 315 µm sieve.

Notes:

1) *Water used to cool drill bits and saw blades could dissolve some of the chloride in the concrete. Air or light oil cooling is preferred.*

2) *Concrete cores may be cut laterally into 10 mm thick disks representative of the concrete core at various depths, or cut longitudinally to provide a 10 mm thick section generally representative of the core.*

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9.3 Sample preparation

9.3.1
The pulverized samples shall be dried to constant mass at 110 ± 5 °C.

9.3.2
If the sample, as collected, does not completely pass a 315 µm sieve, additional pulverizing shall be performed with a mortar and pestle until the entire sample is finer than 315 µm.

10 Test procedure
The test shall be performed as follows:

a) Measure a representative 3 g sample in a disposable weighing boat. Transfer the sample to a mortar and add 10 mL of hot water. Grind the slurry with a pestle until all lumps are eliminated and the resulting particles will pass a 160 µm screen.

Note: *About 75% of a properly ground sample will pass a 80 µm screen. The analyst should grind several trial samples in accordance with the above procedure and then dry the samples and determine the particle size as a means of defining the grinding required for actual samples.*

b) Transfer the slurry from the mortar through a funnel into a 250 mL beaker. Rinse the mortar and pestle with hot water. Finally, wash the funnel with hot water and make up the volume to 75 mL.

c) Cover with a watch glass and boil for 5 min. Then let stand for 24 h from the end of the boil in an atmosphere free of HCl fumes.

Note: *It is important to keep the beaker covered during heating and digestion to prevent the loss of chloride by volatilization.*

d) Fit a 250 mL or 500 mL Buchner funnel and filtration flask with a 9 cm double filter paper consisting of a Whatman No. 41 over a No. 40. Wash the papers with nitric acid before water washing to prevent contamination of the sample. Wash the filter papers with four 25 mL increments of water using suction filtering. Discard the washings and rinse the flask once with a small portion of water. Reassemble the suction apparatus and filter the sample solution. Rinse the beaker and the filter paper twice with small portions of water. Transfer the filtrate from the flask to a clean 250 mL beaker and rinse the flask once with water. Ensure that the volume does not exceed 175 mL.

e) Add three drops of methyl orange indicator to the sample solution and then add HNO_3 dropwise until a permanent pink to red colour is obtained. Make up the volume to 200 mL with water.

f) For instruments equipped with dial readout, establish an approximate “equivalence point” by immersing the electrodes in a beaker of water and adjusting the instrument to read about 20 mV lower than midscale. Record the approximate millivoltmeter reading. Remove the beaker and wipe the electrodes with absorbent paper.

g) To the sample beaker specified in Item d), carefully pipette 2 mL of standard 0.05 N NaCl solution. Place the beaker on a magnetic stirrer and add a TFE fluorocarbon-coated magnetic stirring bar. Immerse the electrodes in the solution, taking care that the stirring bar does not strike the electrodes; begin stirring gently. Place the delivery tip of the 10 mL buret, filled to the mark with standard 0.05 N silver nitrate solution, in (preferably) or above the solution.

Notes:

1) *A constant temperature should be maintained during measurement because the solubility relationship of silver chloride varies markedly with temperature at low concentrations.*
2) *If the tip of the buret is out of the solution, any adhering droplet should be rinsed onto the beaker with a few millilitres of water following each titration increment.*

h) Gradually titrate and record the amount of standard 0.05 N silver nitrate solution required to bring the millivoltmeter reading to –60.0 mV of the equivalence point determined in the water.

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i) Continue the titration at 0.20 mL increments. Record the buret reading and the corresponding millivoltmeter reading in columns 1 and 2 of a four-column recording form as shown in Attachment A1. Allow sufficient time between each addition for the electrodes to reach equilibrium with the sample solution. Experience has shown that acceptable readings are obtained when the minimum scale reading does not change within a 5 s period (usually within 2 min).

j) As the equivalence point is approached, the equal additions of $AgNO_3$ solution will cause larger and larger changes in the millivoltmeter readings. Past the equivalence point, the change per increment will again decrease. Continue to titrate until three readings past the approximate equivalence point have been recorded.

k) Calculate the difference in millivolt readings between successive additions of titrant and enter the values in column 3 of the recording form. Calculate the difference between consecutive values in column 3 and enter the results in column 4. The equivalence point of the titration will be within the maximum ΔmV interval recorded in column 3. The precise equivalence point can be interpolated from the data listed in column 4 as shown in Attachment A1.

l) Make a blank determination using 75 mL of water in place of the sample, following the procedure outlined in Items e) to k). Correct the results obtained in the analysis accordingly by subtracting the blank. If the sample is not a referred analysis, then the blank may be omitted. In such cases, calculate the chloride percentage in the sample, as follows:

$$Cl, \% = 3.5453(VN - 0.10) / M$$

where

V = 0.05 N $AgNO_3$ solution used for sample titration (equivalence point), mL

N = exact normality of 0.05 N $AgNO_3$ solution

0.10 = milliequivalents of NaCl added (52 mL; 0.05 N)

M = mass of sample, g

11 Calculations

The chloride percentage shall be calculated to the nearest 0.001% (10 mg/kg), as follows:

$$\text{Cl}, \% = \frac{3.545VN}{M}$$

where

V = 0.05 N $AgNO_3$ solution used for titration of the sample (equivalence point), mL

N = exact normality of 0.05 N $AgNO_3$ solution

M = mass of sample, g

12 Reporting

12.1 Required information

The following information shall be included in the test report:

a) identification of the certified laboratory that performed the test (i.e., name and address);

b) sample number or identification marks;

c) test age of laboratory cast samples;

d) water-soluble chloride ion content expressed as a percentage of the concrete or grout mass to the nearest 0.001%;

e) name and signature of the person responsible for the review of the test report;

f) any deviations from the test procedure; and

g) optional Information.

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12.2 Optional information

The following information may be included in the test report:

a) name of technician who obtained the sample;
b) date sample was taken or received by the test laboratory;
c) test age of field cast samples; and
d) sample source or sample location, or both.

13 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C1218/C1218M.

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Attachment A1 (informative)
Example of determination of equivalence point for chloride determination

Note: *This Attachment is not a mandatory part of this Test Method.*

1	2	3	4
$AgNO_3$, mL	**Potential, mV**	**ΔmV***	**Δ_2mV†**
1.60	125.3		—
		5.8	
1.80	119.5		1.4
		7.2	
2.00	112.3		1.3
		8.5	
2.20	103.8		1.3
		9.8	
2.40	94.0		0.6
		9.2	
2.60	84.8		2.3
		6.9	
2.80	77.9		0.8
		6.1	
3.00	71.8		1.3
		4.8	
3.20	67.0		—

* *Differences between successive readings in column 2.*

† *Differences between successive Δ readings in column 3 "second differentials".*

Note: *The equivalence point is in the maximum ΔmV interval (column 3) and thus between 2.20 mL and 2.40 mL. The exact equivalence point in this 0.20 increment is calculated from the Δ_2mV (column 4) data as follows:*

$E = 2.2 + \frac{1.3}{1.3 + 0.6} \times 0.20 = 2.337$ m L (round to 2.34 m L)

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A23.2-6B
Determination of bond strength of bonded toppings and overlays and of direct tensile strength of concrete, mortar, and grout

1 Scope
This Test Method specifies the procedure for determining the bond strength of bonded toppings and the direct tensile strength of concrete, mortar, and grout by tensile load. It also applies to all other materials bonded to concrete.

This Test Method specifies two procedures. Procedure A enables the determination in-situ and Procedure B enables the determination in the laboratory of the bond and direct tensile strength of cementitious materials.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-12C:19
Making, curing, and testing compression test specimens of no-slump concrete

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

ASTM International

E4-16
Standard Practices for Force Verification of Testing Machines

3 Summary
In this Test Method, the surface or the two ends of the specimen are gripped or bonded to the machine device and a tensile force is applied to cause rupture. Bond or tensile strength is obtained by dividing the maximum applied load by the cross-sectional area of the specimen.

4 Significance and use
Procedures A and B are used to determine the tensile strength of cylindrical specimens prepared and cured in accordance with CSA A23.2-3C, CSA A23.2-12C, and CSA A23.2-14C.

In addition to providing information on bond strength, this Test Method may also be used to determine the impact of microcracking in concrete affected by alkali-aggregate reaction or fatigue. The location of failure is determined visually and gives an indication regarding the element in the tested system having the lowest tensile strength properties.

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5 Apparatus

5.1 Procedure A

5.1.1 Pulloff and load measuring device

The pulloff and load measuring equipment shall consist of a mechanical or hydraulic pulloff device coupled to a calibrated load cell, bourdon tube gauge, or a dynamometer. The counter pressure ring of the pulloff device shall be designed to accommodate the fastening devices described in Clause 5.1.2.

Note: *The mechanical testing apparatus of Figure 1 has been shown to be functional.*

5.1.2 Fastening devices

The fastening devices shall consist of a rigid plate with pulloff attachment or standard pipe caps; the bottom of the plate or cap shall be machined smooth and shoulder-cut to provide a plane surface. The outside diameter (D1) of the fastening device shall be slightly smaller than the inner diameter of the core bit (D2). The connection between the pulloff device and the fastening device shall ensure a tensile force perpendicular to the bottom plane of the fastening device.

Note: *A schematic diagram is presented in Figure 2.*

5.1.3 Coring drill

A concrete coring drill with the inner diameter of the core bit slightly larger than the fastening device and the outside diameter (D3) smaller than the counter pressure ring (D4) of the pulloff device shall be used to drill an annular ring through the layer under test and into the underlying concrete. The minimum diameter of the core bit shall be 3 times the nominal maximum aggregate size but in no case less than 60 mm.

Note: *A schematic diagram is presented in Figure 2.*

5.1.4 Bonding agent

A commercially available room temperature, rapid-curing epoxy compound adhesive having sufficient tensile adhesive strength to satisfy the requirements of the test shall be used.

5.2 Procedure B

5.2.1 Load measuring device

The testing machine shall have sufficient capacity and capability to provide the rates of loading specified in Clause 8.2.2.

The device shall be verified at suitable time intervals requirements specified in ASTM E4 and under the following conditions:

a) on original installation or relocation of the machine; and
b) after an elapsed interval since the previous verifications of 18 months maximum, but preferably after an interval of 12 months.

5.2.2 Fastening devices

Any kind of grips or epoxy bonded caps that produce a uniform tensile strength in the middle third of the specimens may be acceptable for use in this Test Method.

Note: *Cylindrical or square metal caps of sufficient diameter or dimension, when bonded to the specimen ends provide, for old concrete, a means through which the direct tensile load can be applied. It could be required to have*

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a reduced section in the middle third of the test specimens when the method is applied to the determination of tensile strength of new concrete.

Grips or caps shall be provided with a suitable linkage system for load transfer from the loading device to the test specimen. The linkage system shall be designed so that the load will be transmitted through the axis of test specimens without the application of bending or stresses in torsion. The length of the linkages at each end shall be at least two times the diameter of the metal end caps or grips.

Note: *Roller of link chain of suitable capacity, appropriate universal joints to minimize eccentric loading, and ball-and-socket of suitable dimension have been found to perform quite well in this application. Figure 3 shows a suitable device.*

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Sampling and test specimens

7.1

A minimum of two satisfactory tests shall be performed and each result will provide a test value.

The core specimens for the determination of tensile strength or adhesion shall have a diameter of at least three times the nominal maximum size of the coarse aggregate used in any part of the bonded system or in the cementitious material but in no case less than 50 mm.

Note: *A minimum core diameter of 75 mm should be used whenever practical.*

7.2

The test specimens for Procedure B shall be prepared in accordance with CSA A23.2-14C, except that the degree of flatness and smoothness of the specimen's end is not critical. End surfaces, such as those resulting from sawing with a diamond cut-off wheel, may be acceptable. The ratio of length between grips or caps to diameter of the specimen shall be, as nearly as practicable, between 0.75 and 1.0.

Note: *A smaller ratio results in a greater variability in test results.*

7.3

If required, a reduced section shall be obtained by kerfing. The cross-section shall be reduced all around by a notch 10 mm deep in the middle third of the test specimen. The width of the notch should be between 10 mm and 15 mm.

Note: *Grinding, lapping, or polishing beyond this point serves no useful purpose and, in fact, can adversely affect the adhesion of bonding of medium caps.*

8 Procedure

8.1 Procedure A

The overlay shall be cored to a minimum of 30 mm into the underlying concrete. The surface of the cored disk shall be cleaned and the fastening device shall be bonded to the disk's centre, using the epoxy compound. The fastening device may be heated to facilitate spreading of the adhesive and to accelerate its hardening as long as this does not modify the properties of the material tested.

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When the adhesive has reached sufficient strength, the fastening device shall be attached and the tensile load shall be applied at a rate of approximately 50 N/s to 100 N/s, making sure that the axis of the loading device coincides with the axis of the fastening device. The load indicated on the measuring gauge at failure shall be recorded. A minimum of three satisfactory tests shall be performed (see Clause 7) and averaged to provide a test value.

8.2 Procedure B

8.2.1 Test configuration

The caps or grip shall be bonded to the test specimen to ensure alignment of the cap or grip axes with the longitudinal axis of the specimen. If used, the layer of bonding material layer shall be of uniform thickness to ensure parallelism between the top surfaces of the metal caps attached to both ends of the specimen. This should be checked before the set of bonding agent by measuring the length of the end-cap assembly at three locations 120° apart and near the edge. The maximum difference between these measurements should be less than 0.10 mm for each 25 mm of specimen diameter.

The specimen shall be placed in the testing machine, making certain that the load transfer system is properly aligned.

8.2.2 Rate of loading

The load shall be applied continuously and without shock. The load shall be applied at constant rate within the range of 50 N/s to 250 N/s such that failure will occur in not less than 3 min.

The rate of loading should be as follows:

Diameter of specimens, mm	Rate of loading, N/s
50	50 ± 20
75	50 ± 20
100	100 ± 25
150	250 ± 50

8.2.3 Maximum load

The load shall be increased at the rate specified in Clause 8.2.2 until the specimen fails. The maximum load carried by the specimen during test shall be recorded.

The location of the failure should be described. The location of failure shall be estimated in percentage of cross sectional area for each element of an adhesive system used with concrete. The sum of the values shall equal 100.

9 Calculations

The stress at failure shall be calculated by dividing the maximum load by the cross-sectional area of the core at the failed surface. The result shall be recorded to the nearest 0.05 MPa.

The bonding or tensile strength of each specimen shall be based on the average diameter of the specimen at the location of the failure. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.5 mm by averaging two diameters measured at right angles to each other.

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10 Unsatisfactory tests

If the failure described in Clause 11 g) v) occurs by separation of the epoxy compound and the test plate on the topping, the test shall be repeated when:

a) tensile strength of concrete is required; or
b) the average of three tests from procedure A has not reached the minimum tensile bond strength required.

11 Reporting

The following information shall be included in the test report, as applicable:

a) identification of the certified laboratory conducting the tests (i.e., name and address);
b) name of the certified technician who performed the test;
c) test core diameter, depth drilled, and location on structure;
d) date and time of testing;
e) maximum applied load, kN;
f) cross-sectional area, mm^2;
g) for each test, the stress at failure to the nearest 0.05 MPa and a description of the location and mode of failure plane using one or a combination of the following failure modes:
    i) failure in the underlying concrete;
    ii) failure in the bond between the topping or overlay and the underlying concrete;
    iii) failure in the topping material;
    iv) failure of the concrete core; and
    v) separation of the epoxy compound and the test plate on the topping;
h) name and signature of the person responsible for the review and approval of the test report; and
i) any deviations from the test procedure.

12 Precision and bias

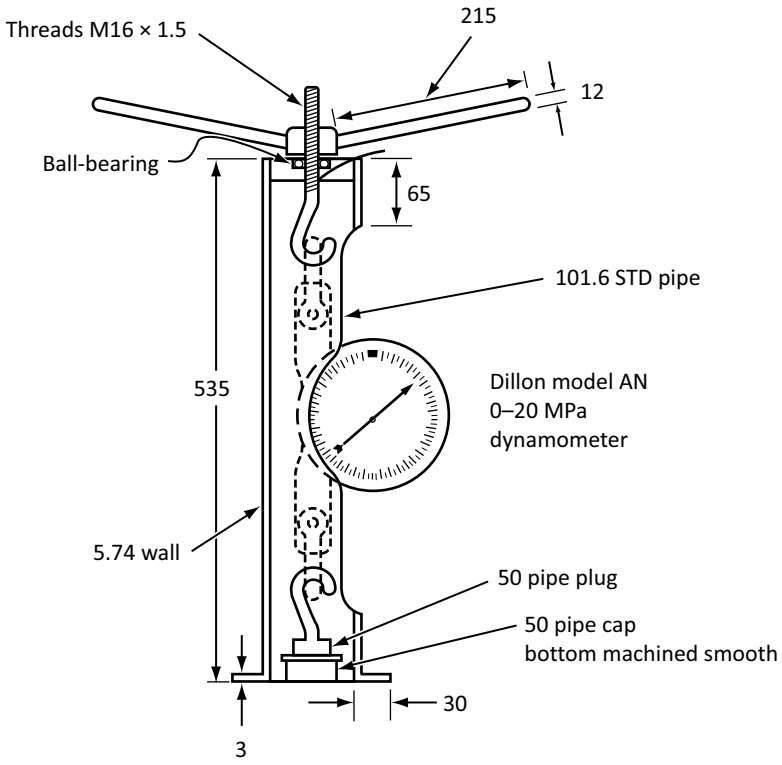
The precision and bias information for this Test Method is not available because direct tensile strength is related to surface preparation, surface roughness, bonding agent, and materials of bonded toppings and overlays.

Note: *The tensile strength of new concrete ranges between 4.5 and 11% of the compressive strength for compressive strength in the range between 20 and 80 MPa. The tensile strength of old concrete (in excess of 10 years) not affected by alkali-aggregate-reaction ranges between 4 and 7% of the compressive strength.*

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Figure 1
Functional sketch of mechanical testing device
(See Clause 5.1.1.)

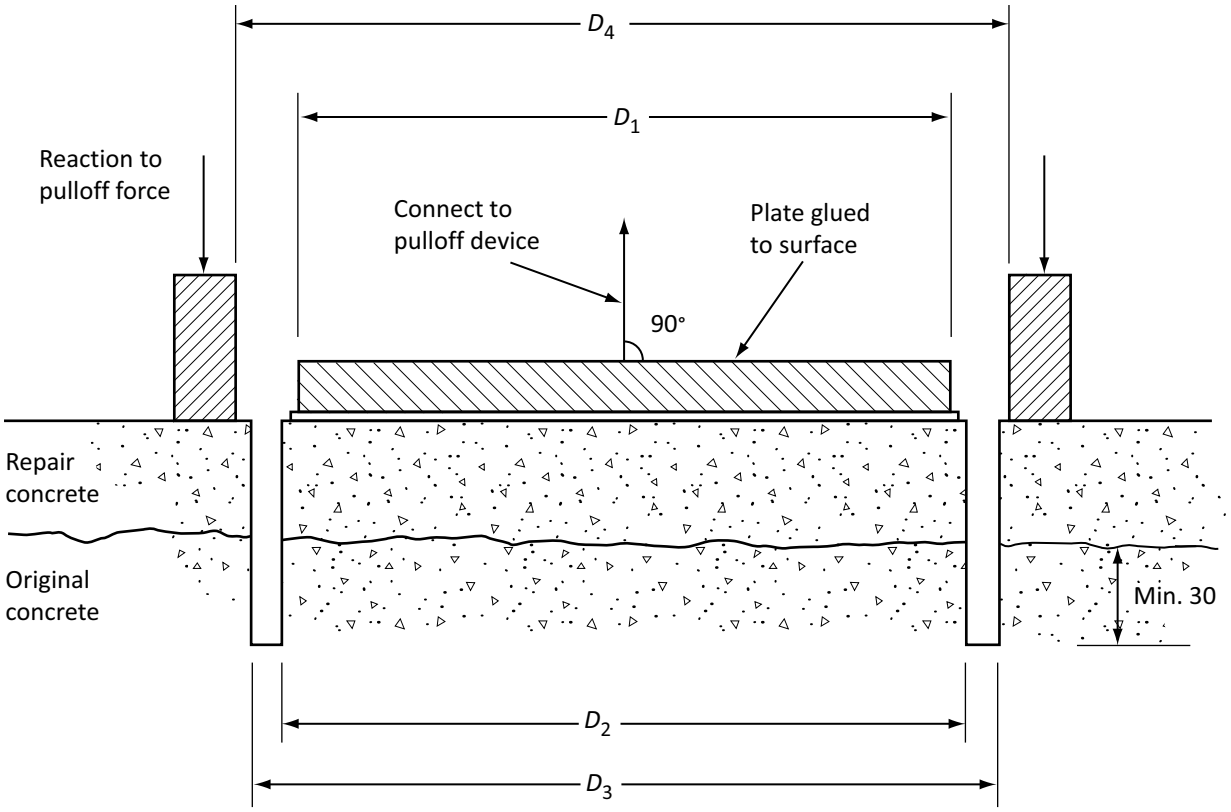


Note: *Unless otherwise stated, dimensions are in millimetres.*

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Figure 2
Schematic diagram of bond test
(See Clause 5.1.2.)



Note: *Dimensions are in millimetres.*

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Figure 3
Suitable device
(See Clause 5.2.2.)



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A23.2-7B
Random sampling of construction materials

1 Scope

This Test Method specifies the procedure for the determination of random locations (or timing) at which samples of construction materials can be obtained. The Test Method may also be used for the determination of random locations for in situ testing of concrete including tensile bond tests in accordance with CSA A23.2-6B, core tests in accordance with CSA A23.2-14C, and non-destructive testing of concrete as discussed in Annex A.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-6B:19
Determination of bond strength of bonded toppings and overlays and of direct tensile strength of concrete, mortar, and grout

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition applies in this Test Method:

Lot — a sizable quantity of bulk material from a single source, assumed to have been produced by the same process.

Note: *Examples are a day's production or a specific mass or volume of material.*

4 Significance and use

This Test Method is useful for determining the location or time, or both, to obtain a sample in order to eliminate any intentional, or minimize any unintentional, bias on the part of the person obtaining the sample. Less detailed procedures are included in Clause 6 for normal usage and are considered the most practical means, except where the sampling is deemed extremely critical or where dispute is anticipated.

For the exact physical procedures for securing the sample, such as a description of the sampling tool, the number of increments needed for a sample, or the size of the sample, reference should be made to the appropriate standard method. The selection procedures in Clause 5 use the three-digit numbers given in Table 1.

Note: *Many calculators have a random number generator that also produces an unbiased method of number selection.*

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5 Sampling and test specimens

5.1 Sampling from a belt or flowing stream of material

The length of time, *t*, shall be determined in minutes for the lot of material to be sampled to pass the sampling point and the number of samples, *n*, to be taken from the lot shall be determined. Following the instructions (see Clause 6) for using Table 1, *n* numbers shall be picked to determine the times to select the necessary samples.

Note: *The following is an example of how sampling times are selected:*

a) *The lot of material to be sampled from a flowing stream at a transfer point is defined as 480 min of production. Five samples are required from the lot. From Table 1, the following five numbers were picked: 0.091, 0.420, 0.217, 0.370, and 0.006.*

b) *These numbers are used directly (decimals disregarded) to determine the sample selection times. Any number over 480 min should be discarded and another chosen. Thus, samples will be taken at the following times after production begins (to the nearest 1 min and arranged in chronological order): 6 min, 91 min, 217 min, 370 min, and 420 min.*

c) *The user may decide a minimum time to allow the plant to become fully operational. In cases where the selected number results in a time less than this, the user should discard this number and choose another.*

d) *While the above exact times were picked, in practice the user may round off actual sampling times to the nearest 5 min.*

5.2 Sampling from a windrow of material

The total length of one windrow that represents a lot of material shall be determined in metres and the number of samples, *n*, to be taken from the lot shall be determined. Following the instructions (see Clause 6) for using Table 1, *n* numbers shall be picked to determine the length, *l*, from the start of the windrow from which samples will be taken.

Note: *The following is an example of how sample locations along the windrow are obtained:*

a) *A lot of material has been placed in windrows 3000 m in length. The purpose is to secure three samples from this lot. From Table 1, the following three numbers are picked: 0.526, 0.704, and 0.193.*

b) *These numbers are then multiplied by 3000, giving the number of metres from the beginning of the windrow at which to sample. Thus, samples (rounded to the nearest metre and arranged in sequence) are selected at the following intervals: 579, 1578, and 2112 m.*

5.3 Sampling in-place paving material

The following shall be determined:

a) the length of pavement, *P*, representing a lot of material;

b) the width of the pavement, *w*; and

c) the number of samples needed for each lot, *n*.

Following the instructions (see Clause 6) for using Table 1, numbers corresponding to the distances from the end of the pavement shall be picked. Then numbers for the distances from the edge of the pavement shall be picked.

Note: *The following is an example of how to select locations for sampling in-place paving material:*

a) *A lot is defined as 1.6 km of in-place, 3.6 m wide pavement. Two samples are to be taken from each lot. Two numbers are picked from Table 1, which are then multiplied by 1600, since there are 1600 m in the lot. In this instance, the two numbers chosen were 0.376 and 0.529. Thus, the two samples will be taken at 602 m and 846 m from the beginning of the pavement.*

b) *The distances from the edge of the pavement are determined by selecting two additional numbers from Table 1, which are then multiplied by 3.6. In this case, the two numbers chosen were 0.512 and 0.708. Thus, the two samples will be taken at 1.8 m and 2.5 m from the designated edge.*

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c) *Therefore, one sample should be taken 602 m from the beginning of the pavement and 1.8 m from the designated (right or left) edge of the pavement. The other sample should be taken 846 m from the beginning of the pavement and 2.5 m from the designated (right or left) edge of the pavement.*

5.4 Sampling from a loaded truck

The following shall be determined:

a) the number of truck loads that represent the lot of material; and
b) the number of samples, *n*, needed from each lot.

To determine which trucks to sample, *n* numbers shall be picked from Table 1 and these numbers shall be multiplied by the number of trucks in the lot. To determine the quadrant in each truck to be sampled, n numbers shall be picked from Table 1 and multiplied by 4. Quadrant locations of the truck shall be numbered as shown in Figure 1. The product of the multiplication shall be rounded up.

Note: *The following is an example of how trucks are selected and which quadrant of the truck to sample:*

a) *Twenty trucks are considered to be a lot and three samples are required. Using Table 1, the following three numbers were picked: 0.251, 0.424, and 0.865. Thus, trucks numbered 6 (0.251 × 20 = 5.02), 9 (0.424 × 20 = 8.48), and 18 (0.865 × 20 = 17.3) should be sampled.*
b) *To determine the quadrant locations, the following numbers were picked: 0.110, 0.380, and 0.064. These are multiplied by 4 with the following results: Quadrant 1 from truck No. 6 (4 × 0.110 = 0.44), Quadrant 2 from truck No. 9 (4 × 0.380 = 1.52), and Quadrant 1 from truck No.18 (4 × 0.064 = 0.26).*

6 Procedure

6.1 Use of table of random numbers

6.1.1

This procedure provides instructions for using the three-digit table of random numbers (Table 1).

6.1.2

Table 1 consists of all numbers from 0.001 to 1.000. Each number appears only once.

6.1.3

To use Table 1 correctly and to eliminate bias, point without looking, to a number in the Table. It might be advantageous to use a pointer, such as a mechanical pencil with the lead retracted, the tip of a letter opener, or a similar pointed object. Any of the pages of the Table may be used but the pages shall be alternated between successive uses.

6.1.4

After picking a number, the basis is established for locating the sought-after number in a more random, unbiased method.

6.1.5

Examine the first two digits of the three-digit number chosen. This number locates the line number (i.e., the vertical column on the left) to be used in finding the sought-after number.

Note: *The digits 0.001 to 0.009 are invalid for choosing the line number. The number 1.000 is used for line number 100.*

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6.1.6
Once the line number is chosen, repeat the procedure in Clause 6.1.3 and, using the first digit, pick the column number (i.e., the horizontal numbers at the top of the Table).

6.1.7
The intersection of the results from Clauses 6.1.5 and 6.1.6 is the sought-after number.

6.1.8
The procedure, to be unbiased, shall be followed as outlined in Clauses 6.1.3 to 6.1.7 or by some other locally devised method by which the user has no control over the numbers chosen. The Table shall be entered separately for any and all numbers selected. The selection procedure shall be repeated if an unusable number results.

6.2 Alternative methods

6.2.1 General
Two alternative methods in using Table 1 are described in Clauses 6.2.2 and 6.2.3. They are not considered as correct theoretically as the procedure described in Clauses 6.1.1. However, except in cases of dispute, they may be used as alternatives for normal usage.

6.2.2 Alternative 1
Enter Table 1 as described in Clause 6.1.3 deciding beforehand that the required number of digits will be selected by moving up, down, right, or left from the number picked. Discard unusable numbers, and continue to the next number in the same direction. Decide beforehand what action to take when a number on the periphery of the Table is reached and additional selections are needed.

6.2.3 Alternative 2
The user shall decide beforehand to begin in the top left corner (or top centre or bottom right, etc.) and move right and down (or left and up) picking the number of required usable numbers. Other variances include moving in the preplanned direction, picking every other number, or every third number, etc. Care shall be exercised using this method to give numbers in the middle of Table 1 an equal chance of being selected.

Table 1
Table of random numbers
(See Clauses 4 to 6.)

	0	1	2	3	4	5	6	7	8	9
1	0.272	0.519	0.098	0.459	1.000	0.554	0.250	0.246	0.736	0.432
2	0.994	0.978	0.693	0.593	0.690	0.028	0.831	0.319	0.073	0.268
3	0.039	0.449	0.737	0.501	0.960	0.254	0.239	0.474	0.031	0.720
4	0.144	0.695	0.339	0.621	0.128	0.032	0.413	0.617	0.764	0.257
5	0.312	0.138	0.670	0.894	0.682	0.061	0.832	0.765	0.226	0.745
6	0.871	0.838	0.595	0.576	0.096	0.581	0.245	0.786	0.412	0.867
7	0.783	0.874	0.795	0.430	0.265	0.059	0.260	0.563	0.632	0.394

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Table 1 (Continued)

	0	1	2	3	4	5	6	7	8	9
8	0.358	0.424	0.684	0.074	0.109	0.345	0.618	0.176	0.352	0.748
9	0.494	0.839	0.337	0.325	0.699	0.083	0.043	0.809	0.981	0.499
10	0.642	0.514	0.297	0.869	0.744	0.824	0.524	0.656	0.608	0.408
11	0.485	0.240	0.292	0.335	0.088	0.589	0.127	0.396	0.401	0.407
12	0.728	0.819	0.557	0.050	0.152	0.816	0.404	0.079	0.703	0.493
13	0.029	0.262	0.558	0.159	0.767	0.175	0.979	0.521	0.781	0.843
14	0.918	0.348	0.311	0.232	0.797	0.921	0.995	0.225	0.397	0.356
15	0.641	0.013	0.780	0.478	0.529	0.520	0.093	0.426	0.323	0.504
16	0.208	0.468	0.045	0.798	0.065	0.315	0.318	0.742	0.597	0.080
17	0.346	0.429	0.537	0.469	0.697	0.124	0.541	0.525	0.281	0.962
18	0.900	0.206	0.539	0.308	0.480	0.293	0.448	0.010	0.836	0.233
19	0.228	0.369	0.513	0.762	0.952	0.856	0.574	0.158	0.689	0.579
20	0.746	0.170	0.974	0.306	0.145	0.139	0.417	0.195	0.338	0.901
21	0.363	0.103	0.931	0.389	0.199	0.488	0.915	0.067	0.878	0.640
22	0.663	0.942	0.278	0.785	0.638	0.002	0.989	0.462	0.927	0.186
23	0.545	0.185	0.054	0.198	0.717	0.247	0.913	0.975	0.555	0.559
24	0.360	0.349	0.569	0.910	0.420	0.492	0.947	0.115	0.884	0.452
25	0.789	0.815	0.464	0.484	0.020	0.007	0.547	0.941	0.365	0.261
26	0.279	0.609	0.086	0.852	0.890	0.108	0.076	0.089	0.662	0.607
27	0.680	0.235	0.706	0.827	0.572	0.769	0.310	0.036	0.329	0.477
28	0.078	0.444	0.178	0.651	0.423	0.672	0.517	0.660	0.657	0.972
29	0.676	0.830	0.531	0.888	0.305	0.421	0.307	0.502	0.112	0.808
30	0.861	0.899	0.643	0.771	0.037	0.241	0.582	0.578	0.634	0.077
31	0.111	0.364	0.970	0.669	0.548	0.687	0.639	0.510	0.105	0.549
32	0.289	0.857	0.948	0.980	0.132	0.094	0.298	0.870	0.309	0.441
33	0.961	0.893	0.392	0.377	0.864	0.472	0.009	0.946	0.766	0.287
34	0.637	0.986	0.753	0.566	0.213	0.807	0.017	0.460	0.515	0.630
35	0.834	0.121	0.255	0.453	0.376	0.583	0.422	0.371	0.399	0.366
36	0.284	0.490	0.402	0.151	0.044	0.436	0.747	0.694	0.136	0.585
37	0.038	0.814	0.594	0.911	0.324	0.322	0.895	0.411	0.160	0.367
38	0.351	0.283	0.027	0.220	0.685	0.527	0.943	0.556	0.853	0.612
39	0.143	0.384	0.645	0.479	0.489	0.052	0.187	0.990	0.912	0.750
40	0.512	0.056	0.018	0.122	0.303	0.803	0.553	0.729	0.205	0.925
41	0.296	0.705	0.156	0.616	0.534	0.168	0.564	0.866	0.739	0.850
42	0.451	0.536	0.768	0.518	0.481	0.880	0.835	0.734	0.427	0.847
43	0.837	0.405	0.591	0.370	0.104	0.848	0.004	0.414	0.354	0.707
44	0.724	0.153	0.841	0.829	0.470	0.391	0.388	0.163	0.817	0.790
45	0.665	0.825	0.671	0.623	0.770	0.400	0.068	0.440	0.019	0.944

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Table 1 (Continued)

	0	1	2	3	4	5	6	7	8	9
46	0.573	0.716	0.266	0.456	0.434	0.467	0.603	0.169	0.721	0.779
47	0.332	0.702	0.300	0.570	0.945	0.968	0.649	0.097	0.118	0.242
48	0.755	0.951	0.937	0.550	0.879	0.162	0.791	0.810	0.625	0.674
49	0.439	0.491	0.855	0.446	0.773	0.542	0.416	0.350	0.957	0.419
50	0.700	0.877	0.442	0.286	0.526	0.071	0.154	0.988	0.333	0.626
51	0.523	0.613	0.752	0.733	0.528	0.072	0.820	0.929	0.777	0.461
52	0.905	0.182	0.567	0.249	0.227	0.229	0.604	0.304	0.217	0.142
53	0.373	0.120	0.602	0.793	0.692	0.863	0.954	0.873	0.107	0.675
54	0.057	0.953	0.041	0.090	0.223	0.508	0.806	0.438	0.203	0.586
55	0.967	0.040	0.708	0.271	0.189	0.342	0.740	0.801	0.985	0.263
56	0.917	0.715	0.758	0.005	0.666	0.599	0.934	0.100	0.987	0.085
57	0.131	0.646	0.659	0.047	0.051	0.562	0.435	0.731	0.362	0.317
58	0.326	0.605	0.443	0.601	0.386	0.560	0.378	0.172	0.445	0.636
59	0.299	0.106	0.237	0.732	0.796	0.476	0.099	0.804	0.735	0.950
60	0.101	0.055	0.776	0.686	0.171	0.533	0.936	0.095	0.982	0.211
61	0.267	0.598	0.754	0.658	0.274	0.215	0.177	0.218	0.330	0.628
62	0.471	0.102	0.454	0.568	0.963	0.357	0.882	0.507	0.157	0.580
63	0.535	0.881	0.014	0.966	0.958	0.190	0.180	0.759	0.433	0.355
64	0.277	0.458	0.295	0.196	0.772	0.148	0.466	0.291	0.688	0.046
65	0.719	0.167	0.181	0.653	0.328	0.070	0.015	0.155	0.631	0.063
66	0.385	0.858	0.713	0.883	0.916	0.084	0.561	0.999	0.379	0.668
67	0.862	0.928	0.822	0.812	0.977	0.395	0.788	0.920	0.673	0.698
68	0.486	0.938	0.757	0.749	0.991	0.219	0.264	0.932	0.898	0.006
69	0.091	0.872	0.959	0.922	0.727	0.811	0.075	0.374	0.133	0.730
70	0.146	0.482	0.930	0.611	0.179	0.011	0.248	0.886	0.344	0.926
71	0.709	0.184	0.390	0.409	0.191	0.117	0.860	0.135	0.406	0.134
72	0.996	0.896	0.760	0.347	0.053	0.372	0.193	0.756	0.565	0.914
73	0.971	0.859	0.147	0.114	0.418	0.889	0.792	0.064	0.652	0.288
74	0.202	0.538	0.026	0.949	0.696	0.008	0.846	0.259	0.415	0.425
75	0.212	0.321	0.778	0.940	0.496	0.231	0.664	0.903	0.473	0.909
76	0.207	0.799	0.487	0.022	0.813	0.891	0.500	0.368	0.725	0.437
77	0.818	0.503	0.906	0.224	0.904	0.892	0.455	0.343	0.924	0.197
78	0.701	0.984	0.174	0.141	0.704	0.908	0.048	0.828	0.997	0.058
79	0.035	0.380	0.001	0.381	0.251	0.497	0.214	0.794	0.552	0.588
80	0.221	0.200	0.587	0.353	0.584	0.270	0.885	0.110	0.956	0.711
81	0.647	0.403	0.530	0.738	0.280	0.457	0.650	0.276	0.661	0.973
82	0.667	0.722	0.327	0.723	0.410	0.635	0.012	0.907	0.316	0.677
83	0.644	0.590	0.021	0.269	0.042	0.062	0.387	0.183	0.964	0.544

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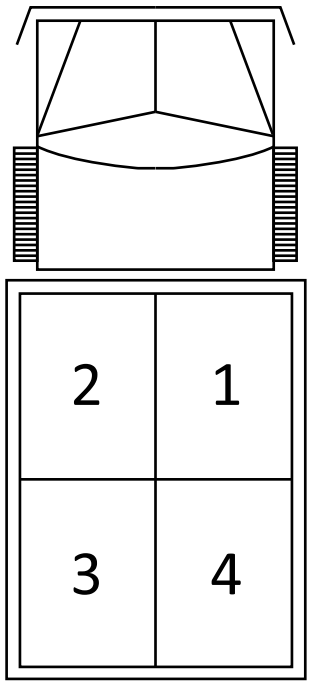
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Table 1 (Concluded)

	0	1	2	3	4	5	6	7	8	9
84	0.302	0.123	0.116	0.282	0.851	0.256	0.648	0.845	0.782	0.993
85	0.633	0.933	0.331	0.546	0.842	0.016	0.236	0.164	0.923	0.976
86	0.060	0.681	0.683	0.775	0.624	0.955	0.126	0.655	0.919	0.113
87	0.165	0.532	0.431	0.341	0.092	0.244	0.222	0.336	0.034	0.216
88	0.875	0.691	0.383	0.382	0.596	0.301	0.275	0.188	0.868	0.805
89	0.726	0.902	0.252	0.130	0.238	0.398	0.763	0.463	0.615	0.140
90	0.273	0.393	0.285	0.161	0.619	0.865	0.551	0.030	0.571	0.258
91	0.253	0.821	0.600	0.023	0.606	0.849	0.610	0.577	0.082	0.774
92	0.340	0.654	0.173	0.495	0.498	0.992	0.192	0.506	0.751	0.129
93	0.194	0.290	0.592	0.983	0.509	0.998	0.522	0.627	0.741	0.540
94	0.166	0.450	0.210	0.204	0.840	0.826	0.833	0.516	0.965	0.375
95	0.712	0.314	0.033	0.823	0.629	0.939	0.887	0.066	0.743	0.081
96	0.622	0.800	0.710	0.575	0.678	0.465	0.802	0.969	0.150	0.784
97	0.313	0.294	0.897	0.718	0.614	0.876	0.025	0.049	0.620	0.125
98	0.137	0.087	0.003	0.483	0.201	0.209	0.320	0.935	0.447	0.787
99	0.243	0.679	0.844	0.069	0.024	0.543	0.714	0.234	0.505	0.428
100	0.361	0.359	0.230	0.761	0.334	0.149	0.511	0.475	0.854	0.119

Note: *See Clauses 5 and 6 for instructions for using this Table.*

Figure 1
Quadrants for random sampling from a loaded truck
(See Clause 5.4.)



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7 Precision and bias

7.1 Precision

It is not possible to specify the precision of the procedure since the Test Method is not a method for measuring but simply sampling.

7.2 Bias

It is not possible to present the bias of the procedure since the Test Method is not a method for measuring but simply sampling.

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A23.2-8B
Determination of water-soluble sulphate ion content of recycled aggregates containing crushed concrete

1 Scope
This Test Method specifies the procedure for the quantitative determination of the water-soluble sulphate ion content of samples of recycled aggregates containing crushed concrete.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

ISO (International Organization for Standardization)

3310-1:2016
Test sieves – Technical requirements and testing — Part 1: Test sieves of metal wire cloth

APHA/AWWA/WEF (American Public Health Association/American Water Works

Association/Water Environment Foundation)
Standard Methods for the Examination of Water and Wastewater, 22nd Edition, 2012

3 Summary
Sulphate ions in the sample are dissolved in hot water. Dissolution in hot water puts water-soluble sulphates in the solution. Water-soluble sulphates are then measured by turbidimetry.

4 Significance and use
This Test Method is intended to measure the water-soluble sulphate ion content of recycled aggregates containing crushed concrete in contact with concrete, in order to evaluate the class of exposure to sulphate attack as described in Table 3 of CSA A23.1.

5 Apparatus, reagents, and materials
The following shall be used for the procedure:

a) a 5 mm sieve conforming to ISO 3310-1 made with the preferred wire diameter;
b) a 1 kg scale, accurate to ±0.1 g;
c) a hotplate appropriate to maintain a water temperature of 60 ± 5 °C and with a magnetic agitator;
d) a thermometer, accurate to ±1 °C;
e) ordinary rapid filters;
f) a time measuring device (i.e., a calendar);
g) a pH measuring device;
h) demineralized or distilled water;
i) nitric acid [1 volume concentrated nitric acid (70%) dissolved in 4 volumes of water]; and
j) appropriate glassware (e.g., beakers, etc.).

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6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Test sample

A minimum sample mass of aggregates of 3000 g shall be used. The test shall be conducted on the 0 mm to 5 mm fraction of the sample. For coarser aggregates (i.e., greater than 5 mm), the sample shall be crushed in such a way that all particles pass the 5 mm sieve. A subsample required for the test shall be obtained by quartering or other suitable means to ensure a representative mass of approximately 25 g. The subsample shall be weighed with a 0.1 g precision.

8 Test procedure

8.1 Sample preparation

The sample shall be prepared as follows:

a) Pour 1000 ± 2 g of demineralized or distilled water in a 1 L beaker and heat to 60 ± 5 °C.
b) Pour the 25 g sample into the beaker, taking care to incorporate the fine fraction of the sample. Cover the beaker.
c) Agitate for 15 min (16 min maximum) using a magnetic stick and maintain a temperature of 60 ± 5 °C, using the thermometer.
d) Filter with a rapid filter about 200 mL of the solution and neutralize (pH = 7 ± 1) with a few drops of nitric acid [1 volume concentrated nitric acid (70%) dissolved in 4 volumes of water].
e) Proceed with dosage not later than 24 h after preparation of the solution. Proceed to a second filtration if necessary.

8.2 Dosage

Proceed with dosage in accordance with Method 4500-S04 of the APHA/AWWA/WEF *Standard Methods for the Examination of Water and Wastewater*.

9 Calculations

Results shall be expressed as a percentage of sulphate ions over the total sample mass, as follows:

SO_4, % = (SO_4 mg/L) × (volume H_2O, L/mass of sample, g) × 0.1 F

where

F = dilution factor = volume of the extracted solution divided by total volume of solution plus water used for dilution

For example, if the dosage of soluble sulphate ions obtained from 25.0 g of sample in 1.000 L of distilled water shows a result of 32.1 mg/L without dilution (F = 1), the result is 0.13%.

10 Reporting

The following information shall be included in the test report, as applicable:

a) specimen identification;
b) source of the specimen;
c) date of sampling;
d) date of testing;
e) percentage of water-soluble sulphate ions measured expressed to the nearest 0.01%;

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f) identification of the laboratory that performed the test (i.e., name and address);
g) name of the technician who performed the test;
h) name and signature of the person responsible for the review and approval of the test report; and
i) any deviations from the test procedure.

11 Precision and bias

No precision and bias statement has been established for this Test Method.

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A23.2-1C
Sampling plastic concrete

1 Scope

This Test Method specifies the procedures, location, and sample size required to obtain a representative sample of fresh concrete and to assess its traceability to the structure it represents.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-25C:19
Standard Practice for sampling, testing, and inspection of concrete for acceptance purposes

A23.4-16
Precast concrete — Materials and construction

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Summary

This Test Method provides standard procedures to obtain a representative sample of fresh concrete from a truck agitator or mixer.

4 Significance and use

This Test Method provides standard procedures to obtain a representative sample of fresh concrete in order to perform tests on fresh concrete or to cast the fresh concrete into moulds used for different tests on hardened concrete.

5 Apparatus

5.1 Sieves

Sieves, as designated, shall conform to ISO 3310-1 made with the preferred wire diameter.

5.2 Wet-sieving equipment

Equipment for wet-sieving concrete shall be a sieve, as specified in Clause 5.1, of suitable size and conveniently arranged and supported so that it can be shaken rapidly either by hand or by mechanical means.

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6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Procedure

7.1 General

7.1.1

The procedures used in sampling include every precaution that will assist in obtaining samples that are truly representative of the nature and conditions of the concrete.

7.1.2

Segregation shall be avoided during sampling and handling of the samples.

7.2 Sampling from a truck agitator or mixer

7.2.1

When sampling from a truck agitator or truck mixer, the sample shall be taken between the 10% and 90% points of the discharge.

7.2.2

Clause 7.2.1 shall not apply under the following conditions:

a) when it is required that concrete be tested for slump immediately prior to the addition of superplasticizer; or
b) when precast concrete is produced in a stationary precast mixer.

Note: *For further guidance see CSA A23.4.*

7.3 Sampling for evaluation of concrete quality

The sample for strength test specimens and the corresponding related plastic concrete properties shall be a grab sample from the designated place of sampling, as defined in Clause 7.2 of CSA A23.2-25C. Grab sampling is the operation of securing at one point of the discharge the required volume of representative material in as short a period of time as possible.

Note: *More than one container may be used to obtain a single grab sample.*

7.4 Sampling for uniformity of mixed concrete

Sampling for uniformity of mixed concrete shall be performed as follows:

a) Obtain three grab samples of concrete for comparative purposes from widely separated portions of the batch while the mixer is being completely emptied.
b) Keep the samples separate to represent the designated portions in the batch rather than combined to form a composite sample. When sampling, discharge the concrete at the normal operating rate for the mixer being tested, while exercising care not to obstruct or retard the discharge by an incompletely opened gate or seal. Between samples, do not allow the mixer to turn in the mixing direction. Do not add water to the batch at any time after sampling has started.

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7.5 Size of sample

7.5.1

When 100 mm × 200 mm cylinders are to be cast, a minimum 20 L sample shall be obtained for moulding three specimens to determine the strength or to determine the uniformity of the mixed concrete. When 150 mm × 300 mm cylinders are to be cast, a minimum 30 L sample shall be obtained. When 150 mm × 150 mm × 535 mm beams are to be cast, a minimum 55 L sample shall be obtained for three beams. For more than three cylinders or beams, the minimum volume shall be increased, equal to the volume of the extra specimens, plus 10%.

Note: *Concrete may be reused from the slump test for other tests provided that it is thoroughly recombined with the whole sample.*

7.5.2

Smaller sample volumes may be used for routine air content and slump tests.

7.6 Method of sampling

7.6.1

Sampling shall be performed by passing a receptacle completely through the discharge stream or by completely diverting the discharge into a sample container. The rate of discharge of the batch shall be regulated by the rate of revolution of the drum and not by the size of the gate opening.

7.6.2

The grab samples shall be transported to the place where plastic concrete tests are to be performed or where test specimens are to be moulded. Each sample shall be remixed with a shovel only as long as required to ensure uniformity. The sample shall be obtained, transported, and remixed within 10 min. When multiple containers are used to obtain a grab sample, the samples shall be remixed into a single composite grab sample.

7.7 Protection of sample

The sample shall be protected from sun, wind, and other sources of rapid evaporation, and from contamination.

7.8 Identification

The concrete represented by the sample shall be identified and noted in the test report, including the information required by Clauses 5.2.5.5.1 and 5.2.5.5.2 of CSA A23.1.

7.9 Additional procedure for large-size aggregate concrete

7.9.1 General

When the concrete contains aggregate larger than that appropriate for the size of the moulds or equipment to be used, the sample shall be wet sieved prior to testing. For all density tests, an unsieved sample shall be used.

Note: *The effect of wet-sieving on the test results should be considered. For example, wet-sieving concrete causes the loss of a small amount of air due to additional handling. The air content of the wet-sieved fraction of concrete is greater than that of the total concrete because the large-size aggregate, which is removed, does not contain air. The apparent strength of wet-sieved concrete in smaller specimens is usually greater than that of the total*

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concrete in larger appropriate size specimens. The effect of these differences might need to be considered or determined by supplementary testing for quality control or test result evaluation purposes.

7.9.2 Procedure

The procedure shall be performed as follows:

a) After sampling, pass the concrete over the designated sieve and remove and discard the aggregate retained. Do this before remixing.
b) Shake or vibrate the sieve by hand or mechanical means until no undersize aggregate remains on the sieve.
c) If any mortar adheres to the aggregate retained on the sieve, do not wipe the mortar from it before it is discarded.
d) Place only enough concrete on the sieve at any one time that after sieving, the thickness of the layer of retained aggregate is not more than the maximum-size particle.
e) Ensure that the concrete that passes the sieve falls into a batch pan of suitable size that has been dampened before use or onto a clean, moist, nonabsorbent surface.
f) Scrape any mortar adhering to the sides of the wet-sieving equipment into the batch.
g) After removing the larger aggregate particles by wet-sieving, remix the batch with a shovel only as long as required to ensure uniformity.

8 Reporting

The following information shall be included in the report, as applicable:

a) concrete mix identification
b) source of the sample (i.e., bill no., batch no., plant identification);
c) date and time of sampling;
d) identification of the project site;
e) location of the sampling operation if other than point of discharge from concrete delivery equipment (e.g., pump discharge);
f) location of the concrete in the structure under construction represented by the sample;
g) the name of the certified technician performing the sampling;
h) identification of the certified laboratory performing the sampling (i.e., name and address);
i) name and signature of the person responsible for the review of the test report; and
j) any deviation from the test procedure.

9 Precision and bias

9.1 Precision

It is not possible to specify the precision of procedure in this Test Method, since the Test Method is not a method for measuring but simply sampling.

9.2 Bias

It is not possible to present the bias of procedure in this Test Method, since the Test Method is not a method for measuring but simply sampling.

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A23.2-2C
Making concrete mixes in the laboratory

1 Scope

This Test Method specifies the procedures for making concrete mixes in the laboratory under accurate control of material quantities and test methods.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-6A:19
Relative density and absorption of fine aggregate

A23.2-9A:19
Soundness of fine and coarse aggregate by use of magnesium sulphate

A23.2-11A:19
Surface moisture in fine and coarse aggregate

A23.2-12A:19
Relative density and absorption of coarse aggregate

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-4C:19
Air content of plastic concrete by the pressure method

A23.2-5C:19
Slump of concrete

A23.2-6C:19
Density and yield of plastic concrete

A23.2-7C:19
Air content of plastic concrete by the volumetric method

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

A23.2-17C:19
Temperature of freshly mixed hydraulic cement concrete

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A23.2-19C:19
Slump flow of concrete

3 Definitions

In addition to the definitions specified in CSA A23.1, the following definitions shall apply in this Test Method:

Air content — the volume of the air voids of plastic concrete, exclusive of pore space in aggregate particles, determined through observations of the change in the volume of air in concrete with a change in pressure in accordance with either CSA A23.2-4C or CSA A23.2-7C and usually expressed as a percentage of total volume of concrete.

Slump — a measure of consistency of freshly mixed hydraulic cement concrete, mortar, or stucco, equal to the subsidence, measured to the nearest 5 mm, of the moulded specimen immediately after removal of the slump cone.

Slump flow — the horizontal spread of concrete immediately upon removal of the slump cone as a measure of the unconfined fluidity of concrete giving a relative indication of the degree to which concrete can travel.

4 Summary

Concrete trial mixes are made in the laboratory using at least three water-to-cementitious materials ratios. For each water-to-cementitious materials ratio, at least three specimens for each age to be tested are made, cured in accordance with CSA A23.2-3C, and tested for strength in accordance with CSA A23.2-9C.

5 Significance and use

This Test Method is intended to provide standard requirements for preparation of materials, mixing concrete, and making and curing test specimens in laboratory conditions. The test specimens resulting from the laboratory trials may be used to develop information for: mixture proportioning to meet project specifications, evaluation of different mixtures and materials, correlation with nondestructive tests, and research.

Where previous data are not available, concrete trial mixes using project materials that have proportions and consistency suitable for the work are made, using at least three water-to-cementitious materials ratios that will produce a range of strengths encompassing those required. For each water-to-cementitious materials ratio, at least three specimens for each age to be tested are made and cured in accordance with CSA A23.2-3C and are tested for strength in accordance with CSA A23.2-9C.

Based on the trial mixes, the concrete supplier will propose an appropriate concrete mix design that will satisfy the project specification requirements and the requirements of the concrete placing contractor.

6 Apparatus

6.1 General

Moulds, consolidation equipment, and small tools shall conform to CSA A23.2-3C.

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6.2 Sampling and mixing pan

The pan shall be of heavy-gauge metal, watertight, of convenient depth, and of sufficient capacity to allow easy mixing by shovel or trowel of the entire batch or to receive the entire batch on discharge of the mixer and allow remixing in the pan by trowel or shovel.

6.3 Scales

A balance or scale sensitive to within 0.1% of the mass of the sample shall be used.

Note: *Small quantities should not be measured on large-capacity scales.*

6.4 Concrete mixer

A power-driven revolving drum, tilting mixer, or suitable pan mixer capable of thoroughly mixing batches of the prescribed sizes shall be provided.

Note: *A pan mixer might be more suitable than a revolving drum mixer for mixing concrete with less than 20 mm slump. The rate of rotation, degree of tilt, and rated capacity of tilting mixers might not always be suitable for laboratory mixed concrete. It can be desirable to reduce the rate of rotation, decrease the angle of tilt from the horizontal, and use the mixer at somewhat less than the maximum capacity stated by the manufacturer.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Preparation of materials

8.1 Materials

Materials shall be brought to a stable temperature, preferably in the range of 23 ± 2 °C (unless the mix temperature is a test parameter) prior to mixing the concrete.

8.2 Cementitious materials

Cementitious materials shall be stored in a dry place, in moisture-proof containers. Cementitious materials shall be thoroughly mixed so that the sample will be uniform throughout the tests. The cementitious materials shall be passed through a 1.25 mm or finer sieve and reject all lumps.

8.3 Aggregate

8.3.1 General

Aggregate for each batch of concrete shall be of the desired grading.

8.3.2 Coarse aggregate

Coarse aggregate shall be separated into two or more size fractions, depending upon the maximum size of aggregate used, and coarse aggregate shall be recombined for each batch in such a manner as to produce the desired grading (see Table 11 of CSA A23.1). Relative density and absorption of the coarse aggregate shall be determined in accordance with CSA A23.2-12A.

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8.3.3 Fine aggregate

Fine aggregate shall be separated into different sizes if unusual gradings are being studied. Otherwise, the fine aggregate grading shall be in accordance with Table 10 of CSA A23.1. Relative density and absorption of the fine aggregate shall be in accordance with CSA A23.2-6A.

8.3.4 Moisture and mass

The aggregate shall be treated before use to ensure a definite and uniform condition of moisture. The mass of aggregate to be used in the batch shall be determined by one of the following five procedures:

a) Each size fraction of the aggregate may be brought to a saturated, surface-dry condition and measured separately.

b) Each size fraction of the aggregate may be brought to a saturated condition with surface moisture in sufficiently small amounts to preclude loss by draining and shall be so maintained until used. The mass of each size fraction of the aggregate shall be measured separately in this condition. When using this method, the amount of surface moisture on both the coarse and the fine aggregate shall be determined prior to making concrete. Surface moisture in fine aggregate may be determined in accordance with CSA A23.2-11A. Surface moisture in fine and coarse aggregate may be determined by drying samples of approximately 500 g and 1000 g or more, respectively, on a hotplate, with due allowance being made for the loss of water due to absorption. The amount of surface moisture in the aggregate shall be counted as part of the required amount of mixing water.

c) The aggregate for the entire batch, after soaking in water for 24 h, in separate containers for the fine and coarse aggregate, may be measured underwater. The required suspended-immersed mass shall be calculated as follows:

$$M_w = \frac{M_a(G - 1)}{G}$$

where

M_w = mass suspended in water of the desired amount of coarse or fine aggregate, determined to an accuracy of ± 0.01 kg

M_a = desired mass in air of the coarse or the fine aggregate in a saturated condition, determined to an accuracy of ± 0.01 kg

G = bulk relative density (saturated surface-dry basis) of the aggregate in a saturated condition, determined to an accuracy of 0.01 kg

Upon removal of the aggregate from the water, an additional mass measurement in air of the aggregate and surface water shall be made to determine the amount of surface moisture in the aggregate. The amount of surface moisture in the aggregate shall be counted as part of the required amount of mixing water.

d) The amount of aggregate required for the batch may be measured in the dry condition into separate tared watertight containers for the fine and coarse aggregate and then immersed for 24 h prior to use. After immersion, excess water shall be decanted off and the combined mass of aggregate and mixing water shall be determined, due allowance being made for the amount of water absorbed by the aggregate.

e) Aggregate of low absorption (less than 1%) may be measured in the dry condition, with allowance made for the amount of water that will be absorbed during mixing.

Note: *The allowance to be made may be computed from tests for absorption of the aggregate during 30 min or by assuming that 80% of the 24 h absorption of both the fine and coarse aggregate will occur during mixing.*

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9 Mixing concrete

9.1 General

Concrete shall be mixed in a suitable mixer in batches of such size as to leave approximately 10% excess after moulding the test specimens.

9.2 Batching and machine mixing

Batching and machine mixing shall be performed as follows:

a) Add the coarse aggregate, some of the mixing water, and when required, the admixtures. When feasible, disperse each admixture in a separate small portion of the mixing water before addition.
b) Start the mixer, then add the fine aggregate, cementitious materials, and water with the mixer running. When it is impractical to add the ingredients while the mixer is running, stop the mixer after permitting it to turn a few revolutions and add the fine aggregate, cementitious materials, and the remaining water.
c) After all ingredients are in the mixer, mix the concrete for 3 min followed by a 3 min rest, followed by 2 min of final mixing. When prolonged mixing is required because of the addition of water in increments while adjusting the slump, discard the batch and make a new batch without interrupting the mixing to make trial slump tests.
d) Cover the open end or top of the mixer to prevent evaporation during the rest period.
e) To eliminate segregation, deposit machine-mixed concrete on a clean pre-dampened floor, suitable damp mixing pan or wheelbarrow, and remix concrete by shovel until it appears to be uniform.
f) Take precautions to compensate for mortar retained by the mixer so that the finished batch, as used, will be correctly proportioned.

Notes:

1) *Particular care should be taken to clean the mixing apparatus and accessories so that chemical additions or admixtures used in certain batches of concrete do not contaminate subsequent batches.*
2) *It is difficult to recover all of the mortar from certain kinds of mixers, particularly revolving-drum mixers. When such difficulty is encountered, one of the following procedures should be used to ensure the correct final proportions in the batch:*
   a) *"buttering" the mixer: just prior to mixing the test batch, the mixer should be "buttered" by mixing a batch with the same proportions as the test batch. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch; or*
   b) *"overmortaring" the mix: the test mix may be proportioned with excess mortar to compensate for that which is expected to adhere to the mixer. In this case, the mixer is cleaned before mixing the test batch.*
3) *It is important not to vary the mixing sequence and procedure from batch to batch unless the effect of such variation is under study.*

9.3 Mixed concrete

Portions of the batch of mixed concrete taken for use in tests and for moulding specimens shall be selected so as to be representative of the actual proportions and condition of the concrete. Concrete shall be covered when it is not being remixed or sampled to prevent evaporation.

10 Slump, slump flow, air content, yield, and temperature

10.1 Slump or slump flow

Depending on the consistency of the concrete, the slump or slump flow of each batch of concrete shall be measured immediately after mixing, in accordance with CSA A23.2-5C or CSA A23.2-19C. The

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concrete sample used for determining slump or slump flow may be reused for other tests or moulding specimens provided it is remixed into the batch.

10.2 Air content

The air content, when required, shall be determined in accordance with either CSA A23.2-4C or CSA A23.2-7C. The concrete used for determining the air content shall be discarded.

10.3 Density, yield, and cementitious materials factor

The density, yield, and cementitious materials factor of each batch of concrete shall be determined in accordance with CSA A23.2-6C. The concrete used for yield tests may be returned to the mixing pan and remixed into the batch.

10.4 Temperature

The temperature of the mix shall be recorded in accordance with CSA A23.2-17C.

11 Strength test specimens

Strength test specimens shall be moulded and cured in accordance with CSA A23.2-3C.

12 Reporting

12.1 Required information

The following information shall be included in the report as applicable:

a) names and sources of mix ingredients (i.e., cementitious materials, fine and coarse aggregates, chemical admixtures, other additives, etc.);
b) mass of individual mix ingredients (i.e., cementitious materials, water, fine and coarse aggregates) to an accuracy of ± 0.01 kg;
c) chemical admixture dosage rates used in the mix to an accuracy of ± 0.5 mL;
d) date and time mix ingredients were sampled;
e) bulk densities of the cementitious materials, and fine and coarse aggregates used in the mix;
f) moisture contents and water absorption of the fine and coarse aggregates;
g) slump of concrete to the nearest 5 mm, or slump flow of concrete to the nearest 10 mm;
h) air content of the concrete to the nearest 0.1%;
i) plastic concrete mix temperature to the nearest 0.5 °C;
j) laboratory temperature during the production of the mix to the nearest 0.5 °C;
k) plastic mass density of the concrete to the nearest 1 kg/m^3;
l) yield of the concrete mix to the nearest 0.001 m^3;
m) converted mass of mix ingredients for cementitious materials, water, and fine and coarse aggregates, in kg/m^3, based on the mix yield and plastic density of the concrete;
n) compressive strength of the concrete at the various tests ages to the nearest 0.1 MPa;
o) chemical admixture dosage rates expressed in mL/100 kg of cementitious materials or mL/m^3 of concrete;
p) name of the certified technician who performed the tests (i.e., slump, air, and yield);
q) name of the certified technician who prepared the concrete mixes;
r) identification of the certified laboratory that performed the preparation and testing of the concrete mix (i.e., name and address);
s) name and signature of the person responsible for the review and approval of the test report; and
t) any deviation from the test procedure.

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12.2 Precision and bias

No precision and bias statement has been established for this Test Method.

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A23.2-3C
Making and curing concrete compression and flexural test specimens

1 Scope

This Test Method specifies the procedure for making and curing compression test cylinders and flexural test beams from samples of plastic concrete. Procedures for both field and laboratory work are included.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

A23.2-8C:19
Flexural strength of concrete (using simple beam with third-point loading)

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

A23.2-12C:19
Making, curing, and testing compression test specimens of no-slump concrete

A23.2-15C:19
Evaluation of concrete strength in place using the pullout test

A23.2-1D:19
Moulds for forming vertical concrete test cylinders

A23.4-16
Precast concrete — Materials and construction

ACI (American Concrete Institute)

211.3R-02 (R2009)
Standard Practice for Selecting Proportions for No-Slump Concrete

ASTM International

C511-13
Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concrete

C1074-17
Standard Practice for Estimating Concrete Strength by the Maturity Method

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E77-14e1
Standard Test Method for Inspection and Verification of Thermometers

3 Summary

This Test Method is used to cast compressive or flexural strength test specimens and cure them on site prior to timely transportation to the laboratory for subsequent curing and strength testing.

4 Significance and use

This Test Method specifies the standard procedure for making, curing, protecting, and transporting concrete specimens.

If the specimens are

a) made and standard cured as specified in this Test Method, the resulting strength data, when the specimens are tested in accordance with the relevant test method, may be used for the following purposes:
   i) acceptance testing for specified strength;
   ii) checking adequacy of mixture proportions for strength; and
   iii) quality control; and
b) made and field-cured as specified in this Test Method, the resulting strength data, when the specimens are tested in accordance with the relevant Test Method, may be used for the following purposes:
   i) consideration of whether the structure is able to be put into service;
   ii) comparison with test results of standard cured specimens or with test results from various in place test methods;
   iii) adequacy of curing and protection of concrete in the concrete structure; and/or
   iv) formwork or shoring removal time requirements.

5 Apparatus

5.1 Moulds for compression test specimens

Moulds for compressions test specimens shall be as follows:

a) Use cylindrical moulds, meeting the requirements of CSA A23.2-1D, having nonabsorbent surfaces and sufficiently rigid to hold their shape during the moulding of the test specimens.
b) Do not use cardboard moulds unless there is satisfactory documentation available indicating that the cylinders produced from them will have compressive strengths equivalent to those obtained from rigid nonabsorbent moulds when tested under the same conditions. Do not use cardboard moulds for specified concrete strengths greater than 35 MPa.
c) Lightly coat reusable moulds with mineral oil or other suitable non-reactive form release material before use.

5.2 Moulds for flexural test specimens

Rectangular moulds of the dimensions specified in Clause 10 shall be used for flexural test specimens. The mould shall be at least 50 mm longer than the length of span prescribed in CSA A23.2-8C. Moulds shall be watertight and made of rigid, nonabsorbent material. Provide means for securing the base plate firmly to the mould. The inside surface of the mould shall be smooth and free of holes, indentations, or ridges. The sides, bottom, and ends shall be at right angles and shall be straight and true so that the specimen will not be warped. Maximum variation from the specified cross-section shall not exceed 3 mm. Lightly coat the assembled mould and base plate with mineral oil before use.

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5.3 Tamping rod

Tamping rods shall be as follows:

a) For 100 mm × 200 mm cylinders, use a round straight steel tamping rod 10 ± 1 mm in diameter and between 450 mm and 600 mm in length, having at least one end rounded to a hemispherical tip.
b) For cylinders 150 mm in diameter or greater and for rectangular moulds, use a round straight steel tamping rod 16 ± 1 mm in diameter and not less than 450 mm nor more than 600 mm in length, having at least one end rounded to a hemispherical tip.

5.4 Vibrators

5.4.1 Internal vibrators

Internal vibrators shall have rigid or flexible shafts and preferably powered by electric motors. The frequency of vibration shall be 120 Hz or greater. The outside diameter of the vibrating element shall be 20 to 40 mm. The minimum length of the vibrating element shall be 50 mm less than the height of the mould being consolidated. For vibration of cylinders, the ratio of the diameter of the cylinder to the diameter of the vibrating element shall be 4.0 or higher. For vibration of beams, the diameter of the vibrating element, or thickness of a square vibrating element, shall not exceed one third of the width of the mould.

5.4.2 External vibrators

External vibrators, if required, shall be of the table or plank type, having a minimum frequency of 60 Hz. A means of clamping the moulds securely to the apparatus shall be provided.

Note: *A tachometer should be used to check frequency of vibration.*

5.5 Small tools

Tools and items, such as shovels, pails, trowels, wood floats, blunted trowels, straightedges, scoops, rubber gloves, rulers, and a rubber or rawhide head mallet weighing approximately 0.6 ± 0.3 kg, shall be provided.

5.6 Sampling and mixing receptacles

A suitable pan, wheelbarrow, or flat, clean, nonabsorbent mixing board of sufficient capacity shall be provided to allow easy mixing by shovel or trowel of the entire sample.

5.7 Strike-off bar

A steel strike-off bar approximately 6 mm × 25 mm × 450 mm shall be provided.

5.8 Water storage tanks

5.8.1 General

Tanks shall be constructed of non-corroding materials. Automatic control of water temperature at 23 ± 2 °C shall be provided where the tank is located in a room not having the temperature controlled within this range and in any instance where difficulty in maintaining temperatures within the specified range is encountered. With the exception of water storage tanks located in a moist room or moist cabinet, all water storage tanks shall be equipped with a temperature recorder with its sensing element in the storage water. Alternatively, manual temperature readings may be used and these readings shall be taken twice daily (e.g., early morning and late afternoon) at least 5 d per week with an accuracy of

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0.5 °C. For the purpose of temperature recording, a group of water storage tanks may be considered one tank if the following three conditions are met:

a) All tanks are interconnected with tubing that allows water to flow between the tanks.
b) Some means of circulation is provided between the tanks.
c) Temperature variation between the tanks shall not exceed 1°C when checked and recorded weekly.

The water in a storage tank shall be saturated with calcium hydroxide (high calcium hydrated lime) to prevent leaching of calcium hydroxide from the specimens (see Note 2). Water not saturated with calcium hydroxide can affect test results due to leaching of lime from the test specimens and shall not be used in storage tanks. To maintain saturation with calcium hydroxide, excess calcium hydroxide shall be present. For the purposes of lime saturation to prevent leaching, lime shall refer to high-calcium hydrated lime, not calcium carbonate (limestone). The water in the storage tank shall be thoroughly stirred at intervals not to exceed one month to help replace calcium ions that have depleted. Tanks shall be cleaned and refilled with water containing 3 g/L of calcium at intervals not to exceed 24 months (see Note 3).

Notes:

1) *The requirements for water storage tanks, moist cabinets, and moist rooms are substantially in agreement with ASTM C511.*
2) *pH is not a reliable indicator of lime saturation in storage tank water since severe reductions in dissolved calcium ions can occur before pH values are significantly reduced.*
3) *The 3 g/L level is intended to provide a quantity of calcium hydroxide approximately two times that required for initial saturation.*

5.8.2

Continuously running fresh water or demineralized water shall not be used in storage tanks because it can affect test results due to excessive leaching. A closed system, circulating the saturated lime water between or among storage tanks, may be used.

5.9 Moist cabinets and moist rooms

5.9.1 General

5.9.1.1

Except during those times when specimens are being placed into or removed from storage, the atmosphere in a moist cabinet or moist room shall be maintained at a temperature of 23 ± 2 °C and a relative humidity of not less than 95%. Atmospheric conditions within a moist cabinet or moist room shall be maintained such that test specimens in storage are saturated with moisture to the degree needed to ensure that the exposed surfaces of all specimens in storage both appear moist and feel moist. All moist cabinets and moist rooms shall be equipped with a temperature recorder. Alternatively, manual temperature readings may be used and these readings shall be taken twice daily (e.g., early morning and late afternoon) at least 5 d per week with an accuracy of 0.5 °C. The use of humidity recording devices is optional.

5.9.1.2

The air temperature inside the moist cabinet or moist room shall be controlled with provisions made for heating or cooling, or both, as may be necessary. This shall be accomplished in one of two ways:

a) Thermostatically control the air temperature within the moist cabinet or moist room when surrounding space is not conditioned. In this case, the sensing element for the controls shall be located inside the moist cabinet or moist room.

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b) Thermostatically control the space surrounding the moist cabinet or moist room and manually control the temperature within the moist cabinet or moist room.

5.9.2 Moist cabinets

A moist cabinet shall be constructed of durable materials and the doors shall be tight fitting. The specified relative humidity shall be maintained by the use of one or more fog sprays, water sprays, or curtains of water on the inner walls that are so directed that the discharge will collect in a pool or near the bottom of the moist storage section.

5.9.3 Moist rooms

5.9.3.1 General

The walls of a moist room shall be constructed of durable materials and all openings shall be provided with tight fitting doors or windows (see Note). The specified humidity in Clause 5.9.1 may be maintained in any convenient and suitable manner.

Note: *Well insulated walls will substantially help maintain necessary conditions.*

5.9.3.2

Atmospheric conditions shall be maintained within each moist room such that the specimens in storage both appear and feel moist. Specimens shall not be exposed to dripping or running water (see Note).

Note: *Maintenance of adequate water spray(s) and adequate spray distribution in the moist room will result in stored specimens appearing and feeling moist and will maintain the required humidity. An inadequate number of spray nozzles, partially obstructed spray nozzles, or disturbances in the moist air system such as open doors, air conditioning or heating drafts, or overly crowed shelf space can result in relative dry spots. Specimen surface texture and age can influence the surface appearance and should be considered when specimens in localized areas of the moist room do not appear or feel moist.*

5.10 Temperature measuring devices

5.10.1 General

A temperature measuring device shall be capable of measuring temperatures in the range of 0 °C to 50 °C, accurate to ± 0.5 °C. Partial immersion liquid glass thermometers or other types shall be provided with an immersion line to which the device shall be immersed without using a correction factor.

5.10.2 Temperature recorder

5.10.2.1

A temperature recorder shall record temperatures every 15 min or less and shall be accurate and readable to 1 °C. The data from the recorder shall be evaluated at a minimum of once each week. A record of this evaluation documenting the date checked, a confirmation that the data is within the required temperature range, and the name of the individual performing this evaluation shall be maintained in the laboratory (Note).

Note: *This requirement may be satisfied by an initialed and dated temperature recorder chart. Brief changes in the temperature due to door openings should be ignored.*

5.10.2.2

The temperature recorder shall be verified at least every six months or whenever there is a question of accuracy.

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5.10.2.3

For moist cabinets and rooms, the reference temperature measuring device shall be positioned in a readable position in air as near as practical to the temperature recorder probe. The door shall be closed for at least 5 min prior to taking readings. The temperature readings of both the temperature recorder and the reference temperature measuring device shall be recorded. When taking these readings, the reference temperature measuring device shall remain in the moist cabinet or room and read immediately upon opening the door.

5.10.2.4

For water storage tanks, the reference temperature measuring device shall be positioned in a readable position in water as near as practical to the temperature recorder probe. Without removing the reference temperature measuring device from the water, the temperature readings of both the temperature recorder and the reference temperature measuring device shall be recorded after the temperatures have stabilized.

5.10.2.5

The accuracy of the temperature recorder shall be verified by comparing the reading of the temperature recorder with that of the reference temperature measuring device during the normal operation of the moist cabinet, moist room, or water storage tanks. If the difference between the temperature readings is greater than 1 °C, the temperature recorder shall be adjusted to within 0.5 °C of the reference temperature measuring device.

5.11 Reference temperature measuring device

A reference temperature measuring device for calibration of the temperature measure device(s) shall be readable and accurate to ±0.2 °C at the two comparison temperatures used in the calibration procedure. The reference temperature measuring device shall have a certificate or report of calibration available for review. Liquid glass temperature measuring devices shall be verified once. Direct reading resistance reference temperature devices shall be verified on a semiannual basis. The reference standard used in the verification shall be traceable to the National Institute of Standards and Technology and confirmation of the traceability of the reference temperature measuring device shall be provided in the certificate or report of calibration (see Note).

Note: *The ice-point method described in ASTM E77 may be used to ensure that no damage to the reference thermometer has occurred during shipping.*

5.12 Temperature records

The laboratory shall demonstrate the ability of the controls to maintain the required temperature in the water storage tank, moist cabinet, or moist room over an extended period of time. Records that indicate that the temperatures are within the temperature limits specified in Clause 5.8.1 shall be required as evidence of this ability.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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7 Sampling concrete

7.1 Field sampling

Samples of concrete for casting test specimens shall be obtained in accordance with CSA A23.2-1C.

Note: *The place of deposition of the batch of concrete that was sampled should be noted in the job records. (See Annex B of CSA A23.2.)*

7.2 Laboratory sampling

The entire mix shall constitute the sample for casting test specimens.

8 Moulding specimens

8.1 Time constraint

The moulding of strength test specimens shall be completed within 20 min after sampling, including transport and remixing.

8.2 Relation between specimen size and aggregate size

The diameter of a cylindrical specimen or the minimum cross-sectional dimension of a beam shall be at least three times the maximum nominal size of the coarse aggregate in the concrete. The occasional oversize aggregate particles shall be removed by handpicking during the moulding of specimens.

8.3 Place of moulding

The specimens shall be moulded on a level, rigid surface, free of vibration and other disturbances and in as close proximity as is practicable to the place where they are to be stored during the first 28 ± 8 h. If it is not practical to mould the specimens where they will be stored, they may be moved to the place of storage immediately after being struck off. When moving the specimens, all jarring, striking, tilting, and deformation of the concrete specimens or scarring of the surface shall be avoided.

8.4 Methods of consolidation of test specimens

To prepare satisfactory test specimens, concretes at different slump levels shall have different methods of consolidation. The selection of the method of consolidation shall be based on specified slump, as indicated in Table 1, unless the method of consolidation of test specimens is stated in the specifications under which the work is being performed.

Table 1
Concrete consolidation of test specimen
(See Clause 8.4.)

Specified slump, mm	Method of consolidation
Greater than 40	Rodding
Equal to or less than 40	Vibration

Notes:

1) *A concrete sample having a specified slump of 80 mm or less may be consolidated by vibration when agreed to by all parties.*
2) *Concrete with no slump and relatively dry mixtures, such as those used in certain foundation piles or paving mixtures, require the use of special means of consolidation. See CSA A23.2-12C and ACI 211.3R.*

(Continued)

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Table 1 (Concluded)

3) *Flowing concrete mixes having a slump greater than 180 mm should be consolidated in accordance with Clause 9.2.1.2.*
4) *Self-consolidating concrete mixes (slump flow greater than 500 mm) does not require rodding (see Clause 9.2.1.3).*

8.5 Placing the concrete

The concrete shall be placed in the moulds in either two or three layers, as required by Clauses 9.2 and 10.2, using a scoop or blunted trowel. During the placing portion of each portion of concrete, the scoop or trowel shall be moved around the top edge of the moulds as the concrete is discharged in order to ensure a symmetrical distribution of the concrete and minimize segregation of the coarse aggregate within the mould. The concrete may be further distributed by the use of a tamping rod prior to the start of consolidation.

8.6 Finishing

8.6.1 General

The surface shall be finished with the minimum manipulation necessary to produce a flat, even surface that is level with the rim or edge of the mould and has no depressions or projections larger than 3 mm for flexural strength specimens or when the specified compressive strength is less than 35 MPa. Depressions and projections shall not exceed 1 mm for compressive strength specimens when the specified compressive strength is equal to or greater than 35 MPa.

8.6.2 Cylinders

The top surface shall be finished after consolidation, by striking off with a strike-off bar or the tamping rod where the consistency of the concrete permits or with a wood float or trowel. If desired, the top surface of freshly made cylinders may be capped with a thin layer of stiff Portland cement paste, which may harden and cure with the specimen (see CSA A23.2-9C).

8.6.3 Beams

Beams shall be finished be with a wood float.

8.7 Covering after finishing

The finished specimens shall be immediately covered with a non-absorptive, non-reactive cap or plastic sheet secured to prevent evaporation of water from the specimens during the initial curing period. Alternatively, finished specimens may be placed in an impervious plastic bag.

9 Compression test specimens

9.1 Specimens

9.1.1 Size of specimens

Compression test specimens shall be cylindrical, with a length equal to twice their diameter.

9.1.2 Moulding specimens

Specimens shall be moulded as described in Clause 8.

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9.2 Method of consolidation

9.2.1 Rodding

9.2.1.1

The concrete shall be placed in the mould in layers of equal volume. Rod each of the layers with the number of strokes indicated in Table 2. The strokes shall be uniformly distributed over the cross-section of the mould. The bottom layer shall be rodded throughout its depth, without forcibly striking the bottom of the measure. The rod shall penetrate about 25 mm into the underlaying layer when rodding the upper layers. The sides of the mould shall be tapped smartly 10 to 15 times with the mallet if voids are left by the tamping rod to close any holes left by rodding and to release any large air bubbles that might have been trapped. An open hand shall be used to tap light-gauge single-use moulds that are susceptible to damage if tapped with a mallet.

Note: *The top layer of a mould should be overfilled to avoid concrete being added to the specimen without adequate consolidation.*

9.2.1.2

Flowing superplasticized concrete mixes having a slump greater than 180 mm shall be consolidated with 40% of the number of strokes per layer required in Table 2.

Table 2
Consolidation of concrete cylinders by rodding
(See Clauses 9.2.1.1 and 9.2.1.2.)

Diameter of cylinder, mm	Number of strokes per layer	Diameter of rod, mm	Number of layers
100	20	10	3
150	25	16	3
200	50	16	3
250	75	16	3

9.2.1.3

Self-consolidating concrete shall be placed continuously in one lift to slightly overfilling the top of the mould. The outer sides of the mould shall be tapped lightly 10 or more times with the mallet until no large bubbles of air appear on the surface and any surface voids are closed.

9.2.2 Vibration

A standard duration of vibration shall be used for the particular kind of concrete, vibrator, and specimen mould involved. The vibration shall continue only long enough to achieve proper consolidation of the concrete.

The mould shall be filled and vibrated in two approximately equal layers. All of the concrete for each layer shall be placed in the mould before starting vibration of that layer. The second layer of concrete shall be added so as to avoid overfilling by more than 6 mm. After vibrating the second layer, enough concrete shall be worked into the surface concrete with a trowel to overfill the mould about 3 mm and then struck off.

Notes:

1) *Over-vibration can cause segregation.*

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2) *The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes smooth in appearance, the egress of entrapped air bubbles has ceased, and bubbles are no longer breaking the surface.*

9.2.3 Internal vibration

One insertion per lift of the vibrator shall be used when 100 mm diameter by 200 mm high cylinder specimens are used. Three insertions of the vibrator shall be used when 150 mm diameter by 300 mm high cylinder specimens are used. The vibrator shall be penetrated through the second layer and into the bottom layer approximately 25 mm. The vibrator shall withdrawn in such a manner that no air pockets are left in the specimens.

9.2.4 External vibration

When the external vibration is used, the mould shall be rigidly attached to or securely held against the vibrating element or vibrating surface.

Notes:

1) *The duration of vibration will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and large bubbles of entrapped air are no longer breaking the surface.*
2) *Over-vibration can cause segregation and loss of appreciable quantities of intentionally entrained air.*

9.3 Curing specimens

9.3.1 Laboratory curing

Laboratory test specimens shall be stored at a temperature of 23 ± 2 °C, unless the purpose of the laboratory mix dictates an alternative storage temperature. The moulds shall be placed on a rigid horizontal surface free from vibration and other disturbances and covered to prevent evaporation (see Clause 8.7). The test specimens shall be removed from the moulds at 20 ± 4 h and stored in a moist condition with free water maintained on all surfaces of the specimens at all times until the time of test. The mass of each test specimen shall be determined, expressed to the nearest gram, immediately upon demoulding.

9.3.2 Field curing

9.3.2.1 Initial curing conditions in the mould

The moulds shall be placed on a rigid horizontal surface free from vibration and other disturbances. During initial curing, the test specimens shall be stored in a controlled environment that maintains the temperature between 15 and 25 °C immediately adjacent to the specimens. The loss of moisture from the specimens shall be prevented as specified in Clause 8.7.

The records of the maximum and minimum temperature within the curing enclosure during the initial curing period shall be reported.

Notes:

1) *These curing requirements necessitate an appropriate temperature- and moisture-controlled curing facility on a project site.*
2) *The laboratory should develop procedures to account for the acclimatization of the maximum and minimum temperature recording or indicating device within the initial curing storage environment so that very brief extremes beyond the specified range are not incurred. The procedures should take into account the size of the initial curing environment, type of insulation (if used), anticipated ambient temperature during the initial storage period, and number of test specimens in the initial curing storage environment.*

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3) *In hot or cold weather, a temperature can be recorded by the temperature measuring device that is only indicative of the air temperature during the very brief time in which the test specimens were initially placed in the curing environment (curing box). In the event a time and temperature data recorder is used, curing temperatures may vary outside the specified range by not more than 5 °C for a period not exceeding 30 min at either extreme. The time and temperature outside the specified range should be accurately recorded and noted on the concrete strength test report.*

9.3.2.2 Final curing conditions

After removing the specimens from their moulds in accordance with Clause 9.3.1, the specimens shall be stored in a moist condition with free water maintained on all surfaces of the specimens at all times at 23 ± 2 °C until the time of the test.

9.3.3 Demoulding time of test specimens

The specimens shall be removed from the moulds at the end of 28 ± 8 h if the test specimens were made for checking the adequacy of the laboratory mixture proportions for strength or as the basis for acceptance. The test specimens shall be stored in accordance with Clause 9.3.2.2.

Demoulding time may be extended to a maximum of 76 h for cylinders representing concrete having a specified strength of less than 35 MPa, provided that

a) the specimens are stored in an environmentally controlled facility at the project site that maintains the temperature between 15 °C and 25 °C immediately adjacent to the specimens;
b) the specimens are protected from moisture loss; and
c) the maximum and minimum temperatures, immediately adjacent to the specimens, continue to be recorded throughout the entire curing period.

The mass of each test specimen shall be determined, expressed to the nearest gram (g), immediately upon demoulding.

9.3.4 Specimens for determining when forms are removed or when a structure is put into service

The test specimens shall be stored in or on the structure as near to the point of use as possible when the test specimens are made for determining when forms can be removed or when a structure can be put into service. The test specimens, insofar as practicable, shall have the same protection from the elements on all surfaces as is given to the portions of the structure that they represent. The specimens shall be tested in the moisture condition resulting from the specified curing treatment. The specimens shall be removed from the moulds at the time of removing the formwork when the specimens are made for the purpose of determining when a structure can be put in service.

In-place testing using CSA A23.2-15C is the preferred alternative when it is difficult to cure the specimens in conditions similar to those of the structure they represent.

Notes:

1) *The requirements of this Clause also apply to specimens representing concrete subjected to accelerated curing, such as steam curing. See Clause 7.5 of CSA A23.4.*
2) *The correlation of the maturity of the specimens and the concrete in the forms should be determined, using thermocouples embedded in the specimens and into the structure. See ASTM C1074 for information determining maturity.*

9.4 Transportation of concrete test samples during curing period

The test specimens shall be transported from the field to the laboratory only after curing for a minimum of 20 h under the curing condition required by Clause 9.3.2.1. The test specimens shall be protected

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during transportation, from any shocks or exposure to adverse conditions. The curing conditions and the date received shall be stated in the laboratory in the test report.

Note: *When concrete specimens are to be transported under curing conditions other than those of Clause 9.3.2.1, the transportation should be delayed as long as possible to minimize the effect of adverse transportation conditions.*

10 Flexural test specimens

10.1 Size of specimens

Rectangular beams with a length at least 50 mm greater than three times their depth formed with their long axes horizontal shall be used. The ratio of width to depth, as moulded, shall not exceed 1.5. The cross-section shall be not less than 150 mm × 150 mm or three times the maximum size of aggregate, whichever is larger.

10.2 Placing and consolidation

10.2.1 Placing the concrete

The concrete shall be placed in the moulds using a scoop or shovel. Moulds 200 mm or less in depth shall be filled in two approximately equal layers. Moulds more than 200 mm in depth shall be filled in three approximately equal layers. The concrete shall be distributed symmetrically within the mould.

Note: *The concrete may be distributed by means of the tamping rod prior to the start of consolidation.*

10.2.2 Rodding

10.2.2.1

Each layer shall be rodded evenly over its area, once for every 10 cm^2 of area. The upper layer shall be rodded so that the strokes penetrate approximately 25 mm into the underlying layer. The top layer shall be slightly overfilled in the mould. The concrete shall be spaded along the sides and ends of the mould with a trowel or other suitable tool after each layer is rodded. The sides of the mould shall be tapped smartly with a mallet 10 to 15 times to close the voids.

10.2.2.2

Self-consolidating concrete shall be placed continuously in one lift to slightly overfill the mould. The outer sides of the mould shall be tapped lightly 10 or more times with the mallet until no large bubbles of air appear on the surface and any surface voids are closed.

10.2.3 Vibration

The concrete shall vibrated only long enough to achieve proper consolidation. A standard duration of vibration shall be used for the particular kind of concrete, vibrator, and specimens involved.

Notes:

1) *Usually, sufficient vibration has been applied when the surface of the concrete becomes relatively smooth in appearance.*
2) *Overvibration can cause segregation. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator.*

10.2.4 Internal vibration

The vibrator shall be inserted at intervals not exceeding 150 mm along the centreline of the long dimension of the specimen. For specimens wider than 150 mm, alternating insertions shall be used

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along two lines. The vibrator shall not rest on the bottom or strike the sides of the mould. The vibrator shall penetrate into the bottom layer approximately 25 mm. The vibrator shall be withdrawn in such a manner that no air pockets are left in the specimen.

10.2.5 External vibration

When external vibration is used, the mould shall be rigidly attached to or securely held against the vibrating element or vibrating surface.

10.3 Curing specimens

10.3.1 Laboratory curing

Laboratory test specimens shall be cured in accordance with the requirements of Clause 9.3.1.

10.3.2 Field curing

10.3.2.1 Initial curing conditions

Initial curing of the test specimens shall be in accordance with the requirements of Clause 9.3.2.1.

10.3.2.2 Final curing conditions

Final curing of the test specimens shall be in accordance with the requirements of Clause 9.3.2.2.

Note: *Relatively small amounts of drying of the surface of flexural specimens induce tensile stresses in the extreme fibres that will reduce the indicated flexural strength.*

10.3.3 Demoulding time of test specimens

Unless otherwise specified, the test specimens shall be demoulded at the time specified in Clause 9.3.3.

10.3.4 Transportation of flexural test samples

Flexural test samples shall be transported in their moulds.

10.4 Specimens for determining when concrete is put into service

Test specimens for determining when a structure can be put into service shall be cured, as nearly as practicable, in the same manner as the concrete in the structure. The test specimens shall be removed from their moulds at the end of 48 ± 4 h after moulding. The specimens representing pavement or slabs on grade shall be stored by placing them on the ground as moulded, with their top surfaces up. The sides and ends of the specimens shall be banked with damp earth or sand kept damp, leaving the top surfaces exposed to the specified curing treatment. Specimens representing structural concrete shall be stored as near to the point in the structure they represent as possible and the same temperature protection and moisture environment shall be provided as the structure. At the end of the curing period, the specimens shall be left in place, exposed to the weather in the same manner as the structure.

All specimens shall be removed from the field storage and store in lime water at 23 ± 2 °C for 24 ± 4 h immediately before the time of testing to ensure that moisture conditions are uniform from specimen to specimen.

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11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) concrete mix identification;
b) source of the sample from which the specimens were made (i.e., bill no., batch no., plant identification);
c) date and time of sampling;
d) identification of the project site;
e) location of the concrete in the structure under construction related to the specimens;
f) type of specimens:
   i) cured under standard conditions; or
   ii) cured to represent the in-place conditions;
g) date and time of moulding of the specimens;
h) type of moulds used (i.e., material and size);
i) location of curing receptacle during initial curing period;
j) minimum and maximum temperatures measured during the initial curing period, as well as the times and temperatures recorded beyond either of the limits of the specified range if a time and temperature data recorder was used;
k) date and time of departure from the site where the specimens were initially stored;
l) date and time of the receipt of the concrete test specimens in the laboratory;
m) mass of each cylindrical test specimen at the time of demoulding, g;
n) curing conditions, if different from standard;
o) the name of the certified technician(s) responsible for the making and initial curing concrete test specimens;
p) identification of the certified laboratory making, initial curing, and transporting specimens (i.e., name and address);
q) identification of the certified laboratory responsible for laboratory curing and testing the specimens;
r) name and signature of the person responsible for the review of the test reports; and
s) any deviation from the test procedure.

11.2 Optional information

The following information may be included in the test report:

a) name of the individual(s) responsible for transporting the concrete test specimens; and
b) the name of the certified technician(s) responsible for laboratory curing of concrete test specimens.

12 Precision and bias

No precision and bias statement has been established for this test procedure.

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A23.2-4C
Air content of plastic concrete by the pressure method

1 Scope
This Test Method specifies the procedure for the determination of the air content of plastic concrete from observations of the change in the volume of air in concrete with a change in pressure. This Test Method is not suitable for determining the air content of concretes containing low-density or other porous aggregates.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-6C:19
Density and yield of plastic concrete

ASTM International

C231/C231M-17a
Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

3 Summary
This Test Method involves the application of air pressure to a known volume of concrete to compress the entrained air in the pore structure. The bowl section of the apparatus is filled with concrete and consolidated and smoothed. The top section of the apparatus is then attached and air is pumped into the air chamber and the initial pressure stabilized. A valve between the air chamber and bowl is opened and the drop in air pressure indicates the air content of the concrete.

4 Significance and use
This Test Method measures the air content of plastic concrete. The air content of hardened concrete can be higher or lower than that determined by this Test Method. This depends upon

a) the method and amount of consolidation applied to the concrete from which the hardened concrete is taken;
b) the uniformity and stability of the air bubbles in the fresh and hardened concrete;
c) the accuracy of microscopic method (if used);
d) the time of comparison;
e) the environmental exposure;
f) the stage in the delivery;
g) the placement and consolidation processes at which the air content of the unhardened concrete is determined (i.e., before and after the concrete goes through a pump); and
h) other factors.

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5 Apparatus

5.1 General

Any type of apparatus employed in determining the air content of plastic concrete by the pressure method shall be used, incorporating the following:

a) a measuring bowl of sufficiently rigid construction to make a pressure-tight container of accurate volume, suitable to hold a representative sample of concrete to be tested (see Table 1);
b) a cover designed to be attached to the measuring bowl so as to make an adequately rigid, pressure-tight assembly;
c) facilities for applying a known pressure to the system and observing its effect on the volume of the sample;
d) a round straight steel tamping rod 16 ± 1 mm in diameter and between 450 mm and 600 mm in length, having at least one end rounded to a hemispherical tip;
e) internal vibrators with rigid or flexible shafts, preferably powered by electric motors. The frequency of vibration shall be 120 Hz or greater. The outside diameter of the vibrating element shall be not smaller than 20 mm or greater than 40 mm. The length of the shaft shall be at least 350 mm;
f) external vibrators of the table or plank type, having a minimum frequency of 60 Hz and preferably higher, with a means to clamp the moulds securely to the table and plank vibrators;

Note: *A tachometer should be used to check frequency of vibration.*

g) a rubber or rawhide head mallet weighing approximately 0.6 ± 0.3 kg;
h) a steel strike-off bar approximately 6 mm × 25 mm × 450 mm long; and
i) miscellaneous equipment, including trowel, syringes, funnel, and other equipment that is necessary to conduct the test.

5.2 Measuring bowl

The measuring bowl shall be cylindrical in shape and made of steel or other metal not readily attacked by the cement paste. It shall be flanged or otherwise constructed to provide for a pressure-tight fit between the bowl and the cover assembly. The interior surface of the bowl and the surfaces of rims or flanges shall be machined smooth. The measuring bowl shall be sufficiently rigid to limit expansion to 0.1% of scale reading at operating pressure. The capacity of the measuring bowl will depend upon the nominal maximum size of coarse aggregate in the concrete being tested and shall be as specified in Table 1.

Notes:

1) *A 7 L bowl may be used for concrete containing aggregate particles that would be retained on a 40 mm sieve if the concrete sample is wet-sieved over a sieve having 40 mm square openings before being tested. In this case, measured air contents should be adjusted for the absolute volume of the stone removed. Wet-sieving procedures are given in CSA A23.2-1C.*
2) *A procedure for the calibration of the apparatus is given in Annex A1 of ASTM C231/C231M.*

Table 1
Capacity of measuring bowl
(See Clauses 5.1 and 5.2.)

Minimum capacity of measuring bowl, L	Nominal maximum size of aggregate, mm
7	40 or less
15	56

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5.3 Cover assembly

The cover assembly shall be made of steel or other metal not readily attacked by cement paste. It shall be flanged or otherwise constructed to provide for a pressure-tight fit between the bowl and the cover assembly and shall be provided with suitable means for clamping the cover and bowl together. The interior surface shall be machined smooth and contoured to provide an air space above the level of the top of the measuring bowl. The cover shall be fitted with

a) an air chamber;
b) a suitable hand pump either attached to the cover or provided as an accessory;
c) a valve for bleeding the air chamber to atmospheric pressure;
d) an operating valve for allowing air in the chamber to enter the measuring bowl;
e) two bypass valves that will release air from the container directly to atmosphere without passing through the air chamber; and
f) a pressure gauge.

5.4 Gauge dial

The dial shall be of sufficient size to permit direct reading to a minimum of 0.2% for air volumes in the usual range of 0 to 8%.

5.5 Calibration cylinder

A calibration cylinder shall have a volume in the range of 1 to 6% of the volume of the base container. Glass plates shall be suitable for striking off the calibration cylinder and base container for calibration.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Calibration

The calibration procedure will vary for different types of air meters; therefore, the manufacturer's calibrating instructions shall be followed for each type of meter used.

Note: *Basically, calibration should be as follows:*

a) *The measuring bowl is filled with water.*
b) *A nipple is screwed into the threaded hole on the underside of the cover directly below a petcock. The nipple should be long enough that its open end is completely submerged in water after the volume of water required to fill the calibration vessel has been drawn off.*
c) *The cover assembly is then clamped to the measuring bowl.*
d) *All remaining air is removed from the measuring bowl by adding water with a syringe through the petcock into which the nipple is screwed from below.*
e) *Water is added until all air is forced out of the other petcock.*
f) *With all valves closed, air is pumped into the air chamber until the needle on the gauge is a little beyond the initial starting point.*
g) *The needle is brought back to the starting point by bleeding air from the chamber by means of the bleed valve.*
h) *The operating valve that allows air to go from the air chamber to the container is then opened and the air is allowed to warm for a few seconds while the gauge is tapped lightly. The indicated air content should be 0%.*
i) *The above procedure is repeated, drawing off successive increments of water into the calibration vessel or measure before each measurement, in accordance with instructions. The indicated air content should be that represented by the amount of water removed from the meter.*

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If the indicated air content does not equal the correct amount, the equipment should be adjusted by changing the initial line, re-marking the dial of the pressure gauge, shifting the dial of the pressure gauge, or adjusting the pressure gauge, as appropriate.

8 Operation of air meter

The manufacturer's instructions for operating the particular meter being used shall be followed.

Note: *The basic procedure should be as follows.*

a) *The measuring bowl is filled with a representative sample of fresh concrete, following the procedure for determining density of concrete in CSA A23.2-6C.*
b) *The flange of the container and the cover are cleaned and the cover clamped in place with the operating valve closed and the petcocks open.*
c) *All air above the concrete is expelled by injecting water with a syringe through one of the petcocks until water flowing from the other valve is free of air bubbles. Slightly jarring the side of the bowl while adding water will assist in the removal of entrapped air.*
d) *When all entrapped air has been removed, air is pumped into the air chamber until a slightly higher pressure than the initial starting point, as determined during calibration, is reached; then the two petcocks are closed.*
e) *The pressure gauge needle is brought back to the initial set point by allowing air to escape from the air chamber through the air bleed valve while lightly tapping the pressure gauge.*
f) *The main valve leading from the air chamber to the measuring bowl is then opened quickly.*
g) *When the air is released into the bowl, strike the bowl smartly with the mallet.*
h) *The gauge is tapped lightly after the gauge needle has come to rest.*
i) *The percentage of air is read and recorded to the closest 0.1%.*
j) *When air meters equipped with double-scale pressure gauges are used, the manufacturer's instructions for measuring high air contents (usually over 10%) should be followed.*

9 Sampling

9.1 Sampling

The sample shall be obtained in accordance with the requirements of CSA A23.2-1C so that the sample of concrete from which test specimens are made is representative of the batch of concrete. The concrete used for determination of air content shall not be used for other tests.

9.2 Time constraint

The test for air content shall be completed within 10 min after obtaining the sample, including transportation and remixing.

10 Procedure for testing

10.1 General

The concrete shall be rodded with a specified slump greater than 40 mm (see Clause 10.4). The concrete shall be vibrated with a specified slump of 40 mm or less (see Clause 10.5).

Note: *A concrete sample having a specified slump of 80 mm or less may be consolidated by vibration when agreed to by all parties.*

10.2 Rodding

10.2.1

The concrete shall be placed in the measure in three layers of approximately equal volume. Each layer shall be rodded with 25 strokes of the tamping rod when a measure equal to or smaller than 15 L is

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used. Each layer shall be rodded with 50 strokes when a measure larger than 15 L is used. The bottom layer shall be rodded throughout its depth, without forcibly striking the bottom of the measure. The strokes shall be distributed uniformly over the cross-section of the measure and, for the top two layers, penetrated about 25 mm into the underlying layer. After each layer is rodded, the outsides of the measure shall be tapped smartly 10 or more times with a mallet until no large bubbles of air appear on the surface and voids left by the tamping rod are closed.

10.2.2

Self-consolidating concrete shall be placed in two equal layers. The sides of the bowl shall be tapped lightly 10–15 times with a mallet to release any large air bubbles that might have been trapped during the bowl-filling process.

10.3 Vibrating

10.3.1 Internal vibration

The measure shall be filled and vibrated in two approximately equal layers. All concrete for each layer shall be placed in the measure before starting vibration of that layer. The vibrator shall be inserted at three points for each layer. In compacting the bottom layer, the vibrator shall not touch the bottom or sides of the measure. In compacting the final layer, the vibrator shall extend into the underlying layer approximately 25 mm. The vibrator shall be withdrawn in such a manner that no air pockets are left in the specimen. Vibration shall continue only long enough to achieve proper consolidation of the concrete. A standard duration of vibration shall be used for each particular kind of concrete, vibrator, and measure involved.

Notes:

1) *The duration of vibration will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth.*
2) *Overvibration can cause segregation and loss of appreciable quantities of intentionally entrained air.*

10.3.2 External vibration

When external vibration is used, the mould shall be rigidly attached to or securely held against the vibrating element or vibrating surface.

Notes:

1) *The duration of vibration will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and bubbles are no longer breaking the surface.*
2) *Overvibration can cause segregation and loss of appreciable quantities of intentionally entrained air.*

10.4 Completion of consolidation

On completion of consolidation, the measure shall not contain a substantial excess or deficiency of concrete. An excess of concrete protruding approximately 3 mm above the top may be considered optimum. A small quantity of concrete may be added to correct a deficiency.

10.5 Strike-off, cleaning, and measuring

After consolidation of the concrete, the top surface shall be struck off and finished smoothly with a strike-off bar or rod with great care being taken to leave the measure level. If the concrete density is to be determined, the strike-off of the concrete shall be completed in accordance with CSA A23.2-6C and all excess concrete shall be cleaned from the exterior of the measure. The mass of the filled measure shall be determined to the nearest 0.05 kg.

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10.6 Air content

The air meter shall be operated as described in Clause 8 and the air content, as a percentage by volume of the concrete sample, shall be recorded to the nearest 0.1%.

11 Reporting

The following information shall be included in the test report, as applicable:

a) source of sample (i.e., bill no., batch no., plant identification);
b) location, date, and time of sampling;
c) location of the concrete in the structure under construction related to the specimens;
d) identification of the certified laboratory that performed the test (i.e., name and address);
e) the name of the certified technician who performed the test;
f) test age of the sample (i.e., date and time of testing);
g) air content as a percentage by volume of the concrete sample, to the nearest 0.1%;
h) name and signature of the person responsible for the review of the test report; and .
i) any deviation from the test procedure.

12 Precision and bias

This Test Method has no bias because the air content of freshly mixed concrete can only be defined in terms of the test methods. No precision statement has been established for this procedure.

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A23.2-5C
Slump of concrete

1 Scope
This Test Method specifies the procedure to be used in the laboratory and in the field for determining slump of hydraulic cement concrete. The Test Method is in substantial agreement with ASTM C143.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-19C:19
Slump flow of concrete

ASTM International

C143/C143M-15a
Standard Test Method for Slump of Hydraulic-Cement Concrete

3 Definition
In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Slump — a measure of consistency of freshly mixed hydraulic cement concrete, mortar, or stucco, equal to the subsidence, measured to the nearest 5 mm, of the moulded specimen immediately after removal of the slump cone.

4 Summary
A sample of freshly mixed concrete is placed and compacted by rodding in a mould shaped as the frustum of a cone. The mould is raised and the concrete allowed to subside. The vertical distance between the original and displaced position of the centre of the top of the concrete is measured and reported as the slump of the concrete.

5 Significance and use
This Test Method provides a procedure to determine slump of plastic hydraulic cement concretes. Slump flow is tested in accordance with A23.2-19C. This Test Method is considered applicable to plastic concrete having coarse aggregate up to 40 mm in size. If the coarse aggregate is larger than 40 mm in size, this Test Method is applicable when it is performed on the fraction of concrete passing a 40 mm

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sieve, with the larger aggregate being removed by seiving. This Test Method is not considered applicable to non-plastic and non-cohesive concrete.

Notes:

1) *Concretes having slumps greater than about 230 mm might not be adequately cohesive for the slump test to have significance. Caution should be exercised in interpreting such results and in such instances, the slump test should be supplemented by the slump flow test of CSA A23.2-19C. In this instance, self consolidation of the concrete sample in the specimen mould should not be relied upon and the concrete sample should be consolidated as described below prior to measuring the slump flow.*
2) *The slump test is not applicable to testing of flowing or self-consolidating concrete.*

6 Apparatus

6.1

A test specimen mould shall be made of metal not thinner than 1.5 mm, not readily attacked by cement paste, and in the form of the lateral surface of the frustum of a cone with the base 200 mm in diameter, the top 100 mm in diameter, and the height 300 mm. Moulds formed by the spinning process may have a minimum thickness of 1.15 mm. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mould shall be provided with foot pieces and handles, as shown in Figure 1.

6.2

A round straight steel tamping rod shall be 16 ± 1 mm in diameter and between 450 and 600 mm in length, having at least one end rounded to a hemispherical tip.

6.3

The surface upon which to perform the slump test shall be rigid, flat, and non-absorbant. Materials, such as sealed plywood, plastic, or a steel plate, are suitable for a base plate for this Test Method. Plywood, if used, shall have a medium density overlay and a minimum thickness of 19 mm.

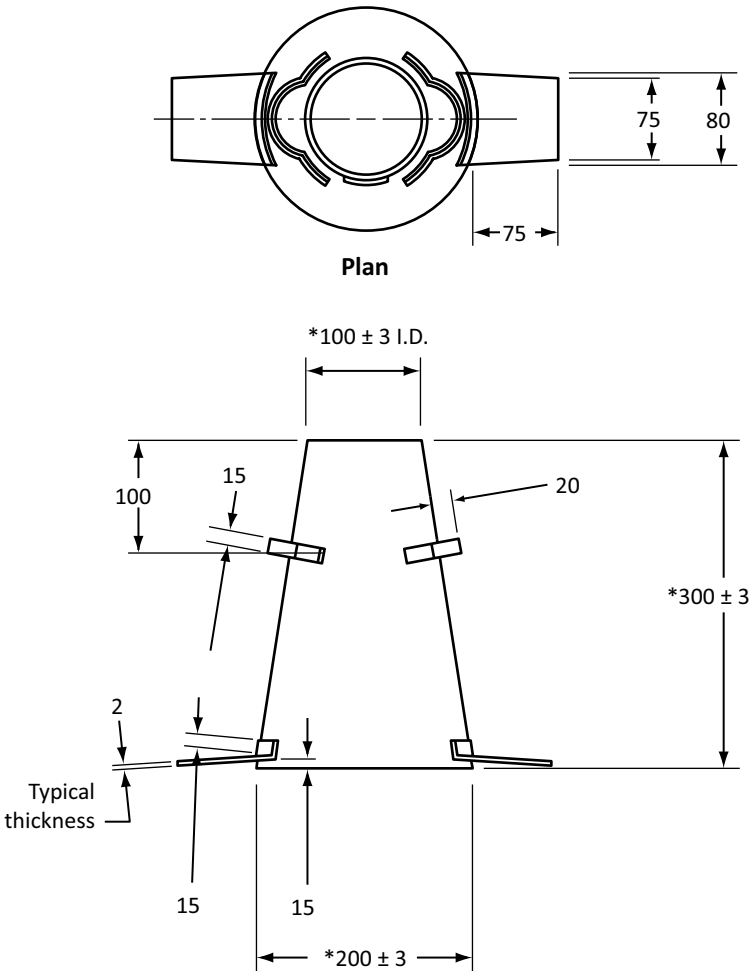
6.4

A measuring tape or measure at least 300 mm in length and having 1 mm graduations shall be used.

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Figure 1
Mould for slump test
(See Clause 6.1.)



Note: *All measurements are in millimetres unless specified.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. It is the responsibility of the user of this Test Method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Sample

8.1

The sample of concrete, from which test specimens are made to represent the entire batch, shall be obtained in accordance with the requirements of CSA A23.2-1C.

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8.2
If the concrete contains coarse aggregate particles that would be retained on a 40 mm sieve, the concrete sample shall be wet-sieved over a sieve having 40 mm square openings before being tested Wet-sieving procedures are given in CSA A23.2-1C.

9 Procedure

9.1 Time constraint
The test for slump shall be completed within 10 min of obtaining the sample including transporting and remixing.

9.2 Slump

9.2.1
The mould shall be dampened and placed on a flat, level, moist, nonabsorbent (rigid) surface not subjected to vibration. The mould shall be held firmly in place during filling by standing on the two foot pieces. From the sample of concrete obtained in accordance with Clause 8, the mould shall be immediately filled in three layers, each approximately one-third the volume of the mould.

Note: *One-third the volume of the slump mould fills it to a depth of 70 mm; two-thirds of the volume fills it to a depth of 160 mm.*

9.2.2
Each layer shall be rodded with 25 strokes of the tamping rod. The strokes shall be uniformly distributed over the cross-section of the each layer. For the bottom layer, this shall necessitate inclining the rod slightly and making approximately half of the strokes near the perimeter and then progressing with vertical strokes in spirals toward the centre. The bottom layer shall be rodded throughout its depth. Both the second layer and the top layer shall be rodded throughout their depth so that the strokes penetrate about 25 mm into the underlying layer.

9.2.3
In filling and rodding the top layer, the concrete shall be heaped above the mould before rodding begins. If the rodding operation results in subsidence of the concrete below the top edge of the mould, additional concrete shall be added to keep an excess of concrete above the top of the mould at all times. After the top layer has been rodded, the surface of the concrete shall be struck off with a screeding and rolling motion of the tamping rod. The spilled concrete shall be removed from the base of the mould. The mould shall be withdrawn immediately from the concrete by raising it carefully in a vertical direction. The mould shall be lifted in approximately 5 s by a steady upward lift. No lateral or torsional movement shall be imparted to the concrete. The entire operation, from the start of the filling to the removal of the mould, shall be completed without interruption and within an elapsed time of 2 min.

9.2.4
The slump immediately shall be determined thereafter by measuring the difference between the height of the mould and the average height of the top surface of the concrete after subsidence. Slump specimens that break or slump laterally give incorrect results. In such cases, the test shall be repeated with an unused portion of the remaining sample or a new sample.

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Prior to conducting a retest of slump, the concrete shall be remixed to ensure uniformity of the concrete.

Notes:

1) *If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, the concrete probably lacks the necessary plasticity and cohesiveness for the slump test to applicable.*
2) *Duplicate tests on two portions of the same sample should not vary by more than 10 mm.*
3) *Concrete from slump tests can be reused after proper mixing.*

10 Reporting

The following information shall be included in the test report, as applicable:

a) identification of the certified laboratory performing the test (i.e., name and address);
b) source of sample (i.e., bill no., batch no., plant identification);
c) location, date and time of sampling ;
d) location of the concrete in the structure under construction related to the specimens; test age of the sample (i.e., date and time of testing);
e) name of the certified technician who performed the field testing;
f) the slump recorded in millimetres, to the nearest 5 mm of subsidence of the specimen during the test;
g) name and signature of the person responsible for the review of the test report; and
h) any deviation from the test procedure.

11 Precision and bias

11.1 Precision

The precision of this Test Method is expected to be similar to that of ASTM C143/C143M.

11.2 Bias

This Test Method has no bias since slump is defined only in terms of this Test Method.

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A23.2-6C
Density and yield of plastic concrete

1 Scope
This Test Method specifies the procedure for determining the density of plastic concrete and includes formulas for calculating the volume of concrete produced from a mixture of known quantities of the component materials (i.e., yield); and actual cementitious materials factor.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-10A:19
Bulk density of aggregate

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-4C:19
Air content of plastic concrete by the pressure method

3 Summary
The mass of consolidated concrete in a container of known volume is used to determine the density of the plastic concrete. This information is compared to the concrete production records to determine yield and cementitious materials factor.

4 Significance and use
This Test Method is intended to provide standard requirements and procedures to determine the density, yield, and cementitious materials factor of plastic concrete for the purpose of concrete production quality control. The density of plastic concrete can be used to verify the air content as determined by CSA A23.2-4C.

5 Apparatus and supplies
The apparatus shall consist of the following:

a) a balance or scale sensitive to within 0.05 kg;
b) a round straight steel tamping rod 16 ± 1 mm in diameter and between 450 mm and 600 mm in length, having at least one end rounded to a hemispherical tip;
c) a cylindrical container made from metal that is not readily attacked by cement paste. It shall be watertight and sufficiently rigid to retain its form and calibrated volume under rough usage. Measures that are machined to accurate dimensions on the inside and provided with handles are preferred. The minimum capacity of the measure shall conform to the requirements of Table 1. All measures, except for the measuring bowls of air meters that are also used for these tests, shall conform to the requirements of CSA A23.2-10A. When measuring bowls of air meters are used,

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they shall conform to the requirements of CSA A23.2-4C. The top rim of the air meter bowls shall be smooth and plane within 0.25 mm;

d) internal vibrators with rigid or flexible shafts. The minimum frequency of vibration shall be 120 Hz. The outside diameter of the vibrator head shall be 20 to 40 mm. The length of the shaft shall be at least 350 mm;

e) a steel strike-off bar approximately 6 mm × 25 mm × 450 mm long;

f) a rubber or rawhide head mallet weighing approximately 0.6 ± 0.3 kg for use with measures of 7 L or smaller, and a mallet weighing approximately 1.0 ± 0.3 kg for use with measures larger than 7 L; and

g) a flat rectangular glass plate at least 6 mm thick or a flat rectangular transparent acrylic plate at least 10 mm thick with a length and width at least 50 mm greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance 1.5 mm.

Table 1
Dimensional requirements for measures
(See Clause 5.)

Capacity, L	Inside dimensions, mm		Minimum thickness of metal, mm		Nominal maximum size of coarse aggregate, mm
	Diameter	Height	Base	Walls	
7	205 ± 2	210 ± 2	5.0	2.5	28 or less
15	255 ± 2	295 ± 2	5.0	3.0	40* and 56
30	355 ± 2	305 ± 2	5.0	3.0	80

** Concrete produced using 40 mm nominal maximum size coarse aggregate with no aggregate retained on the 40 mm sieve may be tested using the 7 L bowl.*

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this test method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Calibration of measure

The measure shall be filled with water between 20 and 25 °C and covered with a glass plate or an acrylic plate in such a way as to eliminate bubbles and excess water. The mass of the water in the measure shall be determined within 1% of the total mass. The temperature of the water shall be measured and the density determined from Table 2, interpolating if necessary. The volume, *V*, of the measure shall be calculated by dividing the mass of the water required to fill the measure by its density. Alternatively, the factor for the measure (1/*V*) may be calculated by dividing the density of the water by the mass required to fill the measure.

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Table 2
Density of water
(See Clause 7.)

Temperature, °C	kg/m³
20	998.23
21	998.02
22	997.80
23	997.56
24	997.32
25	997.07

8 Sample

A sample of freshly mixed concrete shall be obtained in accordance with CSA A23.2-1C.

9 Procedure

9.1 Consolidation

9.1.1 General

Concretes of different slumps require different methods of consolidation to prepare satisfactory test specimens. The selection of the method of consolidation shall be based on the slump of the concrete, as indicated in Table 1 of CSA A23.2-3C.

9.1.2 Rodding

9.1.2.1

Rodding shall be performed in accordance with Clauses 9.1.2.2 to 9.1.2.3.

9.1.2.2

Place the concrete in the measure in three layers of approximately equal volume. Rod each layer with 25 strokes of the tamping rod when a measure equal to or smaller than 15 L is used. Rod each layer with 50 strokes when a measure larger than 15 L is used. Rod the bottom layer throughout its depth, but do not forcibly strike the rod on the bottom of the measure. Uniformly distribute the strokes over the cross-section of the measure. For the top two layers, the tamping rod shall penetrate about 25 mm into the underlying layer. After completion of rodding each layer, tap the outer sides of the measure 10 or more times with a rubber mallet until no large bubbles of air appear on the surface and voids left by the tamping rod are closed. Add the final layer so as to minimize overfilling.

9.1.2.3

Place self-consolidating concrete in two equal layers. Tap the sides of the bowl for each layer lightly 10 to 15 times with a mallet to release any large air bubbles that might have been trapped during the bowl filling process.

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9.1.3 Vibrating

9.1.3.1 General

Vibrations shall be performed as specified in Clauses 9.1.3.2 and 9.1.3.3.

9.1.3.2 Internal vibration

Fill and vibrate the measure in two approximately equal layers. Place all concrete for each layer in the measure before starting vibration of that layer. Insert the vibrator at three points for each layer. While compacting the bottom layer, take precaution so as to not allow the vibrator to touch the bottom or sides of the measure. While compacting the final layer, extend the vibrator into the underlying layer approximately 25 mm. Withdraw the vibrator in such a manner that no air pockets are left in the specimen. Continue vibration only long enough to achieve proper consolidation of the concrete. Use a constant duration of vibration for each particular kind of concrete, vibrator, and measure involved.

9.1.3.3 External vibration

When using external vibration, take care to ensure that the mould is rigidly attached to or securely held against the vibrating element or vibrating surface.

Notes:

1) *The duration of vibration will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and larger entrapped air bubbles are no longer breaking the surface.*
2) *Overvibration can cause segregation and loss of appreciable quantities of intentionally entrained air.*

9.2 Completion of consolidation

On completion of consolidation, the measure shall not contain a substantial excess or deficiency of concrete. An excess of concrete protruding approximately 3 mm above the top is considered optimum. A small quantity of concrete, if required, may be added to correct a deficiency.

9.3 Strike-off, cleaning, and measuring

After consolidation of the concrete, initial, intermediate, and final strike off of the top surface shall be undertaken as follows:

a) Initial strike off with the strike-off bar or the tamping rod.
b) Intermediate strike off: Strike off the measure by pressing the strike-off plate on the top surface of the measure to cover about two thirds of the surface and withdraw the plate with a sawing motion to finish only the area originally covered. Then place the plate on the top of the measure to cover the original two thirds of the surface and advance it with a vertical pressure and a sawing motion to cover the whole surface of the measure and continue to advance it until it slides completely off the measure.
c) Final strike off: Incline the plate and perform final strokes with the edge of the plate to produce a smooth surface.

All excess concrete shall be cleaned from the exterior of the measure and the mass of the filled measure shall be determined to the nearest 0.05 kg.

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10 Calculations

10.1 Density of concrete

The net mass of the concrete shall be calculated by subtracting the mass of the measure from the gross mass. The density of concrete shall be calculated by dividing the net mass by the volume of the measure used, *V*, or by multiplying the net mass by the factor for the measure used, 1/*V*, determined as described in Clause 7.

10.2 Yield of concrete

The yield of concrete produced per batch shall be calculated as follows:

$$Y = \frac{M_a + M_f + M_c + M_w + M_{add}}{D}$$

where

Y = volume of concrete produced by batch, m³

M_a = total mass of cementitious materials added to batch, kg

M_f = total mass of fine aggregate in batch in condition used, kg

M_c = total mass of coarse aggregate in batch in condition used, kg

Mw = total mass of mixing water added to batch, kg

M_{add} = total mass of admixtures and additives (e.g., fibres), kg

D = density of concrete, kg/m³

10.3 Relative yield

The relative yield as shall be calculated follows:

$$R_y = \frac{Y}{Y_d}$$

where

R_y = relative yield

Y = volume of concrete produced per batch, m³

Y_d = volume of concrete that the batch was designed to produce, m³

Notes:

1) *Relative yield is the ratio of the actual volume of concrete obtained to the volume the batch was designed to produce.*
2) *A value for R_y greater than 1.000 indicates an excess of concrete being produced, whereas a value less than this indicates the batch is "short" of its designed volume.*

10.4 Cementitious materials factor

The actual cementitious materials factor shall be calculated as follows:

$$N_1 = \frac{M_a}{Y}$$

where

N_1 = mass of cementitious materials per m³ of concrete produced (actual cementitious materials factor), kg/m³

M_a = mass of cementitious materials in the batch, kg

Y = volume of concrete produced per batch, m³

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11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) identification of the certified laboratory that performed the test (i.e., name and address);
b) name of the certified technician who performed field tests;
c) source of sample (i.e., bill no., batch no. plant identification);
d) location, date and time of the sample;
e) location of the concrete in the structure under construction related to the specimens;
f) test age of the sample (i.e., date and time of testing);
g) density of concrete, to the nearest 1 kg/m^3;
h) yield of concrete (if requested), to the nearest 0.001 m^3;
i) relative yield of concrete (if requested), to the nearest 0.001;
j) cementitious materials factor (if requested), to the nearest 1 kg/m^3;
k) concrete type (i.e., concrete mixture identification number or other descriptor);
l) mix ingredients and mass of each material used to produce the concrete mix, to the nearest 0.01 kg/m^3 for laboratory trial mixes;
m) name and signature of the person responsible for the review and approval of the test report; and
n) any deviation from the test procedure.

11.2 Optional information

The mix ingredients and mass of each material used to produce the concrete mix, to the nearest 0.1 kg for laboratory trial mixes, may be included in the report.

12 Precision and bias

The precision and bias information for this Test Method is not available.

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A23.2-7C
Air content of plastic concrete by the volumetric method

1 Scope

This Test Method specifies the procedure for determining the air content of plastic concrete using the water displacement method. It is suitable for concrete containing any type of aggregate.

Note: *This Test Method is in substantial agreement with ASTM C173/C173M.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

ASTM International

C173/C173M-16
Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

3 Summary

This Test Method involves the removal of air from a known volume of concrete by agitating the concrete in an excess of water and defoaming agent. This Test Method works for all concretes, but is most commonly used for lightweight aggregate concrete. The bowl section of the apparatus is filled with concrete and consolidated and smoothed. The top section of the apparatus is then attached and filled with water and defoaming agent and the unit then rolled and agitated to remove the air. The amount that the liquid column goes down is a measure of the air content.

4 Significance and use

This Test Method covers the determination of the air content of plastic concrete. This Test Method measures the air contained in the mortar fraction of the concrete, but is not affected by air that can be present inside porous aggregate particles. This makes it a more appropriate test method to determine air content of concrete with low-density aggregate.

This Test Method requires the addition of sufficient defoaming agent when the meter is initially being filled with water, so that after the first or subsequent rollings little or no foam collects in the neck of the top section of the meter. If more foam is present than that equivalent to 2% air above the water level, the test is declared invalid and must be repeated using a larger quantity of defoaming agent. Addition of defoaming agent to dispel foam any time after the initial filling of the meter to the zero mark is not permitted.

The air content of hardened concrete may be either higher or lower than that determined by this method depending on

a) the amount of consolidation effort applied to the same concrete;
b) the uniformity and stability of the air bubbles in the fresh and hardened concrete;
c) the accuracy of microscopic method, if used;
d) the time of comparison;

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e) environmental exposure;
f) the stage in the delivery, placement, and consolidation processes at which the air content of the unhardened concrete is determined (i.e., before and after the concrete goes through a pump); and
g) other factors.

5 Apparatus

The apparatus shall consist of the following:

a) an air meter consisting of a bowl and a top section (Figure 1) conforming to the following requirements:
   i) The measuring bowl and top sections shall be of sufficient thickness and rigidity to withstand rough field use. The material shall not be attacked by high pH cement paste, deform when stored at high temperature in close spaces, or become brittle or crack at low temperature. A watertight seal shall be obtained when the top section is attached to the measuring bowl.
   ii) The bowl shall have a diameter approximately equal to 1 to 1.25 times the height and be constructed with a flange at or near the top surface. The bowl capacity shall be not less than 2 L.
   iii) The top section shall have a capacity at least 20% larger than the bowl and shall be equipped with a flexible gasket and a device to attach to the measuring bowl. The top section shall be equipped with a transparent scale, graduated in increments not greater than 0.5% from 0% at the top to 9%, or more, of the volume of the bowl. Graduations shall be accurate to ± 0.1% by volume of the measuring bowl. The upper end of the neck shall be equipped with a watertight cap that will maintain a watertight seal when the meter is inverted and rolled.
b) a funnel with a spout of a size permitting it to be inserted through the neck of the top section and long enough to extend to a point just above the bottom of the top section. The discharge end of the spout shall be constructed so that when water is added to the container there will be a minimum disturbance of the concrete;
c) round straight steel tamping rod 16 ± 1 mm in diameter and between 450 mm and 600 mm in length, having at least one end rounded to a hemispherical tip;
d) a steel strike-off bar approximately 6 mm × 25 mm × 450 mm;
e) a metal or plastic cup either having a capacity of or being graduated in increments equal to 1.00 ± 0.04% of the volume of the measuring bowl of the air meter. The calibrated cup shall only be used to add water when the concrete air content exceeds 9% or the calibrated range of the meter;
f) a small rubber bulb syringe having a capacity of at least that of the measuring cup;
g) a metal or glass pouring container of approximately 1 L capacity;
h) a small metal hand scoop;
i) a rubber or rawhide mallet weighing approximately 0.6 ± 0.3 kg;
j) a vessel with a minimum capacity of at least 500 mL with graduations not larger than 100 mL for measuring a quantity of defoaming agent; and
k) defoaming agent: 70% by volume isopropyl alcohol (approximately 65% by weight)*. Other defoaming agents may be used if tests demonstrate that the use of the agent does not change the indicated air content, in the amounts being used, by more than 0.1% or if correction factors are developed similar to those in Table 1. When other defoaming agents are used, a copy of the records documenting the testing or calculations shall be available in the laboratory.

* *Seventy percent isopropyl alcohol is commonly available as rubbing alcohol. More concentrated grades can be diluted with water to the required concentration.*

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Table 1
Correction for the effect of isopropyl alcohol on air meter reading
(See Clauses 5 and 10.1.)

70% Isopropyl alcohol used	
Litres, L	**Correction, %***
≤ 1.0	0.0†
1.5	0.25
2.0	0.50
2.5	0.75

* *Subtract from final meter reading.*
† *Corrections are applied only when 1.25 L or more of isopropyl alcohol is used. The values given are for air meters that have a measuring bowl of 2.1 L and a top section 1.2 times the volume of the measuring bowl.*

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. It is the responsibility of the user of this Test Method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Calibration of measure

7.1

The measure shall be filled with water at room temperature and covered with a piece of plate glass in such a way as to eliminate bubbles and excess water.

7.2

The mass of the water in the measure shall be determined to within 1%.

7.3

The temperature of the water shall be measured and its density determined from Table 2, interpolating if necessary.

7.4

The volume, V, of the measure shall be calculated by dividing the mass of the water required to fill the measure by its density. Alternatively, the factor for the measure (1/V) may be calculated by dividing the density of the water by the mass required to fill the measure.

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Table 2
Density of water
(See Clause 7.3.)

Temperature, °C	kg/m³
20	998.23
21	998.02
22	997.80
23	997.56
24	997.32
25	997.07

8 Sampling

8.1 Sampling

A representative sample of concrete to be tested shall be obtained in accordance with CSA A23.2-1C. If the concrete contains coarse aggregate particles that would be retained on a 28 mm sieve, the concrete sample shall be wet-sieved over a sieve having 28 mm square openings before being tested. Wet-sieving shall be performed as specified in CSA A23.2-1C.

Note: *The concrete used for determination of air content should be discarded upon completion of the test and should not be used for other tests.*

8.2 Time constraint

The air content test shall start within 5 min after obtaining the sample, including transporting and remixing. The test shall be completed expeditiously.

9 Procedure

9.1 General

The procedures shall be as specified in Clauses 9.2 to 9.7.

9.2 Rodding and tapping

9.2.1 Standard concrete

Dampen the interior of the measuring bowl and remove any standing water from the bottom. Fill the bowl with freshly mixed concrete in two layers of equal depth, using the scoop. While placing the concrete in the measuring bowl, move the scoop around the perimeter of the measuring bowl opening to ensure an even distribution of the concrete with minimal segregation. Rod each layer 25 times with the rounded end of the tamping rod. Rod the bottom layer throughout its depth, without forcibly striking the bottom of the measure. Distribute the strokes uniformly over the cross-section of the measure and, for the top layer, penetrate about 25 mm into the underlying layer. After each layer is rodded, tap the outer sides of the bowl 10 or more times with a rubber mallet until no large bubbles of air appear on the surface and voids left by the tamping rod are closed. After tapping the final layer, a slight excess of concrete, 3 mm or less, above the rim is acceptable. Add or remove a representative sample of concrete if necessary to obtain the required amount of concrete.

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9.2.2 Self-consolidating concrete

After dampening the interior of the measuring bowl as described in Clause 9.2.1, place self-consolidating concrete in two equal layers. Tap the sides of the bowl for each layer lightly 10 to 15 times with a mallet to release any large air bubbles that may have been trapped during the bowl filling process.

After tapping the final layer, a slight excess of concrete, 3 mm or less, above the rim is acceptable. Add a representative sample of concrete if necessary to obtain the required amount of concrete.

9.3 Striking off

After placement of the second layer of concrete in accordance with Clause 9.2, strike off the excess concrete with the strike-off bar or rod until the surface is flush with the top of the bowl. Wipe the flange of the bowl clean.

9.4 Adding water and defoaming agent

Wet the inside of the top section of the meter, including the gasket. Clamp the top section into position on the bowl, insert the funnel, and add at least 0.5 L of water followed by the selected amount* of defoaming agent. Record the amount of defoaming agent added. Continue adding water at least until it appears in the graduated neck of the top section†. Remove the funnel and use the rubber syringe to adjust the liquid level until the bottom of the meniscus is level with the zero mark. Attach the watertight cap.

* *The amount of defoaming agent necessary to obtain a stable reading, and a minimum amount of foam immediately above the liquid column, will depend upon a number of factors. Many concretes made with less than 300 kg/m³ of cementitious material and air contents less than 4% might require less than 0.2 L of defoaming agent. Some high-cementitious material mixes made with silica fume that have air contents of 6% or more might require more than 1.4 L of defoaming agent. The amount required will vary with the concrete air content, the amount and type of air-entraining admixture, the cementitious material content and cement alkali content, and perhaps other factors. Generally, the amount of defoaming agent necessary can be established for given mixture proportions and should not change greatly during the course of a project.*

† *When, if ever, it is necessary to use more than 2.0 L of defoaming agent, it might be necessary to restrict the amount of water added initially to avoid overfilling the meter. However, it is desirable to add at least some water initially to aid in mixing the defoaming agent and limit the contact of the concentrated defoaming agent with the top surface of the concrete.*

9.5 Agitating and rolling

9.5.1 Freeing the concrete from the measuring bowl

Free the concrete from the base of the unit by quickly inverting the meter, shake the base horizontally, and return the meter to the upright position. To prevent aggregate from lodging in the neck of the unit, do not keep it inverted for more than 5 s at a time. Repeat the inversion and shaking process for a minimum of 45 s and until the concrete has broken free and the aggregate can be heard moving in the meter as it is inverted. Then with the neck elevated, roll and rock the unit until air appears to have been removed from the concrete. Set the apparatus upright, jar it lightly, and allow it to stand until the air rises to the top. Repeat rocking and rolling until no further drop in water column is observed.

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9.5.2 Rolling

9.5.2.1

Place one hand on the neck of the meter and the other on the flange. Using the hand on the neck, tilt the top of the meter approximately 45° from the vertical position with the bottom edge of the measuring bowl resting o the floor or on the work surface. Maintain this position through the procedures described in this section. Using the hand on the flange to rotate the meter, vigorously roll the meter 1/4 to 1/2 turn forward and back several times, quickly starting and stopping the roll. Turn the measuring bowl about 1/3 turn and repeat the rolling procedure as stated previously. Continue the turning and rolling procedures for approximately 1 min. The aggregate should be heard sliding in the meter during this process.

9.5.2.2

If, at any time, during the inversion and rolling procedures liquid is found to be leaking from the meter, the test is invalid and a new test shall be started.

9.5.2.3

Set the unit upright and loosen the top to allow any pressure to stabilize. Allow the meter to stand while the air rises to the top and until the liquid level stabilizes. The liquid level is considered stable when it does not change more than 0.25% air within a 2-min period.

9.5.2.4

If it takes more than 6 min for the liquid level to stabilize or if there is more foam than that equivalent to 2 full percent air content divisions on the meter scale over the liquid level, discard the trial and start a new test. Use a larger addition of alcohol than was used in the initial trial.

9.5.2.5

If the level is stable without excessive foam, read the bottom of the meniscus to the nearest 0.25% and record the initial meter reading.

9.5.2.6

If the air content is greater than the range of the meter, add a sufficient number of calibrated cups of water to bring the liquid level within the graduate range. Read the bottom of the meniscus to the nearest 0.25%. Record the number of calibrated cups of water to be added to the final meter reading determined in accordance with Clause 10.

9.6 Confirmation of the initial meter reading

9.6.1

When an initial meter reading is obtained in accordance with Clause 9.5.2.5, retighten the top and repeat the 1-min rolling in accordance with Clause 9.5.2.

9.6.2

When the liquid level is stable in accordance with Clause 9.5.2.3 and the requirements of Clause 9.5.2.4 are met, make a direct reading to the bottom of the meniscus and estimate to 0.25% air. If this reading has not changed more than 0.25% from the initial meter reading in accordance with Clause 9.5.2.5, record it as the final meter reading of the sample tested.

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9.6.3
If the reading has changed from the initial meter reading by more than 0.25% air, record this reading as a new "initial reading" and repeat the 1-min rolling in accordance with Clause 9.5.2.1. Read the indicated air content. If this reading has not changed by more than 0.25 % air from the "newest initial reading" record it as the final meter reading.

9.6.4
If the reading has changed by more than 0.25%, discard the test and start a new test on a new sample of concrete using more alcohol.

9.7 Post-test inspection
Disassemble the air meter by detaching the top section from the measuring bowl. Allow the liquid to discharge from the air meter. Dump the contents of the measuring bowl. Examine the interior of the measuring bowl to be sure that there are no portions of undisturbed, tightly packed concrete present. If portions of undisturbed concrete are found, the test is invalid.

10 Calculation

10.1
If more than 1.25 L of alcohol is used in the step described in Clause 9.4, a correction to the final meter reading shall be applied. Round the volume of alcohol used to the nearest 0.5 L and select the correction factor from Table 1.

Note: *When the top section is initially filled to the zero mark with water and isopropyl alcohol that mixture has a defined volume; however, when that solution is further mixed with the water present in the concrete, the concentration of alcohol changes and the new solution occupies a volume slightly smaller than it did when the meter was initially filled to the zero mark. For this reason, the meter tends to indicate a higher than actual air content when more than about 1.2 L of alcohol is used. Therefore, when large amounts of alcohol are used, the correction factors in Table 1 reduce the air content indicated by the meter.*

10.2 Air content

10.2.1
The air content of the concrete in the measuring bowl shall be calculated as follows:

$$A = A_R - C + W$$

Legend:

A = air content, %

A_R = final meter reading, %

C = correction factor from Table 1, %

W = number of calibrated cups of water added to the meter (see Clause 9.5.2.6)

10.2.2
The air content shall be reported to the nearest 0.25%.

11 Reporting
The following information shall be included in the test report, as applicable:

a) source of sampling (i.e., bill no., batch no., plant identification);

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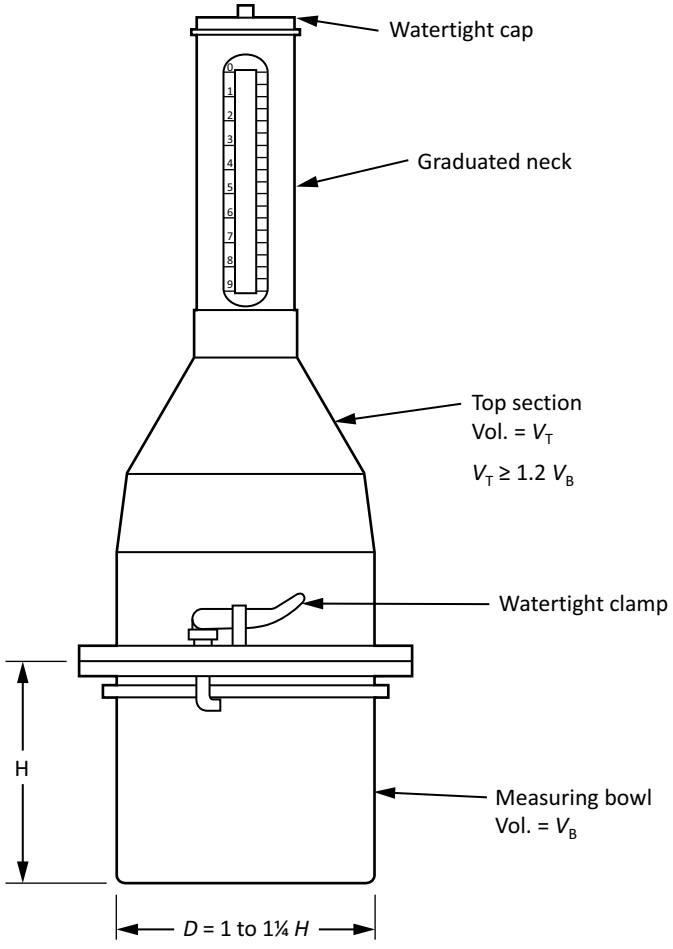
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b) location of the concrete in the structure under construction related to the specimens;
c) location and time at which sample was taken;
d) identification of the certified laboratory performing the test (i.e., name and address);
e) the name of the certified technician performing the test;
f) test age of the sample (i.e., date and time of testing);
g) air content as a percentage by volume of the concrete sample, to the nearest 0.25%;
h) name and signature of the person responsible for the review of the test report; and
i) any deviation from the test procedure.

12 Precision and bias

This Test Method provides volumetric procedures for determining the air content of freshly mixed concrete. When conducted properly, this Test Method has no bias because the value of the air content can only be determined in terms of this Test Method. No precision statement has been established for this procedure.

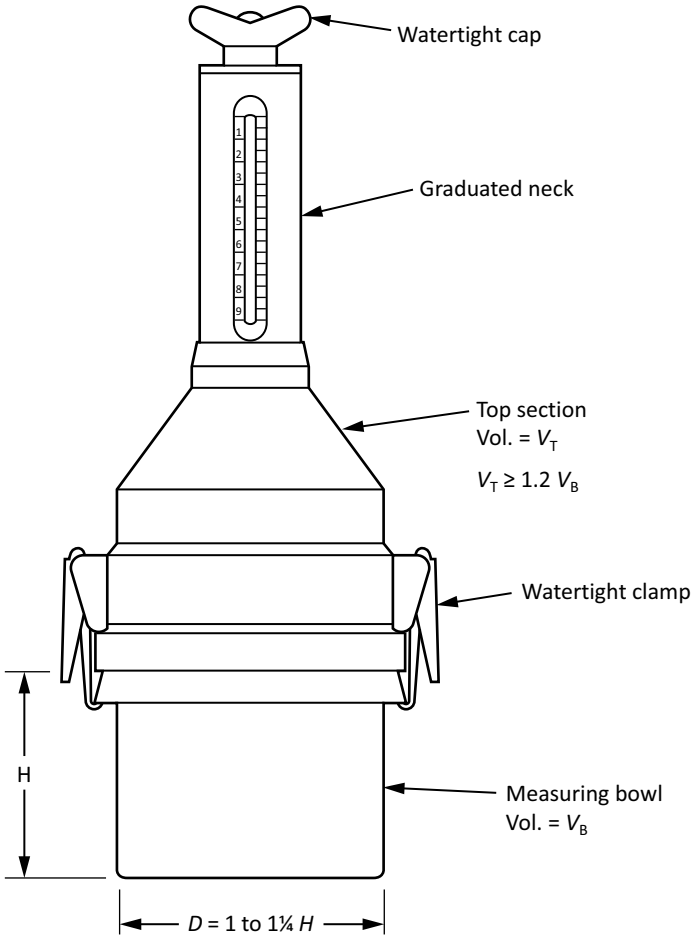
Figure 1
Apparatus for measuring air content of plastic concrete by the volumetric method
(See Clause 5.)



a) Brass meter

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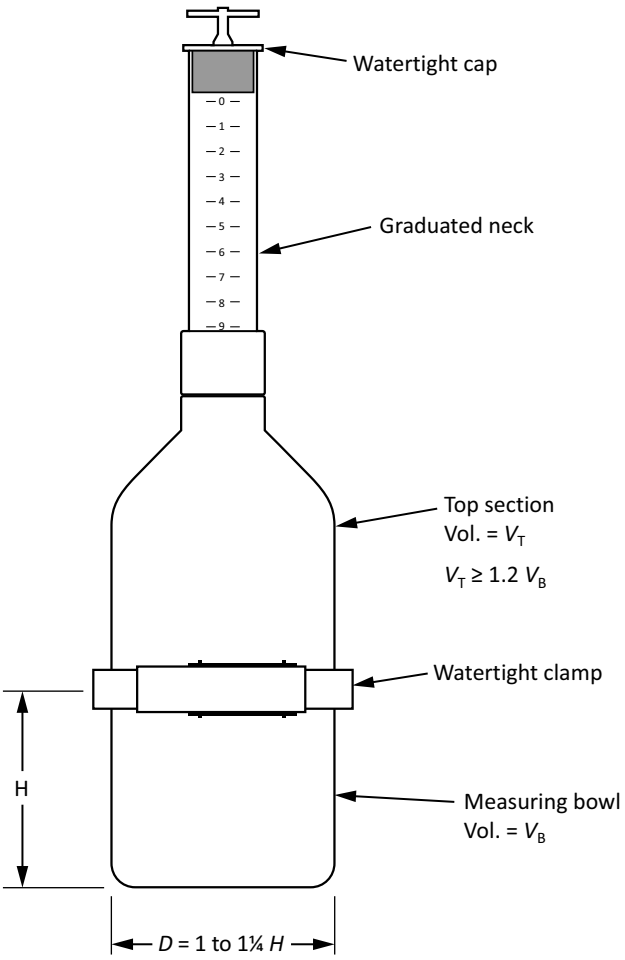
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b) Aluminum meter

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c) High density plastic meter

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A23.2-8C
Flexural strength of concrete (using simple beam with third-point loading)

1 Scope
This Test Method specifies the procedure for determining the flexural strength of concrete by the use of a simple beam with third-point loading.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

ASTM International

C78/C78M-18
Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

3 Summary
A simply supported rectangular concrete beam is set in a three-point loading apparatus and is line loaded from the top of the specimen at two locations (near the center of the beam) separated by one third the span length using the prescribed procedures. The failure load is recorded and its flexural strength computed using the appropriate formulas.

4 Significance and use
The Test Method measures the flexural strength (i.e., modulus of rupture) of concrete, which is commonly used in the design of pavements or slabs on grade.

5 Apparatus
The apparatus shall consist of the following:

a) a testing machine conforming to the requirements stated in CSA A23.2-9C. Motorized pumps or hand-operated positive displacement pumps having sufficient volume in one continuous stroke to complete a test without requiring replenishment may be used, provided that the testing machine is capable of applying loads at uniform rate without shock or interruption. Hand-operated testing machines having pumps that do not provide a continuous loading shall not be used; and

b) an apparatus suitable for third-point loading of the beam and incorporating bearing blocks that will ensure that forces applied to the beam will be vertical only and applied without eccentricity. A diagram of an apparatus that accomplishes this purpose is shown in Figure 1.

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6 Test specimen

The test specimens may be sawn specimens from the concrete structure or specimens cast in accordance with the requirements of CSA A23.2-3C. Sawn flexural test specimens shall be not less than 150 mm × 150 mm or three times the maximum size of aggregate, whichever is larger. Where constrained by element section, cross section of sawn samples shall be not less than 75 mm × 75 mm. The test specimen shall have a span length, as nearly as practicable, that is three times its depth as tested. The minimum specimen length shall be equal to the span length plus 50 mm.

Test specimens shall be kept moist during the period between their removal from the moist room and testing. Test specimens shall be tested in a moist condition.

Note: *Where possible, the cross section of sawn samples should be five times the maximum aggregate size observed in the concrete.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Procedure

The test shall be performed as follows:

a) Turn the test specimen on its side with respect to its position as moulded and centre the specimen on the bearing blocks.
b) Bring into contact the load-applying blocks with the upper surface of the specimen at the third points between the supports.
c) If full contact is not obtained between the specimen and the load-applying blocks and the supports, owing to the surfaces of the specimen being out of plane, purposely grind the surfaces of the specimen where they are in contact with the blocks or supports to meet the requirements specified in Clause 6.1.3 of CSA A23.2-9C.
d) Apply the load until failure, at such a rate that the increase in flexural stress is within the range of 0.85 MPa/min to 1.20 MPa/min. The load may be applied rapidly up to approximately 50% of the failure load at the beginning of the test, after which the rate of loading shall be within the range of 0.85 MPa/min to 1.20 MPa/min.

Note: *Grinding of the lateral surfaces of the specimens should be minimized, as it can change the physical characteristics of the specimens and thereby affect the test results.*

9 Measurement of specimens after test

The average width and average depth of the specimen at the section of failure shall be determined to the nearest millimeter.

10 Calculations

10.1

If the fracture occurs within the middle third of the span length, the flexural strength shall be calculated as follows:

$$R = \frac{Pl}{bd^2}$$

where

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R = flexural strength, MPa

P = maximum applied load indicated by the testing machine, N

l = span length, mm

b = average width of the specimen, mm

d = average depth of the specimen, mm

Note: *Mass of the specimen is not included in the above calculation.*

10.2

If the fracture occurs outside of the middle third of the span length by not more than 5% of the span length, the flexural strength shall be calculated as follows:

$$R = \frac{3Pa}{bd^2}$$

where

a = distance between the line of fracture and the nearest support measured along the centreline of the bottom surface of the beam, mm

10.3

If the fracture occurs outside of the middle third of the span length by more than 5% of the span length, the results of the test shall be discarded.

11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) identification of the certified laboratory performing the test (i.e., name and address);
b) specimen identification number or details(concrete mixture identification number or other descriptor);
c) date and time when the concrete specimen was cast or date when the concrete specimen was sawn from the structure;
d) minimum and maximum temperatures measured during the initial curing period in accordance with A23.2-3C;
e) location of the concrete in the structure under construction related to the specimens;
f) date the specimen was received in the laboratory;
g) date the specimen was tested;
h) age of the specimen at time of flexural testing;
i) average width, depth, and span length, to the nearest mm;
j) flexural strength, calculated to the nearest 0.1 MPa;
k) specified flexural strength, MPa;
l) location in the structure, represented by the tested specimens ;
m) curing conditions, if different from the standard;
n) location of the fracture, if the average specimen flexural strength is less than specified;
o) appearance of the internal concrete structure, if the average specimen flexural strength is less than specified;
p) defects (if any) in the specimen, if the average flexural strength is less than that specified;
q) name of the certified technician who performed the test;
r) name and signature of the person responsible for the review of the test report; and
s) any deviation from the test procedure.

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11.2 Optional information

The report may include the following optional information:

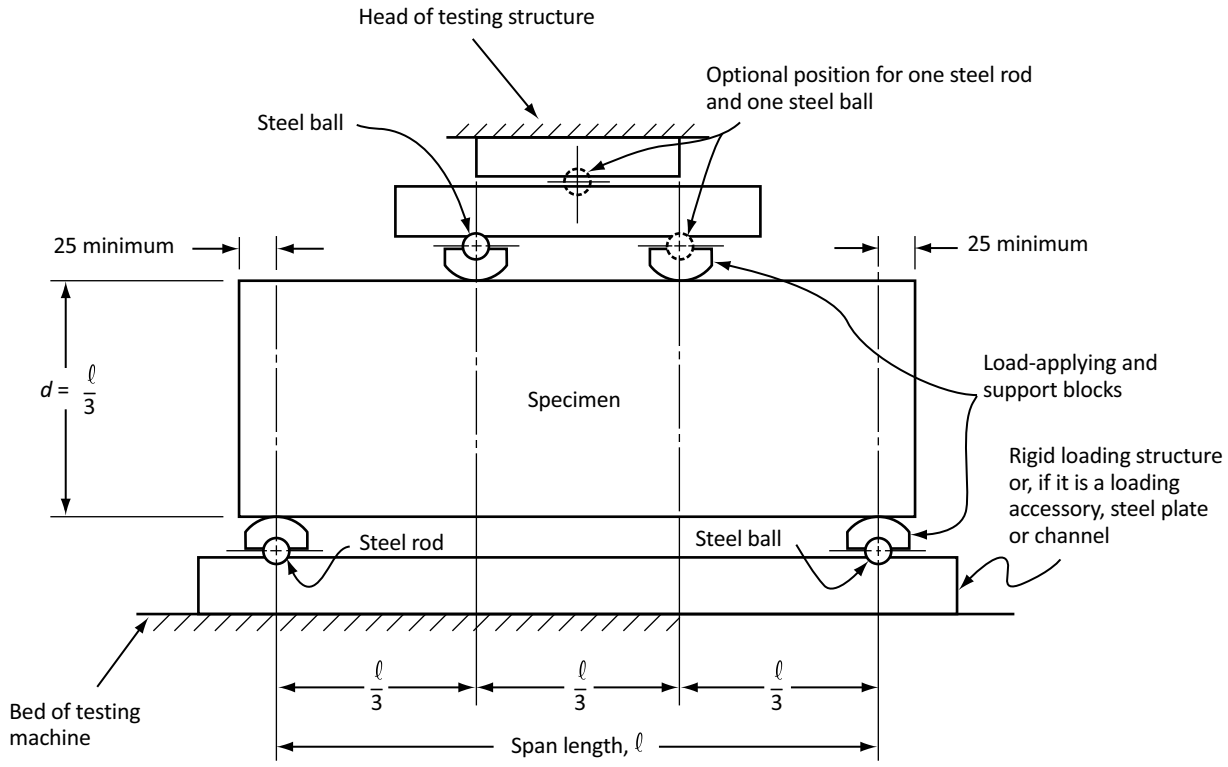
a) maximum applied load, kN; and

b) density of plastic and/or hardened concrete, if required by the client.

12 Precision and bias

The precision and bias of this Test Method is expected to be similar to that of ASTM C78/C78M.

Figure 1
Diagrammatic view of apparatus for flexure test of concrete by third-point loading method
(See Clause 5.)



Notes:

1) *Apparatus may be used in inverted position.*

2) *Dimensions are in millimetres.*

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A23.2-9C
Compressive strength of cylindrical concrete specimens

1 Scope

This Test Method specifies the procedure for conducting compression tests on cylindrical concrete specimens, including moulded cylinders and drilled cores. Testing of high-strength concrete conforms to the requirements of Clause 8.5 of CSA A23.1.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-12C:19
Making, curing, and testing compression test specimens of no-slump concrete

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

A23.2-1D:19
Moulds for forming vertical concrete test cylinders

A3005-18
Test equipment and materials for cementitious materials for use in concrete and masonry

ASTM International

C617/C617M-15
Standard Practice for Capping Cylindrical Concrete Specimens

E4-16
Standard Practices for Force Verification of Testing Machines

E74-18
Standard Practice of Calibration of Force-Measuring Instruments

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3 Significance and use

3.1

This Test Method is used to determine the compressive strength of cylindrical specimens obtained, prepared, and cured in accordance with CSA A23.2-1C, CSA A23.2-3C, CSA A23.2-12C, and CSA A23.2-14C.

3.2

The results of this Test Method are used as a basis for

a) the quality control of concrete proportioning, mixing, transporting, and placing operations;
b) determination of compliance with project specifications and CSA A23.1;
c) control for evaluating effectiveness of admixtures and cementitious materials; and
d) similar uses.

3.3

It should be recognized that the compressive strength determined by this Test Method is not a fundamental or intrinsic property of concrete made from given materials or of concrete as-built in a structure. The compressive strength of concrete obtained will depend on

a) the size and shape of the specimen;
b) batching;
c) mixing procedures;
d) the methods of sampling, moulding, and fabrication;
e) the age, temperature, and moisture conditions during curing and testing;
f) the specific testing machine design;
g) the selected loading rate; and
h) other conditions.

4 Apparatus

4.1 Testing machine

4.1.1 General

4.1.1.1

The testing machine shall be of a type having sufficient capacity and capability to provide the rates of loading prescribed in Clause 7.3.

4.1.1.2

The machine shall be power-operated and shall apply the load continuously rather than intermittently and without shock.

4.1.1.3

The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device that is of sufficient capacity to cover the potential loading range of the testing machine and shall comply with the requirements of ASTM E74.

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4.1.2 Bearing blocks

4.1.2.1 General

The testing machine shall be equipped with two steel bearing blocks with hardened faces, one of which is a spherically seated block that will bear on the upper surface of the specimen and the other a solid block on which the specimen shall rest. The bearing surface shall have a minimum dimension at least 3% greater than the diameter of the specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.025 mm. The new blocks shall be manufactured within one-half of this tolerance. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than 13 mm, concentric circles not more than 0.8 mm deep and not more than 1.2 mm wide shall be inscribed to facilitate proper centering.

Note: *Bearing faces of blocks used for compression testing of concrete should have a Rockwell hardness of not less than 55 HRC.*

4.1.2.2 Bottom bearing blocks

Bottom-bearing blocks shall conform to the following requirements:

a) The bottom-bearing block shall be specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions. The top and bottom surfaces shall be parallel to each other. The block may be fastened to the platen of the testing machine. Its least horizontal dimension shall be at least 3% greater than the diameter of the specimen to be tested. Concentric circles, as described in Clause 4.1.2.1, are optional on the bottom-bearing block.
b) Final centering shall be made with reference to the upper spherical block. When the bottom-bearing block is used to assist in centering the specimen, the center of the concentric rings, when provided, or the centre of the block itself shall be directly below the centre of the spherical head. Provision shall be made on the platen of the machine to ensure such a position.
c) The bottom-bearing block shall be at least 25 mm thick when new and at least 22.5 mm thick after any resurfacing operations.

Note: *If the test machine is so designed that the platen itself can be readily maintained in the specified surface condition, a bottom block is not required.*

4.1.2.3 Spherically seated (upper) bearing block

4.1.2.3.1

The spherically seated bearing block shall conform to the following requirements:

a) The maximum diameter of the bearing face of the suspended spherically seated block shall not exceed the values given in Table 1.
b) The centre of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5% of the radius of the sphere.
c) The ball and the socket shall be so designed by the manufacturer that the steel in the contact area does not permanently deform under repeated use with loading to the capacity of the testing machine.

   Note: *The effects of specimen stress levels on the ball and socket also depend on the specimen size. The limit of 85 MPa is applicable to the historically standard 150 mm diameter cylinders. High-strength concrete having strength over 85 MPa will require test machines with larger loading capacities if 150 mm diameter cylinders are used or extra-high-strength concrete is tested.*

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d) The curved surfaces of the socket and of the spherical portion shall be kept clean and shall be properly lubricated to ensure free rotation. After contacting the specimen and application of small initial load, further tilting of the spherically seated block is not intended and is undesirable.

Note: *It has been found that petroleum-type oil, such as conventional motor oil, is a short-lived lubricant for the application and as a result, the spherically seated platen (spherical seat) needs to be removed periodically to re-oil the sphere in order to ensure free rotation. It has been found that a 3-to-1 mixture of lithium-based grease and petroleum oil can last one year or more for this application. Pressure-type grease should not be used. Failing to properly lubricate and maintain the spherical seat can result in lower strength test results of the concrete.*

4.1.2.3.2

If the radius of the sphere is smaller than the radius of the largest specimen to be tested, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen. The least dimension of the bearing face shall be at least as great as the diameter of the sphere (see Figure 1).

4.1.2.3.3

The movable portion of the bearing block shall be held closely in the spherical seat but the design shall be such that the bearing face can be rotated freely and tilted at least 4° in any direction. There shall be no noticeable gap between the sphere and seat portion to prevent the entering of foreign materials that can cause scratching or scoring of the bearing surface.

Notes:

1) *Square bearing faces may be used, provided that the diameter of the largest possible inscribed circle does not exceed the above diameter.*
2) *The preferred contact area is in the form of a ring (described as the preferred "bearing" area) as shown in Figure 1.*

Table 1
Diameter of bearing face
(See Clause 4.1.2.3.1.)

Diameter of test specimen, mm	Maximum diameter of suspended bearing face, mm
50	100
75	125
100	165
150	250
200	280

4.1.3 Load indication

4.1.3.1

If the load of a compression machine used in concrete testing is registered on a dial, the dial shall be provided with a graduated scale that can be read at least to the nearest 0.1% of the full-scale load. The dial shall be readable within 1% of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line at zero and so numbered. The dial pointer shall be of sufficient length to reach the

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graduation marks and the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment that is easily accessible from the outside of the dial case and with a suitable device that, at all times until reset, will indicate, to within 1% accuracy, the maximum load applied to the specimen.

Note: *As close as can reasonably be read is considered to be 0.5 mm along the arc described by the end of the pointer. Also, one-half of a scale interval is about as close as can reasonably be read when the spacing on the load-indicating mechanism is between 1 and 2 mm. When the spacing is between 2 mm and 3 mm, one-third of a scale interval can be read with reasonable certainty. When the scale is 3 mm or more, one-quarter of a scale interval can be read with reasonable certainty.*

4.1.3.2

If the testing machine load is indicated in digital form, the numerical display shall be large enough to be easily read. The numerical increment shall be equal to or less than 0.10% of the full-scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load shall be within 1.0% for any value displayed within the verified loading range. Provision shall be made for adjusting to indicate true zero at zero load. A maximum load indicator shall be provided that, at all times until reset, will indicate, within 1% system accuracy, the maximum load applied to the specimen.

4.1.4 Verification of calibration

The verification of calibration of the testing machines in accordance with ASTM E4 shall be performed under the following conditions:

a) on original installation or relocation of the machine;
b) after an elapsed interval since the previous verifications of 13 months maximum;
c) whenever there is reason to doubt the accuracy of the results, without regard to the time interval since the last verification; or
d) immediately after making repairs or adjustments that can in any way affect the operation of the weighing system or values displayed, except for zero adjustments that compensate for the weight of tooling or specimen, or both.

4.1.5 Verification of accuracy

The accuracy of the testing machine shall be in accordance with the following provisions:

a) The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed 1.0% of the indicated load.
b) The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one-third of the difference between the maximum and minimum test loads.
c) The test load, as indicated by the testing machine, and the applied load, computed from the readings of the verification device, shall be recorded at each test point. The error, E, and the percentage of error, E_p, shall be calculated for each point from these data as follows:

$$E = A - B$$

$$E_p = \frac{100(A - B)}{B}$$

where

A = load, indicated by the machine being verified, kN

B = applied load, as determined by the calibrating device, kN

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d) The report on the verification of a test machine shall state within what loading range it was found to conform to specification requirements, rather than reporting a blanket acceptance or rejection. The allowable loading range of the testing machine shall be greater than both
   i) 100 times the smallest change of loads; and
   ii) 7.5% of its maximum range capacity.
e) In no case shall the loading range be stated as including loads outside the range of loads applied during the verification test.
f) The indicated load of a testing machine shall not be corrected either by calculation or by the use of a calibration diagram to obtain values within the required permissible variation.

4.2 Capping equipment

4.2.1 Capping plate (capping mould)

The sulphur mortar caps shall be formed against a machined metal plate with a recessed area in a shallow dish shape for receiving molten sulphur. The recess (capping mould) shall have a depth between 5 and 12 mm and it shall be 10 to 25 mm larger than the diameter of the specimen. The metal plate thickness of the recessed area shall not be less than 12 mm. The surface of the recessed area (working surface of the capping mould) shall not depart from a plane by more than 0.05 mm in 152 mm. The surface shall be free from gouges, grooves, or indentations beyond those caused by the finishing operation.

Notes:

1) *A Rockwell hardness of 48 HRC is suggested for the working surface of capping plates.*
2) *Although not as durable as metal, polished hard rocks (e.g., granite or diabase) at least 75 mm thick may also be used to make capping plates (capping moulds).*

4.2.2 Alignment device

Suitable alignment devices, such as guide bars or bull's-eye levels, shall be used in conjunction with capping plates (capping mould) to ensure that no single cap will depart from perpendicularity to the axis of a cylindrical specimen by the limits specified in Clause 6.1.4 and that no cap will be off-centered on a specimen by more than 2 mm. The relationship between the axis of guide bars and the capping plate shall be within these tolerances as well.

4.2.3 Melting pot for sulphur mortar

The pot used for melting sulphur mortar shall be equipped with automatic temperature controls capable of maintaining the molten sulphur within a temperature range of 130 to 145 °C and shall be made of metal or lined with a material that is non-reactive with molten sulphur. Open flame heating systems shall not be allowed.

4.2.4 Sulphur mortar

Proprietary or laboratory-prepared sulphur mortars may be used as capping materials. Filler materials, if employed, shall be in powder form and shall not be coarser than normal cement or fly ash and shall be capable of being thoroughly dispersed in molten sulphur to produce a uniform mortar mix. Fresh sulphur mortar shall be dry and water shall be kept away from the melting pot, as dampness can cause foaming.

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5 Hazards

This test method does not purport to address the safety problems associated with its use. The user of this test method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6 Specimens

6.1 Specimen tolerances

6.1.1 Diameter

Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2%.

The number of individual cylinders measured for determination of average diameter may be reduced to one for every ten specimens or three specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reusable or single-use moulds that consistently produce specimens with average diameters within a range of 0.5 mm. When the average diameters do not fall within the range of 0.5 mm or when the cylinders are not made from a single lot of moulds, each cylinder tested shall be measured and the value used in the calculation of the compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.5 mm by averaging two diameters measured at right angles to each other at about mid-height of the specimen.

6.1.2 Length

The length of the specimen, including caps, if present, shall be measured to the nearest millimetre when the length-to-diameter ratio is less than 1.8 or more than 2.2 or when the volume of the cylinder (e.g., for the calculation of density of the hardened concrete) is to be determined.

6.1.3 Planeness

The ends of the compression test specimens shall not depart from a plane by more than 0.05 mm. Capping or grinding may be used to achieve the planeness. The planeness of the capped or ground specimen ends of every tenth specimen but not less than 3 specimens during each day, representing the start, middle, and end of the day's testing, shall be checked by means of a straightedge and feeler gauge, making a minimum of three measurements on different diameters.

6.1.4 Perpendicularity

Neither end of the compressive test specimens at the time of testing shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to 2 mm in 200 mm).

6.1.5 Specimen moisture conditions

Compression tests of moist cured specimens shall be made as soon as practicable after removal from the moist room. They shall be kept moist until testing.

Note: *The ends of the cylinders may be allowed to dry sufficiently to accommodate bonding of the capping materials, if used.*

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6.1.6 Density

If the purchaser of the testing services requests measurement of density of test specimens, the mass of specimens shall be determined before capping. Any surface moisture shall be removed with a damp towel and the mass of the specimen shall be measured using a balance or scale that is accurate to within 0.3% of the mass being measured. The diameter of the specimen shall be measured to the nearest 0.5 mm by averaging two diameters measured at right angles to each other at about mid-height of the specimen. The length of the specimen shall be measured to the nearest 1 mm at three locations spaced evenly around the circumference. The average length shall be calculated and recorded to the nearest 1 mm. The specimen density shall be calculated in accordance with Clause 8.3.

Alternatively, the specimen density may be determined by removing any surface moisture with a damp towel and weighing the specimen in air and then submerged under water at 23 ± 2 °C. The density of the specimen shall be computed using the net volume (i.e., volume excluding interconnected air voids) in accordance with Clause 8.3.

7 Procedures

7.1 Capping using sulphur mortar

7.1.1 General

Only basic requirements for capping using sulphur mortars are specified in this Test Method. Other capping materials, procedures, and inspection of capping shall conform to the requirements of ASTM C617/C617M. Capping may be used for testing concrete with specified strengths up to 70 MPa, above which grinding shall be used.

7.1.2 Strength and cap thickness requirements

The strength of the capping sulphur mortar and the thickness of the caps shall conform to the requirements of Table 2. The melting pot of sulphur mortar shall be emptied and recharged with fresh material at intervals to ensure that the oldest material in the pot has not been used more than five times.

Table 2
Compressive strength and maximum thickness of capping materials
(See Clauses 7.1.2, 7.1.3, and 7.1.4.4.)

Cylinder (specimen) compressive strength, MPa	Minimum strength of capping material determined in accordance with Clause 7.1.3, MPa	Maximum average thickness of cap, mm	Maximum thickness of any part of cap, mm
3.5–50	35 but not less than cylinder strength	6	8
> 50	Not less than cylinder strength	3	5

Note: *The cap thickness can be checked after removing the capping from the cylinder. The complete removal of a cap in one piece is possible if the entire cap is covered with a duct tape prior to removal (e.g., using a chisel and hammer).*

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7.1.3 Determination of compressive strength of sulphur mortar

The compressive strength of sulphur mortar shall be determined as follows:

a) Prepare test specimens using a cube mould and base plate conforming to the requirements of CSA A3005, and a metal cover plate conforming in principle to the design shown in Figure 2.
b) Bring the various parts of the apparatus to a temperature of 20 °C to 30 °C, lightly coat the surfaces that will be in contact with the sulphur mortar with mineral oil, and assemble near the melting pot.
c) Bring the temperature of the molten sulphur mortar in the pot within a range of 130 to 145 °C, stir thoroughly, and begin casting cubes.
d) Using a ladle or other suitable pouring device, quickly fill each of the three compartments until the molten materials reaches the top of the filling hole.
e) Allow sufficient time for maximum shrinkage due to cooling, and for solidification (approximately 15 min), and refill each hole with molten material.
f) After solidification is complete, remove the cubes from the mould without breaking off the knob formed by the filling hole in the cover plate.
g) Remove oil and sharp fins from the cubes, and check the planeness of the bearing surface (see CSA A3005).
h) After storage at room temperature for a minimum of 2 h but not more than 24 h, test cubes in compression following the procedures described in CSA A3005, and calculate the compressive strength in MPa.

Notes:

1) *If desired, a plane phenol formaldehyde (bakelite) plate of 3 mm thickness, provided with three appropriately spaced filling holes, may be inserted between the cover plate and the mould to slow the rate of cooling of test specimens.*
2) *The second filling helps to prevent the formation of a large void or shrinkage pipe in the body of a cube. However, such defects can occur no matter how much care is exercised and it is therefore advisable to inspect the interior of tested sulphur mortar cubes for homogeneity whenever the strength values obtained are significantly lower than anticipated.*

7.1.4 Capping procedures

7.1.4.1 End conditions of hardened concrete specimens

Any laitance or coating or deposits of oily or waxy materials that would impair the bond of the cap shall be completely removed from the cylinder ends before capping. If necessary, the ends of a specimen may be slightly roughened with a steel file or wire brush to produce proper adhesion of the cap. The ends shall also be dry enough at the time of capping to prevent the formation of steam or foam pockets under or in the cap larger than 6 mm in diameter.

The distance of any point on an uncapped end from the plane that passes through the highest point of the end surface and is perpendicular to the axis of the cylinder shall not exceed 3 mm. If exceeding this limit, the end of the cylinder shall be cut, lapped, or ground prior to capping.

Note: *The distance may be checked using a square with one blade touching the highest point of the end of the cylinder. The distance between the blade of the square and the lowest point on the end of the cylinder is measured.*

7.1.4.2 Capping

Capping shall be performed as follows:

a) Bring the capping plates to a temperature of 20 °C to 30 °C or higher and lightly coat the surfaces that will be in contact with the sulphur mortar with a thin film of mineral oil.
b) Bring the temperature of the molten sulphur mortar in the pot within a range of 130 °C to 145 °C and stir thoroughly immediately prior to casting each cap.

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c) Quickly pour the mortar on to the surface of the capping plate using a ladle or other suitable pouring device, lift the cylinder above the plate and contact the cylinder sides with the alignment guides, and slide the cylinder down the guides onto the capping plate while keeping constant contact with the guides until the mortar has hardened.
d) Use sufficient material to cover the cylinder end after the sulphur solidifies.

7.1.4.3 Checking of caps

The planeness and perpendicularity of caps shall be checked in accordance with the requirements of Clauses 6.1.3 and 6.1.4. Caps shall also be checked, at the same rate as specified in Clause 6.1.3, for hollow areas by tapping with a coin or rubbing a light metal implement on the cap to see if a hollow sound can be detected. Caps failing to meet the planeness or perpendicularity requirements, or having hollow areas or visible cracks, shall be completely removed and recapped.

7.1.4.4 Curing of caps prior to testing

Sulphur mortar caps shall be allowed to harden for a minimum of 2 h before testing concrete with strength not more than 35 MPa. For concrete strength greater than 35 MPa, sulphur mortar caps shall be allowed to harden at least 16 h before testing. In both cases, a shorter time may be used if it has been shown and documented that the requirements specified in Table 2 are met at the time of testing.

If the capped cylinders are to be tested in a moist condition, they shall be kept in moist storage or wrapped wet burlap between the completion of capping and the time of testing.

7.2 Placing the specimen

The plain (lower) bearing block shall be placed with its hardened face up on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated block. As the spherically seated block is brought to bear on the specimen, its movable portion shall be rotated gently by hand so that uniform seating is obtained.

7.3 Rate of loading

The load shall be applied continuously and without shock. In testing of machines of the screw type, the moving head travel shall be set to achieve the required loading rate of 0.15 MPa/s to 0.35 MPa/s. In hydraulically operated machines, the load shall be applied at a constant rate within the range of 0.15 MPa/s to 0.35 MPa/s. No adjustment shall be made in the controls of the testing machine while a specimen is yielding rapidly immediately before failure. During the application of the first half of the maximum load, a higher rate of loading may be used.

7.4 Maximum load

The load shall be increased at the rate specified in Clause 7.3 until the specimen fails (i.e., shows visible cracks). The maximum load carried by the specimen during the test shall be recorded. The type of failure and the appearance (i.e., condition) of the fractured surface shall be noted, if different from the Type 1 failure illustrated in Figure 3.

7.5 Permissible tolerance of test ages

All test specimens for a given test age shall be tested within the permissible time tolerance specified in Table 3.

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Table 3
Tolerances for testing ages
(See Clause 7.5.)

Test age	Permissible tolerance
24 h	± 0.5 h
3 d	± 2 h
7 d	± 6 h
28 d	± 20 h
56 d	± 36 h
91 d	± 48 h

8 Calculations

8.1

The compressive strength of the specimen shall be calculated by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined, as specified in Clause 6.1.1, and the result shall be expressed to the nearest 0.1 MPa.

8.2

If the specimen's length-to-diameter ratio is less than 1.8, the result obtained in Clause 8.1 shall be corrected by multiplying the correction factors in Table 4 or 5 as applicable.

The correction factors in Table 4 are applicable to normal-density (density between approximately 1600 kg/m^3 and 2400 kg/ m^3) concrete with a compressive strength between 15 and 70 MPa. The correction factors in Table 5 are applicable to normal-density concrete with a compressive strength above 70 MPa.

Values for L/D ratios between 1.8 and 1.0 not given in Table 4 or Table 5 shall be determined by interpolation.

Table 4
Correction factors (for compressive strength of 15 to 70 MPa)
(See Clause 8.2.)

L /D	2.0	1.75	1.50	1.25	1.0
Factor	1.0	0.98	0.96	0.93	0.87

Table 5
Correction factors (for compressive strength above 70 MPa)
(See Clause 8.2.)

L /D	2.0	1.75	1.50	1.25	1.0
Factor	1.0	0.98	0.96	0.94	0.92

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8.3

When required, the density of the specimen shall be calculated to the nearest 10 kg/m^3, as follows:

Density = W / V
where
W = mass of specimen, kg
V = volume of specimen computed from the average diameter and average length or net volume from weighing the cylinder in air and submerged in water, m^3

9 Reporting

9.1 Required information

The following information shall be included in the test report, as applicable:
a) specimen identification number or details;
b) identification of the certified testing laboratory (i.e., name and address);
c) date and time when the concrete specimen was cast or date when specimen was submitted to laboratory;
d) minimum and maximum temperatures measured during the initial curing period in accordance with CSA A23.2-3C;
e) date and time the core was taken for cored specimen;
f) date the specimen was tested;
g) age of the specimen at time of testing;
h) specified age in days (or other) and minimum specified strength, MPa;
i) curing conditions, if different from standard;
j) diameter (and length, if the L/D ratio is less than 1.8 or more than 2.2 diameters), mm;
k) compressive strength calculated to nearest 0.1 MPa;
l) type of failure, if different from Type (1) (see Figure 3);
m) name of the certified technician who performed the test;
n) name and signature of the person responsible for the review of the test report;
o) location in structure represented by field-sampled concrete; and
p) any deviations from the test procedure.

9.2 Optional information

The following information may be included in the test report:
a) concrete type (e.g., concrete mixture design identification number or other descriptor);
b) density of hardened concrete, if required by the owner;
c) cross-sectional area, mm^2;
d) maximum applied load, kN;
e) average loading rate, MPa/s; and
f) method of end preparation for test specimens, capping or end grinding.

There should be a standard format for reporting concrete cylinder strength. A sample form is presented in Annex B of CSA A23.2.

9.3 Low-strength cylinders and abnormal results

In cases where the tested cylinder strength is less than specified, the following conditions of the specimen shall be carefully checked and recorded:
a) the appearance of the concrete in the cylinder;
b) any visible consolidation defects or other defects in the specimen; and

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c) any defects in the capping material, if applicable.

10 Precision and bias

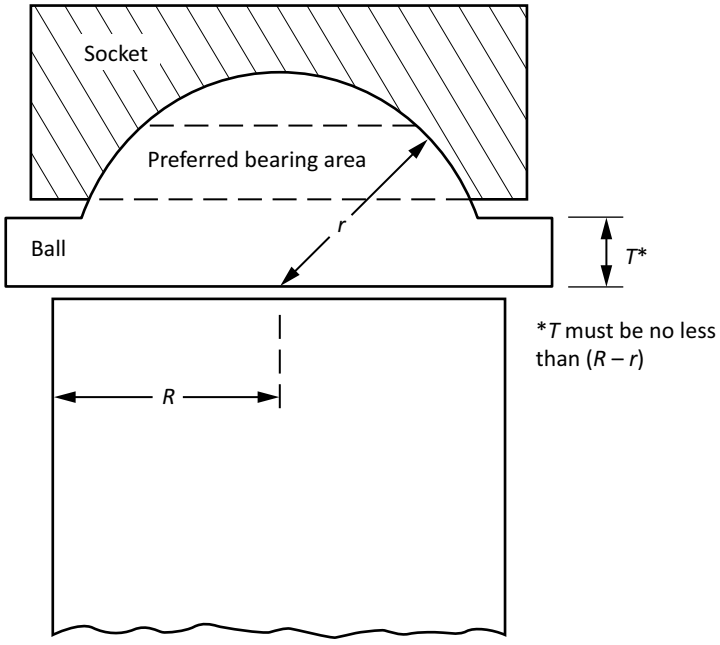
10.1 Precision

Multi-laboratory testing of pairs of 150 mm × 300 mm cylinders conducted by the Ontario Ministry of Transportation between 1998 and 2002 found an average coefficient of variation of 3.89% and 3.44% for tests at 7 d and 28 d, respectively. These cylinders were made from concretes with 28 d compressive strengths ranging between 24 MPa to 53 MPa. Therefore, the results of compressive strength testing of samples of the same batch of concrete in two different laboratories should only exceed 11.0% of the average compressive strength at 7 d and 9.7% of the 28 d strength, 5% of the time.

10.2 Bias

There is no accepted reference material available to produce a statement on bias, as the strength of concrete can only be defined in terms of this Test Method.

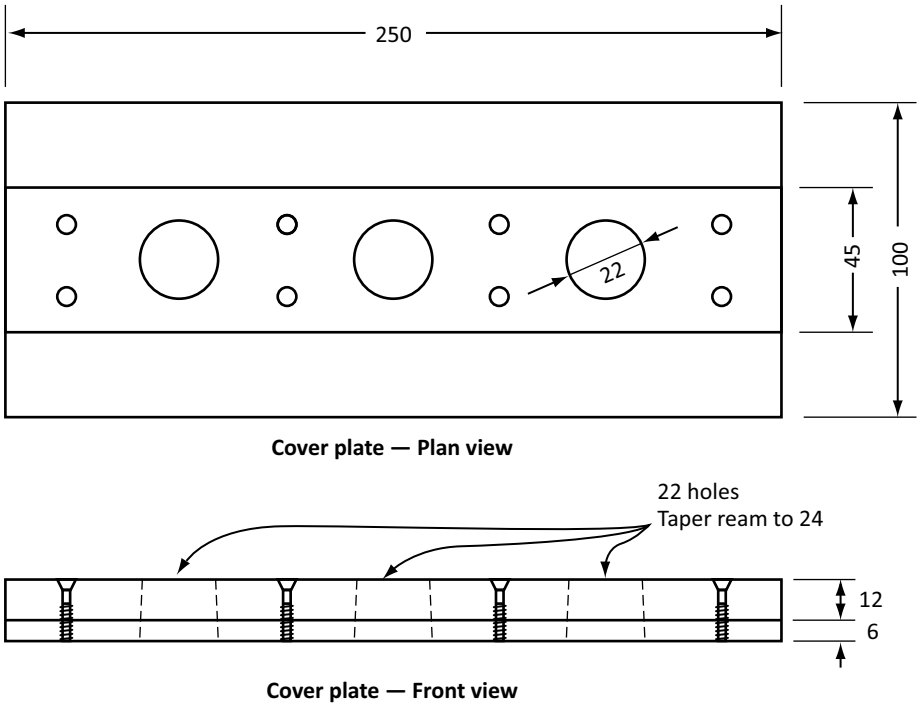
Figure 1
Schematic sketch of a typical spherical bearing block
(See Clauses 4.1.2.3.2 and 4.1.2.3.3.)



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Figure 2
Sketch of cover plate for 50 mm cube mould
(See Clause 7.1.3.)



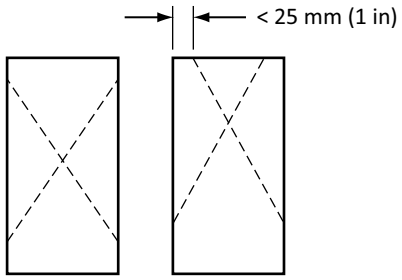
Notes:

1) *Adapted, with permission, from ASTM C617/C617M,* Standard Practice for Capping Cylindrical Concrete Specimens*, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.*
2) *Dimensions are in millimetres.*

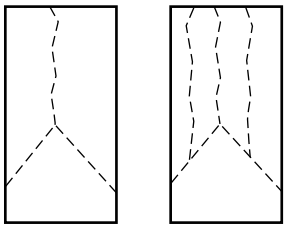
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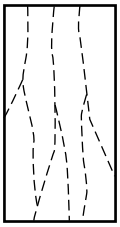
Figure 3
Sketches of types of fracture
(See Clauses 7.4 and 9.1.)



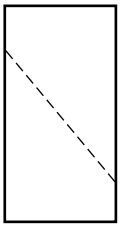
Type 1
Reasonably well-formed cones on both ends, less than 25 mm (1 in) of cracking through caps



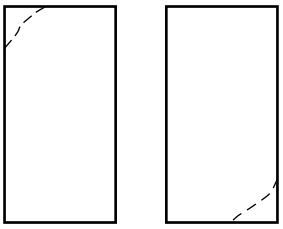
Type 2
Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end



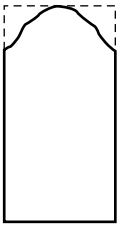
Type 3
Columnar vertical cracking through both ends, no well-formed cones



Type 4
Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1



Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)



Type 6
Similar to Type 5 but end of cylinder is pointed

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A23.2-10C
Accelerating the curing of concrete cylinders and determining their compressive strength

1 Scope

1.1
This Test Method specifies the procedures for making, curing, and testing compression concrete cylinder specimens stored under conditions intended to accelerate the strength development of concrete.

1.2
The three test procedures described are as follows:
a) Procedure A – Boiling test;
b) Procedure B – Autogenous curing test; and
c) Procedure C – Warm water curing test.

Note: *Other accelerated curing systems have also been used for predicting the strength of concrete. These include the high temperature, pressure method, and the polystyrene mould system. For reference, see Bisaillon (1975) for polystyrene moulds.*

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

A23.2-12C:19
Making, curing, and testing compression test specimens of no-slump concrete

A23.2-25C:19
Standard practice for sampling, testing, and inspection of concrete for acceptance purposes

A23.2-1D:19
Moulds for forming vertical concrete test cylinders

Other publications

Bisaillon, A. 1975. *Field Evaluation of Expanded Polystyrene Moulds for Self-Cured, Accelerated Strength Testing of Concrete.* Transportation Research Board Record No. 558. Washington, DC.

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Malhotra, V.M., and Zoldners, N.G. 1970. *Some Field Experience in the Use of an Accelerated Method of Estimating the 28-Day Strength of Concrete.* Department of Energy, Mines and Resources MPl 68-42; Reprint Series RS98. Ottawa.

3 Summary

3.1

Concrete specimens are exposed to accelerated curing conditions that permit specimens to develop significant portion of their ultimate strength within a time period ranging from 5 to 49 h, depending upon the procedure used.

Procedures A and C utilize storage of specimens in heated water at elevated curing temperatures without moisture loss. The primary function of the moderately heated water used in Procedure C is to serve as insulation to conserve the heat generated by hydration. The temperature level employed in Procedure A provides thermal acceleration. Procedure B involves storage of specimens in insulated curing containers in which the elevated curing temperature is obtained from heat of hydration of the cement. The sealed containers also prevent moisture loss.

3.2

If these procedures are to be used, correlations should be established in accordance with Clause 7.2.4 of CSA A23.2-25C.

4 Significance of use

4.1

The accelerated curing procedures provide an indication of the potential strength of the concrete mixture at any specified age. The procedures also provide information for quality control of concrete proportions, mixing, transporting, and placing operations.

4.2

The accelerated early strength obtained from any of the procedures in this Test Method may be used to evaluate concrete strength in the same way conventional 28 d strengths have been used in the past, with suitable changes in the expected strength values.

5 Apparatus

5.1 General

Moulds for compression test specimens, tamping rod, vibrator, small tools, slump apparatus, sampling and mixing receptacle, and air content apparatus shall conform to the appropriate requirements in the CSA Test Methods cited.

5.2 Procedure A — Boiling test

For the accelerated curing tank, a boiling water tank of the type shown in Figure 1 shall be used.

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5.3 Procedure B — Autogenous curing test

5.3.1 Container

The autogenous curing container shall consist of thermal insulation meeting the heat retention requirements of Clause 5.3.2 and closely surrounding the cylindrical concrete specimen.

5.3.2 Heat retention

The watertight 150 mm diameter by 300 mm high cylindrical container shall be placed into the autogenous curing container. The container shall be filled within 6 mm of the top of the cylindrical container with water at a temperature of 82 °C. A thermometer shall be inserted in the water at about the centre of the cylindrical container, and the initial temperature of the water shall be measured with a suitable readout device. Then, the water container shall be sealed with a cap or plastic bag and the autogenous curing container shall be closed. When the autogenous curing container is stored in air at 21 ± 2 °C, the water temperature shall meet the following requirements:

Elapsed time, h	Required water temperature, °C
12	67 ± 3
24	58 ± 3
48	45 ± 4
72	38 ± 4

5.3.3 Stability of the container

5.3.3.1

The autogenous curing container, or any part thereof, shall not display embrittlement, fracturing, or distortion when maintained at a temperature of –30 ± 3 °C for a period of 72 h, nor softening or distortion when maintained at a temperature of 60 ± 3 °C for a period of 72 h. The gasket type heat seal shall immediately recover fully its original thickness after 50% compression under the temperature conditions specified in this Clause.

5.3.3.2

The autogenous curing container should be capable of being opened to permit insertion and withdrawal of the test specimen and should have an outer and inner casing to protect the insulation from mechanical damage.

5.3.3.3

The autogenous curing container should be fabricated to accommodate a maximum-minimum temperature recording device to monitor the interior air temperature inside the autogenous curing box during the curing period.

Note: *Differences in strength caused by differences in temperature are not believed to be significant, but comparison of results among areas so affected should be supported by appropriate correlations and interpreted with knowledge of the temperature variations.*

5.3.3.4

The autogenous curing container should have a lid or other means to provide secure closure during the specified curing period that includes a heat seal that satisfies the requirements of Clause 5.3.2.

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5.3.3.5

The autogenous curing container should be capable of holding one or two specimens.

5.4 Procedure C — Warm water test

For the accelerated curing tank, a warm water tank of the type specified in Figure 1 shall be used.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Test specimens

7.1 Sampling concrete

Samples of concrete for test specimens shall be taken in accordance with CSA A23.2-1C.

7.2 Moulding cylinders

Two test specimens shall be moulded in accordance with CSA A23.2-3C or CSA A23.2-12C, whichever is applicable. The time between sampling and moulding of test specimens shall not exceed 20 min.

Notes:

1) *Paraffined cardboard or similar moulds are not suitable for this Test Method.*
2) *Metal moulds or reusable moulds with end plates and clamps might not be practicable for Procedure B.*

7.3 Testing cylinders for compressive strength

The cylinders shall be tested in compression, at the time intervals required by each accelerated test procedure, in accordance with CSA A23.2-9C.

8 Test procedures

8.1 Procedure A — Boiling test

8.1.1 Curing procedures

8.1.1.1 Initial curing

Immediately after moulding, each specimen shall be covered with a steel plate. The temperature adjacent to the specimens shall be maintained at 20 ± 5 °C, until the commencement of accelerated curing. During this time, the specimens shall not be disturbed or subjected to vibration or jarring.

8.1.1.2 Boiling procedure

At 23 ± 0.25 h after the time of moulding, the specimens in the moulds, with cover plate, shall be placed in boiling water in the tank (see Figure 1). The water shall return to boiling during the next 15 min. Except for the first 15 min, the temperature of the water at any point in the tank shall not fall below 98 °C for the specified curing period. In confined places, excessive evaporation can be avoided if the temperature is kept just below the boiling point. The temperature of the water shall be continuously recorded or periodically measured. After 3.5 ± 0.25 h in the tank, the specimens shall be removed from

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the tank, stripped of the moulds, and allowed to cool at 23 ± 2 °C for 1 h. At this time, the ends of the cylinders shall be prepared by capping or grinding in accordance with CSA A23.2-9C.

Note: *The capping compound used should develop sufficient strength at the time of testing the concrete specimens. For this test, the capping compound should have a minimum compressive strength of 25 MPa at the age of 1 h.*

8.1.2 Testing and interpretation of test results

The cylinders shall be tested in compression, approximately 1 h after capping, in accordance with CSA A23.2-9C. The total elapsed time between moulding and testing the specimens shall be 28.5 ± 0.25 h.

Notes:

1) *Each testing and control agency using the method specified in Clause 5.2 should develop, for its own concrete materials and mixes, a relationship between accelerated curing tests and standard 28 d tests, for the range in water-to-cementitious materials ratios anticipated for use in the work.*
2) *Information on the method described in Clause 5.2 can be found in Malhotra and Zoldners (1970).*

8.2 Procedure B — Autogenous curing test

8.2.1 Curing

8.2.1.1

Immediately after moulding, the moulds shall be covered with a metal plate or tightly fitted cap and place in a heavy duty plastic bag from which as much of the entrapped air as possible is expelled prior to tying the neck. Alternatively, a moisture tight plastic cap may be used. A plastic bag of sufficient strength to resist punctures and that can serve as a lifting grip for placing and removing the specimens from the autogenous container shall be used.

8.2.1.2

The maximum-minimum thermometer shall be re-set and, after the specimens are inserted into the container, the container lid shall be secured.

8.2.1.3

The test specimen identification, time of moulding the test specimens to the nearest 15 min, and the temperature of the freshly moulded concrete shall be recorded on the outside of the curing container for record purposes.

8.2.1.4

The curing container shall be stored for at least 12 h in a location not subjected to disturbance or direct sunlight, and preferably at a temperature 20 ± 5 °C.

8.2.1.5

At the age of 48 h ± 15 min after the test specimens were moulded, the specimens shall be removed from the container and demoulded. The specimens shall stand at room temperature for 20 min.

8.2.1.6

The maximum-minimum temperature during the curing procedure shall be recorded inside the container.

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8.2.2 Testing

The test specimens shall be capped or ground, and tested in accordance with CSA A23.2-9C, except that the age and time of the test shall be 49 h ± 15 min.

Note: *Capping or grinding, and testing may be performed at an age different from that specified in Clause 8.2.1.5. Testing agencies using this procedure have, for convenience, established relationships between test results at 24 h, 72 h, and 96 h with those obtained by standard moist curing. However, at 24 h the relationship is less satisfactory than those obtained by accelerated autogenous curing for 48 h, 72 h and 96 h. Where the curing period other than that specified in Clause 8.2.1.5, the age at testing should be the curing period plus 1 h. The tolerance on time should be 15 min.*

8.3 Procedure C — Warm water test

8.3.1 Curing

8.3.1.1

If necessary, the top of the specimens may be covered with a rigid plate to prevent loss of mortar to the water bath.

8.3.1.2

Immediately after moulding, the specimens shall be placed into the water-curing tank. The water shall be maintained at 35 ± 3 °C during the time of immersion and throughout the curing period.

8.3.1.3

The temperature of the water shall be continuously recorded or periodically measured throughout the curing period.

8.3.1.4

After curing for 23.5 h ± 30 min, the specimens shall be removed from the tank, and the mould shall be removed from the specimens.

8.3.2 Testing and interpretation of test results

The cylinders shall be tested in compression, at 24 h ± 15 min after capping or grinding, in accordance with CSA A23.2-9C.

Notes:

1) *Each testing and control agency using the method specified in Clause 5.2 should develop, for its own concrete materials and mixes, a relationship between accelerated curing tests and standard 28 d tests for the range in water-to-cementitious materials ratios anticipated for use in the work.*
2) *Information on the test described in Clause 5.2 can be found in Malhotra and Zoldners (1970).*

9 Reporting

9.1 Required information

The following information shall be included in the test report, as applicable:

a) specimen identification number or details;
b) location, date and time of sample;
c) identification of the certified testing laboratory (i.e., name and address) that performed the test;
d) date and time when the concrete specimen was made;
e) the test procedure used;

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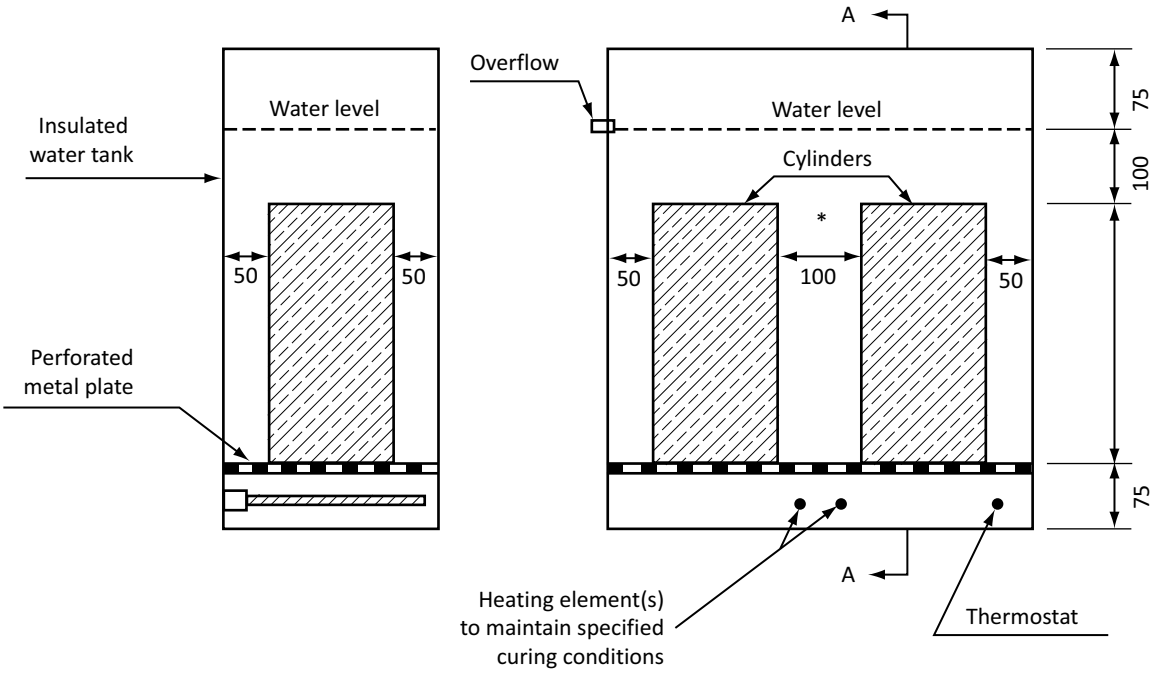
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f) ambient temperature of the specimens during storage for the warm water and boiling water test or of the container during storage for the autogenous curing test;
g) maximum and minimum curing temperature, if the autogenous curing test was performed;
h) date the specimen was tested;
i) age of the specimen at the time of testing;
j) name of the certified technician who performed the test;
k) specified age in days (or other) and specified minimum strength, MPa;
l) curing history, if different from standard;
m) diameter (and length, if the length-to-diameter ratio is less than 1.8 or more than 2.2 diameters), mm;
n) compressive strength calculated, to nearest 0.1 MPa;
o) type of failure, if different from Type (1) (see Figure 3 in CSA A23.2-9C);
p) name and signature of the person responsible for the quality of the test report; and
q) any deviation from the test procedure.

9.2 Optional information

The following information may be included in the test report:
a) concrete type (e.g., concrete mixture design identification number or other descriptor);
b) density of hardened concrete, if required by the owner;
c) cross-sectional area, mm²;
d) maximum applied load, kN; and
e) average loading rate, MPa/s.

Figure 1
Warm water and boiling water tank
(See Clauses 5.2, 5.4, and 8.1.1.2.)



Notes:
1) *All dimensions given are in millimeters.*

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2) *The tank shall be of any configuration suitable for the number of cylinders to be tested and the cylinders shall be arranged in a line or in a square, provided that the minimum clearances specified are maintained. Clearances of 100 mm between the cylinders shall be reduced to 50 mm provided that requirements for temperature uniformity are met.*
3) *The tank should be capable of providing the specified curing conditions. For a tank containing two or three cylinders, two coupled elements (1500 W and 5000 W) have been found suitable. Thermometers or other temperature recording devices shall be used independently of the thermostat to check the temperature of the water.*
4) *The plate supporting the cylinders shall have sufficient open perforations so as not to interfere with the circulation of the water. It is advantageous to insulate the tank with at least 50 mm of suitable insulating material.*
5) *A close-fitting but not pressure-tight lid shall be provided.*
6) *Because of evaporation, arrangements shall be made to maintain the water level in the tank at the specified level.*

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A23.2-11C
Water content, density, absorption, and voids in hardened concrete, grout, or mortar

1 Scope
This Test Method specifies the procedure for determining water content, density, percent absorption, and volume of permeable pore space in hardened low-density, normal-density, and high-density concrete, grout, or mortar. This Test Method is substantially in accordance with ASTM C642.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-10C:19
Accelerating the curing of concrete cylinders and determining their compressive strength

ASTM International

C642-13
Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

E104-02 (2012)
Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions

3 Summary
Following their conditioning, test specimens are weighed in air and in water to determine absorption and density. Permeable pore space is obtained from the difference between density after immersion and boiling and dry density.

4 Significance and use
This Test Method is useful for obtaining data required for mass and volume conversions of the tested material. It may also be used to determine conformance with specifications, uniformity of the tested material, and freeze-thaw durability characteristics of concrete.

5 Apparatus
The apparatus shall consist of the following:

a) a balance or scale sensitive to 0.025% of the mass of the specimens or to 0.2 g or less;
b) a suitable container for immersing the specimens and suitable wire for suspending the specimens in water;
c) a boiling water tank conforming to CSA A23.2-10C;
d) an oven capable of maintaining a uniform temperature of 110 ± 5 °C;
e) a controlled humidity enclosure, room or smaller chamber, at 50 ± 5% relative humidity and 23 ± 2 ˚C meeting the requirements of ASTM E104; and
f) a dessicator of suitable size to contain all the pieces or portions of concrete under test.

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6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Test specimens

The test specimens may be piece(s) of cylinders, beams, cubes, cores, or pieces of any desired shape or size, each to be tested separately. The volume of test specimen shall be not less than 350 cm^3 (0.35 L).

Each test specimen shall be free from observable cracks, fissures, or shattered edges and be free from any form-release agent, sealer, or paint.

Notes:

1) *The minimum test specimen volume of 350 cm^3 (0.35 L) represents approximately 800 g of normal-density concrete.*
2) *No more than three pieces should be grouped together to obtain the required volume.*

8 Procedures

8.1

The test age shall be at least 28 d unless otherwise specified.

8.2

The test specimens shall be weighed in the laboratory in the as-received condition. This mass shall be designated *I*. The specimens shall be wrapped in plastic sheets or other suitable means immediately after sampling in the field if the water content of in-place concrete is required.

If air-dry density is required, the test specimens shall be conditioned in a controlled humidity enclosure as described in Clause 5 until the mass of the specimen changes not more than 0.5 % (gain or loss) in successive determinations of mass 7 d apart. The first mass shall be obtained after a minimum of 28 d conditioning in a humidity enclosure. Designate the last mass after reaching equilibrium *G*.

8.3

The test specimens shall be dried in the oven at 110 ± 5°C for not less than 48 h. The test specimens shall be cooled in dry air (50 ± 5% RH), preferably in a dessicator, to a temperature of 23 ± 2 °C and weighed. The specimens shall be returned to the oven for at least 24 h, then cooled in the same manner, and weighed. If the difference between values obtained from two successive weighings exceeds 0.5% of the lesser mass, the specimens shall be returned to the oven for an additional drying period of not less than 24 h. The procedure shall be repeated until the difference between any two successive weighings is less than 0.5% of the lower mass. The last mass shall be designated A.

8.4

The test specimens shall be submerged in water maintained at a temperature of 23 ± 2 °C for not less than 24 h after the final drying, cooling, and weighing and until two successive weighings of the surface-dried sample show an increase in mass of less than 0.5% of the heavier mass. The specimens shall be surface-dried by wiping with a damp cloth to remove surface water, and then weigh. The final surface-dry mass after immersion shall be designated B.

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8.5

The specimens shall be placed and processed in accordance with Clause 8.4, in a suitable receptacle, covered with tap water and boiled for 5 h. Cooling shall be by natural loss of heat for not less than 14 h to a final temperature of 23 ± 2 °C. The specimens shall be surface-dried by wiping with a damp cloth to remove surface water and then weighed. The boiled, surface-dried mass shall be designated C.

8.6

After immersion and boiling, the specimens shall be suspended by a wire and weighed in water at 23 ± 2 °C. This mass shall be designated D.

9 Calculations

By using the masses determined in accordance with the procedures described in Clause 8, make the following calculations shall be made:

Water content, % (as received condition) = $((I - A)/A) \times 100$

Absorption after immersion, % = $((B - A)/A) \times 100$

Absorption after immersion and boiling, % = $((C - A)/A) \times 100$

Air-dry or equilibrium density, kg/m^3 = $G/(C - D)) \times 1000$, if required

Dry density (oven-dried), kg/m^3 = $A/(C - D)) \times 1000$

Density after immersion, kg/m^3 = $(B/(C - D)) \times 1000$

Density after immersion and boiling, kg/m^3 = $(C/(C - D)) \times 1000$

Volume of permeable pore space (voids), % = $((C - A)/(C - D)) \times 100$
where

I = mass of specimen in the as received condition, g

A = mass of oven-dried specimen in air, g

B = mass of surface-dried specimen in air after immersion, g

C = mass of surface-dried specimen in air after immersion and boiling, g

D = mass of specimen in water after immersion and boiling, g

G = mass of specimen after reaching equilibrium (controlled humidity), g

10 Reporting

The following information shall be included in the test report, as applicable:

a) location, date, and time at which the sample was taken or date the sample was received;
b) identification of the sample;
c) water content and absorptions expressed, to the nearest 0.1%;
d) densities expressed, to the nearest 10 kg/m^3;
e) volume of permeable pore space expressed, to the nearest 0.1%;
f) name of the certified technician who performed the test;
g) identification of the certified laboratory that performed the test (i.e., name and location);
h) name and signature of the person responsible for the review of the test report; and
i) any deviations from the test procedure.

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11 Precision and bias

11.1 Precision

No statement is made about the precision of this Test Method.

Note: *Results of two properly conducted tests by the same operator on the same material should not differ by more than*

a) *absorption: 0.5 %;*
b) *density: 20 kg/m³; and*
c) *volume of permeable pore space: 1%.*

11.2 Bias

Since there is no accepted reference concrete suitable for determining the bias in this Test Method, no statement on bias is made.

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A23.2-12C
Making, curing, and testing compression test specimens of no-slump concrete

1 Scope
This Test Method specifies the procedures for making, curing, and testing specimens of no-slump concrete proportioned for consolidation by heavy vibration or mechanical compaction, or both.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-6C:19
Density and yield of plastic concrete

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

A23.2-18C:19
Determination of total water content of normal weight fresh concrete

A23.2-1D:19
Moulds for forming vertical concrete test cylinders

ASTM International

D1557-12e1
Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))

3 Summary
Concrete cylinders are cast using special compaction procedures and their density and the total water content of the subject concrete is determined. The concrete cylinders cast are considered acceptable for compression testing if the concrete water content and the average concrete cylinder density values are within the specified ranges.

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4 Significance and use

This Test Method is intended to determine the quality of as-produced concrete (i.e., in the precast plant environment for precast elements) and of as-delivered concrete (i.e., on construction sites for construction of foundation piles or pavements).

Notes:

1) *The successful production and use of no-slump concrete requires appropriately proportioned concrete mixture and the presence of appropriate water content. Both these factors significantly affect the compactibility of the concrete mixture and the quality of the final product.*
2) *There should be a preconstruction meeting attended by all concerned parties to discuss the requirements of this Test Method.*

5 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6 Prerequisites

Based on the proposed concrete mix design prepared to satisfy the project specification requirements, the concrete supplier shall specify the design plastic concrete total water content (Md, %)* determined in accordance with Clause 10, the desirable range for field concrete water content, and the design plastic concrete density (Dd, kg/m^3).

To facilitate concrete testing, the general contractor shall provide and maintain, for the sole use of the testing agency, adequately shaded and sheltered facilities that include a firm base for casting concrete cylinders. The facilities shall also include a protected, designated area for safe storage and proper curing of concrete test specimens for the initial curing period at the project site, including provision of a continuous power supply to comply with CSA A23.2-3C.

* *The plastic concrete water content, Md, should represent all water in concrete, including the water absorbed by aggregates.*

7 Apparatus

The apparatus shall consist of the following:

a) metal moulds, 150 mm in diameter × 300 mm in height, formed from heavy steel or cast material capable of withstanding the intended compactive effort, with minimum metal wall thickness of 6 mm, and minimum metal base thickness of 10 mm. The mould base is to be attached by a clamping system. Moulds are to be pre-weighed and pre-calibrated for volume in accordance with CSA A23.2-6C. In addition to the above requirements, moulds shall meet the requirements of CSA A23.2-1D;

b) optional moulds for testing roller compacted concrete (RCC) only, a reusable rigid 150 mm × 300 mm plastic mould as defined in CSA A23.2-1D, contained in a suitably designed cylindrical metal mould with minimum metal wall thickness of 6 mm and minimum metal base thickness of 10 mm;

c) a compacting device capable of producing concrete cylinder specimens with densities comparable to the mix design density specified by the concrete supplier;

   Note: *Proctor hammers (see ASTM D1557) and electric impact hammers, modified by being fitted with a shoe size of a minimum 50 mm diameter and a minimum 20 mm thickness to act as the compactive face, have been used successfully. Some laboratories have also used an external vibrator with a heavy surcharge mass resting on top of the concrete.*

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d) a scale of at least 50 kg capacity, minimum 0.05 kg sensitivity, and suitable for weighing concrete-filled cylinder moulds;
e) a scale of at least 5 kg capacity, minimum 1 g sensitivity, and suitable for weighing concrete samples obtained for the water content test;
f) a microwave oven or a hot plate suitable for determining water content, as per CSA A23.2-18C; and
g) a metal compaction plate for compacting the top thin layer to form a smooth cylinder surface.

8 Sampling concrete

Concrete shall be sampled as follows:
a) Obtain samples of concrete for water content determination and casting test specimens.
b) Identify, handle, and protect the samples in accordance with Clause 7 of CSA A23.2-1C.

For testing foundation pile concrete, the sample shall consist of concrete intended for the pile shaft construction (as opposed to the pile base construction).

9 Compression test specimen acceptance criteria

The cylinder test specimens, cast in accordance with Clause 10.2, shall be considered acceptable for compression testing only when they are cast from the concrete that satisfies the following two conditions:
a) The field water content of the plastic concrete determined in accordance with Clause 10.1 is within the desirable water content range for *Md* specified by the concrete supplier.
b) The average density of the concrete cylinders determined in accordance with Clause 10.3 is 98% to 102% of the mix design plastic concrete density *Dd* specified by the concrete supplier.

Notes:
1) *A test program should be conducted on the proposed no-slump concrete mix prior to the start of construction to define the desirable range for concrete water content, compactive process, and effort required for obtaining the plastic concrete density as stated in Item b).*
2) *The water content of the very first portion of each concrete load should be determined to facilitate any required water content adjustments during concrete placing.*

10 Test procedure

10.1 Step 1 — Plastic concrete field water determination

The water content of plastic concrete shall be determined in accordance with the provisions of CSA A23.2-18C.

10.2 Step 2 — Compression test specimen preparation

The specimen shall be prepared as follows:
a) Confirm that the cylindrical moulds being used for casting compression test cylinders are pre-weighed and are calibrated for volume.
b) Lightly coat the inside surface of all cylinder moulds with mineral oil or another suitable non-reactive form-release material.
c) Thoroughly mix concrete and wet-screen a small portion of the concrete sample on a 5 mm sieve using the procedures in Clause 7.9 of CSA A23.2-1C. Discard the oversize material and use the mortar obtained from the wet-screening to form a thin layer (about 5 mm thick) at the bottom of the cylinder mould. Save the remaining portion of the mortar for forming a thin layer on the top of the cylinder. The mortar should be protected against moisture loss in the same manner as the concrete sample.

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d) Cast cylinders in a shaded facility sheltered from wind and sun to minimize concrete moisture loss. Cast cylinders on a firm base.
e) Fill all cylinder moulds simultaneously with an adequate amount of thoroughly mixed concrete such that the finished compacted concrete lift will be of the desired thickness.
f) Compact the concrete in the moulds in lifts of approximately equal volume. Casting of cylinders might require compaction of concrete in more than three lifts.
g) Provide sufficient number of blows or duration of impact hammer application for each concrete lift to produce a concrete specimen having a plastic density between 98% and 102% of the design plastic concrete density, D_d, specified by the concrete supplier in accordance with Clause 6.
h) Use a large spatula along the inside edge of the steel moulds to remove a lip which might have formed during compaction of each concrete lift.
i) Scarify the surface of each lift after compaction to provide bond between the lifts.
j) Place the mortar obtained from the wet-screening in a thin layer of about 5 mm thickness on the top surface of the cylinder to fill any voids in the top lift surface and also to slightly overfill the mould.
k) Compact the top thin layer after surcharging with a metal compaction plate and applying adequate compactive energy to provide a smooth finish for the top cylinder surface.
l) Trowel the cylinder surface to a smooth finish with a wet trowel.
m) Take special care to minimize moisture loss from the no-slump concrete throughout the test specimen preparation process.
n) Complete casting of all required concrete cylinders within 40 min of sampling.

Note: *Observe the cylinders after demoulding to determine presence, if any, of visible defects such as segregation or compaction planes. Such observations are useful for determining whether modifications to the concrete mix design and/or to the cylinder casting procedures should be considered.*

10.3 Step 3 — Plastic concrete density determination

Plastic concrete density shall be determined as follows:

a) Remove excess concrete from outside of the steel moulds of the concrete cylinders cast in accordance with Clause 10.2.
b) Determine the plastic concrete density, *Df*, of each cylinder in accordance with CSA A23.2-6C. The measures referenced in CSA A23.2-6C shall be the cylinder moulds described in Clause 7 a).

11 Compression test specimen acceptance determination

11.1

If the concrete water content and the average concrete cylinder density values are within the ranges specified in Clauses 9 a) and 9 b), the ends of the cylinders shall be covered and the cylinders shall be transferred to the curing box for initial curing in accordance with CSA A23.2-3C.

11.2

If the field plastic concrete water content, *Mf*, is not within the desirable range specified in Clause 9 a), the concrete purchaser may arrange to implement on-site concrete water content adjustments to the concrete. Such adjustments (if implemented) shall be subject only to Clause 5.2.5.3.2.1 a) of CSA A23.1.

11.3

If the average density of concrete cylinders (average *Df*) is not within the range specified in Clause 9 b), the cylinders shall be re-cast using the procedures specified in Clause 10.2, using a modified compactive process and/or efforts, followed by performing density tests in accordance with Clause 10.3.

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11.4
Inability to obtain the desired average cylinder density in spite of an adequate compaction process and efforts might indicate the presence of insufficient water content in the concrete mix and/or the lack of adequate compactibility of the concrete mix.

11.5
The concrete purchaser shall have the option of accepting or rejecting such concrete and/or requesting the concrete supplier to take appropriate action towards satisfying the two conditions stated in Clause 9 a) and b).

12 Cylinder curing, transportation, and strength testing
The cylinders shall be cured and transported in accordance with CSA A23.2-3C and tested for compressive strength in accordance with CSA A23.2-9C.

13 Reporting

13.1 Required information
The following information shall be included in the test report, as applicable:
a) concrete mix identification;
b) source of sampling (i.e., bill no., batch no., plant identification);
c) date and time of sampling;
d) identification of the project site;
e) target plastic concrete water content range specified by the concrete supplier;
f) date and time when the cylinder specimens were made;
g) specimen identification number or details;
h) field plastic concrete water content, M_f , to the nearest 0.1%;
i) plastic concrete density, D_f , of each cylinder; to the nearest 1 kg/m^3;
j) target density of plastic concrete specified by the concrete supplier;
k) average plastic concrete density of all cylinders; to the nearest kg/m^3;
l) age of the specimen tested;
m) specified compressive strength, MPa;
n) curing history, if different from standard;
o) diameter and length, (if the L/D ratio is less than 1.8 or more than 2.2), mm;
p) compressive strength, calculated to the nearest 0.1 MPa;
q) type of failure, if the cylinders do not satisfy the specified compressive strength (see Figure 3 of CSA A23.2-9C);
r) name of the certified technician who cast the cylinders and performed the field tests;
s) identification of the certified testing laboratory (i.e., name and address);
t) name and signature of the person responsible for the review of the test report; and
u) any deviation from the test procedure.

13.2 Optional information
The density of hardened concrete, to the nearest 1 kg/m^3, may be included in the test report.

Note: *Density of hardened concrete is obtained by dividing the weight of the uncapped cylinder by its volume, as calculated from the average length and average diameter measured before the compressive strength test. It may also be obtained by weighing the uncapped specimen in air and then in water. The moisture condition of the specimen should be noted (e.g., moist or dry).*

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14 Precision and bias

The precision and bias for this Test Method is not available.

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A23.2-13C
Splitting tensile strength of cylindrical concrete specimens

1 Scope

This Test Method specifies the procedure for determining the splitting tensile strength of cylindrical concrete specimens, such as moulded cylinders and drilled cores.

Notes:

1) *This Test Method is in substantial agreement with ASTM C496/C496M, and is predicated on 150 mm diameter moulded cylinders and 140 mm diameter drilled cores. The user is cautioned that results and relationships developed between this Test Method and compressive strength using smaller diameter specimens can be erroneous.*
2) *For methods of moulding cylindrical concrete specimens, see CSA A23.2-3C and for methods of obtaining drilled cores, see CSA A23.2-14C.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

ASTM International

C496/C496M-17
Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

3 Summary

This Test Method consists of applying a diametral compressive force along the length of a cylindrical concrete specimen at a rate of loading that is within the prescribed range until failure occurs. This loading induces tensile stresses on the plane containing the applied load and relatively high stresses in the area immediately around the applied load. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compressive stresses than would be indicated by a uniaxial compressive strength test result.

Thin plywood strips are used to distribute the load applied along the length of the cylinder.

The maximum load sustained by the specimen is divided by the appropriate geometrical factors to the splitting tensile strength.

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4 Significance and use

4.1

Splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength (modulus of rupture).

4.2

Splitting tensile strength is used in the design of structural lightweight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement. It is also used to evaluate flexural strength of concrete pavements.

5 Apparatus

The apparatus shall be as follows:

a) Testing machine: Use the testing machine conforming to the requirements of CSA A23.2-9C that has sufficient capacity to provide the rate of loading prescribed in Clause 8.5.

b) Supplementary bearing bar or plate: Use a supplementary bearing bar or plate having a width of at least 50 mm if the diameter or the largest dimension of the upper bearing face or the lower bearing block is less than the length of the cylinder to be tested. The thickness of the bearing bar or plate shall be not less than the distance from the edge of the spherical or rectangular bearing block to the end of the cylinder. Machine the surfaces of the bar or plate to within 0.025 mm of planeness, as measured on any line of contact of the bearing area. Arrange the bar or plate so that the load will be applied over the entire length of the specimen.

c) Bearing strips: Provide two bearing strips of nominal 3 mm thick plywood, free of imperfections, approximately 25 mm wide and of a length slightly longer than that of the specimen for each specimen. Do not reuse the bearing strips.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Test specimens

7.1

The test specimens shall conform to the size, moulding, and curing requirements specified in CSA A23.2-3C. Drilled cores shall conform to the size and curing requirements specified in CSA A23.2-14C. Test specimens shall consist of 150 mm diameter moulded specimens or 140 mm diameter drilled cores. Moist cured specimens shall be tested in a moist cured condition as soon as practicable. The moisture condition for moist-cured specimens shall be maintained using wet burlap or blanket covering during the period between their removal from the curing environment and testing.

7.2

Lightweight concrete specimens shall be tested at 28 d. The curing regime shall comprise of a 7 d moist curing period followed by 21 d of air drying at 23.0 ± 2 °C and 50 ± 5% relative humidity.

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8 Procedure

8.1 Marking

Diametral lines shall be drawn on each end of the specimen using a suitable device that will ensure that they are in the same axial plane (see Figure 1); as an alternative, the aligning jig shown in Figure 2 may be used.

Notes:

1) *Figure 1 shows a suitable device for drawing diametral lines on each end of the specimen in the same axial plane. The device consists of three parts, as follows:*
   a) *a length of 100 mm steel channel, the flanges of which have been machined flat;*
   b) *a section of a T-bar, B, that is grooved to fit smoothly over the flanges of the channel and that includes a rectangular notch for positioning the vertical member of the T-bar assembly; and*
   c) *a vertical bar, C, containing a longitudinal aperture (cleft), A, for guiding a pencil.*
   The T-bar assembly is not fastened to the channel and is positioned at either end of the channel without disturbing the position of the specimen when marking the diametral lines.
2) *Figure 3 is a detailed drawing of the aligning jig shown in Figure 2, used for the same purpose as the marking of the diametral lines. The device consists of*
   a) *a base for holding the lower bearing strip and cylinder;*
   b) *a supplementary bearing bar conforming to the requirements in Clause 4 as to critical dimensions and planeness; and*
   c) *two uprights to serve for positioning the test cylinder, bearing strips, and supplementary bearing bar.*

8.2 Measurements

The diameter of the test specimen shall be determined to the nearest millimetre by averaging three diameters measured near the ends and the middle of the specimen and lying in the plane containing the lines marked on the two ends. The length of the specimen shall be determined to the nearest millimetre by averaging at least two length measurements taken in the plane containing the lines marked on the two ends.

8.3 Positioning using marked diametral lines

One of the plywood strips shall be centred along the lower bearing block. The specimen shall be placed on the plywood strip and aligned so that the lines marked on the ends of the specimen are vertical and centred over the plywood strip. A second plywood strip shall be placed lengthwise on the cylinder, centred on the lines marked on the ends of the cylinder. The assembly shall be positioned to ensure the following conditions:

a) the projection of the plane of the two lines marked on the ends of the specimen intersects the centre of the upper bearing plate; and
b) the supplementary bearing bar or plate, when used, and the centre of the specimen are directly beneath the centre of thrust of the spherical bearing block (see Figure 4).

8.4 Positioning by use of aligning jig

The bearing strips, test cylinder, and supplementary bearing bar shall be positioned by means of the aligning jig as illustrated in Figure 2, and the jig shall be centred so that the supplementary bearing bar and the centre of the specimen are directly beneath the centre of thrust of the spherical bearing block.

8.5 Rate of loading

The load shall be applied continuously and without shock, at a constant rate within 700 to 1400 kPa/min splitting tensile stress until failure of the specimen. The maximum applied load indicated by the

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testing machine at failure shall be recorded. The type of failure and the appearance of the concrete shall be noted.

Note: *The relationship between splitting tensile stress and applied load is shown in Clause 9. The required loading range in splitting tensile stress corresponds to applied total load in the range of 50 to 100 kN/min for 150 mm × 300 mm cylinders.*

9 Calculation

The splitting tensile strength of the specimen shall be calculated as follows:

$$T = \frac{2P}{\pi l d}$$

where

T = splitting tensile strength, MPa

P = maximum applied load indicated by the testing machine, N

l = length, mm

d = diameter, mm

10 Reporting

10.1 Required information

The following information shall be included in the report, as applicable:

a) concrete mix identification;
b) source of sampling (i.e., bill no., batch no., plant identification);
c) date and time of sampling;
d) identification of the project site;
e) location of the structure;
f) location, date and time at which the sample was taken or date the sample was received;
g) identification of the sample;
h) type of specimen, cast cylinder or core;
i) diameter and length, mm;
j) maximum load, N;
k) splitting tensile strength, calculated to the nearest 0.05 MPa;
l) estimated portion of coarse aggregate fractured during the test;
m) age of the test specimen;
n) curing history of the test specimen;
o) any defects in the test specimen;
p) type of fracture;
q) name of the certified technician who performed the test;
r) identification of the certified laboratory performing the test (i.e., name and address);
s) name and signature of the person responsible for the review of the test report; and
t) any deviation from the test procedure.

10.2 Optional information

The following information may be included in the test report:

a) nominal size aggregate observed in the concrete; and
b) corresponding compressive strength specimen set number.

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11 Precision and bias

11.1 Precision

The precision of this Test Method is expected to be similar to that of ASTM C496/C496M.

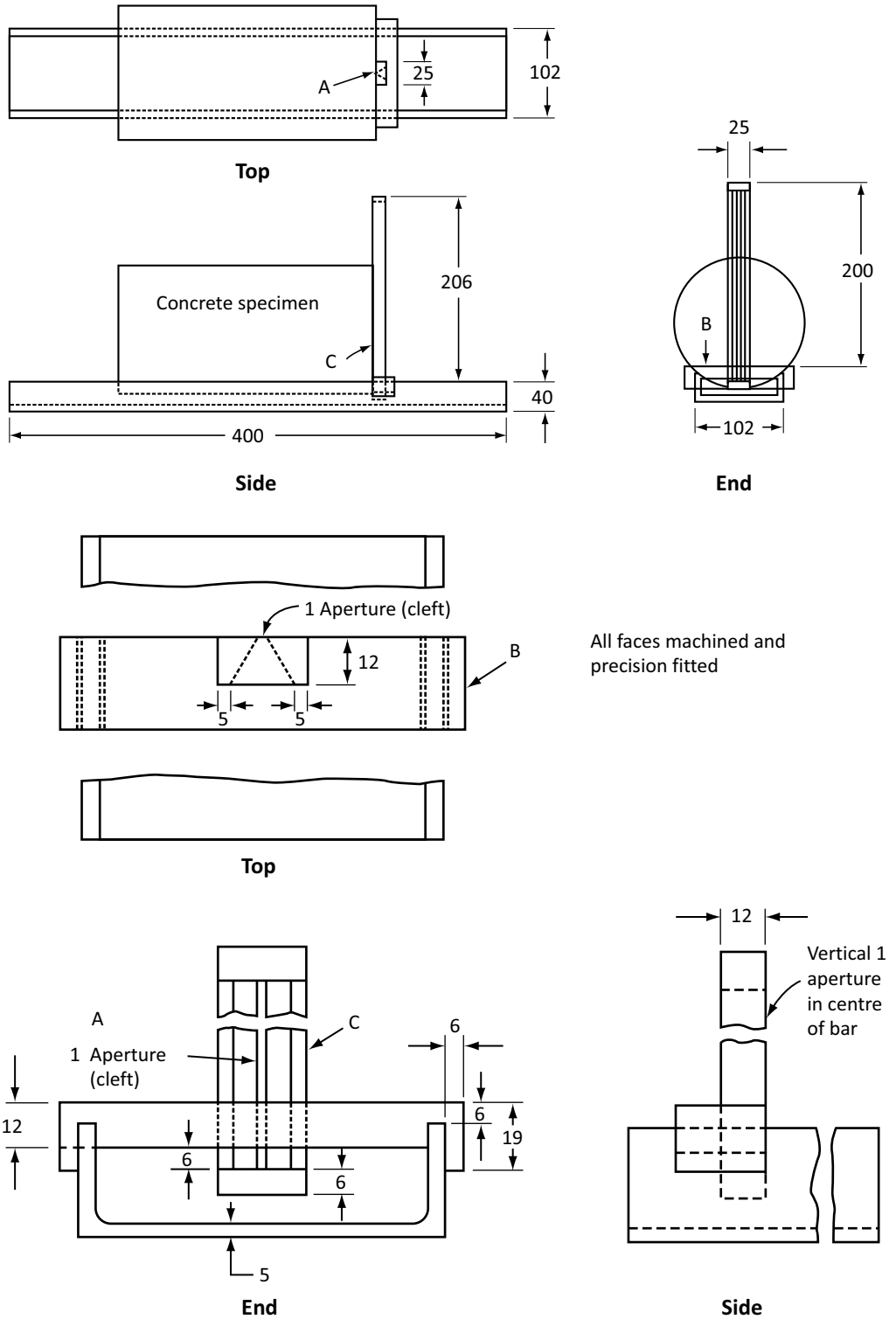
11.2 Bias

The Test Method has no bias because the splitting tensile strength can be defined only in terms of this Test Method.

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Figure 1
Suitable apparatus for marking end diameters used for aligning the specimen
(See Clause 8.1.)



Note: *Dimensions are in millimetres.*

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Figure 2
Jig for aligning concrete cylinder and bearing strips
(See Clauses 8.1 and 8.4.)

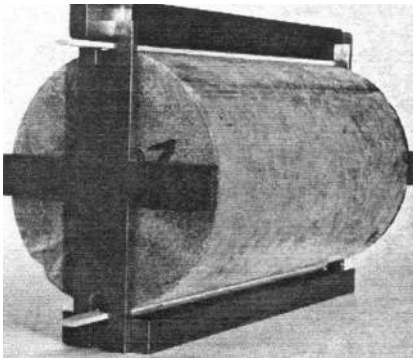
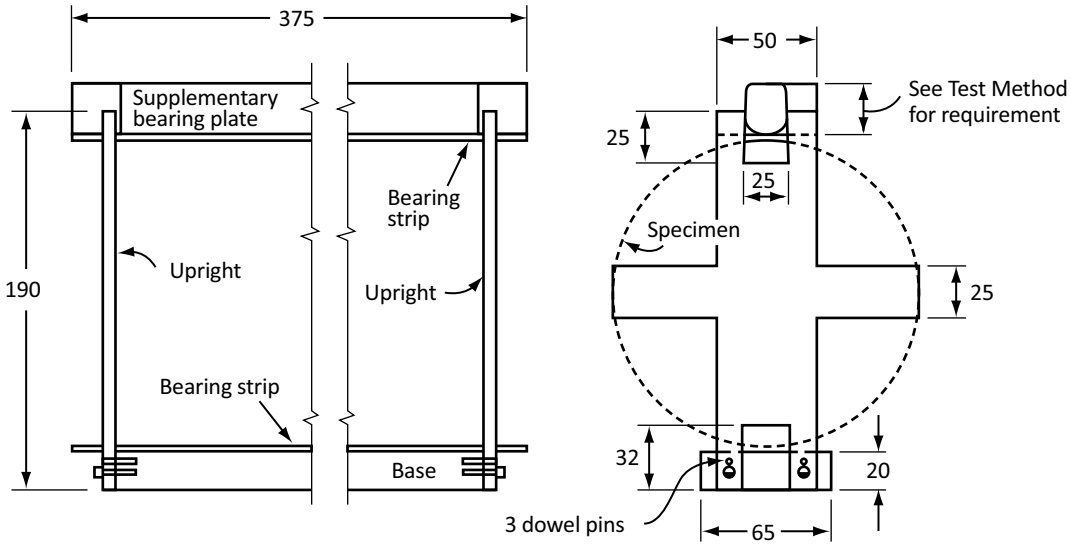


Figure 3
Detailed plans for a suitable aligning jig
(See Clause 8.1.)

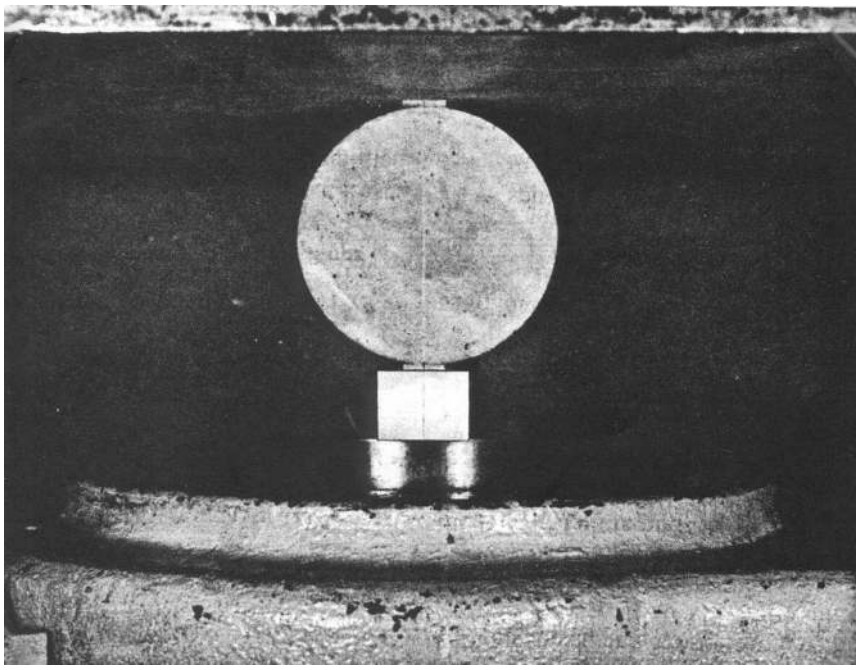


Note: *Dimensions are in millimetres.*

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Figure 4
Specimen positioned in a testing machine for determination of splitting tensile strength
(See Clause 8.3.)



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A23.2-14C
Obtaining and testing drilled cores for compressive strength testing

1 Scope
This Test Method specifies the procedures for obtaining, preparing, and determining the compressive strength of drilled core specimens of hardened concrete.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

CSA A23.2-9C:19
Compressive strength of cylindrical concrete specimens

ASTM International

C42/C42M-18a
Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

3 Summary
Core specimens are obtained from hardened concrete using a diamond-tipped thin walled core drill bit and a powered core drill. The core specimens are then moisture conditioned as appropriate, and their lengths and diameters are measured after end preparation to determine their respective length to diameter ratios. Compression tests are conducted on the prepared cores and compressive strengths are computed using prescribed correction factors as appropriate.

4 Significance and use
This Test Method specifies the procedures for determining compressive strength of hardened in-place concrete and can be useful to determine the in-place concrete strength quality and/or to determine the timing for form removal, application of prestressing or post-tensioning or termination of curing.

5 Apparatus
The apparatus shall consist of the following:

a) a diamond-tipped thin walled drill bit and core drill with provision for a cooling liquid;
b) related accessories to accommodate the coring operation; and
c) a compression testing machine, as described in CSA A23.2-9C.

6 Sampling

6.1 General
Specimens to be tested for strength determination shall not be removed from the structure until the concrete has become hard enough to permit removal without disturbing the bond between the mortar

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and the coarse aggregate. Specimens that show abnormal defects or that have been damaged in removal shall be discarded.

Note: *Generally, the concrete should not be drilled until it has reached a maturity equivalent to at least 7 d of curing at a minimum temperature of 10 °C.*

6.2 Location

When possible, a core specimen shall be located perpendicular to a horizontal surface such that its axis is perpendicular to the bed of the original concrete as placed. When possible, the specimen shall be located near the central portion of the concrete element when it is to be obtained from a perpendicular to a vertical or battered surface. Cores should not be drilled from the tension zone of a structural member because the presence of cracks can adversely affect the measured compressive strength.

7 Compression test

7.1 Specimens

A core specimen for the determination of compressive strength shall have a diameter of at least three times the nominal maximum size of the coarse aggregate used in the concrete. The length of the specimen, when capped or ground, shall be, as nearly as practicable, twice its diameter, and no core shall have a length less than its diameter.

Notes:

1) *Cores for determining compressive strength that contain embedded reinforcement can yield lower values than cores without embedded steel and should be avoided if possible or trimmed to eliminate the reinforcement, provided that a length to diameter ratio of 1.00 or greater can be attained.*
2) *A minimum core diameter of 100 mm should be used whenever practicable.*

7.2 End preparation

Core specimens to be tested in compression shall have ends that are essentially smooth and perpendicular to the axis. The ends of specimens that have projections of 2 mm or more above the normal plane that depart from perpendicularity to the axis by more than 0.5°, or whose diameter departs from the mean by more than 3 mm shall be sawn until they conform to these tolerances.

7.3 Conditioning

7.3.1 Moisture conditioning

All test specimens taken from structures that are normally in a moist or wet condition shall be submerged in water at room temperature for 40 to 48 h immediately prior to the compression test. The specimens shall be tested promptly after removal from the water conditioning. The specimens shall be kept moist during the period between removal from the water and testing, and tested in a moist condition.

7.3.2 Dry conditioning

The core test specimens taken from structures that are normally in a dry condition shall be conditioned to approximate the moisture condition of the structure, but in no case condition them less than 24 h at room temperature and humidity prior to testing. Cores shall be tested in dry condition.

7.4 Core end preparation

The ends of the core specimen shall be capped or ground in order to meet the requirements of CSA A23.2-9C before conducting the compression test.

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7.5 Measurement

Prior to testing, the length of the prepared core specimen shall be measured to the nearest millimetre and its average diameter shall be measured to the nearest millimetre from two measurements taken at right angles near the centre of the length.

7.6 Testing

The specimens shall be tested in accordance with the applicable provisions of CSA A23.2-9C.

8 Calculation

The compressive strength of each specimen shall be calculated in MPa, based on the average diameter of the specimen. If the ratio of length to diameter of a specimen is less than 2.0, the compressive strength shall be multiplied by the correction factor (based on the ratio of length, "L" to diameter "D") given in Tables 1 and 2, as applicable. Correction factor values not given in Tables 1 and 2 shall be obtained by interpolation.

9 Reporting

9.1 Required information

The following information shall be included in the test report, as applicable:

a) identification of the core sample (i.e., location in structure, corresponding compressive strength specimen set number, if applicable);
b) date on which the sample was taken or date the sample was received;
c) test age of the concrete;
d) core diameter, to the nearest mm;
e) core length, as capped (if capped), to the nearest mm;
f) moisture conditioning prior to testing;
g) description of abnormalities in the core sample (if any);
h) calculated corrected compressive strength in accordance with Clause 7, to the nearest 0.01 MPa;
i) name of the certified technician who performed the laboratory testing;
j) identification of the certified laboratory that performed the test (i.e., name and address);
k) name and signature of the person responsible for the review of the test report; and
l) any deviations from the test procedure.

9.2 Optional information

The following information may be included in the test report:

a) density of the core, if requested by the client;
b) direction of the application of the load with reference to the direction of the compaction of the concrete in the structure;
c) maximum applied load, in kN; and
d) nominal size aggregate observed in the concrete.

10 Precision and bias

The precision and bias of this Test Method is expected to be similar to that of ASTM C42/C42M.

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Table 1
Correction factors (compressive strength 15 to 70 MPa)
(See Clause 8.)

L /D	2.0	1.75	1.50	1.25	1.0
Factor	1.0	0.98	0.96	0.93	0.87

Note: *The correction factors in Table 1 are applicable to concrete with a compressive strength between 15 and 70 MPa and a density between approximately 1600 and 2400 kg/m³. Values for L/D ratios between 2.0 and 1.0 not given in Table 1 can be determined by interpolation.*

Table 2
Correction factors (compressive strength above 70 MPa)
(See Clause 8.)

L /D	2.0	1.75	1.50	1.25	1.0
Factor	1.0	0.98	0.96	0.94	0.92

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A23.2-15C
Evaluation of concrete strength in place using the pullout test

1 Scope

This Test Method specifies the procedure for evaluating the in-place hardened concrete compressive strength of a structural element using the pullout test. Pullout strength is obtained through the measurement of the force required to pull a metal insert, previously inserted in a mass of fresh concrete. The force measured is correlated to an equivalent compressive strength of the concrete on standard cylinders, through a correlation curve. This Test Method is applicable to concrete with a nominal maximum aggregate size of 40 mm or less.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

ACI (American Concrete Institute)

228.1R-03
In-Place Methods to Estimate Concrete Strength

ASTM International

C900-15
Standard Test Method for Pullout Strength of Hardened Concrete

E4-16
Standard Practices for Force Verification of Testing Machines

E74-18
Standard Practice of Calibration of Force-Measuring Instruments

Other publications

Bickley, J.A. 1982. The Variability of Pullout Test and In-place Concrete Strength. *Concrete International: Design and Construction* 4 (4): 44–51.

Krenchel, H., and Petersen, C.G. 1984. In-Situ Pullout Testing with Loktest: Ten Years' Experience. *International Conference on In-situ/Non Destructive Testing of Concrete. Proceedings.*

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Stone, W.C., Carino, N.J., and Reeve, C.P. 1986. Statistical Methods for In-Place Strength Predictions by the Pullout Test. *ACI Journal Proceedings* 83: 745–756.

3 Summary

3.1

An insert is cast in fresh concrete. When the concrete has hardened, pullout strength is measured by the maximum force required to pull out the insert from the surrounding concrete mass.

3.2

An alternative is to apply a predetermined force to the insert, without causing the failure of the adjacent concrete, to verify whether a minimum level of in-place strength has been attained.

Notes:

1) *The configuration of the insert and of the bearing surface of the loading apparatus influences the shape of the fractured concrete cone in the concrete mass and the corresponding pullout strength. Accordingly, the dimensions of the insert and the bearing surface are fixed in this Test Method.*
2) *Pullout strength is correlated to compressive strength of standard cylinders.*
3) *For a given configuration of insert, bearing system, and depth of the insert, there is a correlation between pullout strength and standard cylinder's compressive strength.**

   ** See Stone et al. (1986), Krenchel and Petersen (1984), and Bickley (1982).*
4) *When a correlation curve is established for a specific concrete mix, the correlation curve should cover the range of strength to be evaluated. The following provides for a typical set of correlation data points. Figure 1 provides an example of a calibration curve plot for the following data points:*

Compressive strength vs. pullout strength

	Pullout strength, kN					Compressive strength of cylinders, MPa		
Set of data	1	2	3	4	mean	1	2	mean
1	9	10	11	10	10	8.0	10.0	9.0
2	15	17	19	16	16.8	13.8	13.8	13.8
3	24	22	16	18	20	22.2	22.2	22.2
4	24	21	29	30	26	24.5	24.2	24.4

4 Significance and use

4.1

Pullout tests are used to evaluate in-place compressive strength. The following are examples of such applications:

a) evaluation of the earliest age to authorize removal of forms or loading of a structural element;
b) evaluation of the earliest age to release prestressed cables or to apply post-tensioning;
c) evaluation of the earliest age to stop curing or cold weather protection;
d) optimization of the use of high-early strength concrete in order to accelerate construction; and
e) evaluation of the in-place strength of structural element at a given age (e.g., 7 d, 28 d, 91 d) in order to verify in-place concrete strength.

Note: *Evaluation of in-place strength should not be a substitute for the standard strength test.*

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4.2
This Test Method may be used for any type of concrete construction, including structural slabs, slabs on ground, walls, columns, tunnels, precast elements, prestressed and post-tensioned elements, and bridge deck repairs.

5 Apparatus

5.1 Standard insert

5.1.1
The standard insert shall consist of a steel cylindrical head and a shaft. The diameter of the cylindrical head shall be 25 mm. The thickness of cylindrical head and elastic limit of the material shall be sufficient not to reach failure during testing. The shaft shall be conical or cylindrical and perpendicular to the cylindrical head. The diameter of the shaft at the level of the head shall be 7.5 mm. The length of the shaft shall be such that the distance from the cylindrical head to the concrete surface shall be 25 mm.

Note: *Figure 2 shows a standard insert.*

5.1.2
Inserts shall be coated with a release agent to minimize bonding to concrete. When the shaft has to be removed prior to testing, the cylindrical head shall be notched on the opposite side to the direction of the load, in order to prevent its rotation in the concrete.

5.2 Load test apparatus

5.2.1
The test apparatus shall consist of a bearing surface concentric with

a) the insert;
b) a loading system;
c) an anchoring system providing a means to attach the apparatus to the insert; and
d) a gauge for the measure of the applied load.

5.2.2
The internal diameter of the bearing ring shall be 55 mm with an exterior diameter of at least 70 mm and a height of at least 70 mm. The bearing ring and anchoring system shall be made of a material rigid enough to transmit the full-applied load to the insert.

5.2.3
The loading system shall allow a uniform load increase from zero to the maximum load.

5.2.4
The gauge used to measure the pullout force shall have the least division not greater than 5% of the minimum value in the intended range use. The calibration of the loading apparatus shall be performed at least once a year and after all repairs. The pullout apparatus shall be calibrated using a testing machine verified in accordance with ASTM E4 or a Class A load cell as defined in ASTM E74. Calibration shall also be performed after adjustment or repair of the apparatus or in accordance with the requirements of the manufacturer. The indicated pullout force on the gauge based on the calibration relationship shall be within 2% of the force measured by the calibration load cell or testing machine.

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5.3 Centering plate

The loading system shall include the necessary centering equipment to ensure that the bearing face is centered on the insert and that the load is axial and uniform over the bearing ring.

5.4 Hardware

A smooth plate, with an area larger than the exterior area of the bearing ring, shall be attached to the insert in order to provide a smooth and plane concrete surface, allowing for the proper seating of the bearing ring.

5.5 Tolerances

A tolerance of ±2% shall apply to pullout test inserts, the bearing ring, and embedment depth dimensions.

6 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Testing procedure

7.1 Placing of inserts

7.1.1 General

7.1.1.1

Placing of inserts is a critical step requiring trained personnel. Inserts may be placed on a formed or unformed surface. Figures 3, 4, 5, and 6 show the main assembly modes.

7.1.1.2

Inserts shall be attached to the forms before placing of the concrete or inserted within the concrete surface when the concrete is still plastic. The minimum free space between two inserts shall be 250 mm. The minimum free space between the centre of the insert and a free end shall be 100 mm. Inserts shall be installed in such a way that reinforcement or other embedded items are clear of the failure cone. Inserts shall be placed so that the distance from reinforcement shall be at least equal to one bar diameter or one diameter of the maximum size aggregate, whichever is greater.

Note: *Inserts should usually be placed randomly in concrete, within representative locations of the quality of concrete being tested.*

7.1.2 Inserts on a formed surface

Inserts shall be firmly attached to the forms with a threaded bolt, nut, and washer assembly as shown in Figure 3. The shaft of the insert shall be perpendicular to the concrete surface. A smooth metal plate shall be installed between the shaft of the insert and the form in order to produce a smooth bearing surface. This plate may be lightly lubricated in order to help removal before testing. Care shall be exercised in order to make sure that inserts are not damaged during placement of reinforcement or pouring of the plastic concrete.

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7.1.3 Inserts in an unformed surface (floating)

When there is no form on the surface to be tested, inserts shall be installed in plastic concrete using typical inserts shown in Figure 3. The insert shall be installed in such a way that the cylindrical head penetrates the concrete laterally, with a circular motion. A smooth metal plate with holes, as shown in Figure 5, shall be attached at the end of the insert's shaft to allow it to "float" on the surface and to ensure a smooth bearing surface that is free of air voids. The shaft shall then be inclined about 10° from a right angle to the surface to prevent air bubbles from being trapped under the plate. An internal vibrator shall be inserted under the insert in order to achieve a good embedment of the insert. The plate shall then be cleaned of any accumulation of concrete over its surface in order to allow for easy removal at time of testing. All necessary precautions shall be taken to ensure that finishing operations do not damage inserts or the surrounding concrete.

7.2 Number of inserts

7.2.1

At each test age, at least eight inserts shall be tested for each 100 m^3 of concrete placed or for each 500 m^2 of surface area.

Notes:

1) *When the initial pullout strength results are lower than the specified minimum strength requirement, a reduced number of inserts may be tested to obtain an indication of the strength level of the concrete in the structure.*
2) *The number of inserts and their location also depend upon the type of construction, geometry, and uniformity of exposure to temperature, humidity, drying, etc.*

7.2.2

Extra inserts shall be used if strength tests at different ages are required or to allow for retest at a later age.

7.3 Concrete maturity

No pullout testing shall be performed when the concrete temperature is below 0 °C. The location of inserts shall take into account exposure conditions creating a variability of concrete maturity within a construction in order to obtain a representative result of the most critical conditions. For example, for a structural slab heated from under the forms and exposed to cold outside conditions at its top surface, inserts should be installed preferably on top of the slab in order to sample the concrete of lower maturity.

7.4 Loading

Before loading, hardware necessary to the installation of inserts shall be removed (i.e., bolt, smooth metal plate, and shaft). The bearing surface of the concrete shall be smooth and free of loose particles and dust. The loading apparatus shall be connected to the insert by means of the appropriate mechanisms and centered on the insert in order to ensure that the load is axial and uniform over the bearing ring. The load shall be applied at a uniform rate of 500 ± 20 N/s for the total time of the pullout test.

7.5 Test to failure

Loading shall be applied until failure of the concrete cone (i.e., until maximum load is reached). The maximum load shall be recorded to the nearest 0.5 kN.

Note: *In order to minimize damage to the concrete surface, the cracked cone of concrete may be left in place. In the case of doubt about a result, the concrete cone should be extracted completely in order to observe and report*

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potential defects, such as a bad embedding of the insert or the presence of other embedded items in the failure zone of the insert.

7.6 Testing to a predetermined strength level

The load shall be increased to the maximum predetermined force. If failure does not occur, the load shall be maintained for at least 10 s. In a case where failure occurs, the maximum load shall be recorded, in kN, and further testing shall be delayed to a later time.

7.7 Testing period

All inserts used for one strength test at a given age shall be tested within a maximum period of 90 min.

8 Correlation between pullout strength and compressive strength of standard cylinders

The correlation between pullout strength and compressive strength of standard cylinders can vary with aggregate type and with the specified strength of the concrete mix. Unless correlation data are available, a correlation curve shall be established for each type of concrete mix and specified level of strength.

The correlation curve shall be established based on tests with standard 150 mm × 300 mm cylinders in which inserts are attached to the centre of the base (see Figure 6) or 200 mm cubes in which inserts are attached to the centre of the cubes' faces. At various test ages, pullout strength tests shall be carried out until maximum load is reached (i.e., tested to failure). When cylinders are used, care shall be taken not to extract the cracked cone from the bottom of the cylinder. The tested cone area shall be slightly hammered down using an approximate 20 mm thick plywood piece with a diameter approximately equal to the cone area at the surface in order to reduce the raised surface height of the cone caused during testing. The cylinder shall then be immediately capped with an appropriate capping compound, allowing compressive strength tests to be made within 30 min. Concrete for fabrication of cylinder specimens shall be sampled in accordance with CSA A23.2-1C. Fabrication cylinder test specimens shall be carried out in accordance with CSA A23.2-3C. Cylinders shall be tested for compressive strength in accordance with CSA A23.2-9C.

Notes:

1) *Tests have shown that the compressive strength of cylinders is not affected by this procedure. See ASME E4 and Stone et al. (1986).*
2) *Further information on the interpretation of pullout strength and development of the calibration curve can be obtained from ACI 228-1R.*

The set of results obtained for each cylinder (i.e., maximum pullout force, kN, and cylinder compressive strength, MPa) or each group of companion cylinders and cubes shall be recorded.

In the case of higher compressive strengths, if radial cracking of the cylinder is observed after pullout testing, results from these cylinders shall not be used for the correlation curve. When cylinder specimens are used in developing a pullout strength correlation curve and the majority of the cylinder specimens exhibit radial cracking, 200 mm cube specimens shall be used instead of the cylinder specimens.

A minimum of eight compressive strength tests and 16 pullout strength tests on cylinders or cubes shall be used to establish the correlation curve. The correlation shall cover at least a range of compressive strengths of about 5 MPa of the specified minimum strength required to allow for critical construction operations to proceed or to allow for cessation of curing. A least square linear regression shall be calculated to obtain the best fitting line relationship between the sets pullout strength and compressive

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strength of standard cylinders data points. The regression coefficient shall be greater than 0.90 to validate the correlation.

9 Calculations

The pullout test force measured in kilonewtons on the in-place concrete shall be converted to an equivalent compressive strength based on standard cylinders through the use of the established correlation curve for the specific concrete mix being tested.

10 Reporting

10.1 Required information

The following information shall be included in the test report, as applicable:

a) location of inserts;
b) number of inserts installed per pour placement and the corresponding amount of concrete in m^3;
c) type of surface insert used (i.e., unformed or formed);
d) identification of the concrete mix under test;
e) equivalent compressive strength in megapascals measured on standard cylinders to the nearest 0.1 MPa, as established with the correlation curve, for each pullout test performed, along with the mean strength as determined by the pullout tests;
f) date and start and completion times of concrete placing;
g) date and start and completion times of pullout tests;
h) type of failure of the cone, if abnormal;
i) other information about curing or exposure conditions of concrete that can affect in-place strength;
j) name of the certified technician who performed the test;
k) identification of the certified laboratory that performed the test (i.e., name and address);
l) name and signature of the person responsible for review of the test report; and
m) any deviations from the test procedure.

10.2 Optional information

The following information may be included in the test report:

a) equation of the correlation relationship used for a given mix; and
b) maximum pullout load in kN to the nearest 0.5 kN.

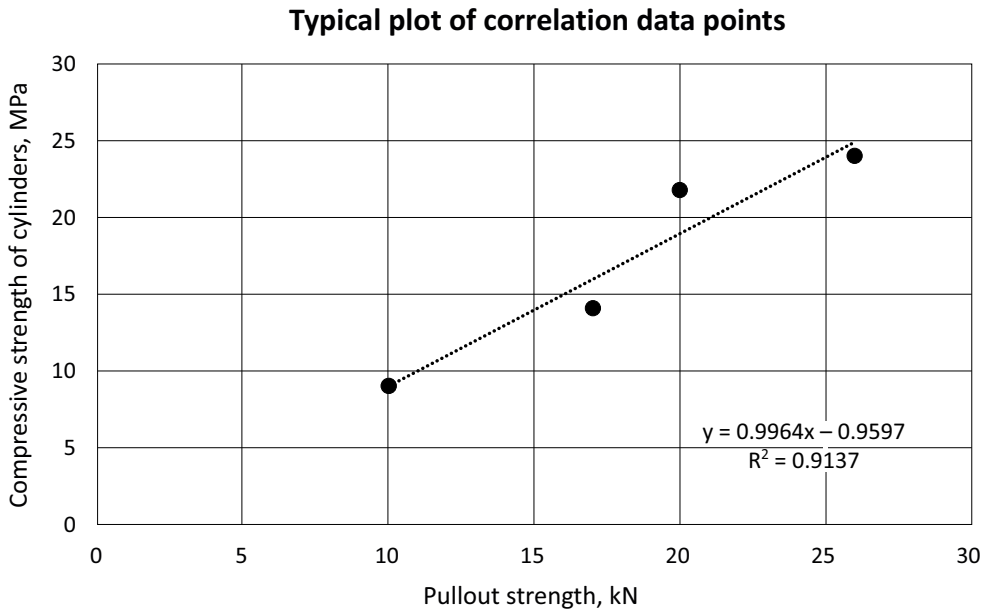
11 Precision and bias

The precision and bias of this Test Method are expected to be similar to that of ASTM C900, which is based on data summarized in ACI 228.1 R.

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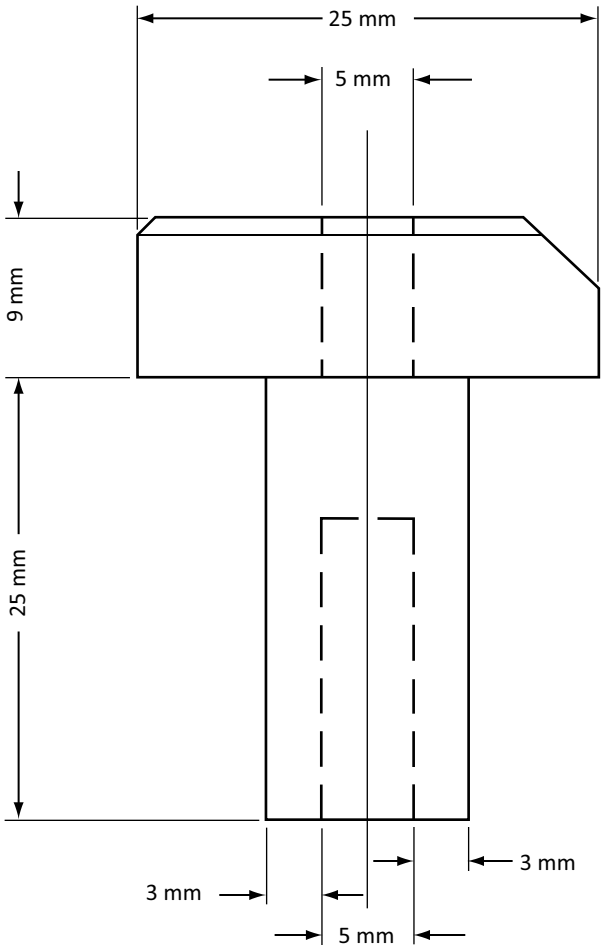
Figure 1
Typical plot of correlation data points
(See Clause 3.2.)



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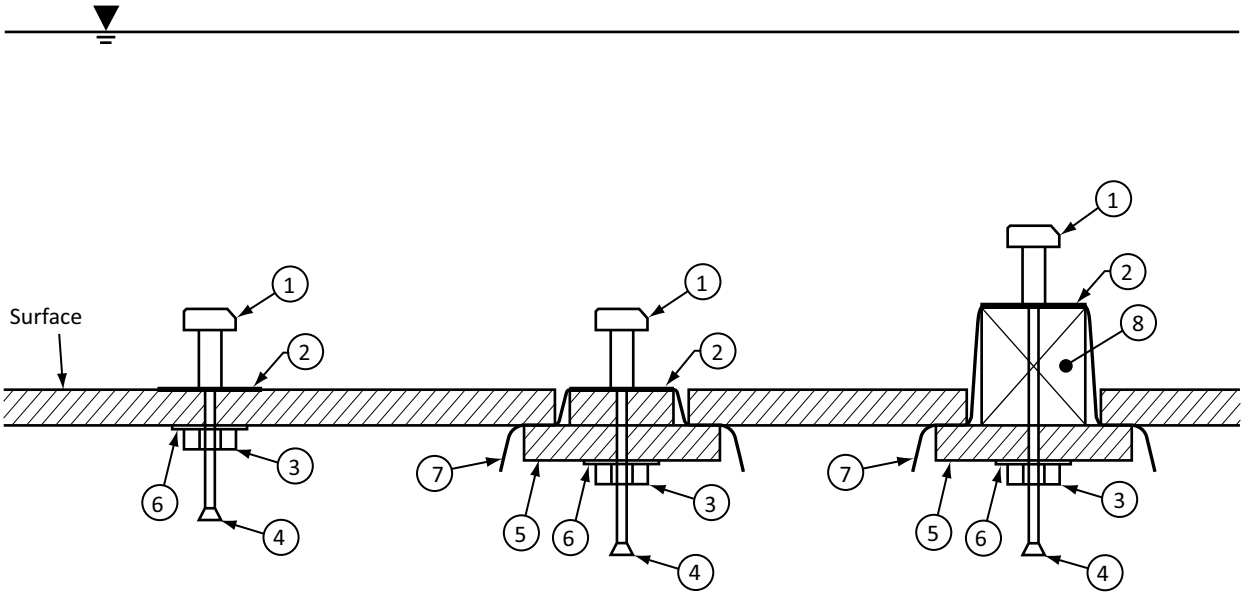
Figure 2
Standard insert
(See Clause 5.1.1.)



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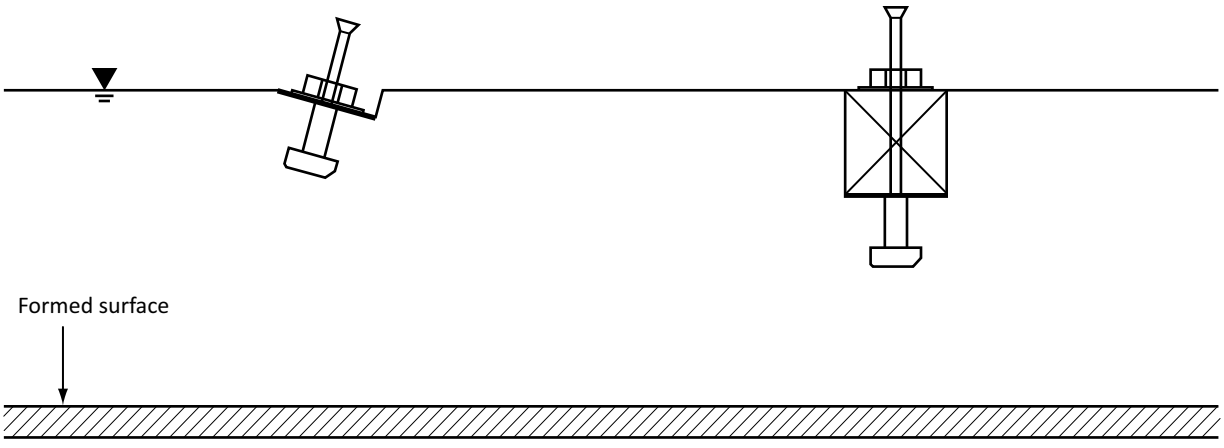
Figure 3
Typical insert installations for formed surfaces
(See Clauses 7.1.1.1, 7.1.2, and 7.1.3.)



Legend:

(1) Insert
(2) Smooth steel plate (no perforations)
(3) Nut
(4) Bolt
(5) Wood block assembly
(6) Lock washer
(7) Plastic sheet
(8) Wood block assembly

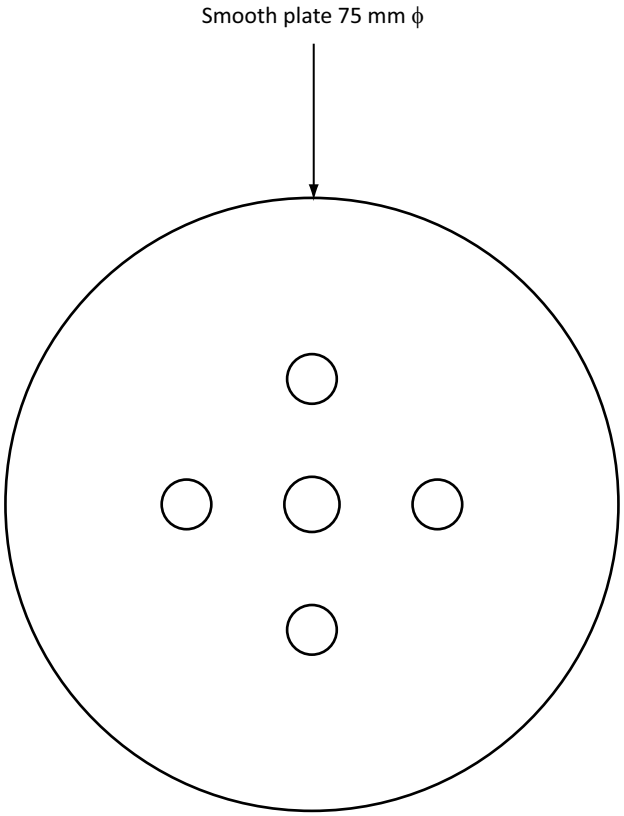
Figure 4
Typical insert installations for unformed surfaces
(See Clause 7.1.1.1.)



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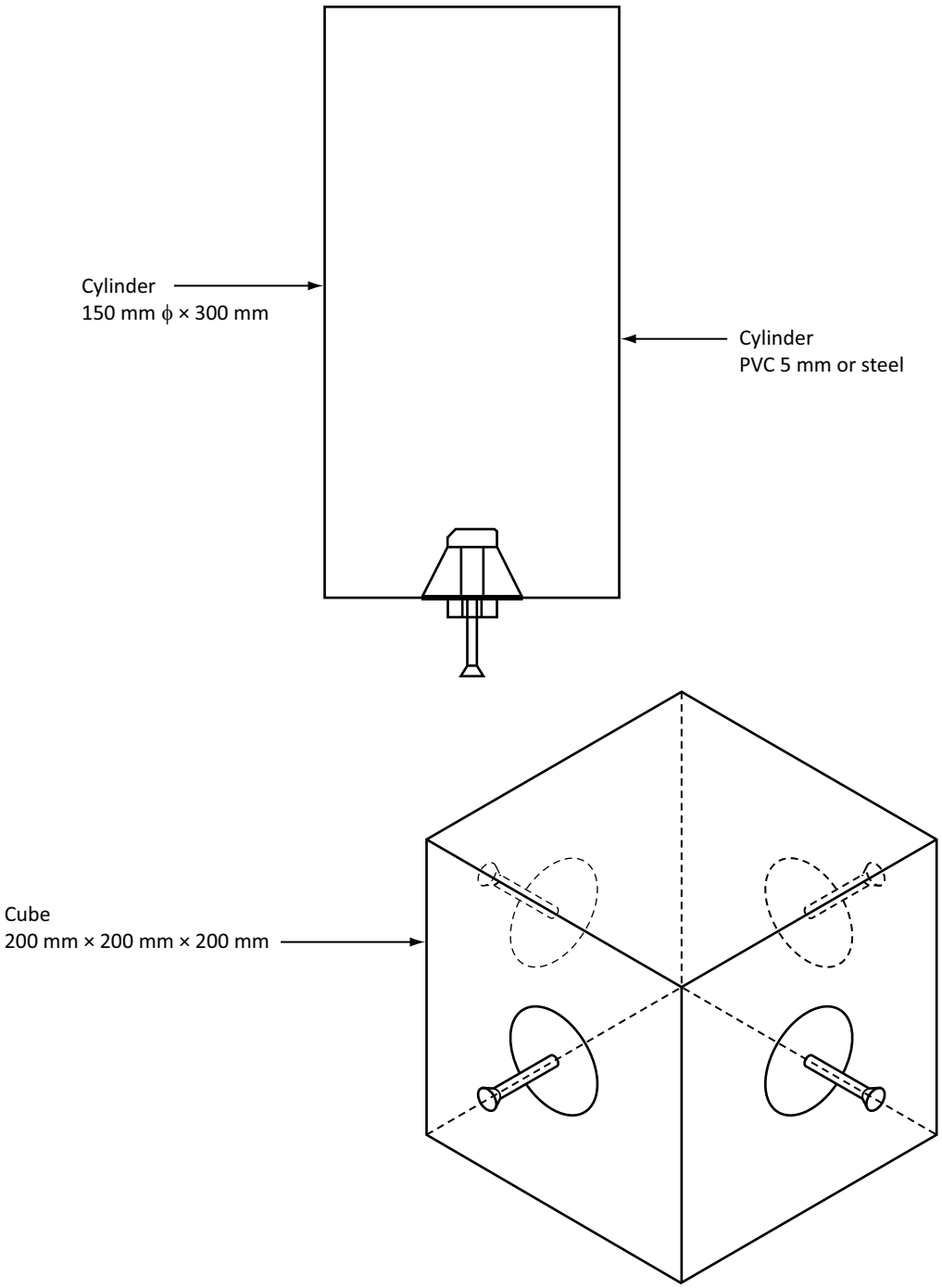
Figure 5
Smooth perforated plate
(See Clauses 7.1.1.1 and 7.1.3.)



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Figure 6
Typical cylinder and cube specimens insert configuration of correlation testing
(See Clauses 7.1.1.1 and 8.)



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A23.2-16C
Determination of steel or synthetic fibre content in plastic concrete

1 Scope
This Test Method specifies the procedure for determining the mass of steel fibres or synthetic fibres in a given volume of plastic concrete.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

A23.2-4C:19
Air content of plastic concrete by the pressure method

A23.2-6C:19
Density and yield of plastic concrete

3 Summary
A sample of concrete of known volume is washed. Fibres are captured for weighing using a magnet (steel fibres) or by flotation (synthetics fibres).

4 Significance and use
This Test Method is used to verify the dosage rate of steel or synthetic fibres in a sample of plastic concrete. The Test Method can also be used to determine the uniformity of the fibre dosage through the load of concrete by obtaining three grab samples of concrete from widely separated portions of the batch while the mixer is being completely emptied.

5 Apparatus
The testing apparatus shall consist of

a) a certified calibrated scale sensitive to 1 g or less for weighing the fibres and a certified calibrated scale sensitive to 0.05 kg or less for weighing the sample of concrete;
b) a tamping rod, which shall be a round straight steel rod, 16 ± 1 mm in diameter and between 450 mm and 600 mm in length, having at least one end rounded to a hemispherical tip;
c) a measuring bowl of sufficiently rigid construction of accurate volume, suitable for accurately measuring 15 L of concrete without deforming when filled. When measuring bowls of air meters are used, they shall conform to the requirements of CSA A23.2-4C or CSA A23.2-6C;
d) a steel strike-off bar approximately 6 mm × 25 mm × 450 mm long;
e) a wet sieve box or plastic container suitable for separating the fibres from the concrete;
f) a rubber or rawhide head mallet weighing 1.0 ± 0.3 kg; and

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g) a flat rectangular glass plate at least 6 mm thick with a length and width at least 50 mm greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance 1.5 mm.

6 Hazards

This test method does not purport to address the safety problems associated with its use. The user of this test method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Sample

7.1

Sampling for fibre content shall be performed between the 10 and 90% points of the discharge.

7.2

Sampling for uniformity of fibre content shall comprise of three samples of concrete obtained in accordance with Clause 7.4 of CSA A23.2-1C. Each sample shall be identified and tested separately.

8 Procedure

8.1

The sample of concrete shall be placed in the measure in three layers of approximately equal volume. Each layer shall be rodded with 25 strokes of the tamping rod. The bottom layer shall be rodded throughout its depth, but the rod shall not forcibly strike the bottom of the measure. The strokes shall be distributed uniformly over the cross-section of the measure, and for the top two layers, shall penetrate about 25 mm into the underlying layer. After each layer is rodded, the outside of the measure shall be tapped smartly 10 or more times with the mallet until no large bubbles of air appear on the surface and all voids left by the tamping rod are closed. The final layer shall be added so as to minimize overfilling.

8.2

After consolidation of the concrete, the top surface shall be struck off with the strike-off bar and use the plate to leave the measure level with a smooth, finished surface. All excess concrete shall be cleaned from the exterior and the mass of the filled measure shall be measured to the nearest 0.05 kg. The net mass of the consolidated concrete shall be calculated by subtracting the mass of the measure from the gross mass. The density of the concrete shall be calculated by multiplying the net mass by the factor for the measure used, determined as described in Clause 10.1 of CSA A23.2-6C.

8.3

The consolidated sample shall be washed out over the sieve box for steel fibres or on the sieve box filled with water for synthetic fibres, or other suitable apparatus capable of retaining the consolidated sample, to separate the fibres from the concrete. All cement paste and fine aggregate shall be completely removed from the fibres during the washing.

A magnet shall be used to separate the steel fibres from the concrete and a drawing device shall be used to separate the synthetic fibres from the concrete.

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8.4

The fibres shall be placed in an oven at a temperature of 110 ± 5 °C for a period of at least 16 h, after which time they shall be allowed to cool.

Note: *For immediate approximate field determination of fibres content, towel drying of fibres may be used in lieu of oven drying.*

8.5

The dry mass of fibres shall be measured and recorded to the nearest gram.

9 Calculations

The dosage rate of fibres in kilograms per cubic metre of concrete in the individual samples shall be calculated by dividing the dry mass of the fibres in kilograms by the volume of the concrete sample in cubic metres. The dosage rate shall be expressed to the nearest 1.0 kg for steel fibres or 0.1 kg for synthetic fibres.

10 Reporting

10.1 Required information

The following information shall be included in the test report, as applicable:

a) concrete mix identification;
b) source of sampling (i.e. bill no., batch no., plant identification);
c) identification of the sample including concrete producer, truck number, and concrete load volume;
d) identification of the project site;
e) date and time of the sampling;
f) location in the structure;
g) name of concrete flooring contractor;
h) type of fibre, fibre manufacturer, manufacturer's designation, bag weight, and specified dosage rate;
i) individual fibre dosage test result for each sample;
j) name of the certified technician who performed the test;
k) identification of the certified laboratory that performed the test (i.e., name and location);
l) name and signature of the person responsible for the review of the test report; and
m) any deviations from the test procedure.

11 Precision and bias

The precision and bias information for this Test Method has not been determined. The data in Table 1 show the variation experienced in steel fibre concrete of a number of projects.

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Table 1
Variation in steel fibre content
(See Clause 11.)

Design requirement, kg/m³	Overall average, kg/m³	Number of loads tested	Maximum range between loads, kg/m³	Average within load variation, kg/m³*
25	24.2	15	7.9	3.9
25	21.8	8	3.6	3.2
25	27.3	16	14.6	3.4
30	29.3	5	2.9	4.8
30	29.2	6	3.2	4.2
40	40.1	21	5.0	3.3

** Within load variation is the difference between the highest and lowest fibre content measured on three samples obtained at approximatedly 25%, 50%, and 75% of the discharge.*

Note: *The subcommittee is seeking pertinent data from users of this method which may be used to develop meaningful statements of precision and bias.*

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A23.2-17C
Temperature of freshly mixed hydraulic cement concrete

1 Scope

This Test Method specifies the procedure for determining the temperature of freshly mixed hydraulic cement concrete. The Test Method is in substantial agreement with ASTM C1064/C1064M.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

ACI (American Concrete Institute)

207.1R-05
Guide to Mass Concrete

ASTM International

C1064/C1064M-17
Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete

3 Significance and use

This Test Method provides a means for measuring the temperature of freshly mixed concrete and to verify conformance to a specified requirement for temperature of concrete.

4 Apparatus

The apparatus shall consist of the following:

a) A sample container shall be made of a non-absorptive material large enough to provide the greater of 75 mm of concrete material in all directions around the temperature sensor or at least three times the nominal maximum size of the coarse aggregate.

b) A temperature measuring device shall be capable of measuring temperatures in the range of 0 °C to 50 °C, accurate to ± 0.5 °C, and provide immersion to at least 75 mm of concrete cover.

c) Partial immersion liquid glass thermometers or other types shall be provided with an immersion line to which the device shall be immersed without using a correction factor.

d) A reference temperature measuring device for calibration of the temperature measure device shall be readable and accurate to ± 0.2 °C at the two comparison temperatures used in the calibration procedure. The reference temperature measuring device shall have a certificate or report of calibration available for review. Liquid glass temperature measuring devices shall be verified once. Direct reading resistance reference temperature devices shall be verified on an annual basis. The reference standard used in the verification shall be traceable to the National Institute of Standards and Technology and confirmation of the traceability of the reference temperature measuring device shall be provided in the certificate or report of calibration.

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5 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6 Sampling, test specimens

Sampling shall be performed as follows:

a) Measure the temperature of freshly mixed concrete in the transporting device, provided there is at least 75 mm of concrete cover around the temperature measuring device in all directions.
b) Measure the temperature of freshly mixed concrete directly in the forms after placement, provided there is at least 75 mm of concrete cover around the temperature measuring device in all directions.

Alternatively, the temperature of a sample of concrete obtained in accordance with the requirements of CSA A23.2-1C may be measured. The sample of freshly mixed concrete shall be placed in a dampened container large enough to provide at least 75 mm of concrete cover in all directions. The sample of concrete shall be obtained in accordance with the requirements of Clause 7.3 of CSA A23.2-1C if the only purpose of securing the sample is to measure temperature.

7 Calibration and reference materials

7.1 Calibration frequency

The temperature measuring devices used in this Test Method shall be calibrated annually or when there is a question of accuracy.

7.2 Calibration method

Calibration shall be performed as follows:

a) Calibrate the temperature measuring device by comparing the readings to those of the reference temperature measuring device at two temperatures at least 15 °C apart. The two temperatures shall be in the range 0 °C to 50 °C.
b) Calibrate the temperature measuring device in a continuously circulating oil bath or other suitable bath of uniform density.
c) Maintain the bath at the first temperature to within ± 0.2 °C.
d) Place the reference temperature and temperature measuring device in the bath for a minimum of 5 min before taking a reading of each. Record the readings.
e) Tap liquid glass thermometers slightly to avoid liquid adhering to the glass.
f) Increase the bath temperature to the second temperature and maintain to within ± 0.2 °C. Follow the instructions in Items d) and e) to obtain readings at the second temperature.

8 Procedure

The test shall be performed as follows:

a) Place the temperature measuring device in the concrete, ensuring that the temperature sensing portion is submerged a minimum of 75 mm into the concrete. Gently press the concrete at the surface around the temperature measuring device to close any void left by the placement and prevent ambient air temperature from affecting the reading.

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17C

b) Leave the temperature measuring device in the concrete for a minimum of 2 min or until the reading stabilizes. Read and record the temperature while the temperature measuring device remains in the concrete.

Note: *If the concrete contains coarse aggregate particles that are greater than 80 mm, it can take up to 20 min for the transfer of heat from the aggregate to the mortar. For more information, see ACI Committee 207.1 Report.*

c) Complete the temperature measurement of the freshly mixed concrete within 5 min immediately after obtaining the sample, except for concrete that contains a nominal maximum size aggregate greater than 80 mm. With aggregate greater than 80 mm, ensure the temperature has stabilized before recording the reading [see Note to Item b)].

9 Reporting

The following information shall be included in the report, as applicable:

a) location, date and time at which sample was taken;
b) source of the sample (i.e., bill no., batch no., plant identification);
c) identification of the project site and location in the structure;
d) date and time of testing;
e) the measured temperature to the nearest 0.5 °C;
f) the name of the certified technician who performed the temperature measurement;
g) identification of the certified laboratory that performed the test (i.e., name and address);
h) name and signature of the person responsible for the review of the test report; and
i) any deviation from the test procedure.

10 Precision and bias

10.1 Precision

Precision of this Test Method has not been determined.

10.2 Bias

Bias of this Test Method has not been determined.

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A23.2-18C
Determination of total water content of normal weight fresh concrete

1 Scope

This Test Method specifies the procedures for the quantitative determination of total water content of fresh concrete samples. The Test Method specifies two alternative procedures:

a) hot plate procedure; and
b) microwave oven procedure.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-1C:19
Sampling plastic concrete

A23.2-6C:19
Density and yield of plastic concrete

A23.2-12C:19
Making, curing, and testing compression test specimens of no-slump concrete

AASHTO (American Association of State Highway and Transportation Officials)

T 318:2002 (R2011)
Standard Method of Test for Water Content of Freshly Mixed Concrete Using Microwave Oven Drying

3 Summary

A test sample of freshly mixed concrete is dried in a microwave oven or on a hot plate using a minimum of two drying intervals. The test sample is broken up, the coarse aggregate is segregated from the mortar, and the mortar is ground with a pestle after the first drying interval. The test sample is stirred and its mass is determined after subsequent drying intervals. The water content of the test sample is calculated based on loss in mass of the test sample at completion of the test. Total drying time is usually about 15 min.

4 Significance and use

This Test Method measures the total amount of water (including water absorbed by aggregates) in fresh concrete. This Test Method is applicable to both laboratory and field tests. The water content information obtained through this Test Method can be useful for quality control or quality assurance of no-slump concrete, as well as for obtaining an approximation of the water-to-cementitious-materials ratio (*w/cm* ratio) of any normal weight fresh concrete, only if all the relevant information on the same load of fresh concrete is available. This Test Method is not considered accurate enough to compute *w/cm* ratio for acceptance or rejection of field concrete.

Note: *The accuracy and repeatability of this Test Method has not been determined as yet.*

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5 Apparatus

5.1 Hot plate procedure

The apparatus shall consist of

a) a balance with a capacity of 5 kg and sensitive to 1 g;
b) a shallow pan (approximately 450 mm × 300 mm × 50 mm) adequate for thinly spreading about 1.5 kg of fresh concrete;
c) a stirring rod or a small scoop;
d) a double burner hotplate (electric or gas fuelled, such as a propane stove with the rated output of 3000W per burner);
e) a metal scraper with a sharp edge and a 25 mm wide blade; and
f) a grinding pestle with a 50 mm size porcelain grinding head.

5.2 Microwave procedure

The apparatus shall consist of the following:

a) a microwave oven with a power setting of 900 W, a turntable, and sufficient capacity to accept the specified tray and test sample;
b) a heat-resistant glass tray with dimensions of approximately 230 mm × 230 mm × 50 mm;
c) a balance with a capacity of 5 kg and sensitive to 1 g;
d) a small metal scraper having a sharp edge and a blade approximately 25 mm wide;
e) a pestle having a porcelain grinding head with a diameter of approximately 50 mm; and
f) a plain weave fibreglass cloth having a minimum mass of 0.34 kg/m^2 and a minimum thickness of 0.35 mm.

6 Test sample

6.1

A test sample representative of the concrete being tested shall be obtained and remixed as specified in CSA A23.2-1C. A representative mass of 1.5 ± 0.3 kg shall be selected from the test sample to conduct this test.

6.2

The sample drying process (hot plate or microwave oven procedures) shall be started within 10 min of obtaining and remixing the fresh concrete sample.

7 Hazards

This Test Method does not purport to include all safety issues associated with its use. It should be noted, however, that microwave radiation can be hazardous. The operator should follow the safety precautions provided by the microwave oven manufacturer at all times. Additionally, it should be noted that rapid cooling of the glass tray used in the microwave oven procedure should be avoided since the glass tray can shatter causing injury. A fibreglass cloth to cover the test sample and the glass tray should be used. Due to the safety hazard, steel fibre reinforced concrete should not be subjected to the microwave oven procedure of this Test Method.

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8 Procedure

8.1 Hot plate method

The hot plate method shall be performed as follows:

a) Thoroughly mix the fresh concrete sample as specified in Clause 6. Accurately weigh the fresh concrete sample, A, after accounting for the weight of the pan to the nearest 1 g. Spread the sample in a thin layer in the pan.

b) Place the pan on the hotplate and heat it on high heat for 5 ± 0.5 min while frequently stirring the fresh concrete with the stirring rod or a small scoop. Do not heat the test sample above 100 °C. Exercise caution to avoid loss of material when stirring the sample.

c) Remove the pan with the test concrete sample from the hotplate and break down the partially dried concrete using the metal scraper to separate the coarse aggregate from the mortar. Grind the sample with the grinding pestle for approximately 1 min to increase the surface area of the sample. Reheat the sample again on high heat for another 5 ± 0.5 min while frequently stirring the concrete with the stirring rod or a small scoop. Exercise caution to avoid loss of material when stirring, breaking, and grinding the sample. Obtain the mass of the dry concrete test sample after accounting for the weight of the pan.

d) After the second drying period, stir the test sample with the scraper and dry it for another 2 ± 0.5 min and determine the mass of the test sample. If the change in mass is 1 g or more, repeat the 2 min drying period until the change in mass is less than 1 g. Cool the sample for 2 ± 0.5 min and obtain the mass of the dry concrete test sample, B, after accounting for the weight of the pan.

8.2 Microwave oven procedure

The microwave oven method shall be performed as follows:

a) Cut a piece of fibreglass cloth large enough to completely wrap the test sample of freshly mixed concrete. Place the fibreglass cloth on the heat-resistant glass tray with the cloth uniformly overhanging outside the edges of the tray. Determine the mass of the tray and cloth together, WS. Make this mass determination and all subsequent mass determinations to the nearest 1 g. Leave the tray and cloth on the balance. Record the tare weight. Place the test sample on the fibreglass cloth and wrap the test sample completely with the cloth. Determine the mass of the tray, cloth, and freshly mixed concrete test sample together, WF.

   Note: *The minimum size fibreglass cloth which has generally been found to be adequate is 0.5 m × 0.5 m.*

b) Place the tray with the completely wrapped test sample on the turntable in the microwave oven. Dry the test sample with the turntable rotating for a period of 5 ± 0.5 min at the 900-W-power setting.

c) At the end of the first drying period,

   i) remove the tray and test sample from the microwave oven and quickly unwrap the test sample. With the edge of the scraper, break the mass of concrete until the coarse aggregate is separated from the mortar. Carefully grind the mortar with the pestle for no more than 60 s to increase the surface area of the sample. Avoid losing any material;

   ii) rewrap the test sample, place the tray with the completely wrapped test sample on the turntable in the microwave oven, and dry it with the turntable rotating for 5 ± 0.5 min at the 900-W-power setting; and

   iii) remove the tray and test sample from the microwave oven and unwrap the test sample. Stir the test sample with the scraper and determine the mass of the tray, fibreglass cloth, and sample together.

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d) After the end of the second drying period,
   i) rewrap the test sample, place the tray with the completely wrapped test sample on the turntable in the microwave oven, and dry it with the turntable rotating for 2 ± 0.5 min at the 900-W-power setting; and
   ii) remove the tray containing the test sample from the microwave oven and determine the mass. If the change in mass is 1 g or more, repeat the 2 min drying period until the change in mass is less than 1 g. Cool the sample for 2 ± 0.5 min and obtain the mass of the tray, cloth, and dry test sample together, WD.

Caution shall be exercised: Rapid cooling of the concrete test sample in the glass tray can cause the glass tray to shatter or explode. Therefore, rapid cooling of the sample shall be avoided . A fibreglass cloth to cover the test sample and the glass tray should be used.

Note: *The microwave oven test procedure is in substantial agreement with AASHTO T 318.*

9 Calculations

9.1 Hot plate method

9.1.1

The total water content, as a percentage, of the fresh concrete shall be calculated as follows:

$WC = 100(A - B)/A$

where

WC = total water content, %

A = mass of fresh concrete sample, g

B = mass of dry concrete sample, g

9.1.2

The total water content, as kg/m^3, shall be calculated as follows:

$WT = [(WC)*(D)]/100$

where

WT = total water content, kg/m^3

D = density of fresh concrete, kg/m^3

The density of concrete shall be determined in accordance with CSA A23.2-6C or CSA A23.2-12C.

9.2 Microwave method

9.2.1

The total water content, as a percentage, of fresh concrete shall be calculated as follows:

$WC = 100\ (WF - WD)/(WF - WS)$

where

WC = total water content, %

WD = mass of the tray, cloth, and dry concrete test sample, g

WF = mass of the tray, cloth, and fresh concrete test sample, g

WS = mass of the tray and cloth, g

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9.2.2

The total water content, as kg/m³, shall be calculated as follows:

$WT = [(WC)*(D)]/100$

where

WT = total water content, kg/m³

D = density of the fresh concrete, kg/m³

The density of fresh concrete shall be determined in accordance with CSA A23.2-6C or CSA A23.2-12C.

10 Reporting

10.1 Required information

The following information shall be included in the test report, as applicable:

a) concrete mix identification;
b) source of sampling (i.e., bill no., batch no., plant identification);
c) identification of the project site and location in the structure sample identification number and location;
d) total water content (to the nearest tenth of a percent) as a percentage of the fresh concrete sample;
e) name of the certified technician who performed the test;
f) identification of the certified laboratory that performed the test (i.e., name and address);
g) name and signature of the person responsible for the review of the test report; and
h) any deviations from the test procedures.

10.2 Optional information

The report may include the total water content, expressed to the nearest kg/m³.

11 Precision and bias

Precision and bias for the test procedures have not been determined.

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A23.2-19C
Slump flow of concrete

1 Scope

This Test Method specifies the procedures to be used in the laboratory and in the field for determining slump flow of self-consolidating hydraulic cement concrete (SCC). In the procedure for determining the T_{50} time, an indication of flowability of SCC is also provided for use in conjunction with the slump flow test.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-5C:19
Slump of concrete

3 Definitions

In addition to the definitions specified in CSA A23.1, the following definitions shall apply in this Test Method:

Halo — an observed cement paste or mortar ring that has clearly separated from the coarse aggregate, around the outside circumference of concrete after flowing from the slump cone.

Self-consolidating concrete (SCC) — non-segregating, stable concrete mixtures proportioned to consolidate during the placement process without the use of any consolidation efforts.

Slump flow — the horizontal spread of concrete immediately upon removal of the slump cone as a measure of the unconfined fluidity of concrete giving a relative indication of the degree to which concrete can travel.

Spread — the distance of lateral flow that concrete travels using the slump flow test method.

Stability — the ability of a concrete mixture to resist segregation of the paste from the aggregates.

T_{50} cm — the time, in seconds, recorded to the nearest second, of the spread of the concrete from release of the mould to reach a 500 mm diameter circle marked or scribed on the rigid, non-absorbent surface.

Viscosity — the property of a material to resist flow as a result of an applied stress.

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4 Summary

A sample of plastic concrete is placed in a mould shaped as a frustum of a cone. The concrete is placed in one lift without tamping or vibration. The mould is raised and the concrete allowed to spread after which two diameters of the concrete mass are measured approximately 90 degrees apart. The slump flow is the average of the two diameters.

5 Significance and use

The slump flow test is used to assess the stability and horizontal free flow of SCC in the absence of obstructions. The diameter of the concrete circle is a measure of the filling ability of the concrete, and visual observation of the concrete spread is noted to characterize the stability of the mixture. The slump flow test, however, gives no indication of the ability of the concrete to pass between reinforcement without blocking. However, it can give some indication of resistance to segregation. A visual observation of the concrete spread is noted to characterize the stability of the mixture. The index assigned to describe the visual observation of mixture stability is subjective and is intended for use in developing SCC mixtures and for internal quality control purposes by producers. The T_{50} cm time is a secondary indication of flow. A lower time indicates greater flowability.

This Test Method for slump flow is considered applicable to SCC having coarse aggregate up to 28 mm in size. If the coarse aggregate is larger than 28 mm in size, this Test Method is applicable when it is performed on the fraction of concrete passing a 28 mm sieve, with the larger aggregate being removed in accordance with CSA A23.2-1C.

6 Apparatus

The following shall be used for this test:

a) a test specimen mould meeting the requirements of CSA A23.2-5C (see Figure 1). The foot pieces specified as part of the mould are not mandatory for this Test Method;
b) a round straight steel tamping rod, 16 ± 1 mm in diameter and between 450 and 600 mm in length, having at least one end rounded to a hemispherical tip;
c) a rigid non-absorbent smooth plastic surface having a minimum thickness of 12 mm upon which to perform the slump flow test. The non-absorbent surface is to be at least 800 mm square to accommodate the horizontal spread of the concrete for the slump flow measurements. Clearly mark the surface with two concentric circles centred on the surface when the T_{50} cm time is to be determined. The inner circle is to centrally locate the position of the mould. The outer circle is to have a diameter of 500 mm;

   Note: *Rigid non-absorbent surfaces made of other materials are considered to influence the results for slump flow, visual stability index and T_{50} cm time. The use of a smooth plastic surface is intended to provide consistent results.*
d) a stopwatch to measure the T_{50} cm time; and
e) a measuring tape graduated in mm.

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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8 Sample

8.1

The sample of concrete from which test specimens are made shall represent the entire batch. The sample shall be obtained in accordance with the requirements of CSA A23.2-1C.

8.2

If the concrete contains coarse aggregate particles that would be retained on a 28 mm sieve, the concrete sample shall be wet-sieved over a sieve having 28 mm square openings before being tested Wet-sieving procedures are given in CSA A23.2-1C.

9 Procedure

9.1 Time constraint

The test for slump flow shall be completed within 10 min of obtaining the sample, including transportation and remixing.

9.2 Slump flow

Slump flow shall be performed as follows:

a) Dampen the rigid non-absorbent surface with a damp sponge immediately prior to performing the test. Place the mould in the centre of the rigid non-absorbent surface in a flat and level position not subjected to vibration. Hold the mould firmly in place during filling by the operator standing on the two foot pieces, if provided. Alternatively, the mould may be inverted to act as a funnel to aid in the filling of the mould, with the smaller opening of the mould held down on the centre of the non-absorbent surface.

b) Fill the mould, without rodding, to slightly above the mould. Strike off the surface of the concrete with a screeding and rolling motion of the tamping rod. Remove the spilled concrete from the base of the mould.

c) Withdraw the mould immediately from the concrete by raising it carefully in a vertical direction. Raise the mould approximately 225 ± 75 mm above the surface in approximately 3 ± 1 s by a steady upward lift. Ensure that no lateral or torsional movement is imparted to the concrete.

d) Upon removal of the mould, allow the concrete to achieve maximum horizontal spread or until 2 min has lapsed. Determine the diameter in the direction of horizontal spread in two perpendicular directions. Repeat the test if the measurement of the two diameters differs by more than 50 mm. Calculate the average of the two measured diameters.

e) Carry out the entire operation, from the start of the filling to the removal of the mould, without interruption and within an elapsed time of 3 min.

f) Visually inspect the circular spread of the concrete mixture by observing the distribution of the coarse aggregate fraction throughout the spread, particularly along the perimeter, and the bleeding characteristics. Assign a visual stability index (VSI) value to the concrete sample using the criteria shown in Table 1 and illustrated in Figures 1 to 4. When a halo is observed in the resulting circular spread of concrete, it shall be included as part of the diameter of the concrete.

9.3 T_{50} cm time

T_{50} cm time shall be performed as follows:

a) Place the mould on the marked inner circle to centrally position the cone on the surface.

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b) Fill the mould using the procedures described in Clause 9.2, except that the mould shall be used in the upright position for this test.

Note: *While the test is easier to perform with the mould in the inverted position, the time of efflux of the concrete sample from the mould is influenced by the restriction of the narrower opening of the mould and hence the T_{50} time is also influenced.*

c) Two persons shall conduct the test: one person to fill and manipulate the mould while the other person operates the stopwatch. Start the stopwatch as soon as the mould is released fully from the concrete. Stop the stopwatch once the horizontal spread of the concrete reaches the 500 mm diameter circle marked or scribed on the surface. The T_{50} time test shall be conducted by a certified technician, however, the person operating the stopwatch under the direction of the technician need not be certified.

10 Reporting

The following information shall be included in the report, as applicable:

a) concrete mix identification;
b) source of sampling (i.e., bill no., batch no., plant identification);
c) identification of the project site and location in the structure;
d) date and time of testing;
e) slump flow, to the nearest 10 mm, of horizontal spread of the sample during the test. Note any halo at the edge of the horizontal spread of concrete;
f) VSI value for the concrete mixture;
g) the T_{50} cm time, if determined, to the nearest second;
h) name of the certified technician who performed the test;
i) certified laboratory that performed the test (i.e., name and address);
j) name and signature of the person responsible for the review of the test report; and
k) any deviations from the test procedure.

11 Precision and bias

11.1 Precision

Precision is not available for this Test Method.

11.2 Bias

The procedure used in this Test Method has no bias since slump flow and stability are defined only in terms of this Test Method.

Table 1
Visual stability index values
(See Clause 9.2.)

VSI value	Criteria
0 = Highly stable	No evidence of segregation in slump flow spread
1 = Stable	No mortar halo or aggregate pile in the slump flow spread; slight bleeding visible at leading edge

(Continued)

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Table 1 (Concluded)

VSI value	Criteria
2 = Unstable	A slight mortar halo (< 10 mm) and/or aggregate pile in the slump flow spread
3 = Highly unstable	Clearly segregating by evidence of a large mortar halo (> 10 mm) and/or a large aggregate pile in the center of the concrete spread

Figure 1
(See Clause 9.2.)

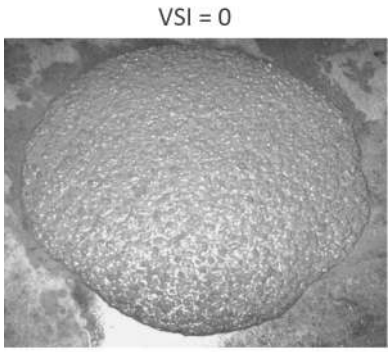


Figure 2
(See Clause 9.2.)

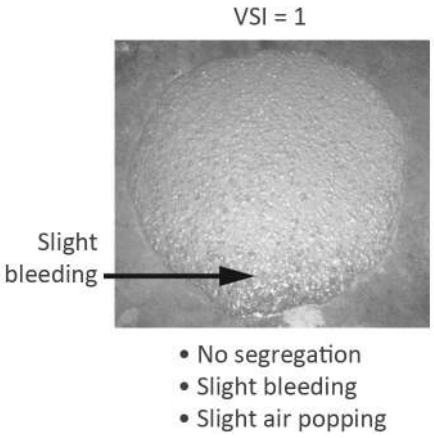


Figure 3
(See Clause 9.2.)

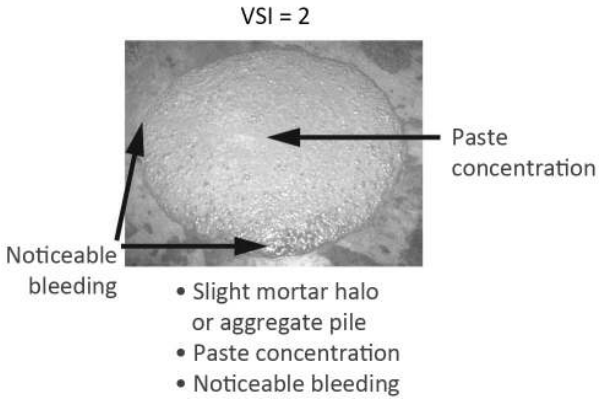
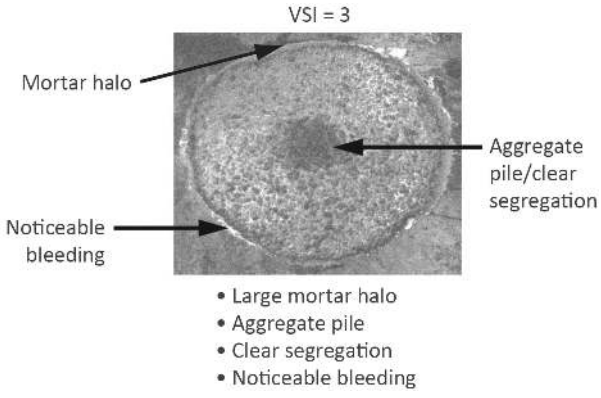


Figure 4
(See Clause 9.2.)



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A23.2-20C
Passing ability of self-consolidating concrete by J-ring and slump cone

1 Scope
This Test Method specifies the procedure for determining the passing ability of self-consolidating concrete (SCC) through reinforcing bars, both in the laboratory and in the field using the J-ring and slump cone apparatus.

2 Reference publications
This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-5C:19
Slump of concrete

A23.2-19C:19
Slump flow of concrete

3 Definitions
In addition to the definitions specified in CSA A23.1, the following definitions apply in this Test Method:

J-ring — an apparatus consisting of a metal ring and sixteen 16 mm diameter rods, as shown in Figures 1 to 3.

J-ring flow/spread — the distance of lateral flow that concrete travels through the J-ring apparatus.

Passing ability — the ability of SCC to flow under its own weight (i.e., without any external effort) and fill completely all spaces within intricate formwork containing obstacles such as steel reinforcement.

Self-consolidating concrete (SCC) — non-segregating, stable concrete mixtures proportioned to self-consolidate during the placement process without the use any consolidation efforts.

4 Summary
A sample of freshly mixed concrete is placed in a mould shaped as the frustum of a cone concentric with the J-ring apparatus (see Figures 1 to 3). The concrete is placed in one lift and not consolidated by any means of mechanical agitation. The mould is raised and the SCC allowed to pass through the J-ring apparatus and subside. The average of two diameters, measured perpendicular to each other of the resulting spread, is reported as the J-ring flow of the concrete.

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5 Significance and use

This Test Method is intended to provide the user with a procedure to determine the passing ability of SCC mixtures through reinforcing bars. The difference between the J-ring flow and the slump flow is an indication of the passing ability of SCC mixtures containing coarse aggregates.

This Test Method is considered applicable to very fluid plastic concrete having coarse aggregate up to 28 mm in size. If the coarse aggregate is larger than 28 mm in size, this Test Method is applicable when it is performed on the fraction of concrete passing a 28 mm sieve, with the larger aggregate being removed in accordance with CSA A23.2-1C.

6 Apparatus

The following shall be used for this Test Method:

a) a J-ring made of a steel or stainless steel ring and sixteen 16 mm diameter rods (see Figures 1 to 3);
b) a mould that meets the requirements of CSA A23.2-5C, as illustrated in Figure 1 of the referenced Test Method. The foot pieces specified as part of the slump cone mould are not mandatory for this Test Method;
c) a round straight steel tamping rod 16 ± 1 mm in diameter and between 450 mm and 600 mm in length, having one end rounded to a hemispherical tip; and
d) a rigid non-absorbent smooth plastic surface, upon which to perform the slump flow test, at least 800 mm² to accommodate the horizontal spread of the concrete of the passing ability measurements.

Note: *Rigid non-absorbent surfaces made of other materials are considered to influence the results of passing ability and slump flow. The use of a smooth (untextured) plastic surface is intended to provide consistent results.*

7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Sample

8.1

The sample of concrete, from which test specimens are made to represent the entire batch, shall be obtained in accordance with the requirements of CSA A23.2-1C.

8.2

If the concrete contains coarse aggregate particles that would be retained on a 28 mm sieve, the sample shall be wet-sieved over a 28 mm screen using the procedures specified in CSA A23.2-1C.

9 Procedure

The test shall be performed as follows:

a) Dampen the rigid non-absorbent surface with a damp sponge immediately prior to performing the test. Place the rigid non-absorbent surface in as nearly a level position as possible and place the J-ring apparatus in the centre of the base plate.
b) Dampen the slump cone mould and place it in an inverted position concentric with the J-ring in the centre of the flat and moistened rigid surface. From the sample of concrete obtained in accordance

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with Clause 8, immediately fill the inverted slump cone mould in one lift. Heap the concrete above the top of the mould.

c) Strike off the surface of the concrete level with the top of the mould by means of a screeding and rolling motion of the tamping rod.
d) Remove concrete from the area surrounding the base of the mould to preclude interference with the movement of the flowing concrete.
e) Remove the mould immediately from the concrete by raising it carefully in a vertical action. Raise the mould a distance of 230 ± 75 mm in 3 ± 1 s by a steady upward lift with no lateral or torsional motion. Complete the entire test from start of the filling through removal of the mould without interruption and complete it within an elapsed time of 3 min.
f) Upon removal of the mould, allow the concrete to achieve maximum horizontal spread or until 2 min has lapsed. Determine if the diameter in the two diameters differs by more than 50 mm.
g) Calculate the average of the two measured diameters and record the average as the J-ring flow.
h) Conduct slump flow without the J-ring in accordance with CSA A23.2-19C.
i) Calculate the difference between the J-ring flow and the slump flow of the companion tests. This number is a representation of the passing ability of the SCC being tested.

10 Reporting

The following information shall be included in the report:

a) concrete mix identification;
b) source of sampling (i.e., bill no., batch no., plant identification);
c) identification of the project site and location in the structure;
d) date and time at which the sample was taken;
e) name of the technician who performed field test;
f) J-ring flow as the average of the two measured diameters, to the nearest 10 mm;
g) slump flow without the J-ring, to the nearest 10 mm;
h) passing ability rating as defined in Table 1;
i) name of the certified technician who performed the test;
j) identification of the certified laboratory that performed the test (i.e., name and address);
k) name and signature of the person responsible for the review of the test report; and
l) any deviation from the test procedure.

11 Precision and bias

11.1 Precision

A precision statement is not available for this Test Method.

11.2 Bias

The procedure used in this Test Method has no bias since the passing ability is defined only in terms of this Test Method.

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Table 1
Passing ability
(See Clause 10.)

Difference between J-ring flow and slump flow, mm	Passing ability rating	Remarks
0 to 25	0	High passing ability
> 25 to 50	1	Moderate passing ability
> 50	2	Low passing ability

Figure 1
J-ring setup with inverted mould and concrete
(See Clauses 3, 4, and 6.)



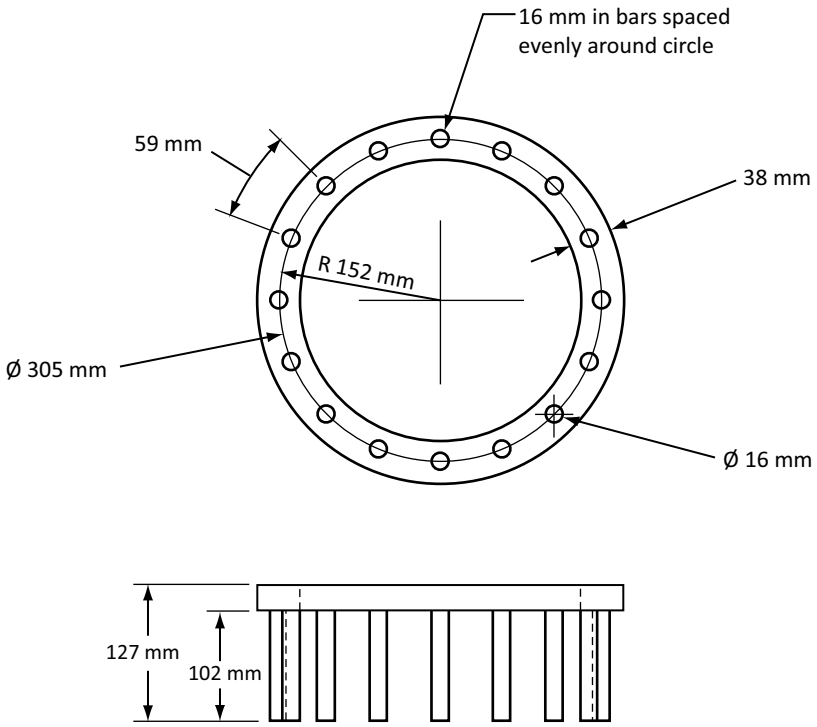
Figure 2
J-ring flow
(See Clauses 3, 4, and 6.)



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Figure 3
Configuration and dimensions of J-ring
(See Clauses 3, 4, and 6.)



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A23.2-21C
Test Method for length change of hardened concrete

1 Scope

This Test Method specifies the procedures for casting concrete prism specimens and determine the length change produced by causes other than externally applied forces and temperature changes in hardened concrete specimens made in the laboratory or job site conditions, and exposed to controlled conditions of temperature and moisture.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-14A:19
Potential expansivity of aggregates

A23.2-1C:19
Sampling plastic concrete

A23.2-2C:19
Making concrete mixes in the laboratory

A23.2-3C:19
Making and curing concrete compression and flexural specimens

A23.2-4C:19
Air content of plastic concrete by pressure method

A23.2-5C:19
Slump of concrete

A23.2-7C:19
Air content of plastic concrete by volumetric method

A23.2-17C:19
Temperature of freshly mixed hydraulic cement concrete

A23.2-19C:19
Slump flow of concrete

ASTM International

E337-15
Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

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3 Significance and use

3.1

Measurement of length changes provides a means of assessment of the potential for volumetric expansion or contraction due to various causes other than applied forces or temperature change. This Test Method is useful for comparative evaluation of this potential in different concrete mixtures.

3.2

This Test Method provides useful information for experimental purposes or for concrete mixes that require testing under non-standard mixing, placing, handling, or curing conditions or different demoulding times.

3.3

If conditions for mixing, curing, sampling, and storage other than these specified in this Test Method are used, they shall be reported but are not considered as standard conditions of this Test Method. Non-standard conditions and the reasons for departure from the standard conditions shall be reported.

4 Apparatus

4.1 Mould and length comparator

The moulds for casting test specimens, stainless steel studs, and the length comparator for measuring the length change shall conform to the requirements of Clause 5 of CSA A23.2-14A, except as modified by Clause 6 of this Test Method.

4.2 Tamping rod

The tamping rod shall normally be a round, straight steel rod, 10 ± 1 mm in diameter and between 450 mm and 600 mm in length. At least one end of the rod shall be rounded to a hemispherical tip.

4.3 Small tools

Tools and items such as shovels, pails, trowels, wood floats, blunted trowels, straightedges, scoops, rubber gloves, and rulers, and a rubber or rawhide mallet weighing approximately 0.6 ± 0.6 kg shall be provided.

4.4 Sampling and mixing receptacles

A suitable pan, wheelbarrow, or flat, clean, non-absorbent mixing board of sufficient capacity to allow easy mixing by shovel or trowel of the entire sample shall be provided.

4.5 Strike-off bar

A steel strike-off bar, approximately 6 mm × 25 mm × 450 mm, shall be provided.

4.6 Drying room and controls

4.6.1

A drying room with suitable racks shall be provided, such that the racks shall be designed to allow for free circulation of air around specimens, except for necessary supports, and shall be so situated with respect to the nearest wall or other obstructions that the air circulation is not restricted. The specimen supports shall consist of two non-absorptive members not deeper than 25 mm and have a bearing area

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not more than 6 mm in width. Conditioned air shall be circulated into and out of the room in a uniform manner so that the specified rate of evaporation is attained adjacent to all specimens.

4.6.2

The air in the drying room shall be maintained at a temperature of 23 ± 2 °C, and relative humidity of 50 ± 4%. The air movement past all specimens shall be such that the rate of evaporation is 13 ± 5 mL/24 h from a 400 mL Griffin low form beaker filled to 20 mm from the top. The temperature and relative humidity of the room shall be measured with either a sling or Assmann psychrometer at least twice each working day (i.e., early morning and late afternoon). The psychrometer shall comply with ASTM E337, except that thermometers having an overall length of about 250 mm and marked in subdivisions of 0.5 °C may be used. The rate of evaporation within the room shall be determined daily by loss of mass of water from a Griffin low form beaker filled initially to 20 mm from the top of the beaker.

5 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6 Test Specimens

Test specimens for concrete, in which all of the aggregate passes a 56 mm sieve, shall be a prism 100 mm square in cross-section and approximately 285 mm in length. However, test specimens for concrete, in which all of the aggregate passes a 28 mm sieve, shall be a prism 75 mm square in cross-section and approximately 285 mm in length. Three specimens shall be prepared for each test condition. Since length change is capable of being influenced by the size of the specimen, specimens to be compared shall have the same dimensions and any specification limit based upon this Test Method shall be applied to a specified size of specimen.

7 Sampling concrete

7.1 Field sampling

Samples of concrete for plastic concrete tests and casting test specimens shall be obtained in accordance with CSA A23.2-1C. The place of deposition of the batch of concrete that was sampled shall be recorded.

7.2 Laboratory concrete preparation, batching, mixing, sampling, and testing

7.2.1 Material preparation, batching, and mixing concrete

Preparation of materials, batching, and mixing shall be carried out in accordance with the procedures specified in CSA A23.2-2C, using the specific concrete mix design ingredients being evaluated.

7.2.2 Laboratory sampling

The entire mix shall constitute the sample for testing the plastic properties of concrete and casting test specimens.

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8 Concrete testing

8.1 Slump

The slump of the batch of concrete shall be measured immediately after mixing, in accordance with CSA A23.2-5C.

8.2 Slump flow

If a SCC is used, the slump flow of the batch of concrete shall be measured immediately after mixing, in accordance with CSA A23.2-19C.

8.3 Air content

The air content shall be determined in accordance with either CSA A23.2-4C or CSA A23.2-7C. The concrete used for determination of air content shall be discarded.

8.4 Density, yield, and cementitious materials factor

The density, yield, and cementitious materials factor of each batch of concrete shall be determined in accordance with CSA A23.2-6C. All concrete used for slump and yield tests may be returned to the mixing pan and remixed into the batch, where laboratory concrete mixes are being tested.

8.5 Temperature

The temperature of the mix shall be recorded in accordance with CSA A23.2-17C.

8.6 Strength test specimens

Strength test specimens shall be moulded and cured in accordance with CSA A23.2-3C. Two specimens shall be fabricated and tested at the specified strength age, in accordance with CSA A23.2-9C, unless otherwise specified.

9 Procedure for moulding length change specimens

Prisms shall be cast, consolidated, and finished using the following procedures:

a) The samples shall be cast from the same truckload of concrete or laboratory produced concrete batch as the compressive strength samples. Concrete samples shall be obtained following the procedure in CSA A23.2-1C.

b) The release agent shall be applied to the prism mould surfaces prior to the installation of the gauge studs. Prism moulds shall be free of excess form release agent prior to casting specimens. Excess form release agent shall be wiped off using a cloth or paper towel.

c) Immediately prior to concrete moulding, a bar with a preset gauge length between 250 to 255 mm shall be used to properly space the gauge length between the ends of the studs. This preset gauge length shall be used in the calculation of the length change.

d) The prisms shall be consolidated in two equal layers using a 10 mm diameter rod (as defined in Clause 5.3 of CSA A23.2-3C), rodding 30 times per layer for 75 mm square in cross-section test specimens, or rodding 40 times per layer for 100 mm square in cross-section test specimens, distributed the rodding evenly across the cross-section. After rodding each layer, the sides of the moulds shall be lightly tapped with a mallet as specified in Clause 4.3 ten to fifteen times uniformly around the sample mould to close the voids left by the rodding operation. During the rodding operation, work the concrete into the corners, and around the gauge studs, and along the surfaces of the mould with the tamper until a homogeneous specimen is obtained.

Note: *For flowing plastic mixes having a slump greater than 180 mm, the sample should only be rodded 12 times per layer. For slumps under 40 mm, external vibration is to be used. When SCC is being used the*

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concrete should be placed into the mould in one lift without any consolidation other than lightly tapping the external sides of the mould 5 to 10 times with a mallet.

e) Strike-off shall be completed using a strike-off bar as specified in Clause 4.5 or tamping rod as specified in Clause 4.2 or wood float and blunted trowel as specified in Clause 4.3. Excessive finishing should be avoided.

f) Immediately after completion of moulding, the device holding the gauge studs in position at each end of the mould shall be loosened in order to prevent any restraint of the gauge studs before the test specimens are demoulded.

10 Procedure for storage and measurement of length change specimens

10.1 Laboratory prepared length change specimens

Immediately after finishing, the prisms shall be covered with polyethylene sheeting and placed in a moist room at 23 ± 2 °C and relative humidity of 100%. Alternatively, the prisms may be covered with wet burlap and maintained at 23 ± 2 °C. In this case, the burlap shall be saturated but not dripping with water and shall cover the top and sides of the samples without being in direct contact with the concrete surface. The burlap shall be completely covered with a polyethylene sheet in such a manner as to prevent drying of the burlap.

10.2 Field prepared length change specimens

The initial site curing for the first day shall be provided in a curing box at 20 ± 5 °C as specified in Clause 9.3.2.1 of CSA A23.2-3C. The samples shall be properly protected to prevent moisture loss. At a minimum, the prisms shall be placed in a sealed plastic bag to prevent moisture loss. If this is not possible, the sample shall be covered with plastic, followed by a covering of wet burlap, and finally a covering of plastic (i.e., three layers of protection).

10.3 Handling, demoulding, and storage of specimens, and length change measurement

10.3.1

For field prepared specimens, the prisms shall be retrieved and delivered in the moulds to the laboratory in 20 ± 4 h in a curing box maintained at 20 ± 5 °C*. Field prepared specimens shall be demoulded immediately upon receipt in the laboratory. For the laboratory prepared specimens, the specimens shall be demoulded at an age of 23.5 ± 0.5 h. The demoulded specimens shall be placed in a saturated lime water solution at 23 ± 2 °C for at least 30 min and shall be measured within 30 min thereafter to determine the original length. the time of measurement shall be recorded. Upon completion of demoulding, the concrete prisms shall be examined for evidence of poor consolidation around the studs. If the gauge studs are loose or there is evidence of improper consolidation, the samples shall be discarded and the casting process repeated. Each specimen shall be identified with a sample identification number and also marked to identify the direction that the beam is to be placed in the measuring apparatus (i.e., to ensure that the beams are measured in the same manner each time).

* *The technician should verify that prisms have developed sufficient strength to allow for the transportation of the specimens to the laboratory without damage.*

10.3.2

Upon completion of the demoulding and marking procedure, the specimens shall be submerged in saturated lime water and cured in the laboratory 6 d further at 23 ± 2 °C (total curing time, including the initial 24 h curing period shall be 7 d).

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10.3.3
The prisms shall be measured at age 7 d to determine the length of the specimens*. The length at age 7 d shall be the base length for drying shrinkage calculations (0 d drying age).

* *Due to the critical nature of the initial measurement, the technician should repeat this measurement at least twice for an accurate measurement. The sample should be completely removed from the test apparatus between measurements.*

10.3.4
Upon completion of the base length measurements, the prisms shall be placed in a humidity- and temperature-controlled room or chamber at 23 ± 2 °C and 50 ± 4% relative humidity.

10.3.5
The prisms shall be measured at 1 d, 4 d, 7 d, 14 d, and 28 d after the placing in the humidity- and temperature- controlled room or chamber*. These measurements should be made in a temperature-controlled room or chamber at 23 ± 2 °C and 50% ± 4% relative humidity.

* *The owner may specify additional measurements beyond 28 d.*

10.3.6
At each measurement age, the measurement apparatus reference bar length shall also be recorded. If a digital gauge capable of being zeroed is used when measuring the reference bar length, then when measuring the reference bar, the gauge shall be zeroed prior to measuring the length of the prism specimen.

11 Procedure for calculating length change

11.1
The length change of any specimen at any age after the base length comparator reading shall be calculated as follows (for drying shrinkage calculations (0 d drying age)):

$$L = \frac{(L_x - L_b)}{G} \times 100$$

L = change in length at any age, %

L_x = comparator reading of specimen at any age minus comparator reading of reference bar at any age, mm

L_b = base length comparator reading (0 d drying age), mm

G = gauge length as determined in Clause 9 c), mm

11.2
The length change values for each specimen shall be calculated to the nearest 0.001%.

12 Reporting

12.1 Required information
The following information shall be included in the test report, as applicable:

a) concrete mix identification;
b) source of sampling (i.e., bill no., batch no., plant identification);
c) identification of the certified laboratory performing the test (i.e., name and address);

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d) location in structure represented by field-sampled concrete, when applicable;
e) date when concrete specimen was made;
f) measured slump or slump flow;
g) measured air content;
h) concrete and ambient temperatures at time of moulding specimens;
i) average and individual compressive strength of concrete at the specified age;
j) test specimen identification numbers or details;
k) average length change at each reading of the prisms, with individual values for each prism to the nearest 0.001%, at ages of 1 d, 4 d, 7 d, 14 d, and 28 d after the placing in the humidity- and temperature-controlled room or chamber;
l) name of the certified technician who performed tests;
m) name and signature of the person responsible for the review of the test report; and
n) any deviations from the test procedure.

12.2 Optional information

The following information may be included in the test report:
a) concrete mix ingredients and proportions;
b) sources mix ingredients;
c) unit weight of concrete, yield, and cementitious materials content; and
d) density of hardened concrete to the nearest 1kg/m^3.

13 Precision and bias

13.1 Precision

For concrete length change specimens stored in accordance with this Test Method, the following precision statement is provided for 75 mm and 100 mm square in cross-section test specimens:
a) 75 mm specimen: For the drying period of 28 d and 56 d, the multi-laboratory standard deviation, where a test result is, as defined in this test method, the average of measures of three beam specimens, has been found to be 0.004%. Therefore, results of two properly-conducted tests (each consists of measurements of three specimens) are not expected to differ by more than 0.011%.
b) 100 mm specimen: For the drying period of 28 d and 56 d, the multi-laboratory standard deviation, where a test result is, as defined in this test method, the average of measures of three beam specimens, has been found to be 0.006%. Therefore, results of two properly-conducted tests (each consists of measurements of three specimens) are not expected to differ by more than 0.017%.

13.2 Bias

No statement bias is being made since there is no accepted reference material for determining the bias of the test procedures.

Note: *The precision and bias statements of Clause 13 were provided by a multilaboratory study carried out by the Ontario Ministry of Transportation and The Ready Mixed Concrete Association of Ontario in 2011.*

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A23.2-22C
Scaling resistance of concrete surfaces exposed to deicing chemicals using mass loss

1 Scope

This Test Method specifies the procedure for determining of the resistance to scaling of a horizontal concrete surface exposed to freezing-and-thawing cycles in the presence of deicing chemicals. It is intended for use in evaluating this surface resistance both qualitatively by visual examination and quantitatively using scaling mass loss.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-2C:19
Making concrete mixes in the laboratory

A23.2-3C:19
Making and curing concrete compression and flexural specimens

A23.2-4C:19
Air content of concrete by the pressure method

A23.2-5C:19
Slump of concrete

A23.2-7C:19
Air content of concrete by the volumetric method

A23.2-17C:19
Temperature of freshly mixed hydraulic cement concrete

A231.1-14
Precast concrete paving slabs

ASTM International

C156-11
Standard Test Method for Water Loss [from a Mortar Specimen] Through Liquid Membrane-Forming Curing Compounds for Concrete

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BNQ (Bureau de normalisation du Québec)
2621-905/2012
Béton prêt à l'emploi — Programme de certification, annexe B — détermination de la résistance à l'écaillage du béton soumis à des cycles de gel-dégel en contact avec des sel de déglaçage

MTO (Ontario Ministry of Transportation)
LS-412
Method of Test for Scaling Resistance of Concrete Exposed to Deicing Chemicals

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Scaling — the loss of surface from a concrete element due to the expansive crystallization of salts due to evaporation and/or freezing of salt solutions in contact with the concrete surface.

4 Significance and use

4.1

This Test Method may be used to evaluate the effect of mixture proportioning, surface treatment, curing, or other variables on resistance to scaling.

4.2

This Test Method is not intended to be used in determining the durability of aggregates.

4.3

This Test Method described is a manual method based on a testing cycle frequency of 5 d for a total of 50 cycles. Automated equipment is available and its use is mandated by some jurisdictions. The automated equipment available operates to provide the characteristics specified in this Test Method; however, the testing cycle frequency is 7 d per week for a total of 56 cycles.

The owner should specify the test method, the number of cycles to complete a test, and the limits of mass loss at the completion of the test.

Note: *The principal specified limits for mass loss by various jurisdictions in Canada are 0.5 kg/m² by BNQ and 0.8 kg/m² by MTO when tested in accordance to BNQ 2621-905 or MTO LS-412, respectively.*

5 Apparatus

5.1 Freezing and thawing apparatus

The apparatus shall consist of a cold room or a cabinet in which the ambient air goes down to –18 ± 3 °C during the freezing period and goes no higher than 23 ± 2 °C during the thawing period.

The capacity of the apparatus shall be so that the temperature at the interface of the deicing saline solution and the concrete specimen can be maintained to –18 ± 3 °C during the last 7 h of the freezing period and be greater or equal to 5 °C at the end of the thawing period. The duration of the freezing period for which the temperature at the interface of the saline solution and the concrete specimen is at –18 ± 3 °C shall not exceed 12 h (see Note 1). These requirements shall be met throughout the chamber.

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The freeze thaw apparatus shall be provided with a temperature data recorder and sufficient temperature probes to record the ambient temperature of the chamber as well as the interface temperature at the concrete specimen surface and the saline solution, at intervals not exceeding 15 min, with an accuracy of ± 0.5 °C.

The two distinct apparatus for the periods of freezing and thawing may be used if the two conditions alternate in a continuous manner (i.e., there is no delay between the end of a given period and the beginning of the following period).

Notes:

1) *The temperature at the interface of deicing solution and the concrete specimen can be measured using a control sample slab to evaluate the cooling capacity of the freezer being used. Temperature measuring devices require sufficient lead length at the interface to prevent concrete and/or air temperature from interfering with accurate measurement.*
2) *On weekends or during other delays in temperature cycling, maintain the specimens in a frozen condition at –18 ± 3 °C. For extended periods, a polyethylene cover may be used to prevent sublimation of ponded ice.*
3) *The freezing apparatus in accordance with Clause 7.3 of CSA A231.1 will satisfy this Clause.*

5.2 Oven, heat chamber, or environmental chamber

A chamber in which the temperature that can be maintained at 110 ± 5 °C while keeping an average evaporation rate of at least 25 g/h shall be used. This requirement shall be determined by the water loss measured in 1 L Griffin beakers filled with 500 g of water at 23 ± 2 °C, placed at the corners and the center of each shelf of the heat chamber and heated for at least 4 h with the doors of the heat chamber closed.

5.3 Moulds

Moulds shall be rectangular in shape having a minimum depth of 75 mm and of sufficient size to provide a minimum specimen surface area of 0.045 m^2, excluding the area of the ponding dyke. The bottom of the mould shall be lined with geotextile fabric, the thickness of which shall not reduce the minimum specimen thickness. The inside surface of the moulds shall be smooth and fee of indentations. The sides, bottom, and ends of the moulds shall be at right angles to each other and shall be straight, true, and free of warpage. Moulds made of 19 mm thick plywood may be acceptable provided that they are waterproofed to make them non absorptive and leak proof.

5.4 Tamping rod

A round straight steel tamping rod 16 ± 1 mm in diameter and not less than 450 mm nor more than 600 mm in length, having at least one end rounded to a hemispherical tip shall be used.

5.5 Small tools

Smoothly planed clean wood strike off board approximately 40 × 90 mm in cross section, or a purpose made clean wood float, to provide the desired texture of the test surface and a rubber or rawhide head mallet weighing approximately 0.6 ± 0.3 kg shall be used.

Note: *The use of a steel trowel should be avoided to prevent surface scaling.*

5.6 Slump cone

A slump cone conforming to the requirements of CSA A23.2-5C shall be used.

5.7 Air meter

An air meter conforming to the requirements of CSA A23.2-4C or A23.2-7C shall be used.

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5.8 Thermometer
A thermometer conforming to the requirements of CSA A23.2-17C shall be used.

5.9 Balance
A calibrated balance with a minimum capacity of 500 g and an accuracy of 0.1 g for measuring the quantity of spalled material from the surface of the concrete shall be used.

5.10 Concrete mixer
The concrete mixer shall conform to the requirements of CSA A23.2-2C.

6 Reagents and materials

6.1 Sodium chloride solution
Sodium chloride solution shall be 3.0% by mass (reagent grade) in distilled water.

6.2 Dike material
The dike shall be made of a freeze/thaw durable, non-reactive material that will adhere to the specimen and shall protrude approximately 20 mm above the surface of the specimen to maintain the brine pond on top of the specimen throughout the period of the test.

Any pre-applied coating shall be removed from the bond area prior to the application of the dike.

Note: *Strips of rigid, closed-cell extruded polystyrene insulation or rubber material of suitable cross section, bonded with silicone sealant have been found to work well as dikes. If the dike is of mortar, it should be applied immediately after the final finishing operation, and the surface where the mortar is to be applied should be roughened to provide a mechanical bond. If an epoxy mortar dike is to be formed or a proven satisfactory bonding material is used to bond the dike to the surface, the dike may be applied after the concrete has set.*

6.3 Filter media
Filter media shall be No. 2, 320 mm diameter filter paper, or 80 µm sieve, for collection of the spalled material.

6.4 Geotextile
A non-woven polypropylene geotextile shall be used that has a thickness of 7 ± 1 mm, and a mass per unit area of 900 ± 50 g/m^2 or sufficient number of layers of a thinner geotextile to meet the thickness and mass requirements.

6.5 Protective coatings
If protective coatings are to be evaluated, they shall be applied in accordance with the manufacturer's recommendations regarding quantity and method of application at the age of 21 d. When a material proposed as dual-purpose curing compound/protective coating is being evaluated, it shall be applied at the proper time of application for curing compounds, as described in ASTM C156.

Note: *When evaluating penetration-type coatings for application to pavement surfaces subject to traffic wear, the treated surface of the test specimens may be lightly abraded by abrasive blasting, wire brushing, or other means sufficient to break any films remaining on the surface after drying.*

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7 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

8 Proportioning and mixing

8.1 Proportioning

The air content, cement factor, slump, water-to-cementitious materials ratio, and other characteristics of the concrete and its ingredients shall be those appropriate for the purposes for which the tests are to be made, or represent concrete intended for use in construction.

Notes:

1) *Concrete with the following characteristics has been found useful for the purposes for which this Test Method is generally used:*
   a) *air content, 6 ± 1%;*
   b) *cement content, 335 ± 5 kg/m³;*
   c) *maximum w/cm of 0.45; and*
   d) *durable aggregate of 20 mm or 28 mm maximum nominal size.*
2) *Care should be taken to use an aggregate which has a good performance record in freezing and thawing exposure.*

8.2 Mixing and testing of freshly mixed concrete

The concrete shall be machine mix and tested in accordance with the applicable provisions of CSA A23.2-2C. For test specimens cast in the field, the concrete shall be sampled from delivery equipment in accordance with CSA A23.2-1C.

9 Test specimens

9.1 Fabrication

9.1.1

Specimens shall have an exposed surface area [see Clauses 6.2 and 9.2 e)] of at least 0.045 m² and be at least 75 mm in thickness. At least two duplicate specimens for each combination of variables to be tested shall be made.

9.1.2

Specimens shall be prepared as follows:

a) Coat the inside surface of the mould with a light coat of mineral oil or a suitable nonreactive release material just prior to fabrication of the specimens.
b) Cover completely the bottom of the mould with the geotextile fabric. The geotextile shall be in a dry condition and have never been used before being placed in the bottom of the mould.
c) Fill the mould in one layer. Rod one time for each 1300 mm² of surface, leaving a slight excess of material after the final rodding. Tap the mould with the mallet to close any voids and spade around the periphery with a flat trowel.
d) Immediately after consolidation, level the surface using a clean screeding board or bar of smoothly planed wood approximately 40 mm × 90 mm in cross section and of sufficient length to touch the sides of the mould at all times with the 40 mm section laid flat on the concrete surface. Alternatively, a purpose made clean wood float of sufficient length may be used. Proceed in a back-

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and-forth (horizontal sawing) motion with an amplitude of approximately 50 mm, first lengthwise, then widthwise, one pass in each direction. Avoid excessive finishing.

Notes:

1) *The use of a steel trowel should be avoided to prevent surface scaling.*
2) *Test specimens may also be slabs meeting the exposed test area requirements cut from hardened concrete in a structure. In this case, the specimens should not be cut or damaged on the surface to be tested and should not be allowed to dry to a moisture condition below that of the structure from which they have been taken. This may be accomplished by wrapping the specimens in some waterproof material or by other suitable means.*

9.2 Curing

Curing shall be performed as follows:

a) Except where the method of curing is an element of study or is otherwise specified, cover the specimens with a polyethylene sheet immediately after finishing. The sheet shall not make contact with the concrete surface.

b) Remove the specimens from the moulds at an age of 22 ± 2 h after addition of water to the mix and place in moist storage as provided for in CSA A23.2-3C.

c) If concretes with differing rates of strength gain are to be compared, maintain the specimens in moist storage until such time as the desired strength level has been obtained. When the desired strength level has been reached, remove the specimens from moist storage and store in air for 14 d at 23.0 ± 2.0 °C and 45 to 55 % relative humidity.

Note: *Concrete mixtures containing slag or fly ash as part of the cementitious material should be kept in moist storage for at least 28 days prior to air storage to allow for sufficient hydration.*

d) For all other concretes, remove the specimens from moist storage at the age of 14 d and store in air for 14 d at 23.0 ± 2.0 °C and 45 to 55 % relative humidity.

e) At an appropriate time, place a 20 mm high ponding dike conforming to Clause 6.2 along the perimeter of the top surface of the specimens.

f) Fill the dike with the saline solution at the end of the 14 d dry storage. The saturation period shall be 7 d during which a layer of 5 ± 2 mm of saline solution shall be maintained at the surface. Prevent any evaporation of the solution by covering the surface with a waterproof material being careful that it does not touch the surface.

Note: *Other curing periods and conditions and other chemical deicers and different concentrations may be used when there is a need to evaluate their specific effect.*

10 Test procedure

The test shall be performed as follows:

a) Place specimens in the freezing-and-thawing apparatus. The freezing-and-thawing cycle has a duration of 24 h divided into a freezing period of 16 ± 1 h followed by a thawing period of 8 ± 1 h. This cycle shall be repeated 50 times for manual cycles of freezing and thawing or 56 times for automated equipment. Maintain continuous temperature records of the ambient temperature of the freezing and thawing chamber as well as the interface of the concrete surface/saline solution at intervals not exceeding 15 min.

b) Measure the mass of the scaling residue from the surface every 5, 15, 30, and 50 cycles or every 7, 21, 35 and 56 cycles of automated equipment. Rinse the surface of the specimen with new saline solution to remove all flaked off particles. Collect the scaling residue in a pre-weighed filter paper, then dry the filter paper and residue in the oven at 110 °C, and weigh. Measure the surface

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exposed to the saline solution to the nearest one square centimeter. Add water between each cycle as necessary to maintain the proper depth of solution.

Note: *Generally, 50 cycles are sufficient to evaluate a surface or surface treatment. However, where comparative tests are being made, the tests should be continued beyond the recommended minimum number of cycles if differences have not developed between treated and control specimens.*

c) After each measuring operation, apply new saline solution and resume the test until 50 cycles for manual tests and 56 cycles for automated equipment have been completed.

d) Either keep specimens frozen during any interruption in the daily cycling or maintain them in a damp condition after removal of solution and flushing of surfaces.

11 Calculations and interpretation

11.1 Calculations

For tests performed using manual freezing and thawing, the mass loss shall be calculated, expressed in kg/m^2 after 5, 15, 30, and 50 cycles. For automated freezing and thawing equipment, the mass loss shall be calculated, expressed in kg/m^2 after 7, 21, 35, and 56 cycles.

11.2 Interpretation

When manual freezing and thawing tests are employed, the visual rating of the surface shall be determined after 5, 15, 30, and 50 cycles in accordance with the scale provided in Table 1. For automated freezing and thawing equipment, the visual rating of the surface shall be determined after 7, 21, 35, and 56 cycles in accordance with the scale provided in Table 1.

Table 1
Visual rating scale for concrete surface
(See Clauses 11.2 and 12.1.)

Category	Characteristics of the scaling surface
0	No significant scaling observed
1	Slight scaling (3 mm depth, maximum, no coarse aggregate visible)
2-A	Slight to moderate scaling of the surface mortar (possibly a few popouts*)
2-B	Slight to moderate scaling of the surface mortar, (several popouts*)
3	Moderate scaling of the surface mortar (some exposed coarse aggregate)
4	Moderate to severe scaling (significant surface mortar loss with exposed coarse aggregate)
5	Severe scaling (coarse aggregate visible over entire surface)

* *The formation of popouts might be caused by the rupture of the aggregate or the sudden detachment of the mortar over the aggregate.*

12 Reporting

12.1 Required information

The following information shall be included in the test report, as applicable:

a) specimen identification (i.e., location and date at which sample was cast or received);

b) slump, or slump flow and air content of mix;

c) type of surface treatment, time of application, and rate of application;

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d) type of deicer, whether solution or solid, concentration of the solution if used, rate of application, and time of application;
e) curing history of specimen;
f) mass loss in kg/m^2 after 5, 15, 30, and 50 cycles for manual tests, or after 7, 21, 35, and 56 cycles for automated equipment;
g) visual rating of the surface, in accordance with Table 1, after 5, 15, 30, and 56 cycles for manual tests, or after 7, 21, 35 and 56 cycles for automated equipment;
h) if the test specimens are cut from hardened concrete, the size, shape, orientation of the specimens in the structure, and any other pertinent information available;
i) photographs or a word description of the surface appearance at the end of the test, or both;
j) identification of the certified laboratory responsible for testing the specimens;
k) name of the certified technician(s) who performed the testing;
l) name of the certified technician(s) responsible for the making, curing, and transporting of specimens;
m) name and signature of the person responsible for the review of the test report; and
n) any deviation from the test procedure.

12.2 Optional information

The following information may be included in the test report:
a) concrete mix ingredients and proportions; and
b) the kind and amount of any admixture.

13 Precision and bias

A precision statement has not been prepared for this Test Method.

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A23.2-23C
Electrical indication of concrete's ability to resist chloride ion penetration

1 Scope

This Test Method specifies the procedure for determining the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This Test Method is applicable to types of concrete where correlations have been established between this test procedure and long-term chloride ponding procedures.

Note: *This Test Method is substantially in agreement with ASTM C1202.*

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

ASTM International

C1202-19
Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

3 Summary

This Test Method consists of monitoring the amount of electrical current passed through 50 mm thick slices of 100 mm nominal diameter cores or cylinders during a 6 h period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

4 Significance and use

4.1

This Test Method covers the laboratory evaluation of the electrical conductance of concrete samples to provide a rapid indication of their resistance to chloride ion penetration. In most cases the electrical conductance results have shown good correlation with chloride ponding tests on companion slabs cast from the same concrete mixtures.

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4.2

This Test Method is suitable for evaluation of materials and material proportions for design purposes and research and development.

4.3

Sample age has significant effects on the test results, depending on the type of concrete and the curing procedure. Most concretes, if properly cured, become progressively and significantly less permeable with time. The numerical results (total charge passed, in coulombs) from this Test Method must be used with caution, especially in applications such as quality control and acceptance testing. The qualitative terms in the right-hand column of Table 1 should be used in most cases.

4.4

This Test Method was developed originally for evaluation of alternative materials, but in practice its use has evolved to applications such as quality control and acceptance testing. In such cases it is imperative that the curing procedures and the age of at time of testing be clearly specified.

4.5

Table 1 provides a qualitative relationship between the results of this test and the chloride ion penetrability of concrete.

Table 1
Chloride ion penetrability based on charge passed
(See Clauses 4.3, 4.5, 10.2, and 11.1.)

Charge passed (coulombs)	Chloride ion penetrability
> 4000	High
2000–4000	Moderate
1000–2000	Low
100–1000	Very low
< 100	Negligible

4.6

Care should be taken in interpreting results of this test when it is used on surface-treated concretes, for example, concretes treated with penetrating sealers. The results from this test on some such concretes indicate low resistance to chloride ion penetration, while 91 d chloride ponding tests on companion slabs show a higher resistance.

4.7

The details of the test method apply to 100 mm nominal diameter specimens. This includes specimens with actual diameters ranging from 95 mm to 102 mm (see Clause 5.1 and Figure 1).

For specimen diameters other than 95 mm, the test result value for total charge passed must be adjusted following the procedure in Clause 10.1.2. For specimens with diameters less than 95 mm, particular care must be taken in coating and mounting the specimens to ensure that the conductive solutions are able to contact the entire end areas during the test.

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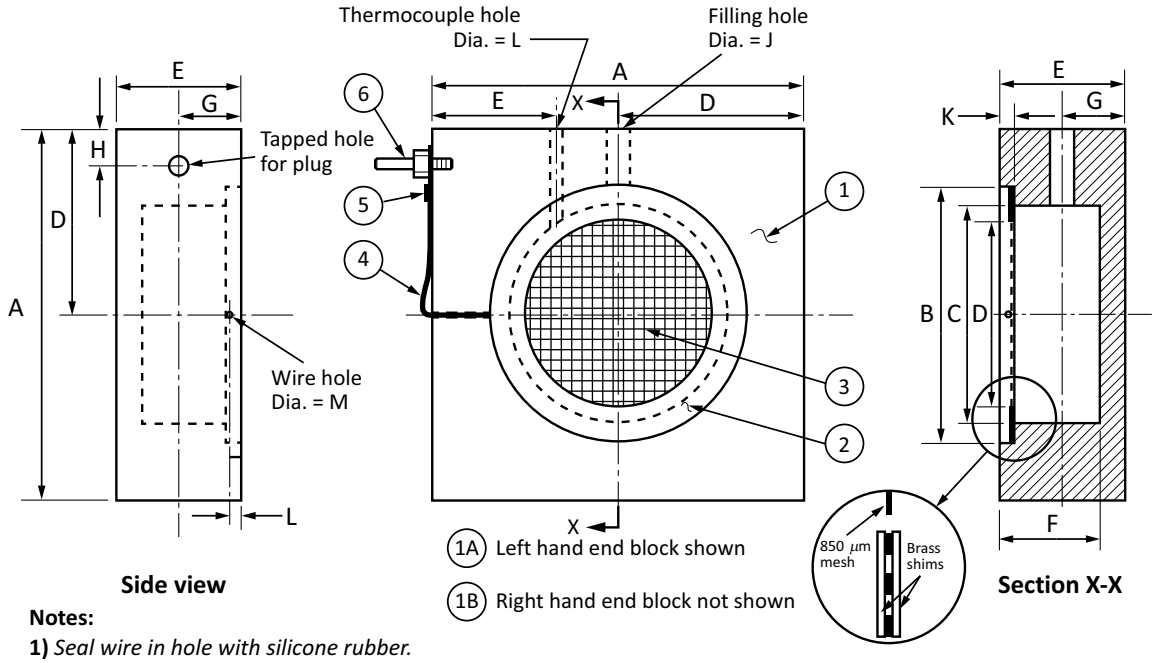
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5 Apparatus

5.1 Applied voltage cell (see Figures 1 and 2)

Two symmetric poly (methyl methacrylate) chambers, each containing electrically conductive mesh and external connectors shall be used. One design in common use is shown in Figures 1 and 2. However, other designs may be used, provided that overall dimensions (including dimensions of the fluid reservoir) are the same as shown in Figure 1 and width of the screen and shims are as shown.

Figure 1
Applied voltage cell (construction drawing)
(See Clauses 4.7 and 5.1.)



Notes:
1) *Seal wire in hole with silicone rubber.*
2) *Solder screen between shims.*
3) *Solder wire to shim.*

Dimensions, mm

A	B	C	D	E	F	G	H	J	K	L	M
150	105	89	75	50	41	25	15	10	6	5	2.5

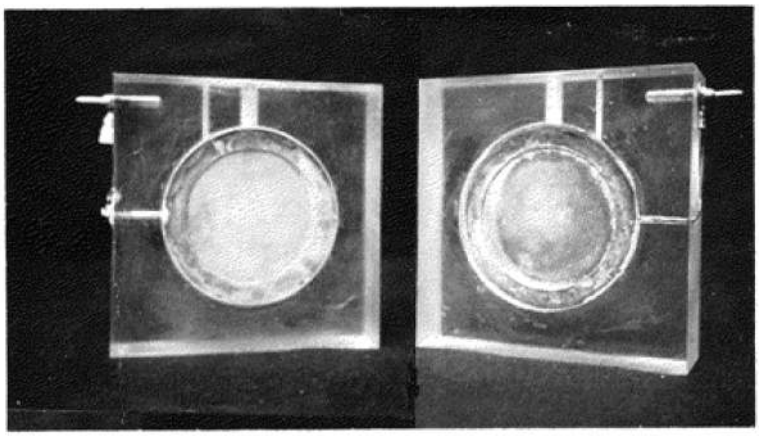
Parts List

Item No.	Quantity	Description	Specification
1A 1B	1 1	Cell block end	Poly (methyl methacrylate)
2	4	Brass shim	0.5 mm thick
3	2	Brass screen	850 μm (No. 20) mesh
4	2	Solid copper wire	2 mm (14 gauge) nylon cladding
5	2	Ring terminal	For 2 mm (14 gauge) wire
6	2	Banana plug	6.4 mm with threaded stud

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Figure 2
Applied voltage cell-face view
(See Clause 5.1.)



5.2 Temperature measuring device

A temperature measuring device (optional) shall have a range of 0 to 120 °C.

5.3 Voltage application and data readout apparatus

A voltage application and data readout apparatus capable shall be used that is capable of holding 60 ± 0.1 V dc across applied voltage cell over entire range of currents and of displaying voltage accurate to ± 0.1 V and current to ± 1 mA. The apparatus listed in Items a) to e) are possible systems meeting this requirement:

a) voltmeter: Digital (DVM), 3 digit, minimum 0–99.9 V range, rated accuracy ± 0.1%;
b) voltmeter: Digital (DVM), 41/2 digit, 0–200 mV range, rated accuracy ± 0.1%;
c) shunt resistor: 100 mV, 10A rating, tolerance ± 0.1%. Alternatively, a 0.01 Ω resistor, tolerance ± 0.1%, may be used, but care shall be taken to establish very low resistance connections;
d) constant voltage power supply: 0–80 V dc, 0–2 A, capable of holding voltage constant at 60 ± 0.1 V over entire range of currents; and
e) cable: Two conductor, 1.6 mm, insulated, 600 V.

5.4 Vacuum saturation apparatus

Note: *See Figure 3 for example of a vacuum saturation apparatus to be used for this test.*

5.4.1 Separatory funnel

A separatory funnel or other sealable, bottom-draining container with a minimum capacity of 500 mL shall be used.

5.4.2 Beaker

A beaker, 1000 mL or larger, or other container shall be used. It shall be capable of holding concrete specimen(s) and water and of fitting into vacuum desiccator (see Clause 5.4.3).

5.4.3 Vacuum desiccator

A vacuum desiccator with a 250 mm inside diameter or larger shall be used. The desiccator shall allow two hose connections through a rubber stopper and sleeve or through a rubber stopper only. Each connection shall be equipped with a stopcock.

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5.4.4 Vacuum pump

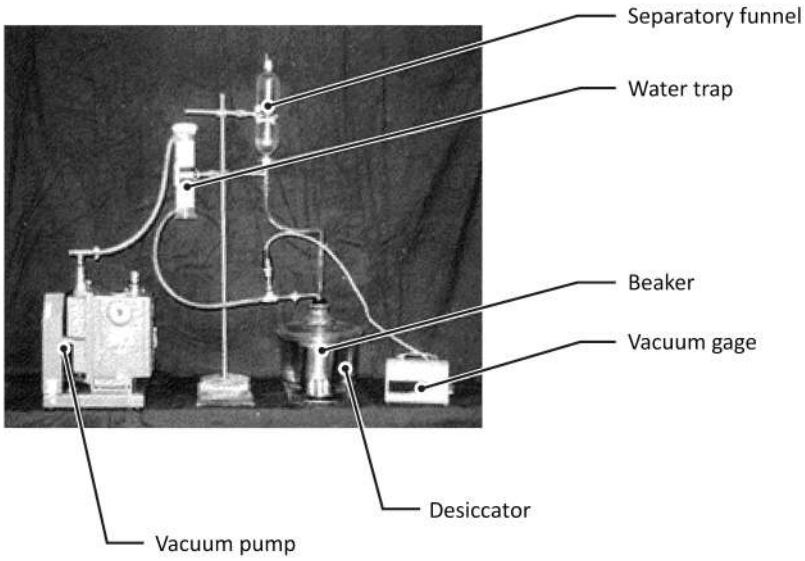
A vacuum pump capable of maintaining a pressure of less than 50 mm Hg (6650 Pa) in desiccator shall be used.

Note: *Since the vacuum will be drawn over water, the pump should be protected with a water trap, or the pump oil should be changed after each operation.*

5.4.5 Vacuum gage or manometer

Vacuum gage or manometer shall be used that is accurate to ± 5 mm Hg (± 665 Pa) over a range 0 to 100 mm Hg (0 to 13 300 Pa) pressure.

Figure 3
Vacuum saturation apparatus
(See Clause 5.4.)



5.5 Coating apparatus and materials

5.5.1 Coating

Coating shall be rapid setting, electrically nonconductive, capable of sealing side surface of concrete cores.

5.5.2 Balance or scale, paper cups, wooden spatulas, and disposable brushes

Balance or scale, paper cups, wooden spatulas, and disposable brushes shall be used for mixing and applying coating.

5.6 Specimen sizing equipment

A movable bed water-cooled diamond saw or silicon carbide saw shall be used; however, it is not required if samples are cast to final specimen size.

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6 Reagents and materials

6.1 Specimen-cell sealant

Specimen-cell sealant shall be capable of sealing concrete to poly (methyl methacrylate), for example, plexiglas, against water and dilute sodium hydroxide and sodium chloride solutions at temperatures up to 90 °C (examples include RTV silicone rubbers, silicone rubber caulkings, other synthetic rubber sealants, silicone greases, and rubber gaskets).

6.2 Sodium chloride solution

Sodium chloride solution shall be 3.0% by mass (reagent grade) in distilled water.

6.3 Sodium hydroxide solution

Sodium hydroxide solution shall be 0.3 N (reagent grade) in distilled water.

6.4 Filter papers

Filter papers shall be used that are No. 2, 90 mm diameter; however, they are not required if rubber gasket is used for sealant (see Clause 6.1) or if sealant can be applied without overflowing from shim onto mesh.

7 Hazards

7.1

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7.2

Before using NaOH, the safety precautions for using the following shall be reviewed:

a) NaOH;
b) first aid for burns; and
c) the emergency response to spills, as described in the manufacturer's Material Safety Data Sheet or other reliable safety literature.

NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pin holes.

8 Test specimens

8.1 Interferences

8.1.1

This Test Method can produce misleading results when calcium nitrite has been admixed into a concrete. The results from this Test Method on some such concretes indicate higher coulomb values,

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that is, lower resistance to chloride ion penetration, than from tests on identical concrete mixtures (controls) without calcium nitrite.

Note: *Other admixtures might affect results of this test similarly. Long term ponding tests should be performed if an admixture effect is suspected.In the case of latex or acrylic modified concrete, the latex or acrylic modifier manufacturer's instruction regarding curing regime should be followed.*

8.1.2

Since the test results are a function of the electrical resistance of the specimen, the presence of reinforcing steel or other embedded electrically conductive materials can have a significant effect. The test is not valid for specimens containing reinforcing steel positioned longitudinally, that is, providing a continuous electrical path between the two ends of the specimen.

Note: *Caution should be taken when testing steel fibre reinforced concrete testing as discrete steel fibres can provide a near continuous electrical path and rapid heating of specimens has been observed.*

8.2 Sample preparation

8.2.1

Sample preparation and selection shall depend on the purpose of the test. For evaluation of materials or their proportions, samples may be cores from test slabs or from large diameter cylinders or 100 mm diameter cast cylinders. For evaluation of structures, samples may be cores from the structure or 100 mm diameter cylinders cast and cured at the field site. Coring shall be done with a drilling rig equipped with a 100 mm diameter diamond-dressed core bit. Samples shall be selected and cored in accordance with CSA A23.2-14C. Cylinders cast in the laboratory shall be prepared following procedures in CSA A23.2-3C. When cylinders are cast in the field to evaluate a structure, care shall be taken that the cylinders receive the same treatment as the structure (e.g., similar degree of consolidation, curing, and temperature history during curing). Samples of concrete for casting test specimens shall be obtained in accordance with CSA A23.2-1C.

Note: *The maximum allowable aggregate size has not been established for this test. Users have indicated that test repeatability is satisfactory on specimens from the same concrete batch for aggregates up to 28 mm nominal maximum size.*

8.2.2

Two specimens shall be prepared for each test. When results of this Test Method are used for evaluation of materials or mixture proportions based on cast specimens for purposes of quality control, mixture submittals, or acceptance of concrete, at least two 100 mm diameter cylindrical specimens shall be prepared. When evaluating a structure, two individual cores shall be retrieved from a structure under consideration for each test. Moist cure specimens in accordance with Items a) to c), unless the accelerated moist curing method in Item c) is specified (see Note):

a) Moist curing: Moist cure specimens until the age of test.

b) Extended moist curing: Cure test specimens for 56 d in accordance with CSA A23.2-3C.

   Note: *The 56 d moist curing period is to allow for some supplementary cementitious materials to develop potential properties because of their slower rate of hydration. Concrete containing supplementary cementitious materials may continue to show reductions in results of this test beyond 56 d, and in some cases, it may be appropriate to test at later ages, such as 91 d, consistent with the requirements of Table 2 of CSA A23.1 for Class C-XL and Class C-1 exposures.*

c) Accelerated moist curing: Provide 7 d of moist curing in accordance with CSA A23.2-3C. After 7 d of moist curing, immerse the specimens for 21 d in lime-saturated water at 38.0 ± 2.0 °C.

   Note: *The accelerated moist curing procedure has been found useful in providing an earlier indication of potential property development with slower hydrating supplementary cementitious materials. Because the*

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two different curing methods may not provide the same results, the specifier of the test may require a correlation between results for extended moist cured and accelerated moist cured specimens and establish appropriate acceptance criteria when the accelerated moist curing procedure is used or permitted.

Alternatives to these curing methods and durations may be used when specified. The same method and duration of curing shall be used for preparing mixture submittals, for subsequent acceptance testing, and for comparing two or more mixtures.

8.2.3

The cores or field-cured cylinders shall be transported to the laboratory in sealed (tied) plastic bags. If specimens are to be shipped, they should be packed so as to be properly protected from freezing and from damage in transit or storage.

8.2.4

Using the water-cooled diamond saw or silicon carbide saw, a 50 ± 3 mm slice shall be cut from the cores or cast cylinders. For cores drilled from a structure, the saw cut slice shall consist of the core with the cut parallel to the top of the core. This slice shall be the test specimen. A single slice specimen prepared from a cylinders cast in the field or laboratory shall be saw cut about the transverse midpoint of the height of cylinder. Where two specimens shall be obtained from a single cylinder, each slice shall be saw cut on either side of the transverse midpoint of the cylinder. A belt sander shall be used to remove any burrs on the end of the specimens.

8.2.5

Special processing shall be carried out for core samples where the surface has been modified, for example, by texturing or by applying curing compounds, sealers, or other surface treatments, and where the intent of the test is not to include the effect of the modifications. In those cases, the modified portion of the core shall be removed and the adjacent 50 ± 3 mm slice shall be used for the test.

Note: *Where the intent of the test on cores is to evaluate the quality of curing and cover concrete, the depth of surface removal should be limited to approximately 5 mm. The depth of surface removal should be increased to approximately 20 mm for cores representing concrete that have surface treatments applied.*

8.3 Conditioning

Conditioning shall be performed as follows:

a) Vigorously boil a litre or more of tap water in a large sealable container. Remove container from heat, cap tightly, and allow water to cool to ambient temperature.

b) Allow the specimen prepared in Clause 8.2 to surface dry in air for at least 1 h. Prepare approximately 10 mL of rapid setting coating and brush onto the side surface of specimen. Place the sample on a suitable support while coating to ensure complete coating of sides. Allow the coating to cure in accordance with the manufacturer's instructions.

c) Allow the coating to cure until it is no longer sticky to the touch. Fill any apparent holes in the coating and allow additional curing time, as necessary. Place specimen in beaker or other container (see Clause 5.4.2), then place container in vacuum desiccator. Alternatively, place specimen directly in the vacuum desiccator. Both end faces of specimen shall be exposed. Seal the desiccator and start the vacuum pump. Pressure should decrease to less than 50 mm Hg (6650 Pa) within a few minutes. Maintain the vacuum for 3 h.

d) Fill the separatory funnel or other container (see Clause 5.4.1) with the de-aerated water prepared in Item a). With the vacuum pump still running, open the water stopcock and drain sufficient water

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into the beaker or container to cover the specimen (do not allow air to enter desiccator through this stopcock).

e) Close the water stopcock and allow the vacuum pump to run for one additional hour.

f) Close the vacuum line stopcock, then turn off the pump. (Change the pump oil if a water trap is not being used.) Turn the vacuum line stopcock to allow air to re-enter the desiccator.

g) Soak the specimen under water [the water used in Items d) to f)] in the beaker for 18 ± 2 h.

9 Test procedure

The test shall be performed as follows:

a) Remove the specimen from water, blot off excess water, and transfer specimen to a sealed can or other container which will maintain the specimen in 95 % or higher relative humidity.

b) Mount the specimen in the apparatus:

i) For all sealants other than rubber gaskets, use the methods Item iii) or iv), as appropriate.

ii) If using two-part specimen-cell sealant, prepare approximately 20 to 40 g.

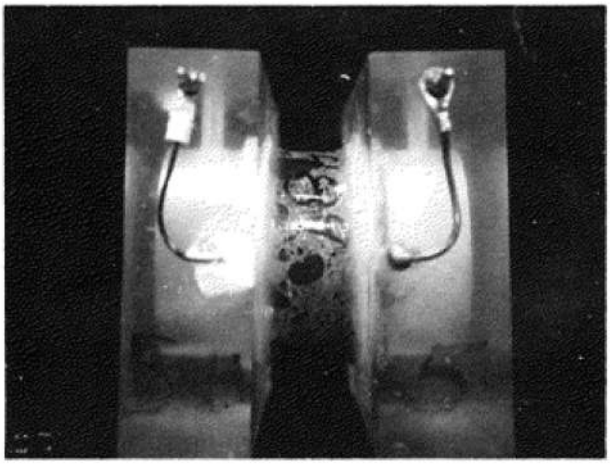
iii) For low viscosity specimen-cell sealant, if filter paper is necessary, centre the filter paper over one screen of the applied voltage cell. Trowel sealant over brass shims adjacent to the applied voltage cell body. Carefully remove the filter paper. Press the specimen onto the screen. Remove or smooth excess sealant which has flowed out of the specimen-cell boundary.

iv) For high viscosity specimen-cell sealant, set the specimen onto the screen. Apply sealant around the specimen-cell boundary.

v) Cover the exposed face of the specimen with an impermeable material such as rubber or plastic sheeting. Place a rubber stopper in the cell filling hole to restrict moisture movement. Allow the sealant to cure in accordance with the manufacturer's instructions.

vi) Repeat steps in Items iii) (or iv)) and v) on the second half of the cell. (The specimen in the applied voltage cell now appears as shown in Figure 4.)

Figure 4
Specimen ready for test
(See Clause 9.)



vii) Specimen mounting (rubber gasket alternative): Place a 100 mm outside diameter by 75 mm inside diameter by 6 mm circular vulcanized rubber gasket in each half of the test cell. Insert the sample and clamp the two halves of the test cell together to seal.

c) Fill the side of the cell containing the top surface of the specimen with 3.0% NaCl solution. [That side of the cell will be connected to the negative terminal of the power supply in Item d).] Fill the

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other side of the cell (which will be connected to the positive terminal of the power supply) with 0.3 N NaOH solution.

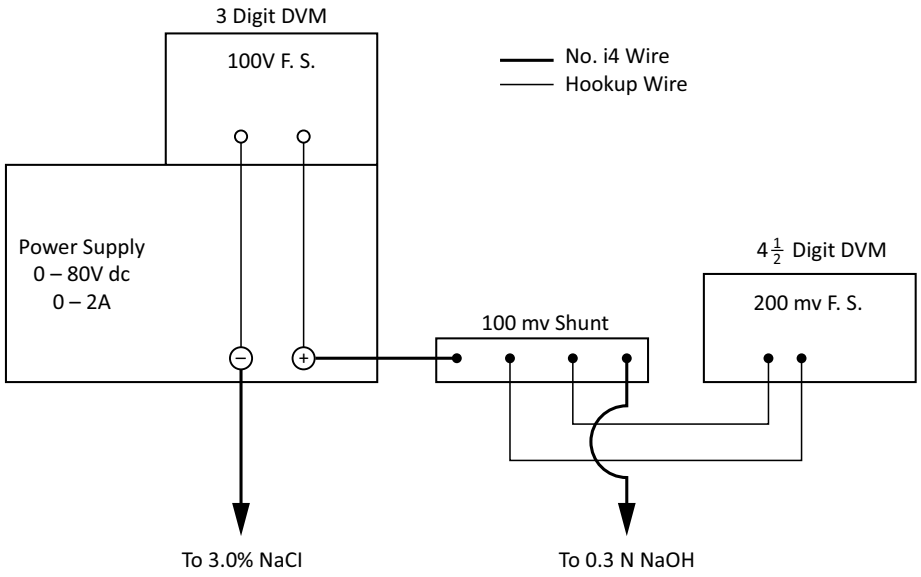
d) Attach lead wires to cell banana posts. Make electrical connections to the voltage application and data readout apparatus as appropriate (e.g., for the system listed in Items a) to e) in Clause 5.3, connect as shown in Figure 5). Turn the power supply on, set to 60.0 ± 0.1 V, and record the initial current reading. The temperatures of the specimen, applied voltage cell, and solutions shall be 20 °C to 25 °C at the time the test is initiated, that is, when the power supply is turned on.

e) During the test, the air temperature around the specimens shall be maintained in the range of 20 °C to 25 °C.

f) Read and record current at least every 30 min. If a voltmeter is being used in combination with a shunt resistor for the current reading (see Figure 5), use appropriate scale factors to convert voltage reading to amperes. Each half of the test cell shall remain filled with the appropriate solution for the entire period of the test.

Note: *During the test, the temperature of the solutions should not exceed 90 °C in order to avoid damage to the cell and to avoid boiling off the solutions. Although it is not a requirement of this Test Method, the temperature of the solutions may be monitored with thermocouples installed through the 3-mm vent hole in the top of the cell. High temperatures occur only for highly penetrable concretes. If a test of a 50 mm thick specimen is terminated because of high temperatures, this should be noted in the report, along with the time of termination, and the concrete rated as having very high chloride ion penetrability [see Clause 11.1, Item i)].*

Figure 5
Electrical block diagram (example)
(See Clause 9.)



g) Terminate the test after 6 h, except as discussed in the Note in Item f).

h) Remove the specimen and rinse the cell thoroughly in tapwater; strip out and discard any residual sealant.

i) Repeat this procedure for the companion test specimen.

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10 Calculations and interpretation

10.1 Calculations

10.1.1

For each test specimen, current (in amperes) versus time (in seconds) shall be plotted. A smooth curve shall be drawn through the data, and the area underneath the curve shall be integrated in order to obtain the ampere-seconds, or coulombs, of charge passed during the 6 h test period. (See Note.) Alternatively, automatic data processing equipment may be used to perform the integration during or after the test and to display the coulomb value. The total charge passed is a measure of the electrical conductance of the concrete during the period of the test.

Note: *Sample calculation — If the current is recorded at 30 min intervals, the following formula, based on the trapezoidal rule, can be used with an electronic calculator to perform the integration:*

$$Q = 900 (I_0 + 2I_{30} + 2I_{60} + \ldots + 2I_{300} + 2I_{330} + I_{360}) \quad (1)$$

where

Q = charge passed (coulombs)

I_0 = current (amperes) immediately after voltage is applied

I_t = current (amperes) at t min after voltage is applied

10.1.2

If the specimen diameter is other than 95 mm, the value for total charge passed established in Clause 10.1.1 shall be adjusted. The adjustment shall be made by multiplying the value established in Clause 10.1.1 by the ratio of the cross-sectional areas of the standard and the actual specimens:

$$Q_s = Q_x \times \left(\frac{95}{x}\right)^2$$

where

Q_s = charge passed (coulombs) through a 95 mm diameter specimen

Q_x = charge passed (coulombs) through × mm diameter specimen

x = diameter, mm, of the nonstandard specimen

10.1.3

The average of the total charge passed for each specimen shall be calculated to determine the test result for the concrete under consideration.

10.2 Interpretation

Table 1 shall be used to evaluate the test result.

Note: *Factors which are known to affect chloride ion penetration include: water-cement ratio, the presence of polymeric admixtures, sample age, air-void system, aggregate type, degree of consolidation, and type of curing.*

11 Reporting

11.1 Required information

The following information shall be included in the test report, as applicable:

a) specimen identification (i.e., location and date at which sample was cast or retrieved);
b) location of the concrete in the structure under construction related to the specimens;
c) type of specimens, core or cast cylinder;

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d) curing history of specimen;
e) location of specimen within core or cylinder;
f) type of concrete including cementitious material composition, water-to-cementitious materials ratio, and other relevant data supplied with the samples;
g) specimen preparation (e.g., removal of surface treatment);
h) test result, average of the total charge passed on two companion specimens during the test period, expressed in coulombs;
i) the qualitative chloride ion penetrability equivalent to the calculated charge passed from Table 1;
j) name of the certified technician who performed the test;
k) identification of the certified laboratory that performed the test (i.e., name and address);
l) name and signature of the person responsible for the review of the test reports; and
m) any deviation from the test procedure.

11.2 Optional information

The name of the technician responsible for the making, curing, and transporting of specimens may be included in the test report.

12 Precision and bias

12.1 Precision

The precision of this Test Method is expected to be similar to that of ASTM C1202.

12.2 Bias

The procedure of this Test Method for measuring the resistance of concrete to chloride ion penetration has no bias because the value of this resistance can be defined only in terms of a Test Method.

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A23.2-24C
Standard Practice for sampling, testing, and inspection of concrete for qualification purposes

1 Scope

This Standard Practice specifies the procedures for sampling and testing of concrete for purposes of qualifying materials and mix designs and assessing compliance with this Standard.

Note: *See Table 5 and Clause 4.4 of CSA A23.1.*

2 Reference publications

This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2:19
Test methods and standard practices for concrete

A23.2-30A:19
Standard practice for sampling, testing, and inspection of aggregates for use in concrete

A23.2-4B:19
Sampling and determination of water-soluble chloride ion content in hardened grout or concrete

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-4C:19
Air content of plastic concrete by the pressure method

A23.2-5C:19
Slump of concrete

A23.2-6C:19
Density and yield of plastic concrete

A23.2-7C:19
Air content of plastic concrete by the volumetric method

A23.2-8C:19
Flexural strength of concrete (using simple beam with third-point loading)

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A23.2-9C:19
Compressive strength of cylindrical concrete specimens

A23.2-11C:19
Water content, density, absorption, and voids in hardened concrete, grout, or mortar

A23.2-13C:19
Splitting tensile strength of cylindrical concrete specimens

A23.2-19C:19
Slump flow of concrete

A23.2-21C:19
Test Method for length change of hardened concrete

A23.2-22C:19
Scaling resistance of concrete surfaces exposed to deicing chemicals using mass loss

A23.2-23C:19
Electrical indication of concrete's ability to resist chloride ion penetration

A3004-A1-18
Standard Practice for sampling, testing, and inspection

ACI (American Concrete Institute)

ACI 214R-11
Guide to Evaluation of Strength Test Results of Concrete

ASTM International

C114-18
Standard Test Methods for Chemical Analysis of Hydraulic Cement

C457-16
Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C494/C494M-17
Standard Specification for Chemical Admixtures for Concrete

C1152/C1152M-04 (2010)e1
Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

C1524-02a
Standard Test Method for Water-Extractable Chloride in Aggregate (Soxhlet Method)

BNQ (Bureau de normalisation du Québec)

2621-905/2012
Béton prêt à l'emploi — Programme de certification (élaboré à partir des exigences des chapitres 4, 5, et 8 de la norme CSA A23.1-F09/A23.2-F09)

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3 Summary

The sampling and testing described are intended for use in the qualification of materials and mix designs.

These procedures specify the amount of testing to be done and the requirements for reporting on the conformance or non-conformance of products with specifications. See Clause 8.

Qualification testing is intended to assess the properties and characteristics of a proposed concrete mix design in advance of its use on a project, for the purpose of determining whether the proposed product complies with the requirements of this Standard, and whether it is acceptable to the owner. The producer may use alternative sampling and testing procedures for internal quality control purposes during production.

The qualification testing requirements for the concrete should be appropriate to the scope, size, and nature of the project. Optional test methods should be used when appropriate to address significant performance requirements based on the applicable exposure conditions or size and scope of project.

4 Concrete test procedures

Laboratory test procedures undertaken to assess concrete and concrete aggregate quality shall be carried out by a testing laboratory meeting the requirements of Clause 4.4.1.6 of CSA A23.1.

Note: *Depending on the nature and scope of the project, internal concrete results from the concrete supplier might be acceptable for qualification purposes if personnel are certified in accordance with Clause 4.4.1.6 of CSA A23.1 and testing is carried out in accordance with CSA A23.2.*

5 Equipment and materials

The equipment and materials for sampling and testing shall meet the requirements of the applicable procedures of CSA A23.2, unless otherwise specified in this Standard Practice.

6 Submittals — General

6.1

The project specifications shall identify submittal requirements that are appropriate to the scope, size, and nature of the project.

Note: *See Clause 8.2.1.*

6.2

The contractor shall submit documentation for qualification in accordance with Clause 7 demonstrating that the owner's performance requirements will be met.

6.3

The concrete supplier shall submit the following documentation:

a) Under Alternative 1 of Table 5 of CSA A23.1: Submit documentation to the satisfaction of the owner, demonstrating that the proposed mix design will achieve the required strength, durability, and performance requirements.

   Note: *Prequalification test results may be supplied using similar materials and mix designs to those proposed for the project.*

b) Under Alternative 2 of Table 5 of CSA A23.1: Submit documentation to the satisfaction of the owner, demonstrating that the concrete complies with the prescriptive criteria as specified by the owner.

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7 Qualification

7.1 General

7.1.1

Unless otherwise specified by the owner, qualification of concrete shall include review of test data demonstrating the potential performance of a proposed mix design. If required by the contract documents, sampling and testing of one or more trial batches of a proposed mix design shall be performed in order to obtain test data on which a qualification assessment can be made.

Notes:

1) *There might be significant lead time required to conduct the testing required to obtain this information, in accordance with Table 1.*
2) *Test information should be current within one year. (i.e., within one year of the date of the test report.)*

7.1.2

Where previous data are not available, concrete trial mixes using project materials that have proportions and consistency suitable for the work shall be made and tested as specified by the owner. Alternatively, the owner may accept test data from similar combinations of materials for similar performance requirements.

Note: *Refer to ACI 214R for further information.*

7.1.3

For concrete supplied under Alternative 1, Table 5 of CSA A23.1, the concrete supplier shall

a) certify that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard;
b) certify that the mix design satisfies the requirements of this Standard;
c) certify that production and delivery of concrete will meet the requirements of this Standard;
d) certify that the concrete complies with the performance criteria specified;
e) prepare and implement a quality control plan for concrete as delivered to ensure that the owner's and contractor's performance requirements will be met, if required; and
f) provide documentation verifying that the concrete supplier meets industry certification requirements, if specified.

7.2 Submittals

When specified in the contract documents by the owner, submittals for qualification of concrete shall include the following:

a) cementitious materials report in accordance with CSA A3004-A1;
b) aggregate report in accordance with CSA A23.2-30A. Sampling, testing, and acceptance of aggregates for use in concrete shall be conducted in accordance with CSA A23.2-30A;
c) water quality test data in accordance with Clause 4.2.2 of CSA A23.1 or declaration of potability;

   Note: *Declaration of potability is not required for water drawn from a municipal water supply system.*
d) admixture product data with certification by the manufacturer that the requirements of Clause 4.2.4 of CSA A23.1 will be met;
e) when concrete is specified under Alternative 1 of Table 5 of CSA A23.1, mix design submittal with documentation to the satisfaction of the owner, demonstrating that the proposed mix design will achieve the required plastic properties, strength, durability, and performance requirements; and

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f) when concrete is specified under Alternative 2 of Table 5 of CSA A23.1, documentation demonstrating that the concrete complies with the prescriptive requirements specified by the owner.

7.3 Tests submitted by the concrete supplier

For qualification purposes, the concrete supplier shall submit test results or information representative of the concrete to be produced, as required, in accordance with Table 1, together with the certifications listed in Clause 7.1.3.

8 Qualification testing of concrete

8.1 General

Concrete testing used as the basis for qualification shall comply with all aspects of the applicable CSA A23.2 field and laboratory test methods and standard practices. Qualification of the concrete shall be subject to the responsibilities in Clause 4 of CSA A23.1.

8.2 Concrete test methods

8.2.1 Qualification testing of concrete

Qualification of concrete shall include the following as applicable in accordance with the project specifications and the specified exposure class:

a) compressive strength of concrete. Specimens used as a basis for acceptance of concrete shall be made and cured in accordance with CSA A23.2-3C and standard tests shall be carried out in accordance with CSA A23.2-9C;
b) slump tests made in accordance with CSA A23.2-5C, or slump flow tests made in accordance with CSA A23.2-19C;
c) plastic air content in accordance with CSA A23.2-4C or A23.2-7C. Where low-density aggregate concrete is used, air content determinations shall be made in accordance with CSA A23.2-7C (volumetric method), except that CSA A23.2-4C (pressure method) may be used if comparative conditions are established and are frequently checked;
d) air void system parameters from tests performed in accordance with ASTM C457 where concrete is subject to the exposures requiring Category 1 air entrainment as described in Tables 1 and 2 of CSA A23.1. Testing shall be carried out in accordance with ASTM C457, using a magnification between 100 and 125;
e) chloride ion penetrability for steel reinforced or pre-stressed concrete or as described in Table 1, or as specified. Test specimens shall be moulded in accordance with CSA A23.2-3C and tested in accordance with CSA A23.2-23C;
f) density of plastic concrete measured in accordance with CSA A23.2-6C if specified when a non-standard density of concrete is specified. When tests are required on low-density and semi-low-density concrete, the air-dry density shall be measured in accordance with CSA A23.2-11C;
g) flexural strength of concrete measured in accordance with CSA A23.2-8C;
h) linear shrinkage as determined by CSA A23.2-21C;
i) salt scaling resistance as determined by CSA A23.2-22C, where limits are specified in the contract documents; and
j) chloride ion content in accordance with Clause 4.1.1.2 of CSA A23.1. The acid-soluble chloride content of hardened concrete shall be determined in accordance with ASTM C1152 on the proposed mix, prior to commencement of work. The water-soluble chloride ion content of

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hardened concrete shall be determined in accordance with CSA A23.2-4B on the proposed mix, prior to commencement of work. The tests shall be carried out at a minimum concrete age of 28 d.

Note: *The water-soluble chloride ion content as determined by CSA A23.2-4B and expressed as a percentage by mass of concrete should be converted to a percentage by mass of the cementitious material when checking against the limits specified in Clause 4.1.1.2.1 of CSA A23.1.*

When measurement of the water-soluble chloride ion content is made on the separate constituents, the following test methods shall be used:

i) Cementitious materials: ASTM C114.

Note: *With finely divided cementitious materials the water-soluble chloride ion content will be approximated by the acid-soluble or total chloride contents measured in ASTM C114.*

ii) Coarse aggregate: ASTM C1524.

Note: *If aggregates do not contain appreciable amounts of chloride, test methods for total chloride content may be used in the calculations.*

iii) Fine aggregate: ASTM C1524.

Note: *If aggregates do not contain appreciable amounts of chloride, test methods for total or acid soluble chloride content may be used in the calculations.*

iv) Chemical admixtures: As stated in ASTM C494/C494M, the manufacturer shall state in writing the chloride content of each admixture and whether or not chloride has been added during its manufacture.

Note: *Instrumental methods such as X-ray Fluorescence (XRF) measure total chloride content of a solid, while in test methods such as ASTM C1152, samples are dissolved in acid, and the acid-soluble chloride content is measured. In most cases, the total and acid-soluble chloride contents are equal, but if the sample is not totally dissolved in the acid, it is possible that the acid-soluble chloride content might be less than the total chloride content.*

Notes:

1) *The requirements for information for qualification of concrete based on the exposure class are found in Table 1.*
2) *The chloride ion penetrability test should not be measured on concrete containing corrosion-inhibiting admixtures or metallic fibres, since the standard acceptance limits are not applicable.*
3) *The samples for chloride ion penetrability test may be obtained from three different portions in a load of concrete, or from different batches or loads of concrete of the same mix design.*

8.2.2 Compressive strength

8.2.2.1 Cylinder size

For standard strength tests, 100 mm × 200 mm cylinders shall be used. The cylinder size shall, however, meet the aggregate size limitations specified in Clause 8.2 of CSA A23.2-3C. Where required by the specific test method, 150 mm × 300 mm cylinders shall be used.

Note: *Other situations requiring 150 mm × 300 mm cylinders include autogenous strength, no-slump concrete and splitting tensile tests.*

8.2.2.2 Test age

Cylinders shall be tested at an age of 28 days unless otherwise specified.

Note: *When structural requirements permit, the specified strength requirements for mass concrete, high strength concrete, high performance concrete, concrete with high volumes of supplementary cementitious materials and concrete subjected to sulphate attack may be evaluated at a later age (56 or 91 days), as specified by the owner.*

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8.2.3 Splitting tensile strength

When tests are required, the splitting tensile strength of concrete shall be measured in accordance with CSA A23.2-13C from tests performed on 150 mm × 300 mm cylinders.

Table 1
Summary of test methods for concrete for qualification information requirements
(See Clauses 7.3 and 8.2.1.)

	Test methods	Typical test duration	Required for
Compressive strength	CSA A23.2-3C, CSA A23.2-9C	Normally 28 days, up to 56, or as otherwise specified	All concrete
Slump	CSA A23.2-5C	N/A	All conventional concrete
Slump flow	CSA A23.2-19C	N/A	All self-consolidating concrete
Air content by pressure method	CSA A23.2-4C or 7C	N/A	All normal weight concrete
Air content by volumetric method	CSA A23.2-7C	N/A	All lightweight concrete
Air void system*	CSA A23.2-3C, ASTM C457	Minimum 7 days	C-XL, A-XL, C1, A1, C2, A2, F1, S1, S2, S3
Density of plastic concrete	CSA A23.2-6C, or CSA A23.2-11C	N/A	If specified
Flexural strength	CSA A23.2-8C	Normally 28 days, up to 56, or as otherwise specified	If specified
Chloride ion penetrability	CSA A23.2-3C, CSA A23.2-23C	91 days or as specified	C-XL, A-XL, C1, A1
Linear shrinkage	CSA A23.2-21C	7-day cure plus 28 days	If specified
Salt scaling resistance	CSA A23.2-22C, BNQ NQ 2621-905/ 2012, Annex B, Article 7.6	105 days	If specified
Chloride ion content	CSA A23.2-4B, ASTM C1152/C1152M	28 days	If specified for all steel reinforced or pre-stressed concrete

* *See Clause 8.2.1 d).*

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A23.2-25C
Standard Practice for sampling, testing, and inspection of concrete for acceptance purposes

1 Scope

This Standard Practice specifies the procedures for sampling, testing, and inspection of concrete for purposes of assessing compliance with this Standard, and for acceptance of concrete by the owner.

Note: *See Table 5 and Clause 4.4 of CSA A23.1.*

2 Reference publications

This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2:19
Test methods and standard practices for concrete

A23.2-4B:19
Sampling and determination of water-soluble chloride ion content in hardened grout or concrete

A23.2-1C:19
Sampling plastic concrete

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-4C:19
Air content of plastic concrete by the pressure method

A23.2-5C:19
Slump of concrete

A23.2-6C:19
Density and yield of plastic concrete

A23.2-7C:19
Air content of plastic concrete by the volumetric method

A23.2-8C:19
Flexural strength of concrete (using simple beam with third-point loading)

A23.2-9C:19
Compressive strength of cylindrical concrete specimens

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A23.2-10C:19
Accelerating the curing of concrete cylinders and determining their compressive strength

A23.2-11C:19
Water content, density, absorption, and voids in hardened concrete, grout, or mortar

A23.2-13C:19
Splitting tensile strength of cylindrical concrete specimens

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

A23.2-15C:19
Evaluation of concrete strength in place using the pullout test

A23.2-16C:19
Determination of steel or synthetic fibre content in plastic concrete

A23.2-17C:19
Temperature of freshly mixed hydraulic cement concrete

A23.2-19C:19
Slump flow of concrete

A23.2-21C:19
Test Method for length change of hardened concrete

A23.2-22C:19
Scaling resistance of concrete surfaces exposed to deicing chemicals using mass loss

A23.2-23C:19
Electrical indication of concrete's ability to resist chloride ion penetration

A283-06 (R2016)
Qualification Code for concrete testing laboratories

CAN/CSA-ISO 9001:16
Quality management systems — Requirements

ACI (American Concrete Institute)

ACI 214R-11
Guide to Evaluation of Strength Test Results of Concrete

ACI 228.2R-98 (R2004)
Nondestructive Test Methods for Evaluation of Concrete in Structures

ASTM International

C457-16
Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

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C597-16
Standard Test Method for Pulse Velocity Through Concrete

C803/C803M-18
Standard Test Method for Penetration Resistance of Hardened Concrete

C805/C805M-18
Standard Test Method for Rebound Number of Hardened Concrete

C873/C873M-15
Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Moulds

C1074-17
Standard Practice for Estimating Concrete Strength by the Maturity Method

C1152/C1152M-04 (2010)e1
Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

BNQ (Bureau de normalisation du Québec)

2621-905/2012
Béton prêt à l'emploi — Programme de certification (élaboré à partir des exigences des chapitres 4, 5, et 8 de la norme CSA A23.1-F09/A23.2-F09)

3 Summary

The sampling, testing, and inspection procedures described are intended for assessment of concrete for compliance as delivered, and for acceptance of concrete by the owner based on physical properties of the concrete as delivered. The producer may use alternative sampling and testing procedures for internal quality control purposes during production.

These procedures specify the amount of testing to be done and the requirements for reporting on the conformance or non-conformance of products with specifications. See Clause 8.

Testing during construction is intended to assess the properties and characteristics of a concrete product as delivered and incorporated into the project, for the purpose of determining compliance with the requirements of this Standard and its acceptability to the owner.

4 Concrete test procedures

4.1

The project specifications shall identify testing requirements for the concrete that are appropriate to the scope, size, and nature of the project. Optional test methods should be used when appropriate to address significant performance requirements based on the applicable exposure conditions or size and scope of project.

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4.2

Laboratory test procedures undertaken to assess concrete quality shall be carried out by a testing laboratory meeting the requirements of Clause 4.4.1.6 of CSA A23.1.

Note: *Depending on the nature and scope of the project, internal concrete results from the concrete supplier might be acceptable for qualification purposes if personnel are certified in accordance with Clause 4.4.1.6 of CSA A23.1 and testing is carried out in accordance with the applicable procedures of CSA A23.2.*

4.3

Field sampling and test procedures undertaken to assess concrete quality at the point of delivery shall be carried out in accordance with the applicable procedures of CSA A23.2 by personnel certified to the requirements of Clause 4.4.1.6 of CSA A23.1 or under an industry-recognized program.

Note: *Such industry-recognized programs include*

a) *CSA A283, BNQ 2621-905 or CAN/CSA-ISO 9001 with equivalent scope to CSA A283; and*
b) *ACI Concrete Field Testing Technician Grade 1.*

5 Equipment and materials

The equipment and materials for sampling and testing shall meet the requirements of CSA A23.2, unless otherwise specified in this Standard Practice.

6 Reporting

Unless otherwise agreed, test results shall be provided to the owner, contractor, and concrete supplier within five working days of completion of the test. Both field and laboratory test reports shall include all information required by the applicable test methods of CSA A23.2.

Note: *Annex B of CSA A23.2 contains a sample report form for strength test results.*

7 Acceptance testing of concrete

7.1 Concrete acceptance

7.1.1 General

Concrete testing used as the basis for acceptance shall comply with all aspects of the applicable CSA A23.2 field and laboratory test methods and standard practices. Acceptance of the concrete shall be subject to the responsibilities in Clause 4 of CSA A23.1. Acceptance tests are summarized in Table 1.

Where there is more than one set of test results representing the same concrete sample available from multiple independent testing laboratories certified in accordance with the requirements of Clause 4.4.1.6 of CSA A23.1, all test results shall be considered by the owner unless there is a defined referee testing program in place.

Notes:

1) *The owner may implement a referee testing process to provide formalized means for challenge of concrete acceptance test results.*
2) *See ACI 214R for information regarding statistical evaluation of test results.*

7.1.2 Non-compliant test specimens

If any test specimen shows distinct evidence of improper sampling, making, curing, transporting, de-moulding, handling, curing, or testing, the test specimen shall be disregarded and declared invalid. The test results of the remaining test specimen(s) shall be considered the test result.

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7.2 Concrete test methods

7.2.1 Sampling concrete

Samples of concrete for testing purposes shall be obtained in accordance with CSA A23.2-1C. When the owner elects to assess the quality of concrete at a location other than the point of discharge from the delivery equipment, the owner shall state in the project specification the point at which the samples shall be taken.

Note: *The point at which the concrete is sampled will depend on the intended use of the test information. Where the test data are intended to give information on the properties of the concrete*

a) *as delivered to the site and used for the purposes of accepting the concrete, the concrete should be sampled at the point of discharge from the delivery equipment; or*

b) *as incorporated into the structure, the concrete should be sampled as close to the point of final deposit in the form as is practicable.*

7.2.2 Air content of concrete

7.2.2.1

Where concrete will be subjected to frequent cycles of freezing and thawing in the presence of moisture or de-icing chemicals [i.e., Class F-1, Classes C-XL, A-XL, C-1 and A-1 when exposed to freezing and thawing, and Class C-2 (see Table 1 of CSA A23.1)], every load or batch of concrete shall be tested until satisfactory control of the air content is established and fewer tests are required by the owner. Whenever a test falls outside the specified limits (see Table 4 of CSA A23.1), the testing frequency shall revert to one test per load or batch until satisfactory control is re-established.

7.2.2.2

Where exposure is less severe [i.e., Class F-2 (see Table 1 of CSA A23.1)], air content determinations may, at the discretion of the owner, be less frequent than those specified in Clause 7.2.2.1.

7.2.2.3

An air content determination shall be made with every strength test for all classes of concrete.

7.2.3 Compressive strength

7.2.3.1 Cylinder size

For standard strength tests, 100 mm × 200 mm cylinders shall be used. The cylinder size shall, however, meet the aggregate size limitations specified in Clause 8.2 of CSA A23.2-3C. Where required by the specific test method, 150 mm × 300 mm cylinders shall be used.

Note: *Other situations requiring 150 mm × 300 mm cylinders include autogenous strength, no-slump concrete and splitting tensile tests.*

7.2.3.2 Test age

Cylinders shall be tested at an age of 28 days unless otherwise specified.

Note: *When structural requirements permit, the specified strength requirements for mass concrete, high strength concrete, high performance concrete, concrete with high volumes of supplementary cementitious materials and concrete subjected to sulphate attack may be evaluated at a later age (56 or 91 days), as specified by the owner.*

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7.2.3.3 Frequency of acceptance testing of concrete

Not less than one set of tests in accordance with Clause 7.2.3.4 shall be made for each 100 m³ (or part thereof) of concrete placed for all concrete classes. When the frequency of testing stipulated will provide fewer than three sets of tests results for a given class of concrete, the testing shall be performed from at least three randomly selected batches on a single project.

For concrete classes subject to particular exposure conditions as described in Table 1 of CSA A23.1 or subject to specific performance requirements, additional tests in accordance with Clause 7.2.3.5 may be required at a frequency as specified by the owner in the contract documents.

A minimum of one set of test results shall be required per day for concrete of a single mix design. When high-performance or high-strength concrete is involved, or where structural requirements are critical, the owner may require a higher frequency of testing, which shall be defined in the contract documents.

Note: *When the total quantities of concrete produced from the same mix design are less than 50 m³, the testing may be waived by the owner if, in the owner's judgment, adequate evidence of satisfactory performance is provided.*

7.2.3.4 Testing for concrete acceptance for all concrete classes

Test results for the acceptance of concrete shall include:

a) Compressive strength of concrete for all classes of concrete. Specimens used as a basis for acceptance of concrete shall be made and cured in accordance with CSA A23.2-3C and standard tests shall be carried out in accordance with CSA A23.2-9C. For a strength determination a minimum of two test cylinders shall be tested.
b) The temperature of plastic concrete determined in accordance with CSA A23.2-17C.
c) Slump tests made in accordance with CSA A23.2-5C, or slump flow tests made in accordance with CSA A23.2-19C. A slump or slump flow test shall be made with every strength test and every second or third air test.
d) Plastic air content in accordance with CSA A23.2-4C or A23.2-7C. Where low-density aggregate concrete is used, air content determinations shall be made in accordance with CSA A23.2-7C (volumetric method), except that CSA A23.2-4C (pressure method) may be used if comparative conditions are established and are frequently checked.

Notes:

1) *Since it is essential to know whether the total air content of concrete is within specified limits, air content determinations may be made on samples taken from the first portion of the concrete prior to placement. The amount of entrained air for acceptance purposes, however, should be determined on samples taken in accordance with Clause 7.2.1.*
2) *A sufficient number of tests should be made to ensure uniform slump or slump flow of the concrete.*

7.2.3.5 Additional testing for concrete acceptance based on concrete class or application

7.2.3.5.1 Plastic concrete testing

When specified by the owner in the contract documents, acceptance testing of concrete may include the following at a specified frequency:

a) density of plastic concrete measured in accordance with CSA A23.2-6C, if required when a value or range of density of concrete is specified; and
b) determination of fibre content measured in accordance with CSA A23.2-16C.

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7.2.3.5.2 Hardened concrete testing

7.2.3.5.2.1 Air void testing of concrete

Where concrete requires Category 1 air-entrainment as noted in Table 2 of CSA A23.1 and the owner deems that testing be done for acceptance purposes, testing shall be carried out in accordance with ASTM C457, using a magnification between 100 and 125. Testing shall be carried out on cylinders made from concrete as delivered to the job site and moulded in accordance with CSA A23.2-3C. Testing may be done using cores if specified by the owner in the contract documents.

7.2.3.5.2.2 Other acceptance testing

Acceptance testing of concrete may also include the following:

a) chloride ion penetrability, for steel reinforced or pre-stressed concrete, carried out on cylinders made from concrete as delivered to the job site and moulded in accordance with CSA A23.2-3C, or on cores drilled from hardened concrete in the structure, tested in accordance with CSA A23.2-23C;
b) air-dry density, for low-density and semi-low-density concrete, measured in accordance with CSA A23.2-11C; and
c) flexural strength of concrete, measured in accordance with CSA A23.2-8C.

Notes:

1) *Materials, mix proportions, and mixing procedures are subject to normal variation during production. Provided that the air content is maintained within the specified tolerances, normal changes encountered in production do not require the re-evaluation of the spacing factor unless the sources or types of the cementitious material, admixture, or fine aggregate are different.*
2) *Transporting (especially pumping), along with consolidation of the concrete after discharge from the delivery equipment, usually reduces its air content and can cause significant changes in air-void systems. Air content should therefore be determined in the concrete as placed if freeze-thaw durability is important.*
3) *The chloride ion penetrability test should not be measured on concrete containing corrosion-inhibiting admixtures or metallic fibres, since the standard acceptance limits are not applicable.*
4) *The owner should establish sampling and testing frequency for acceptance of air void system parameters and chloride penetrability based on the needs of the specific project.*

7.2.4 Accelerated strength tests

When the accelerated strength test is used as an alternative to the standard cylinder test for the acceptance of concrete on the basis of strength, adequate correlation data to the standard 28 d compressive strength test shall be provided to the satisfaction of the owner. The owner shall specify in the contract documents if this alternative is to be used and state the basis for acceptance.

7.2.5 In-place strength tests

For in-place tests, a statistically valid number of tests shall be made. See Clause 7.2.10.

Note: *The number of tests will vary based on the test method used, the age at which tests are made, and the size of the placement that they represent. See ACI 228.2R or Annex A of CSA A23.2 for guidance.*

7.2.6 In-place strength

Unless otherwise specified by the owner, the in-place strength shall be determined in accordance with CSA A23.2-14C, CSA A23.2-15C, or ASTM C1074 for the purposes of determining:

a) when forms shall be removed or when prestressing or post-tensioning shall be applied;
b) when curing shall be terminated; and
c) when re-shores shall be removed.

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7.2.7 Cores from existing structures

Drilled cores shall be sampled and tested in accordance with CSA A23.2-14C.

Note: *If the cored specimen is to be used for determination of compressive strength at a given age, the specimen should be removed at that age.*

7.2.8 Field-cured specimens — Test procedure

When tests are required on specimens cured to simulate field conditions, additional specimens shall be made in accordance with CSA A23.2-3C. The test results of the field-cured specimens shall not be used as a basis for acceptance or rejection of the concrete.

Note: *Field-cured cylinders are subject to many types of variation and might not represent the strength of the structural element. In-place testing using CSA A23.2-15C is the preferred alternative when it is difficult to cure the specimens in conditions similar to the structural element they represent.*

7.2.9 Accelerated tests

When accelerated tests are specified, they shall be made in accordance with CSA A23.2-10C and standard cured 28 d compressive strength tests shall be made for at least every other accelerated test.

Notes:

1) *The standard cured 28 d compressive strength results can be predicted with reasonable accuracy using an accelerated test procedure. Such a procedure can be useful for quality control purposes, since it allows early adjustment to be made to the concrete mix proportions if required.*
2) *These tests do not indicate the strength gain of concrete under field conditions.*
3) *Three accelerated curing tests are currently in use in Canada (see CSA A23.2-10C for procedures). They are*
   a) *the modified boiling test;*
   b) *the autogenous curing test; and*
   c) *the warm water curing test.*
4) *Accelerated tests should only be used on projects in which there is a high degree of control of materials.*

7.2.10 Non-destructive in-place tests

Where in-place tests are specified, they shall be made in accordance with the appropriate test methods, as follows:

a) CSA A23.2-15C;
b) ASTM C597;
c) ASTM C803/C803M;
d) ASTM C805/C805M;
e) ASTM C873/C873M; and
f) ASTM C1074.

Note: *Testing programs to assess the strength of concrete in situ and interpretation of the results of non-destructive tests should follow the guidelines and recommendations provided in ACI 228.1R.*

7.2.11 Splitting tensile strength

When tests are required, the splitting tensile strength of concrete shall be measured in accordance with CSA A23.2-13C from tests performed on 150 mm × 300 mm cylinders.

8 Quality control

8.1 Owner's responsibility

The owner shall be responsible for quality assurance processes to verify that the requirements for concrete are met.

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8.2 Concrete supplier's responsibility

The concrete supplier shall be responsible for quality control processes to ensure and verify that the requirements for concrete as delivered are met.

Notes:

1) *The owner may require or accept an industry-recognized Concrete Facility Certification Program that is operated by members of the Canadian Ready Mixed Concrete Association.*
2) *Refer to BNQ 2621-905 for information on certification in the Province of Québec.*

Table 1
Acceptance information requirements
(See Clause 7.1.1.)

	Test methods	Typical test duration	Required for
Compressive strength	CSA A23.2-3C, CSA A23.2-9C	Normally 28 days, up to 56, or as otherwise specified	All concrete
Plastic concrete temperature	CSA A23.2-17C	N/A	All concrete
Slump	CSA A23.2-5C	N/A	All conventional concrete
Slump flow	CSA A23.2-19C	N/A	All self-consolidating concrete
Air content by pressure method	CSA A23.2-4C or 7C	N/A	All normal weight concrete
Air content by volumetric method	CSA A23.2-7C	N/A	All lightweight concrete
Air void system	CSA A23.2-3C, ASTM C457	Minimum 7 days	When required by owner*
Density of plastic concrete	CSA A23.2-6C, or CSA A23.2-11C	N/A	If specified
Flexural strength	CSA A23.2-8C	Normally 28 days, up to 56, or as otherwise specified	If specified
Chloride ion penetrability	CSA A23.2-3C, CSA A23.2-23C	91 days or as specified	C-XL, A-XL, C1, A1
Linear shrinkage	CSA A23.2-21C	7-day cure plus 28 days	If specified
Salt scaling resistance	CSA A23.2-22C; BNQ NQ 2621-905/2012, Annex B, Article 7.6	105 days	If specified
Chloride ion content	CSA A23.2-4B; ASTM C1152/C1152M	28 days	If specified for all steel reinforced or pre-stressed concrete

* *See Clause 7.2.3.5.2.*

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A23.2-26C
Bulk electrical resistivity of concrete

1 Scope

This Test Method covers the determination of the bulk electrical resistivity of saturated specimens of hardened concrete in order to provide an indication of its resistance to the penetration of fluids and aggressive ions.

2 Reference publications

This Test Method refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

A23.2-14C:19
Obtaining and testing drilled cores for compressive strength testing

A23.2-23C:19
Electrical indication of concrete's ability to resist chloride ion penetration

ASTM International

C1556-11a (2016)
Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion

C1760-12
Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete

Other publications

Barrett, T. 2015. *Improving Service Life of Concrete Structures Through the Use of Internal Curing: Impact on Practice*. Ph.D. thesis, Purdue University, West Lafayette, IN.

Hooton, R.D. and G. Charmchi. 2015. Adoption of Resistivity Tests for Concrete Acceptance. *ACI Special Publication SP-303, Proceedings, Recent Advances in Concrete Technology and Sustainability Issues*, 269–279.

Hooton, R.D., G. Charmchi, and E. Karkar. 2014. Development and Standardization of Rapid Methods for Assessing the Fluid Penetration Resistance of Concrete. *Proceedings, XIII International conference on the Durability of Building Materials*, 1111–1117.

Shahroodi, A. 2010. *Development of Test Methods for Assessment of Concrete Durability for Use in Performance-Based Specifications*. Toronto: MASc thesis, Department of Civil Engineering, University of Toronto.

Snyder, K.A., X. Feng, B.D. Keen, and T.O. Mason. 2003. Estimating the Electrical Conductivity of Cement Paste Pore Solutions from OH-, K+, and Na+ Concentrations. *Cement and Concrete Research* 33(6): 793–798.

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Spragg, R. P., J. Castro, T. E. Nantung, M. A. Paredes, and Weiss, J. 2012. Variability Analysis of the Uniaxial Resistivity Measured Using Concrete Cylinders. *Advances in Civil Engineering Materials*. 1(1):1–17.

Spragg, R., C. Villani, and J. Weiss. 2016. Electrical Properties of Cementitious Systems: Formation Factor Determination and the Influence of Conditioning Procedures. *Advances in Civil Engineering Materials*. 5:24–48.

Spragg, R., C. Villani, K. Snyder, D. Bentz, J.W. Bullard, and J. Weiss. 2013. Factors That Influence Electrical Resistivity Measurements in Cementitious Systems. *Transportation Research Record: Journal of the Transportation Research Board*. 2342:90–98.

3 Definition

In addition to the definitions specified in CSA A23.1, the following definition shall apply in this Test Method:

Concrete bulk resistivity — the electrical resistance through a saturated concrete specimen of a uniform measured thickness and uniform measured cross-section.

4 Summary

4.1

The electrical resistance of a saturated hardened concrete cylindrical specimen is measured using two plate electrodes with dimensions large enough to contact the entire end surfaces of the concrete specimen. A voltage is applied between the two electrodes across the whole cross-section of a specimen of uniform length, and the current is measured. The resistance is calculated from the ratio of the applied voltage to the measured current.

4.2

The bulk electrical resistivity is an intrinsic material property that is independent of the specimen shape or size. Resistivity is calculated from the measured electrical resistance and the specimen dimensions.

5 Significance and use

5.1

The electrical resistivity of a concrete is a measure of how fast charged species in the pore solution can be transported through the concrete under an applied electric field. This is directly related to the resistance of the pore system to ingress of fluids. The electrical resistivity is a material property that depends upon the pore volume, the pore structure (size and connectivity), the pore solution composition, the degree of saturation of the concrete specimen, and the specimen's temperature. Except for degree of saturation, pore solution composition, and temperature, these material properties are related to concrete quality, so the electrical resistivity of concrete may be used as part of a quality assurance program. Information and precautions contained in CSA A23.2-23C (Clause 4) are applicable.

5.2

The bulk electrical resistivity (ohm-m) of concrete is the inverse of its bulk electrical conductivity (S/m). Bulk electrical conductivity can also be measured by ASTM C1760.

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5.3

Factors that are known to affect concrete electrical resistivity, as well as chloride ion penetration include water-cementitious materials ratio, supplementary cementitious materials, the presence of chemical admixtures, air-entrainment, aggregate type, paste volume fraction, degree of consolidation, curing, and age.

5.4

This Test Method covers the determination of the electrical resistivity of water-saturated specimens of hardened concrete. The purpose of using lime-saturated water conditioning is to bring the test specimen to a level of near complete saturation. When comparing two different concrete samples, it is important to have both samples conditioned to the same saturation state so that values can be compared in a meaningful way. This is particularly true for using the resistivity, along with other information, to estimate the diffusivity. Resistivity measurements have shown good correlations with other electrical indication tests including CSA A23.2-23C (see Hooton and Charmchi, 2015; Hooton *et al.*, 2014). Bulk electrical resistivity results have shown good correlation with ASTM C1556 chloride bulk diffusion tests on companion cylinders cast from the same concrete mixtures (see Shahroodi, 2010).

Note: *Acceptance and rejection criteria for the various classes of exposure have yet to be determined for CSA A23.1.*

6 Interferences

6.1

When the test method is used to compare different concrete mixtures, the results can be misleading when certain admixtures containing water-soluble ionic compounds, such as calcium nitrite, are present in the concrete mixture. Chemical admixtures such as calcium nitrite can contribute to a lower electrical resistivity because they increase the conductivity of the pore solution*. This effect can be independent of the overall quality of the concrete because it has been shown that concretes with calcium nitrite can perform as well as control mixtures in long-term chloride ponding tests.

* *Other admixtures containing water-soluble ionic compounds might affect results of this test similarly. Additional tests are recommended if an admixture effect is suspected.*

6.2

Because the test results are a function of the electrical resistance of the specimen, the presence of reinforcing steel, metal fibers, or other embedded electrically conductive materials, including some types of aggregates, can yield unrepresentative results, as these will result in higher conductivity than a concrete of similar quality but with no embedded conductive material. The test is not valid for specimens containing reinforcing steel positioned longitudinally that is providing a continuous electrical path between the two ends of the specimen.

6.3

Leaching of ions from the pore solution of concrete is known to have a large impact on measured resistivity values. Even standard curing in saturated lime water can significantly influence the resistivity of the solution inside the pores of the concrete as alkali hydroxides are leached out. As such, if the concrete test specimens are immersed during conditioning, the volume of solution surrounding the test specimens should be minimized during curing such that a solution to specimen volumetric ratio of 2.0 is not exceeded (see Spragg *et al.*, 2016).

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6.4

Because concrete has a capacitive component, its electrical response is characterized by a magnitude and a phase difference that is a function of the AC frequency. This can have an effect on the measured test result. The desired quantity is the magnitude of the impedance that is measured at the frequency that yields the minimum phase difference between the applied current and the measured voltage; the system is behaving most like a resistor. A number of commercial devices operate at a single fixed frequency, typically between 10 Hz and 1 kHz. The degree to which a limited frequency range impacts the result has been found to be as high as 5% (see Spragg *et al.*, 2016).

6.5

Electrical resistivity is temperature-dependent, so all tests should be performed at the same temperature within ±2 °C (see Spragg *et al.*, 2016 and Spragg *et al.*, 2013).

7 Apparatus

The apparatus shall consist of the following:

a) bulk resistivity test device capable of supplying a voltage across the entire cross-section of the specimen, and measure the electrical current passing through the specimen and voltage drop across the ends of the specimen;

   Note: *Several bulk resistivity test devices are available commercially, but the voltage, frequency, and wave form are different with each device. Some devices display resistance or resistivity based on specimen geometry and others might display the electrical resistance of the specimen. In this Test Method, different devices may be used as long as they meet verification requirements in Clause 10.4.3.*

b) electrically conductive plate electrodes that will not corrode in a wet, alkaline exposure and with at least the same nominal diameter* as the ends of the specimens to be tested. Plate electrodes may be larger than the specimen diameter or cross-section;

   * *Rectangular specimens such as cubes or prisms may also be measured using electrodes of matching size and shape as the section to be tested.*

c) sponges or other water absorbent material to electrically connect the electrodes to the ends of the test specimen and that will not readily deteriorate in a wet alkaline exposure;

d) specimen holder to support the cylindrical specimen for tests conducted horizontally. It shall be made of rigid plastic or other non-electrically conductive material; and

e) non-electrically conductive surface, such as a rubber or plastic base or mat.

8 Reagents

The reagent shall be conductive fluid consisting of an electrically conductive liquid that is applied to each electrode to ensure electrical contact with the surface of the concrete. The apparatus manufacturer's instructions regarding the composition and use of a conductance fluid shall be followed.

Note: *In the absence of specific instructions, potable water is sufficiently conductive to be used as a conductance fluid. Distilled or deionized water should not be used due to its low electrical conductivity.*

9 Hazards

This Test Method does not purport to address the safety problems associated with its use. The user of this Test Method shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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10 Test specimens

10.1 Specimen selection

10.1.1

A test result shall be the average of determinations from at least two specimens.

10.1.2

Specimen preparation and selection depends on the purpose of the test. For evaluation of concrete-making materials or their proportions, specimens may be either

a) cores of 95–102 mm diameter;
b) 100–102 mm diameter cast cylinders; or
c) any specimen of constant cross-section and thickness.

Note: *In Items b) and c), cubes, prisms, or larger size cylinders may also be used, provided that the resistivity values take into account the different dimensions. The nominal maximum coarse aggregate size in the concrete test specimen should be no greater than 1/3 of the minimum specimen dimension.*

10.1.3

Samples shall be selected and cored following procedures in CSA A23.2-14C. Cylinders cast in the laboratory shall be prepared following procedures in CSA A23.2-3C. When cylinders are cast in the field to evaluate a structure, the cylinders shall be provided with the same temperature and moisture environment as the structural work and shall receive the same treatment as the structure (for example, similar degree of consolidation, curing, and temperature history during curing).

Note: *Cylinders are saturated for at least 7 days prior to test in accordance with Clause 10.3.*

10.1.4

Unless specified otherwise, test specimens shall be moist cured in accordance with CSA A23.2-9C, but shall be saturated for at least 7 days immediately prior to testing following the procedure in Clause 10.3.

Note: *This Test Method may be performed at various test ages and after various curing regimens to meet guidelines or specifications of specifying authorities.*

10.2 Preparation of specimen end surfaces

The end surfaces of concrete test specimens may be ground or saw cut before performing the bulk resistivity test.

Note: *Saw cutting or grinding may be used to make ends of test specimens sufficiently plane and parallel for measurement of length.*

10.3 Specimen saturation

Concrete specimens shall be continuously immersed in lime-saturated water for at least 7 days prior to test (see Clause 6.3). This shall be assumed to be sufficiently saturated for the purposes of this test.

Note: *The degree of saturation of the pores inside the test specimen is known to greatly influence the measured resistivity.*

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10.4 Verification

10.4.1

Prior to testing concrete specimens on a given day, the accuracy of measurements made by the bulk resistivity device shall be verified over the range of expected values of resistivity by following the procedure specified in Clauses 10.4.2 to 10.4.5.

10.4.2

The accuracy of the instrument shall be verified with a verification cylinder that has fixed resistivity values, switchable in order to cover the range of expected test values.

Note: *Use of a verification cylinder allows testing of the bulk resistivity device together with electrodes and sponges saturated with conductive fluid.*

10.4.3

The verification cylinder shall be a cylinder of 100 mm diameter and 200 mm length or one having the same cross-section as the concrete specimens to be tested, made of electrically non-conductive material and fitted with conductive stainless steel plates at each end. Inside the cylinder, at least five precision resistors with tolerances no greater than ± 0.01% of their nominal value shall be connected in parallel between the two end plates and provided with switches so that only one resistor is connected at any one time.

Note: *A suitable verification cylinder with six known resistivity values is produced by Germann Instruments Inc., 8845 Forest View Road, Evanston, Illinois 60203 USA. Because the dimensions of the cylinder are fixed, resistor values are shown on the cylinder as resistivity values in unit of ohm-m.*

10.4.4

Conductive fluid shall be applied to saturate sponges at each electrode of the resistivity instrument and the sponges shall be connected to the end plates of the verification cylinder using the same procedure as to be used when testing concrete specimens. The resistance or calculated resistivity shall be measured across each of the five resistors sequentially. Each of the five measured values shall be within 2% of the certified values provided with the verification test device.

10.4.5

If verification is not initially achieved, then the following steps shall be conducted:

a) remove the verification cylinder;
b) apply more conductive fluid to the sponges; and
c) re-insert the verification cylinder into the test device, using the manufacturer's recommended procedures.

If the instrument does not read within 2% of known values, it shall not be used.

11 Procedure

11.1

The specimen shall be conditioned and maintained at 23 ± 2 °C for at least 1 h prior to test.

11.2

The test shall be conducted on a non-electrically conductive surface such as a rubber or plastic base or mat.

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11.3
The test specimen shall be removed from the water tank, excess water shall be blotted off, and the specimen shall be transferred to sample holder. To minimize drying of the concrete surface, the specimen shall not be left exposed to air for longer than 5 min before performing resistivity test.

11.4
Four specimen lengths and two cross-sectional diameters taken at 90° to each other shall be measured and the average values shall be recorded to the nearest millimeter.

11.5
The sponges shall be saturated with conductive fluid and placed between the plate electrodes and end surfaces of the specimen with water. The bulk resistivity electrodes and sponges shall be centered on the ends of the specimen and the sponges shall be pressed against the end faces of the specimen.

Note: *To obtain reproducible measurements, sufficient pressure needs to be applied to provide firm contact between the electrodes and the specimen. This can be provided using a clamping device, bolts, or use of a weight of at least 1 kg on top of the top electrode of a vertically oriented test setup.*

11.6
Measurements shall be made on the test specimen in accordance with the manufacturer's instructions.

Note: *For test instruments with capabilities to measure alternating current at variable frequency, tests should be performed at 1 kHz, unless otherwise specified.*

11.7
The values shall be recorded after the readings stabilize, which could take 2 s or more. For devices that perform this calculation internally, the resistivity shall be recorded. For devices that display electrical resistance, the value of resistance shall be recorded in ohms. The electrodes shall be removed from the specimen, the electrodes shall be reapplied, and the measurement shall be repeated. At least two measurements shall be taken and measurements shall be repeated until two consecutive measurements do not differ by more than 0.5 ohm-m of each other for readings lower than 100 ohm-m, and 1.0 ohm-m for readings equal to or greater than 100 ohm-m. The average of the final two measurements shall be recorded.

12 Calculation

12.1
For devices that measure the current and voltage, bulk electrical resistivity in ohm-m shall be calculated as follows:

$$\rho = \frac{V}{I}\frac{A}{L}$$

where

L = specimen length, m

A = specimen cross-sectional area, m²

V = voltage, volts

I = current passed through the specimen, amperes

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12.2
For devices that display the electrical resistance, *R*, of the specimen, the bulk electrical resistivity shall be calculated as follows:

$\rho = RA/L$

12.3
The average resistivity for the set of replicate samples tested shall be calculated in ohm-m and shall be reported to the nearest 0.1 ohm-m.

13 Reporting

13.1 Required information
The report shall include following information:
a) source of core, if removed from a structure, report location from within the structure;
b) sample number or identification marks of core or cylinder specimen;
c) type of concrete, including cementitious materials type, water to cementitious materials ratio, and other relevant data supplied with samples;
d) description of specimen, including diameter and length to nearest mm, presence and location of reinforcing steel, presence and thickness of an overlay, and presence and thickness of a surface treatment;
e) curing history and age of specimen;
f) date of test;
g) bulk electrical resistivity;
h) type of resistivity device used as well as current frequency, for devices with variable frequency;
i) identification of the certified laboratory (i.e., name and address) responsible for laboratory curing and testing the specimens;
j) name of the certified technician(s) who performed the test;
k) name and signature of the person responsible for the review of the test reports; and
l) any deviation from the test procedure.

13.2 Optional information
The report may include the following information:
a) name of certified technician who sampled the concrete;
b) date sample was taken;
c) date received by the test laboratory; and
d) sample source or sample location, or both.

14 Precision and bias

14.1 Precision

14.1.1
A test program was completed with 12 laboratories using one of the commercially available devices. Tests were conducted on nominal 100 × 200 mm concrete cylinders stored in saturated in saturated lime water and using thin sponges also saturated with lime water to connect the electrodes to the concrete specimen. Tests were conducted on seven 28-day old concrete mixtures and twelve 56-day and 91-day old concrete mixtures (Spragg *et al.*, 2012).

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14.1.2

The maximum pooled single-operator coefficient of variation was found to be 4.36%. Therefore, the results of two properly conducted tests by the same operator on the same concrete material at the same age are not expected to differ by more than 12.34% of their average.

14.1.3

The maximum pooled multi-laboratory coefficient of variation was found to be 13.22%. Therefore, the results of two properly conducted tests by different laboratories on the same concrete material at the same age are not expected to differ by more than 37.38% of their average.

14.2 Bias

Because there is no accepted reference material suitable for determining the bias in this Test Method, no statement of bias is made.

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Attachment A1 (informative)
Interpretation of results

Note: *This Attachment is not a mandatory part of this Test Method.*

A1.1 Interpretation of results

The qualitative terms in the left-hand column of Table A1.1 correspond with qualitative chloride ion penetration values provided in Test Method CSA A23.2-23C. The numerical bulk electric resistivity, in ohm-m and bulk electric conductivity values were calculated from the charge passed CSA A23.2-23C Coulomb values using Ohm's law and specimen dimensions.

Table A1.1
Theoretical equivalence of CSA A23.2-23C coulomb ranges to equivalent ranges of bulk electrical resistivity and bulk electric conductivity (adapted from Spragg et al 2012)

Chloride ion penetrability	CSA A23.2-23C charge passed (coulombs)	Bulk electrical resistivity (Ω.m)	Bulk electrical conductivity (mS/m)
High	> 4000	< 50	> 190
Moderate	2000–4000	50–100	190–100
Low	1000–2000	100–200	100–50
Very low	100–1000	200–2000	50–5
Negligible	< 100	> 2000	< 5

A1.2 Formation factor

A1.2.1

Electrical tests of concrete including CSA A23.2-23C and ASTM C1760 are influenced by the conductivity of the pore fluid in addition to the porosity and pore connectivity. Only the latter factors, however, are indicative of the resistance of concrete to fluid penetration. This interference can be removed by converting electrical resistivity values to results expressed as a formation factor.

A1.2.2

The formation factor is a material property that only depends on the pore geometry and connectivity. The formation factor is defined as the ratio of the resistivity of a bulk body (ρ) to the resistivity of the pore solution in the body (ρo), $F = \rho/\rho o$. The resistivity of the pore fluid can be determined by calculation using a mathematical model (see Clause A1.2.3) based on mixture proportions and the alkali content of the binder, by pore solution extraction and conductivity measurement, or by direct measurement of conductivity with an embedded sensor (Barrett, 2015).

A1.2.3

The resistivity of the pore solution (ρo) (ohm-m) is the inverse of pore solution conductivity (S/m). Based on the work reported by Snyder (Snyder *et al.*, 2003), pore solution conductivity can be estimated using the on-line calculator by following the link: https://www.nist.gov/el/materials-and-structural-systems-division-73100/inorganic-materials-group-73103/estimation-pore.

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A1.2.4

If corrections for testing temperature, degree of saturation, and leaching of alkalis in the pore solution from immersion in lime-saturated water are neglected, the measured resistivity is divided by the resistivity of the pore solution resistivity at saturation, and the uncorrected formation factor can be obtained. If concretes are conditioned to the same degree of saturation and resistivity is measured at 23 ± 2 °C, then no degree of saturation or temperature correction is required.

A1.2.5

Because of alkali leaching, curing in lime-saturated water was found to overestimate uniaxial resistivity measurements by approximately 40%. However, storage in an artificial pore solution, similar to the real pore solution of the system being analyzed, reduced this error (Spragg *et al.*, 2016).

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A23.2-1D
Moulds for forming vertical concrete test cylinders

1 Scope
This Standard Practice specifies the requirements for moulds used as cylindrical concrete specimens. The provisions of this Standard Practice include requirements for both reusable and limited-use moulds and test methods for elongation, absorption, and watertightness of paper moulds.

2 Reference publications
This Standard Practice refers to the following publications, and where such reference is made, it shall be to the editions listed below, including all amendments published thereto:

CSA Group

A23.1:19
Concrete materials and methods of concrete construction

A23.2-7B:19
Random sampling of construction materials

A23.2-3C:19
Making and curing concrete compression and flexural test specimens

ISO (International Organization for Standardization)

3310-1:2016
Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth

3 Definitions
In addition to the definitions specified in CSA A23.1, the following definitions shall apply in this Standard Practice:

Limited-use moulds — moulds that are made of non-absorptive materials and used for a maximum of five times and discarded.

Reusable moulds — moulds that are made of non-absorptive materials and designed with sufficient thickness to be used more than five times.

4 Significance and use
This Standard Practice is intended to provide standard requirements for moulds, both reusable and limited-use, when used to cast cylindrical concrete specimens.

5 Hazards
This Standard Practice does not purport to address the safety problems associated with its use. The user of this Standard Practice shall establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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6 General requirements

6.1
Moulds shall be constructed with the cylindrical axis vertical and the top open to receive the concrete.

6.2
Moulds shall be made of materials that do not react with concrete containing Portland or other hydraulic cementitious material.

6.3
Moulds shall be watertight, sufficiently strong, and impermeable to permit their use without scratching, tearing, crushing, or deforming.

6.4
Reusable and limited-use moulds shall be constructed in such a fashion as to preserve their characteristics for the number of reuses foreseen by the manufacturer and by the requirements outlined in this Standard Practice. They shall be considered reusable for as long as they permit the moulding of concrete cylinders to conform to the requirements of Clause 6.

6.5
Limited-use moulds shall be used a maximum of five times, marked after every use, and stored properly to eliminate deformation.

6.6
The construction of the mould shall permit the demoulding operation to be carried out without affecting the characteristics of the mould.

7 Dimensions

7.1
Moulds shall have a nominal inside height equal to twice the nominal inside diameter.

7.2
The average diameter of a mould shall not differ from the nominal diameter by more than 1%.

7.3
The average height shall not differ from the nominal height by more than 2%.

7.4
The planes of the top rim of the mould and the bottom shall be perpendicular to the axis of the mould within 0.5° (approximately equivalent to 3 mm in 300 mm).

7.5
No diameter of a mould shall differ from any other diameter of the same mould by more than 2%.

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7.6
An inside crimp, if used, shall produce an indentation around the circumference of the cylinder of no more than 5 mm.

8 Precision and bias
Precision and bias information for this Standard Practice is not applicable.

9 Test methods for elongation, absorption, and watertightness of paper moulds

9.1 Scope
This Test Method provides requirements for paper moulds used as cylindrical concrete specimens.

9.2 Summary of test method
A paper mould is assembled on an absorption-elongation test apparatus and the dimensions of the mould are measured before and after the test with a precision of ±0.1 mm.

9.3 Significance and use
This Test Method is intended to provide standard requirements and procedures to determine elongation, absorption, and watertightness of paper moulds.

9.4 Apparatus
The apparatus shall include an assembly for the absorption-elongation test of paper moulds that follow the principles illustrated in Figure 1.

9.5 Sampling
Sample moulds shall be selected at random, as described in CSA A23.2-7B, in such numbers as are necessary to ensure that the moulds are in compliance with the requirements.

9.6 Test procedure
The test shall be performed as follows:

a) Assemble moulds with the sealant to be used, if required, or as delivered by the manufacturer with the proper release agent.
b) Measure the dimensions of the mould before and after the test with a precision of ± 0.1 mm.
c) Measure two interior diameters at a right angle to each other at 25%, 50%, and 75% of the height of the mould, and average the six measured diameters.
d) At each end of two diameters at a right angle to each other, measure the height of the cylinder at a distance of 10 mm from the side and average the four measurements.
e) Fill and compact the mould by the rodding procedure specified in CSA A23.2-3C, using a dry, crushed stone coarse aggregate meeting the grading shown in Table 1.

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Table 1
Grading of coarse aggregate
(See Clause 9.6.)

Nominal size sieves with square opening	Percent passing by weight
28	100
20	90-100
14	*
10	20-55
5	0-10
2.5	0-5

* *No passing requirement.*

Notes:

1) *In some instances, it will not be possible to obtain the penetration of the tamping rod specified in CSA A23.2-3C.*
2) *Sieve designations are nominal aperture sizes in accordance with Table 1 of ISO 3310-1 made with the preferred wire diameter.*

f) After rodding the final layer, empty the coarse aggregate, wipe lightly with a dry cloth, and examine the mould for physical damage. Determine the mass of the mould and record to the nearest ±0.004 g/mm of mould height. Place the mould on a firm, flat surface and fill with water at room temperature to a depth of 90% to 95% of the mould height. Then place the mould on the dial stand, cover with the glass or metal plate, and record the initial length by dial micrometer to the nearest 0.02 mm.

g) Allow the mould to stand for 3 h and take a final reading of the micrometer. Examine and record any visible leakage. Empty water from the mould, dry lightly with a towel, and record the final mass to the nearest ±0.004 g/mm of mould height.

h) Calculate the elongation as the difference between the final and initial height. Calculate the absorption, expressed as mg/mm², as the difference between the final mass and initial mass of the mould and divide by the exposed interior surface of the mould in mm².

9.7 Requirements

When tested in accordance with Clauses 9.1 to 9.6, the moulds shall meet the following criteria:

a) watertightness: there shall be no visible leakage;
b) absorption: the absorption shall not exceed 0.17 mg/mm² of exposed surface;
c) dimensions: the mould shall meet the requirements of Clause 7; and
d) dimensional stability: the elongation of the height shall be not more than 0.2%.

9.8 Reporting

9.8.1 Required information

The report shall include the following information:

a) the brand or source of mould;
b) the shipment or lot from which the mould was taken;
c) the date sampled and date tested;
d) a brief, general description of the mould, including nominal dimensions, type of mould, and materials of which it is made;
e) the total absorption, mg/mm²;

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f) the total expansion in percentage of the height;
g) watertightness, reported in terms of compliance or failure by leakage; and
h) name of certified technician who performed the testing.

9.8.2 Failure to meet specification

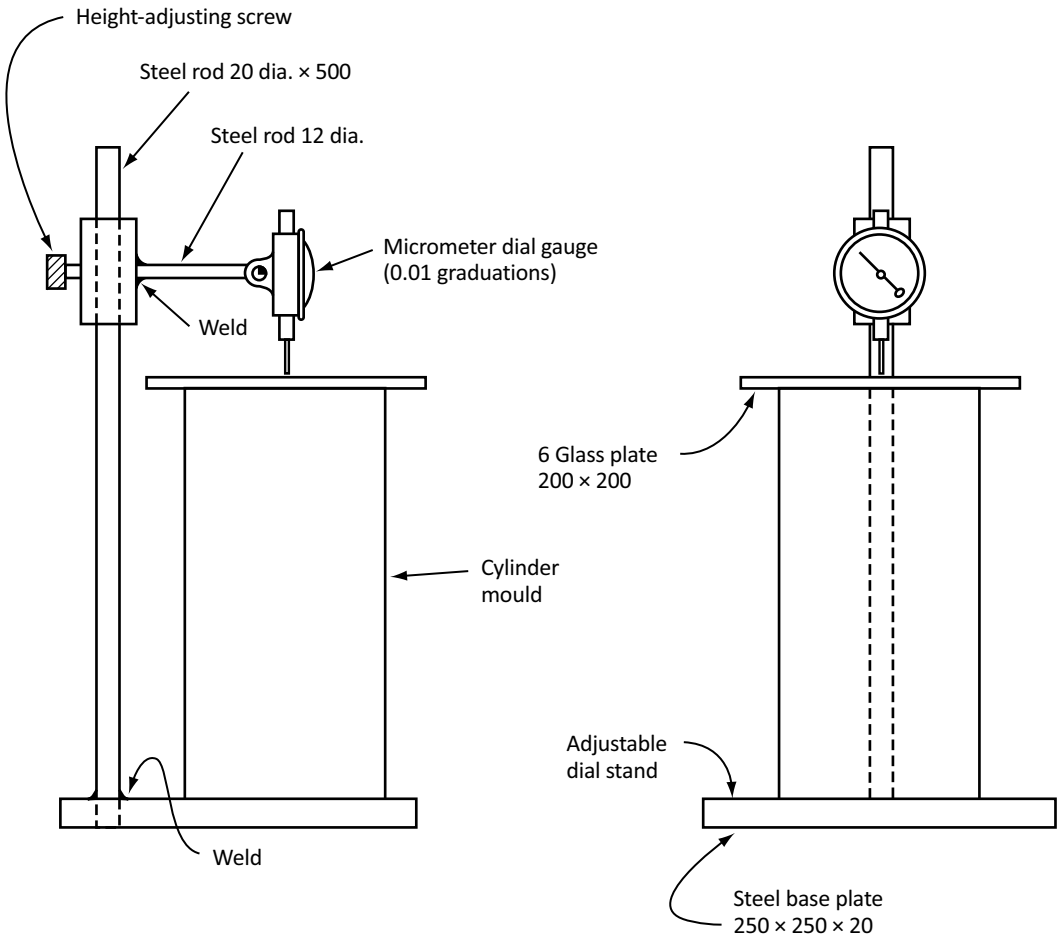
Where applicable to the type of mould tested, the report for samples that do not meet the requirements of the specification shall include the following:

a) the average diameter or height, mm;
b) the maximum and minimum diameters or heights, mm;
c) any nonconformance with required perpendicularity of rim or base to the axis of the mould; and
d) any apparent reaction between mould materials and concrete or mortar or corrosion of metal in contact with concrete.

9.9 Precision and bias

No precision and bias statement has been established for this Standard Practice.

Figure 1
Apparatus for absorption-elongation test of paper moulds
(See Clause 9.4.)



Note: *Dimensions are in millimetres.*

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Annex A (informative)
Nondestructive methods for testing concrete

Note: *This Annex is not a mandatory part of this Standard.*

A.1 Introduction

A variety of methods are in use in Canada, as well as other countries, for evaluation of hardened, in-place concrete by nondestructive means. In general, it must be realized that each method has definite limitations and that interpretation of the various test results requires an awareness of these limitations. Because of this, the examination of concrete by these methods should be undertaken only in accordance with a scope, an objective, and systematic procedures, all agreed upon in advance by the responsible parties. Users are cautioned against accepting nondestructive test data under the assumption that they have an exact and definite constant correlation to the traditional 28 d compression test cylinder results. Any such estimation of strength data requires a full correlation of the test method in question with the specific concrete being tested, and must be performed over a range of compression strength values. Evaluation of a number of nondestructive test methods has been conducted both in the laboratory and in field practice.

Note: *Further details can be obtained by consulting the publications listed in Clause A.4.*

A.2 Purpose of nondestructive tests (NDT)

A.2.1

An NDT program can be undertaken for a variety of purposes, including

a) the estimation of in situ concrete strength;
b) the estimation of rate of strength gain, such as would be required to determine the earliest safe time for form removal or post-tensioning, or, in cold weather, to monitor the effectiveness and economics of curing and protection;
c) the detection of nonhomogeneity in concrete masses (i.e., the delineation of regions differing from the bulk concrete properties);
d) the estimation of the relative strength of comparable concrete members; and
e) the evaluation of concrete deterioration.

A.2.2

Regardless of the type of NDT test used, adequate and reliable correlation with compressive strength data, or other properties of interest, is necessary. In addition, design of the NDT program and interpretation of results by an experienced concrete technologist is mandatory.

A.3 NDT methods

A.3.1 General

This Clause concerns the tests commonly used in Canada for the evaluation of in situ concrete. Unlike the ultrasonic, maturity, impact-echo, and ground penetrating radar techniques, some test methods typically described as NDT are not truly nondestructive, though the amount of concrete surface repair required is usually nominal.

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A.3.2 Methods

A.3.2.1 NDT methods

In recent years, a number of NDT methods have become practical and economical through commercial development of suitable apparatuses. These include the tests described in Clauses A.3.2.2 to A.3.2.9.

A.3.2.2 Surface impact test

This test involves recording the rebound distance of a spring-activated plunger that strikes the concrete surface. The test is expeditious and economical. Large areas can be tested quickly. Results are only representative of the immediate area being tested and are affected by surface conditions, moisture content, aggregate properties, existence of frost, and the degree of surface carbonation. ASTM C805/C805M describes the test procedure.

A.3.2.3 Penetration test

Either a spring driven pin or a gunpowder-activated projectile is driven into the concrete, with the depth of penetration being the measurement of interest. This test is influenced by the condition of the concrete surface and the type of aggregate used. Correction for aggregate hardness is required. ASTM C803/C803M describes the test procedures.

A.3.2.4 Cast-in-place test

This procedure consists of casting a cylindrical sample within the structure by use of a mould, which can later be removed. The retrieved cylinder sample is then tested for compressive strength. ASTM C873/C873M describes the procedure.

A.3.2.5 Ultrasonic pulse velocity (UPV) test

An instrument measures the time required for an ultrasonic sound pulse to travel through the concrete, from a transmitting transducer to a receiving transducer. The transducers can be placed on two different surfaces of the concrete, or on at different locations on the same surface. From this transit time, a velocity is calculated using the measured straight-line distance between the two transducer locations. The velocity of sound through a solid medium is proportional to the density of the material, and thus variations in density can be detected by observing changes in the calculated velocity. Since the strength of concrete is related to density the UPV test can be used to roughly estimate concrete strength, though a proper correlation is necessary. Even with reliable calibration, the correlation between pulse velocity and strength is not strong. By the same principle, the UPV technique can be effective in delineating areas of porosity, deterioration, damage, or cracking within a concrete member due to changes in the transit time as the sound pulse travels around such voids. The presence of reinforcing steel will have a large influence on test results and thus care must be taken when using the test on reinforced concrete sections in order to correctly assess the combined effect of the concrete and steel. ASTM C597 describes the test procedure.

A.3.2.6 Maturity tests

The maturity principle is based upon the theory that concrete strength gain is a function of the time and temperature history of the concrete. Temperature is monitored via a probe inserted into the concrete during casting, thus allowing a continuous estimation of concrete strength as hydration progresses. Results are particularly suitable in monitoring early strength gain. ASTM C1074 describes the procedure.

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A.3.2.7 Impact-echo tests

The impact-echo test method is used to estimate the distance between the surface of a concrete mass and another interface. For thin plates (e.g., slabs, decks, pavements) the second interface is typically the back face, thus providing an estimate of slab or deck thickness. It can also be used to detect other interfaces within a concrete mass, such as delaminations or large voids. Such measurements first require the user to determine the P-wave-dilatational or compression wave) velocity within the concrete. This is determined by measuring the time required for a stress wave generated by a short-duration point impact to travel between two transducers located a specified distance apart on the surface of the concrete and then calculating a velocity that is used to represent the through-thickness P-wave velocity. Separately, the frequency at which a P-wave is reflected between the surface of the concrete and the interface in question is measured. These two values (P-wave velocity and frequency of reflection) can then be used to calculate distance to the interface. Since the P-wave speed can vary from point-to-point in the structure due to differences in concrete age or batch-to-batch variability, the P-wave speed is measured at each point where a thickness determination is required. The impact-echo test can be used as a substitute for, or in conjunction with, coring to determine the thickness of concrete slabs, pavements, bridge decks, walls, or other plate-like structure. This test method is not applicable to plate structures with overlays, such as a concrete bridge deck with an asphalt or Portland cement concrete overlay. Additionally, implementation of the impact-echo method on deteriorated or damaged concrete is not advised due to the differential properties within the concrete caused by damage gradients and by changes to the relative magnitudes of surface measured and through-thickness P-wave velocities. ASTM C1383 describes the test procedure.

A.3.2.8 Ground penetrating radar

Ground penetrating radar (GPR) uses radar reflections to identify radar signatures of characteristic events such as layer interface, void events, and embedded objects such as rebar or pipes. Different dielectric constants (or the electrical properties) between two material layers will create an echo at the material boundary, which can be detected within the GPR trace. Variations in moisture content (such as moisture in cracks) can produce significantly different dielectric constants. These differences in dielectric constants will be detected as distinct layers in the GPR traces. GPR may not be effective in penetrating steel-fibre reinforced concrete. GPR evaluation procedures can be used to evaluate the condition of concrete bridge decks with or without asphalt concrete wearing surfaces. This test method predicts the presence or absence of concrete or rebar deterioration at or above the level of the top layer of reinforcing. ASTM D6087 provides test procedures.

A.3.2.9 Pullout strength tests

The pullout strength of concrete is obtained by measuring the force required to pull a metal insert cast into a mass of fresh concrete. The measured force can be correlated to an equivalent compressive strength of the concrete on standard cylinders through a correlation curve. Results are suitable for monitoring early strength gain, strength to determine form removal or post-tensioning times. Inserts are available that can be inserted into existing hardened concrete through drilled openings, though a proper correlation with compressive strength would be difficult or impossible. CSA A23.2-15C describes the test procedure.

A.4 Bibliography

ACI (American Concrete Institute)

228.1R-03
In-Place Methods to Estimate Concrete Strength

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228.2R-13
Nondestructive Test Methods for Evaluation of Concrete in Structures

ASTM International

C597-16
Standard Test Method for Pulse Velocity Through Concrete

C803/C803M-18
Standard Test Method for Penetration Resistance of Hardened Concrete

C805/C805M-18
Standard Test Method for Rebound Number of Hardened Concrete

C873/C873M-15
Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds

C1074-17
Standard Practice for Estimating Concrete Strength by the Maturity Method

C1383-15
Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method

D4748-10 (2015)
Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar

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Sansalone, M 1997. Impact-Echo The Complete story. *ACI Structural Journal* 94 (6): 777–786.

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Annex B (informative)
Form for reporting compressive strength of concrete test cylinders

Note: *This Annex is not a mandatory part of this Standard.*

Figure B.1
Sample form

CONCRETE FIELD TEST RESULTS

Project No.: _____

Project: _____

_____

Client: _____

_____

_____

Element Cast & Location Tested: _____

_____

_____

_____

_____

Placing Method: Chute: ☐ Pump: ☐ Extruder: ☐ Bucket: ☐

Test No.: _____ Other: _____

Information from Delivery Ticket

Supplier: _____

Truck No.: _____ Batch Time: _____

Ticket No.: _____ Mix No.: _____

Load Amount: _____ m^3 Cumulative: _____ m^3

Strength: _____ MPa Max Agg. Size: _____ mm

Cement Type: _____ Slump/Flow: _____ mm

Admixture: Air ☐ SP ☐ Acc. ☐ Air Content: _____ %

Other: _____ Winter Heat ☐

Contract Specifications as Provided

Same as Delivery Ticket: ☐ Not Available ☐

Strength: _____ MPa Test Age: _____ days

Slump/Flow: _____ ± _____ mm Air Content: _____ ± _____ %

Class of Concrete: _____ Cement Type: _____

Other: _____

Field Test Data

Sample Time: _____ Unit Weight: _____ kg/m³

Temperature: Air: _____ °C Concrete: _____ °C

Cast Slump/Flow: _____ mm Cast Air Content: _____ %

Initial Slump/Flow: _____ mm Initial Air Content: _____ %

VSI: _____ T_{50} cm: _____ seconds

Initial Slump before SP? ☐ AEA Added? ☐ Water Added? ☐

Initial Curing Temperatures: Minimum: _____ °C Maximum: _____ °C

Mould Type: Plastic ☐ Other: _____

MouldSize: 100 x 200 mm ☐ 150 x 300 mm ☐

Box ID/Location: _____

Sample Cast: yyyy / mm / dd hr:min By: _____

Transported: yyyy / mm / dd hr:min By: _____

Received: yyyy / mm / dd hr:min By: _____

Concrete samples cast by others? ☐ (If yes, see remarks)

Laboratory Test Data

Cylinder Number	Cylinder Mass (g)	Test Date YYYY/MM/DD	Age Days	Test By	Load kN	Strength MPa	Type of Fracture	Comments (note L/D if <1.8 or > 2.2

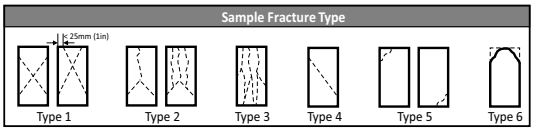
Distribution: _____

_____

_____

_____

Sample Fracture Type



Remarks: _____

_____

_____

_____

Reviewed By (name and signature) :

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