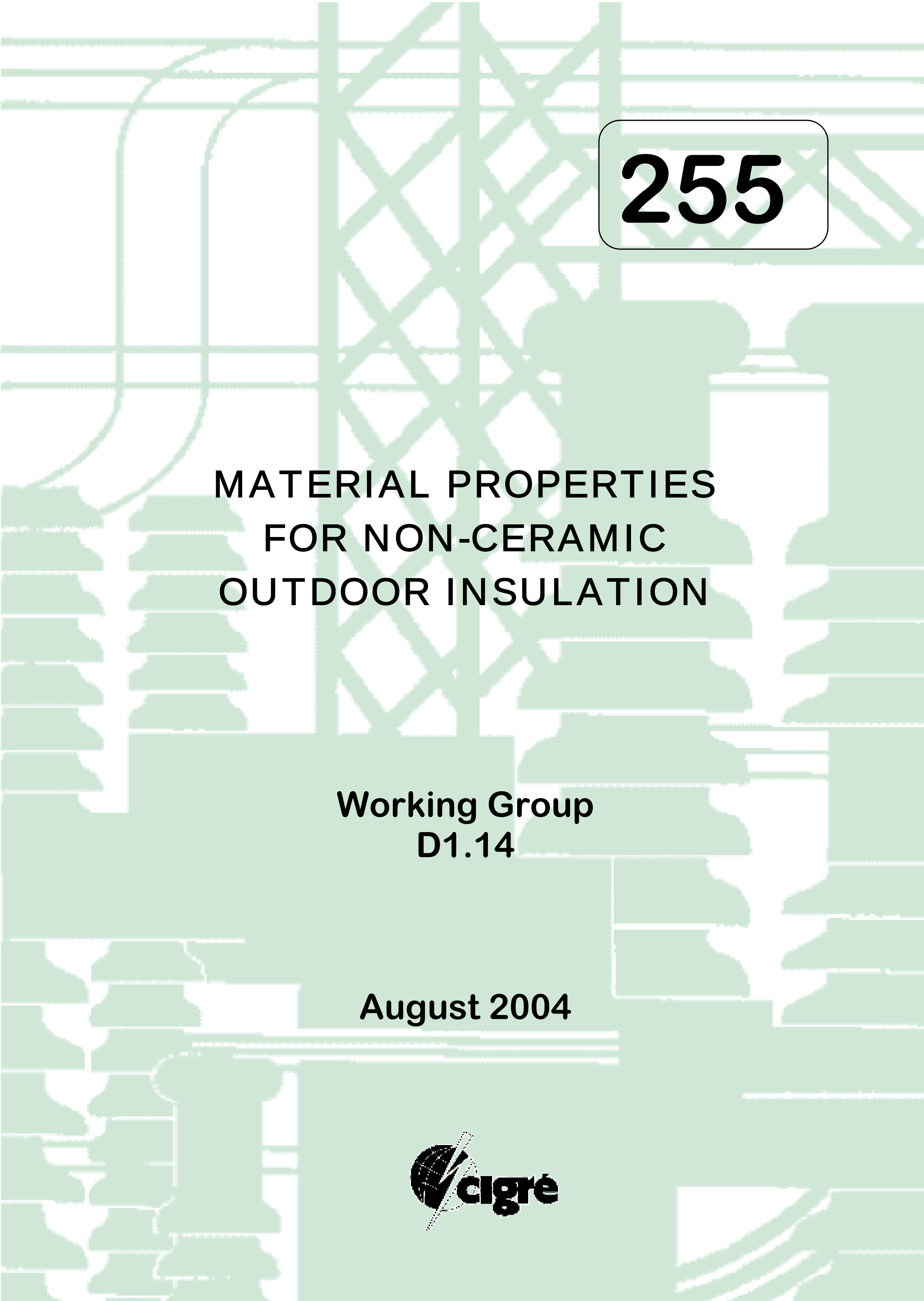


255

MATERIAL PROPERTIES FOR NON-CERAMIC OUTDOOR INSULATION

Working Group
D1.14

August 2004

Material properties for non-ceramic outdoor insulation

State of the art

prepared by

Working Group D1-14

Members: Birtwhistle, D. (AU), Brocard, E. (FR), Gorur, R. (US), Greyling, C. (ZA), Gubanski, S. (SE), Henriksen, M. (DK), Janssen, H. (DE), Kindersberger, J. (DE), Lambrecht, J. (DE), Lumb, C. (FR), Massen, U. (CH), Nagao, M. (JP), Ross, R. (NL), Schmuck, F. (CH), Seifert, J. (DE), Windmar, D. (SE), Winter, H-J. (DE), Vosloo, W. (ZA)

Copyright © 2004
"Ownership of a CIGRE publication, whether in paper form or on electronic support only infers right of use for personal purposes. Are prohibited, except if explicitly agreed by CIGRE, total or partial reproduction of the publication for use other than personal and transfer to a third party; hence circulation on any intranet or other company network is forbidden".
Disclaimer notice
"CIGRE gives no warranty or assurance about the contents of this publication, nor does it accept any responsibility, as to the accuracy or exhaustiveness of the information. All implied warranties and conditions are excluded to the maximum extent permitted by law".

SUMMARY

Within utilities and industry an urgent need was indicated for material standards, which define the physical properties of polymers applied for outdoor insulation. After discussions with IEC TC 36 and IEC TC 15, CIGRE SC D1 formed a WG with the specific task of defining the physical parameters important for the polymeric materials applied in outdoor insulation and to develop the relevant test methods where necessary.

This report lists the important material properties for polymeric materials used in outdoor insulation and where applicable, the standardised test methods already existing including the minimum requirements. If no standardised tests are available, then test methods reported in literature are summarised. According to their function in the insulation, three categories of insulating materials were considered:

1. Housing materials (in general a silicone rubber, EPDM, EVA etc)
2. Core materials (FRP etc)
3. Structural materials (Epoxy etc)

The properties are specified for housing, core and / or structural materials. For some properties several standardised test procedures are available. In such cases the most widely used is listed.

The conclusions made in this report are valid for insulating materials used in outdoor high voltage electrical applications with a system voltage greater than 1000 V (AC) having polymeric insulation including where the housing is an integral part of the devices such as in a surge arrester and cable terminations. The scope of the WG is limited to the materials only.

Twelve properties have been identified. Standardised test methods and minimum requirements where available for eight of them. For the remaining four properties, test methods and minimum requirements need to be defined. This is the future task of WG D1-14.

1 INTRODUCTION

There is an urgent need within utilities and industry for material standards, which define the physical properties of the polymers applied for outdoor insulation. This requirement was identified during discussions in IEC TC 36 and IEC TC 15. As a consequence, in the year 2001, CIGRE SC 15 formed a WG with the specific task of defining the physical parameters important for the polymeric materials applied in outdoor insulation and to develop the relevant test methods where necessary.

As a first step, this report lists the important material properties for polymeric materials used in outdoor insulation and where applicable, lists the standardised test methods already existing including the minimum requirements. If no standardised tests are available, then test methods reported in literature are summarised.

The conclusions made in this report are valid for insulating materials used in outdoor high voltage electrical applications with a system voltage greater than 1000 V (AC) having polymeric insulation including where the housing is an integral part of the devices such as in a surge arrester and cable terminations. The scope of the WG is limited to the materials only. The performance of insulators in service depends on several factors such as the type of material, the design, environmental conditions etc. Consequently, the choice of materials that fulfil the requirements listed below is a necessary condition but does not guarantee satisfactory performance when used in outdoor insulation.

1.1 IMPORTANT MATERIAL PROPERTIES

The WG has applied their existing experience in order to define the important properties that need to be tested on the material itself in order to ensure the functioning of the material under normal operating service conditions. Physical, mechanical and chemical properties of the materials have been considered

According to their function in the insulation, three categories of insulating materials were considered:

4. Housing materials (in general a silicone rubber, EPDM, EVA etc)
5. Core materials (FRP etc)
6. Structural materials (Epoxy etc)

Each property is explained in detail below with reasons why the specific property is considered to be of importance. The minimum requirements are, as far as possible, based on the experience of performance of non-ceramic insulators in service.

2 RESISTANCE TO TRACKING AND EROSION

2.1 INTRODUCTION

Electrical erosion is the wearing away of electrical insulating material by the action of electrical discharges [1]. Electrical erosion may appear as surface erosion or as digging erosion.

Tracking is the process that produces tracks as a result of the action of electrical discharges on or close to a contaminated surface of an insulating material. The *track* is a conducting path created by localized deterioration on the surface of an insulating material [1].

Why is the evaluation of the resistance to tracking and erosion important?

Surfaces of wet and polluted outdoor insulators may become stressed by surface discharges (dry band arcing). Dry band arcing may lead to erosion and/or tracking of the insulating material. Housing materials must show resistance to tracking and erosion to prevent non-erosion-resistive core and structural materials from being exposed to electrical discharges.

Erosion of the insulating materials leads to increased roughness. The more rough the surface is, the higher is the thickness of wet layers and the higher is the layer conductivity. That is why erosion may lead to a decreased pollution flashover voltage in comparison to a non-eroded insulator or an insulator without tracks.

Tracking of the most insulating materials leads to conductive tracking paths. The bridging of insulating material by such paths reduces the insulating ability of an insulating part.

Applicability

The evaluation of resistance to tracking and erosion is applicable to housing and structural materials only.

2.2 AVAILABLE TESTS

- "Inclined-Plane-Procedure" - the test procedure is described in the test standards IEC 60587, ASTM D 2303 or DIN IEC 60587

- "Dust- and- Fog-Procedure" - a test procedure is described in the test standard ASTM 2132. For the dust and fog procedure no international standard exists

- "Rotating-Wheel-Procedure" - the test procedure is described in the test standard IEC 61302 or European Standard EN 61302 - (German translation: DIN EN 61302)

2.3 TESTS AND MINIMUM REQUIREMENTS

All test procedures are applicable to all classes of materials.

The failure criteria of all procedures clearly indicate the tracking of the samples of the insulating materials (IEC 60587: leakage current of 60 mA, ASTM 2132: leakage current 100 ... 150 mA, IEC 61302: leakage current 300 mA).

The preferred procedure should be the inclined plane test procedure according to IEC 60587 (figure 2.1). The Inclined Plane procedure is the easiest, less time-consuming and the most reproducible test method of the above-mentioned.

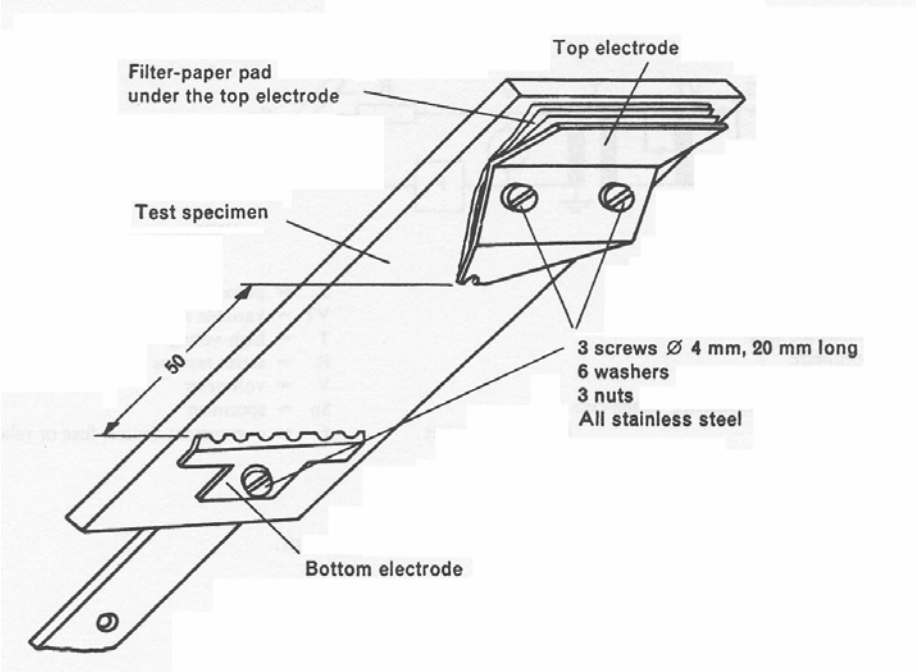


Figure 2.1 inclined plane test arrangement (in principle)

It is recommended to test according to method 1 (constant tracking voltage) and to classify according to criterion A (current criterion – 60 mA).

Field experience with polymeric housing and structural materials proof a minimum requirement of 1A3,5 according to IEC 60587.

Insulating materials for special medium voltage applications (for example x-linked PE) show a stability of class 1A2,5 but work well under service conditions. It has to be decided whether the minimum required class for insulating materials for medium voltage applications could be set to 1A2,5.

The specific weight loss of the specimen is useful additional information for the comparison of different insulating materials (especially if the materials have reached the same classification).

The test according to IEC 60587 requires sanding of the surface of the test specimens before testing to allow the test solution to wet the surface properly. Experience shows that sanding is not necessary. If sanding is applied, e.g. with hydrophobic surfaces, attention shall be given to possible surface changes by sanding.

2.4 CONCLUSION

The inclined-plane-test according to IEC 60587 is easily applicable, shows a good reproducibility and allows a good differentiation between insulating materials with respect to the resistance of electrical insulating materials against erosion and tracking.

Based on service experience with high voltage insulators the minimum requirement according to classification 1A3,5 (IEC 60587) is recommended in general. For some medium voltage applications materials are in use that fulfils classification 1A2,5 with satisfying performance. There is not sufficient evidence to define the general applicability of materials that fulfils the classification 1A2,5.

2.5 REFERENCES

[1] IEC 60587, Test methods for evaluating resistance to tracking and erosion of electrical insulating materials used under severe ambient conditions

3 RESISTANCE TO CORONA AND OZONE

3.1 INTRODUCTION

Many researchers have investigated ageing damage caused by exposing housing materials for outdoor applications to electrical discharges (corona or plasma). The loss of hydrophobicity was also observed on hydrophobic materials. The complexity of the electrical discharge exposure is due to the fact that the polymer surface is subjected to a mixture of energetic species and radiation, e.g. electrons, ions, ozone, UV and high temperature, simultaneously. Different reactions take place, but the main effects can be summarised as follows: (i) an increase of the oxygen content at the surface by the formation of silanol and hydroxyl groups [1-3], (ii) oxidative crosslinking [4-6], (iii) degradation of the polymer network structure resulting in the formation of low molecular mass compounds [7, 8]. These reactions lead to a change in the mechanical and electrical properties of the surface layer, as well as, to the exposure of fillers.

3.2 AVAILABLE STANDARDS

There are some international standards for corona and ozone testing. IEC 60343 "Recommended test methods for determining the relative resistance of insulating materials to breakdown by surface discharges" can be used for testing the resistance to corona discharges. Full information is given in the standard. On a flat specimen, between a cylinder plate electrode set, corona is generated on the plate surface and the duration until breakdown is reported as lifetime behaviour.

Procedures for ozone testing are provided in ISO 1431, ASTM D-1149 and DIN 53509:

ISO 1431-1:1989 Rubber, vulcanised or thermoplastic - Resistance to ozone cracking - Part 1: Static strain test;

ISO 1431-2:1994 Rubber, vulcanised or thermoplastic - Resistance to ozone cracking - Part 2: Dynamic strain test;

ISO 1431-3:2000 Rubber, vulcanised or thermoplastic - Resistance to ozone cracking - Part 3: Reference and alternative methods for determining the ozone concentration in laboratory test chambers (available in English only);

ASTM D1149-99 Standard Test Method for Rubber Deterioration-Surface Ozone Cracking in a Chamber;

DIN 53509-1, Ausgabe:2001-01 Prüfung von Kautschuk und Elastomeren - Bestimmung der Beständigkeit gegen Rissbildung unter Ozoneinwirkung - Teil 1: Statische Beanspruchung;

DIN 53509-2, Ausgabe:1994-11 Prüfung von Kautschuk und Elastomeren - Bestimmung der Beständigkeit gegen Rißbildung unter Ozoneinwirkung - Teil 2: Referenz-Verfahren zur Bestimmung der Ozonkonzentration in Prüfkammern.

3.3 DISCUSSION ON AVAILABLE TESTS AND MINIMUM REQUIREMENTS

Ozone tests

The ozone tests listed above allow quite high ozone concentrations (e.g. max. 200 pphm (parts per hundred million) in DIN 53509-1). In [9] results from ozone tests on 3 different silicone rubbers (insulating HTV and RTV and an electrically conductive HTV) are presented. The test was run for 168 hours under an ozone concentration of 300 pphm at temperature of 40°C and relative humidity of 55%. The samples (60x48x6mm) were bent on a U-bar and did not show any cracks after the test. In general the ozone resistance of silicone rubbers is good, because they do not contain unsaturated functions, but at higher concentrations of ozone one may expect degradation as for all other polymers. Data from a manufacturer of silicone rubber [10] indicates that silicone elastomers, including fluorosilicones, provide excellent resistance to both ozone and corona. Only very high concentrations of ozone (greater than 200 pphm) exposed for long periods (28 day) can lead to changes in the mechanical properties of silicone rubber, i.e. an increase of the Shore A hardness by 7 points, as well as, a 15% and a 5% reduction of tensile strength and elongation, respectively. A Japanese industrial standard JIS K6301 "Testing methods for vulcanised rubber" for testing material resistance to ozone, is also available. In the test elongated material plates (tensioned length 120%) are exposed to ozone at a concentration of 50 ± 5 pphm at 40°C for 100 hours. The samples should not show any crazing or other type of visible deterioration. One believes however that the housings of composite insulators should withstand the chemical degradation associated with the action of corona discharges through their service lifetime and therefore such testing is necessary. Some manufacturers have compiled their own test procedures.

Corona tests

It seems reasonable to assume that for applications in outdoor insulation, polymeric housing materials should firstly retain their mechanical integrity. Damage in the form of cracking, splitting or cutting is not acceptable. On the other hand, loss of hydrophobic properties can be tolerated although it is not desired. Therefore the main purpose of corona testing should concentrate predominantly on assessing the influence of corona on the mechanical properties of materials.

At Ohio Brass a test called The Corona-cutting Test has been developed [11]. The chamber used combines the presence of corona (UV and heat with a high level of ozone) as well as, mechanical stress to accelerate the degradation of the polymer, as illustrated in Figure 3.1. The material samples tested (57x70x6 mm^3) are first bent over a sized, grounded mandrel to apply 30% strain to the uppermost surface of the sample. Then a needle electrode is positioned 1 mm above the centre of the upper surface and energised at 12 kV ac (r.m.s). This results in a continuous corona directly above the strained surface of the sample. The chamber in which the test is performed is sealed, yielding a build-up of ozone within the chamber. The test is usually run until failure of the sample. To pass the test, the sample should be capable of surviving for at least 1000 hours without cracking, splitting, cutting or electrical failure (flashover).

Arrangements with a single needle have also been used for studying the effect of long-term exposure to corona by Moreno et al [12, 13]. Samples with and without mechanical stressing were tested, as illustrated in Figures 3.1 and 3.2. The arrangement with mechanical stressing is similar to the one used by Ohio Brass. Humidity was found to play a major role in the degradation process. It has been estimated from the investigations that even if one assumes extremely severe weather conditions to be present during field operations, the time to crack of a housing material, which is attributable to degradation due to water droplet corona, amounts to many years.

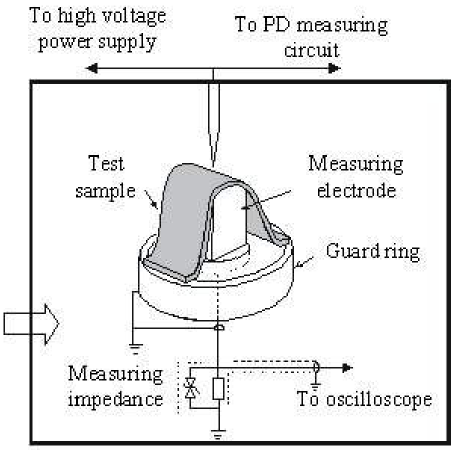


Figure 3.1 Single needle arrangements used by Ohio Brass and Moreno et al [13] for corona treatment of silicone rubber - mechanical stress applied.

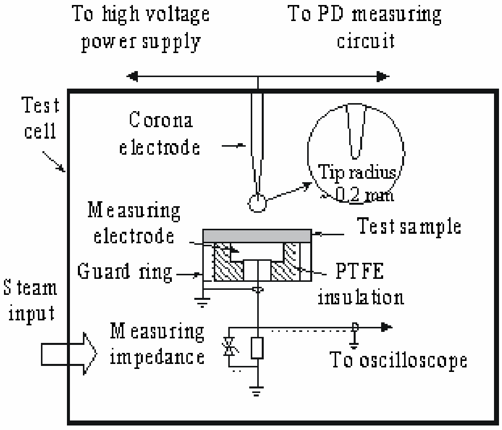


Figure 3.2 Single needle arrangements used by Moreno et al [13] for corona treatment of silicone rubber - no mechanical stress is applied.

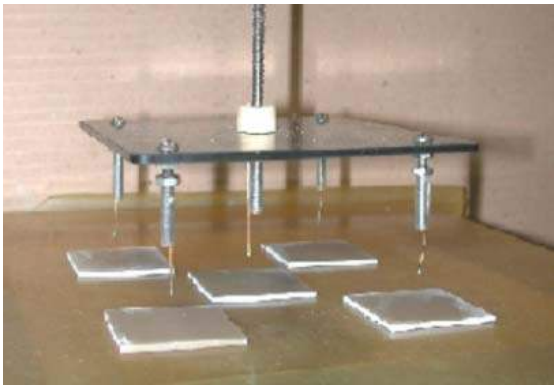
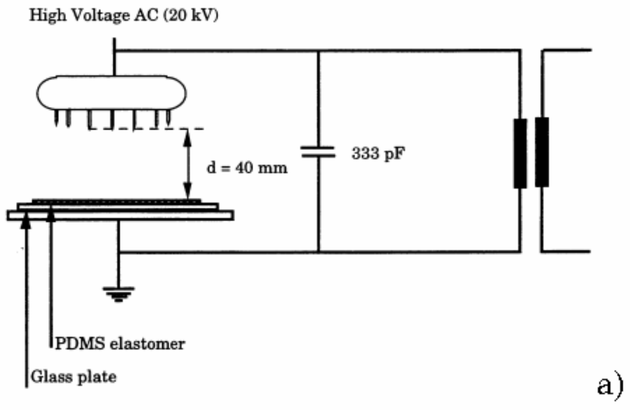
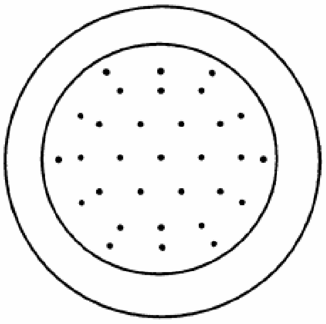


Figure 3.3 Needle arrangements used at Huntsman Advanced Materials [14] for corona treatment of material samples.

Yet another typical needle-plane arrangement has been used for corona testing at Huntsman Advanced Materials [14] to evaluate the loss and recovery of hydrophobicity, as shown in Figure 3.3. A needle electrode is positioned 10 mm above the test specimens that are lying on a grounded plane. A voltage of 18 kV ac (r.m.s) is applied for 150 min. Undoubtedly, this test uses much lower stresses than that of Ohio Brass.

A multiple needle arrangement has recently been used by Hillborg [5] when studying the mechanism of hydrophobicity loss and recovery on model polydimethylsiloxane (PDMS) materials. It is shown in Figure 3.4. In this case the corona electrode was equipped with 31 needles, which have tips with a radius of 56 μm. The treated sample is placed on a circular glass plates (3mm thick) on the grounded plane electrode at a distance of 40 mm from the needle tips. The applied voltage is 20 kV_{max} ac (r.m.s) and the power released was controlled (2,6 W). The electrodes were mounted in a desiccator to provide a control over the surrounding atmosphere. The desiccator was supplied with a continuous flow of dry air (<2% RH) and the temperature was kept constant at 22 ± 2°C. The investigations revealed the formation of a silica-like layer on the PDMS surface during corona treatment.





b)

Figure 3.4. Multiple needle arrangement used by Hillborg [5] for corona treatment of silicone rubber (a) and positioning of the needle electrodes as seen from below (b).

Experience at the University of Stellenbosch, South Africa have shown that the analysis of samples after corona treatment, with the discharging electrode placed about 5 mm above the sample surface for 30 minutes, showed distinct differences in the degree of ageing dependant on the material formulation [15]. The corona discharger (BD-20C) was supplied by Electro-Technic Products. The investigations confirmed formation of silica-like layer under corona treatment.

At Lapp Insulators a plane-parallel electrode arrangement is used instead for corona testing, as shown in Figure 3.5. A material sample (120 x 50 x 10 mm) is placed between two horizontal glass plates (each 3 mm thick), to which steel electrodes are attached externally. The diameter of the upper electrode (HV electrode) is 28 mm, whereas the base electrode is made of silver conducting paste deposited on the external part of the lower glass plate. The air gap between the sample and the upper plate is set at 2mm. A voltage of approximately 20 kV ac (r.m.s) is applied to the upper electrode. The voltage is adjusted so that a visual corona incepts and a current of 300 mA through the arrangements is reached. The test duration is 100 hours. Silicone materials must not show any visible changes during and after the test. Colour stability is checked in accordance with WP 64002 (DIN5033) in comparison to a reference sample. Appearance of small white strips at the surface is acceptable.

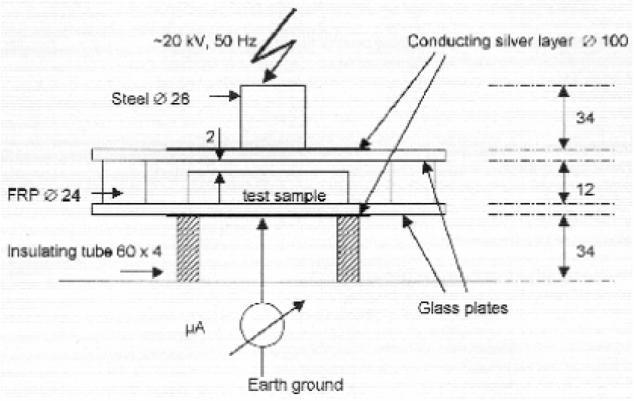


Figure 3.5 Arrangement used by Lapp Insulators for corona treatment of silicone rubber.

Thus far further information regarding the corona testing of materials within IEEE and elsewhere is available. No information on separate ozone testing has been sourced.

3.4 CONCLUSIONS

The resistance against corona and ozone is an important material property that should be verified for housing and structural polymeric materials.

There are a few standards procedures for testing corona and ozone resistance of materials. Manufacturers also use in-house test procedures. However, neither the test procedures nor the test results can be compared.

Evidence for good correlation between in-service performance and results of the corona test procedures for different materials is also missing. It is therefore recommended that one of future activities of CIGRE D1 is to concentrate on this issue. It is suggested that the testing of corona resistance on materials for outdoor applications should be performed in a system allowing for simultaneous application of mechanical stress.

With regards to the ozone test standards, they seem to be using unrealistically high ozone concentrations. In none of the methods for corona testing is the level of ozone controlled, although one of the methods (Ohio Brass) is considered as a simultaneous ozone test. This is because the test is performed in a sealed chamber. In general, the resistance against ozone may possibly be covered by a corona test.

3.5 REFERENCES

[1] Morra M., Occhiello E., Marola R., Garbassi F., Humprey P., Johnson D., *J Colloid Sci*, 1990, vol. 137, p. 11.

[2] Delman A. D., Landy M., Simms B. B., *J Pol Sci,* A-1, 1969, vol 7, p. 3375.

[3] Hollahan J. R., Carlson G. L., *J Appl Pol Sci*, 1970, vol. 14, p. 2499.

[4] Lacoste J., Israeli Y., Lemaire Y., in Polymer Durability. Degradation Stabilisation and Lifetime Prediction, Eds. Clough R.L., Billingham N.C., and Gillen K.T., Advances in Chemistry Series 249, American Chemical Society, Washington DC, 1996.

[5] Hillborg H. C. ”Loss and Recovery of Hydrophobicity of Polydimethyl-siloxane after Exposure to Electrical Discharges”, PhD thesis, Dept. of Polymer Technology, Royal Institute of Technology, Stockholm Sweden, 2001, ISBN 91-7283-029-8.

[6] Kim S. H. Cherney E. A., Hackam R., Rutherford K. G., IEEE Trans. Diel. Electr. Insul, 1994, vol. 1, p. 106.

[7] Hillborg H., Karlsson S., GeddeU. W. - "Characterisation of low molar mass siloxanes extracted from crosslinked polydimethylsiloxanes exposed to corona discharges", *Polymer*, vol. 42, p. 8883, (2001).

[8] Gustavsson T. G., Gubanski S. M., Hillborg H., Karlsson S., Gedde U. W. - "Ageing of Silicone Rubber Materials under AC and DC Voltages in a Coastal Environment", IEEE Trans. on D and EI, vol. 8. no. 6, 2001, p. 1029.

[9] internal information from DIK (Deutsches Institute für Kautschuktechniologie e.V.)

[10] private communication

[11] Hubbel Power Systems – Ohio Brass "Applying Technology for Better Reliability; Materials Testing and Evaluation", Proc. of the 2001 World Insulator Congress, Shanghai China, November 2001, pp. 245-253.

[12] Moreno V. M., Gorur R. S., "AC and DC Performance of Polymeric High Voltage Insulating Materials", IEEE Trans. Dielectrics and Electrical Insulation, Vol. 6, No. 3, pp. 342-350, 1999.

[13] Moreno V. M., Gorur R. S., "Effect of Long-term Corona on Non-Ceramic Outdoor Insulator Housing Materials", IEEE Trans. Dielectrics and Electrical Insulation, Vol. 8, No. 1, pp. 117-128, 2001.

[14] Beisele C. "Hydrophobic Cycloaliphatic Epoxy – Latest Findings and Future Developments", Proc. of the 2001 World Insulator Congress, Shanghai China, November 2001, pp. 141-153.

[15] Mallon P. E., Greyling C. J., Vosloo W., Jean Y. C. "Positron Annihilation spectroscopy of high-voltage polidimethylsiloxane (PDMS) insulators", J. Radiat. Phys. Chem., 2003, in press.

4 RESISTANCE TO CHEMICAL AND PHYSICAL DEGRADATION BY WATER

4.1 INTRODUCTION

The most severe influence on the degradation of polymeric materials caused by water is the result of the effect of hydrolysis. "Hydrolysis" is a chemical definition from the sub discipline of organic chemistry. The term hydrolysis describes a chemical reaction in which a chemical bond is broken due to the influence of water (H_2O) according to the following chemical formula equation:

$$\text{A-B} + \text{H-OH} \rightleftharpoons \text{A-H} + \text{B-OH}.$$

When evaluating the hydrolysis resistance of a polymeric material, the ability to withstand the hydrolysis degradation mechanism permanently or temporarily is understood.

The changes of the relevant measured property must remain within acceptable limits, despite the influence of hydrolysis. Concerning materials for outdoor polymeric and composite insulators the following physical-chemical ageing mechanisms are relevant:

- Dissolution of the polymeric matrix system of core, housing and structural materials, for example non-hydrolysis resistant polyester matrix systems subjected to H_2O attack [1], [2].

- H_2O or moisture induced interfacial phenomena between the matrix system and filler(s) or structural materials [1], [2].

Hydrolysis reactions are dependent on the presence of H_2O, temperature and time. In the most critical case, the polymeric material is subjected to H_2O in its gaseous state in the form of water vapour. Water vapour is able to penetrate polymeric materials by diffusion mechanisms, which are strongly dependent on both the temperature (diffusion coefficient follows the Arrhenius' law, i.e. the value of the coefficient doubles if the temperature is increased by 10K) and time, which is controlled by the Fick's diffusion law [1], [2]. All hydrolysis mechanisms follow similar patterns:

- Diffusion of H_2O molecules into the polymeric matrix system,
- Occurrence of one of the above described H_2O induced ageing mechanisms,
- Change of material parameters ("ageing") due to "hydrolysis".

In addition to chemical degradation, physical degradation may also occur. Insulators in service are exposed to electrical stress along with influence of water. In the case of poor insulation materials the dielectric losses may increase leading to an increase in the temperature that could lead to failure of the insulator. This behaviour can be simulated with a water immersion test. With such a test, materials are immersed in water at 50 °C and the dielectric properties are measured as a function of time.

Materials that are sensitive to chemical and physical degradation by water should not be used in the manufacturing of polymeric outdoor insulation.

Polymeric materials are known to absorb water. However, there is no quantified correlation between amount of water absorbed and the degradation of the polymeric materials. Well proven, long term experienced outdoor epoxy insulation systems typically show water absorption values in the magnitude of 0.05 % to 0.3 % (according to ISO 62, 10 days 23 °C). Silicones may absorb up to 2 % water. Nevertheless they are good materials for insulators. Therefore, testing the water absorption and defining a minimum requirement appears to not be necessary. For further details, see appendix A.

4.2 AVAILABLE TESTS

- A high-voltage "water diffusion test" is available in IEC 61109 Clause 5.4.2 [3] that is intended to check the hydrolysis resistance of core materials.

- A very similar test is available in VDE 0441 [4] for core and housing materials but with a more refined verification and evaluation procedure (electrical aspects of hydrolysis).

- A hardness test is described in IEC 62217 [5] to check the hydrolysis resistance of housing materials.

- Long-term water immersion test procedures are published in [1] and [2] to test and study hydrolysis phenomena of core, structural and housing materials. Such procedures can also supply acceptance limits regarding parameter changes if enough test data is available for all kinds of relevant materials (for Example from Round Robin Tests).

- In order to test the dielectric properties after water immersion Stietzel [7] introduced a method with decisive criteria for the suitability of polymeric insulation materials for HV outdoor insulators. Since then over 100 different formulations have been investigated, most of them based on cycloaliphatic epoxy, but some also based on butyl rubber [11], acrylic polymer concrete [11] and silicone [12]. In addition, the type, content and treatment of fillers have been investigated [8]. A publication in Electra 2002 has been approved by CIGRE SC 15 describing and making use of this test. [2]. There are no other similar tests in place. However, there are some tests, which measure properties like weight gain, breakdown voltage etc. after immersion in boiling water (DIN VDE 0441) and others).

- The temperature of the water determines the mechanism of the degradation that occurs in a water immersion test. For a water temperature greater than 50 °C, the occurrence of hydrolysis is very likely while for temperatures up to 50 °C the phenomena is limited to physical degradation only [7].

4.3 DISCUSSION ON AVAILABLE TESTS AND MINIMUM REQUIREMENTS

4.3.1 Test methods to verify the resistance to chemical degradation by boiling

All hydrolysis mechanisms can be simulated and accelerated by simple laboratory test methods such as described in IEC 61109 [3] ″water diffusion test″, sub clause 5.4.2.1. This test is also included in some other composite insulator test standards consisting of a pre-stress procedure with a subsequent verification procedure of the relevant material property. It should be noted that boiling is not intended to simulate service conditions. The test is based on the experience that results from boiling tests and performance of materials with respect to their degradation by water do correlate well.

In IEC 61109 [3], samples are pre-stressed by boiling in a specified container for 100 ± 0.5 h in deionised water with a specified conductivity. A very similar method for a hydrolysis resistance test is presented in DIN VDE 0441 [4], Sub clause 3.3 (″high-voltage water diffusion test″) [4] which contains a more sophisticated evaluation procedure of the test results with precisely defined classes HD0, HD1 and HD2. As a minimum requirement for housing, core and structural materials used in outdoor insulators VDE 0441 requires HD1 [4]. Experiences with different types of polymeric insulators (silicone composite, PTFE, CEP, PUR) in a long-term test [6, 17] in a 20 kV test line on the German North-sea island Nordstrand showed that most of the materials with HD2 did not suffer from hydrolysis effects. So, the HD2 should be a minimum requirement for material used as outdoor insulation, which is in line with IEC 61109.

In both test methods, IEC 61109 and DIN VDE 0441, the electrical breakdown strength or 1 minute voltage endurance after pre-stressing is verified by a defined voltage test. Other material properties, e.g. the dielectric loss factor or permittivity seem to also be suitable to detect hydrolysis phenomena [1], [2] after the described boiling procedure. The current through the test sample in the test according to [3] and [4] is a suitable indicator for the intensity of material degradation due to hydrolysis and it is thus a type of quality indicator.

Test specimen:

IEC 61109 sub clause 5.4.2.1 specifies 6 samples made from core materials with or without housing materials as sheath (rods with 30 ± 0,5 mm length).

DIN VDE 0441, part 1 specifies 12 samples made from housing material and from core materials with or without the housing material as sheath (dimensions 30 mm x 15 mm x 10 mm).

Pre-stress method:

100± 0.5 h boiling test in deionised water as described in IEC 61109, sub clause 5.4.2.2, equal to DIN VDE 0441, part 1, sub clause 3.3.2.1.

Verification procedure(s):

- IEC 61109, ″voltage test″: withstand voltage (no breakdown, no flashover) of 12 kV required for 1 minute, current during test shall not exceed 1 mA (r.m.s.) (equal to classification HD2 in DIN VDE 0441, part 1).

- DIN VDE 0441, part 1, ″voltage verification″: withstand voltages in different classifications:

HD0	withstand voltage of 6 kV for 1 minute not reached or current exceeds 1 mA for one sample (r.m.s.) during voltage test.
HD1:	withstand voltage 6 kV (no breakdown, no flashover) for 1 minute, current not exceeding 1 mA (r.m.s.) during voltage test.
HD2:	withstand voltage 12 kV (no breakdown, no flashover) for 1 minute, current not exceeding 1 mA (r.m.s.) during voltage test. Class HD2 is equal to the requirements of IEC 61109 ″water diffusion test″.

The resistance to chemical degradation by water, e.g. by hydrolysis, shall be tested for housing, core and structural materials by a 100h boiling test according to IEC 61109 and VDE 0441. The minimum requirements after 100h boiling are a withstand voltage of 12 kV for 1 minute having no flashover or breakdown and the current must not exceed 1 mA (r.m.s.)

4.3.2 Test methods to verify the resistance to chemical degradation by water immersion

Other test methods are described in [1] and [2]. They use long-term water immersion procedures of material samples at a temperature of 50 or 70°C in deionised water, including a time scheduled verification of the most important parameters such as water content, electrical breakdown strength, dielectric parameters, glass transition temperature etc. With this test method, a better study and understanding of the different ″ageing stages″ is possible during hydrolysis reactions. Further identification of the individual hydrolysis reaction mechanism is easily possible [1].

The “Water immersion test” [1, 2] can be used for housing, core and structural materials.

4.3.3 Test method to verify the resistance to chemical degradation by a hardness test

In Draft IEC 62217 Ed.1 “Common Clauses for Polymeric Indoor and Outdoor Insulators” [5] a “Hardness Test” pp.11 in accordance with ISO 868 with a Shore A or D Durometer is applied after a boiling period for the regarded housing material test samples. After 3 hours the sample hardness is measured again and compared to the initial value before boiling. At the same measuring temperature, hardness shall not change from the pre-boiled value by more than ±20%.

In IEC 62217 [5] the "hardness in combination with boiling test" applies to housing materials only. The test does not give additional information regarding the resistance to chemical degradation. The absolute value of the hardness is not regarded as an important property. However, the relative change in hardness value when comparing the hardness of the material before and after boiling is considered important.

4.3.4 Test method to verify the resistance to physical degradation by water immersion (dielectric properties)

The test can be applied to all three parts of an insulator, housing, structural and also to cores of composite insulators (GFR rod), as shown by Schrijver [16].

Test specimen: 6 samples (including 1 reference sample) are prepared. The samples are disk shaped with a diameter of 70 ± 1 mm. To keep the test time short a thickness of 2 ± 0.1 mm is chosen. The sample surface and the plate shaped electrodes used must be very smooth to prevent enclosed air layers.

Electrode system: For plate shaped samples disk shaped guard electrodes are used (59.5 mm ∅, insulating gap of 1 mm and guard ring of 10 mm) according to IEC 60250.

Measuring system: The measurement is performed with a Schering-Bridge or any other comparable equipment for the determination of ε_r and tan δ. The experiment is performed under ambient conditions (IEC 60660), with an applied voltage of 1 kV and a frequency of 50 Hz or 60 Hz. The values of ε_r and tan δ are recorded 1 minute after applying the voltage.

Drying and Weighing: The samples are dried at 50°C in a vacuum oven till constant weight (weight loss less than 0.01 mg per 2 days). In most cases the drying takes about 14 days. Before storing the samples in distilled water the weight m_o and the dielectric properties ε_{ro} and tan δ_o of the dry samples are determined. To avoid a temperature drift of the balance, the samples must be cooled 15 min before weighing otherwise a heat insulating material must be placed between the sample and the balance.

Water immersion: The times of the measurement procedures must be carefully recorded. The defined water immersion time is only the time during which the samples are immersed in water at 50 °C. The time for cooling and measurement of the samples is ignored. The weight and dielectric properties are measured within the following intervals (in days): 0, 1, 2, 3, 4, 8, 11, 15, 22, 29, 35, 43 and 50.

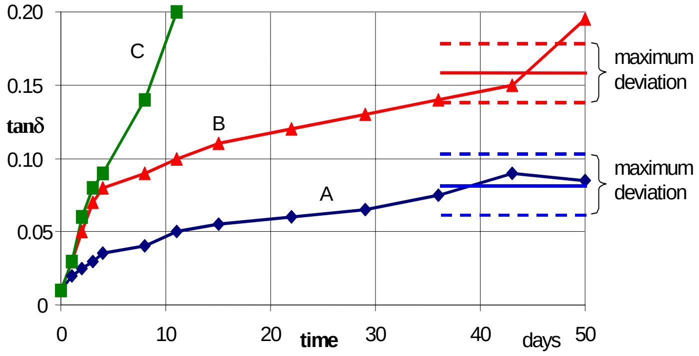


Figure 4.1: Principal loss factor curves for insulating material during immersion in distilled water at 50 °C (material B and C are not suitable for outdoor insulation)

Weighing procedure: Before weighing, the samples are cooled for 20 minutes in distilled water at room temperature. Then the samples must be carefully dried with filter paper. The drying procedure shall be the same for each sample and before each measurement. Each side of the sample is wiped three times. The order of the five samples is fixed at the first measurement and must not be changed during subsequent measurements.

Dielectric measurement: The measurement of the dielectric properties is carried out immediately after the weighing of the samples. The time for the measurement should be kept as short as possible. The experiment is carried out at ambient conditions (IEC 60660), with an applied voltage of 1 kV and a frequency of 50 Hz or 60 Hz. The values of ε_r and tan δ are recorded 1 minute after applying the voltage.

Minimum requirements:

The loss factor must not exceed the value 0.2 within 50 days of water immersion and must have reached stability (“saturation”). To check the variability of the dielectric properties within the measurement, the last 3 values (day 35, 43, and 50) at the end of water immersion experiment are compared and the average value of the final 3 values is calculated. The deviation of the last 3 values from the average value must not exceed ± 0.02. Figure 2.3-1 illustrates these criteria.

As can be seen from figure 2.3-1, type A shows only a small increase of the loss factor after 50 days of water immersion approving its outdoor suitability, whereas system C as an example for a poor system gives a by far too high dielectric loss factor and is therefore not suited for outdoor insulation. System B shows a tan δ below 0.2 after 50 days and fulfils the first minimum requirement; however, it misses the stability criterion (second minimum requirement) and is also not suited for outdoor applications according to this test. Only after approx. 50 days can this clear distinction between good and poor materials be made.

Materials with purposely implemented artificial defects (wrong stoichiometry, no or poor filler treatment etc.) exceed the maximum criterion [8, 9, 10, 14].

Poor commercial materials show either a run-away effect of the loss factor or lead to high values, which are not acceptable [8, 11].

Good commercial materials like silicone or (hydrophobic) cycloaliphatic epoxy with appropriate formulations having a loss factor below 0.2 after 50 days of water immersion are proven in service up to 35 years [12 – 15].

However, the weight gain (mass increase) cannot be accepted as a criterion since there are good materials like silicone that show rather high water uptake, but meet the loss factor criterion nonetheless [12].

4.4 CONCLUSIONS

A suitable test method to verify the resistance of housing, core and structural materials to chemical degradation is the "water diffusion test" (100 hour boiling test) according to IEC 61109 [3]. VDE 0441 [4] specifies a refined evaluation procedure that allows one to rank materials. Further, it also defines samples size for housing materials. The minimum requirement is 12 kV withstand voltage with duration of 1 minute (IEC 61109), which is identical to HD 2 (VDE 0441).

The resistance to physical degradation (dielectric properties after water immersion) can be verified by evaluating the loss factor of materials during a long-term water immersion test. The minimum requirement is that the loss factor does not exceed a value of 0,2 after 50 days of water immersion at 50 °C. Water diffusion test gives all necessary information about suitability of materials for outdoor insulation.

For the time being it is not clear how the results from the "water diffusion test" correlate with the results from the "water immersion test". It is considered that materials passing the "water diffusion test" show good resistance to physical degradation under service conditions. The "water immersion test" gives useful information for material development and allows ranking of materials with respect to resistance against physical degradation.

4.5 REFERENCES

[1] Seifert, J. M., Interfacial and microscopic bonding problems in minerally filled epoxy casting products for high-voltage insulation", PhD thesis (in German), TU Braunschweig, 1998.

[2] CIGRE WG 15-10: Kärner, H., Kodoll, W., Seifert, J., Tanaka, T., Nagao, M., Henriksen, M., Ross, R., Kahle, M., Ichikawa, K., Fukuda, A., Ezoe, M., Interfacial phenomena affecting electrical insulating properties in composites -proposal of test method, results and discussion of CIGRE RRT", ELECTRA No. 202, June 2002

[3] IEC Publication 61109, Composite insulators for a.c. overhead lines with a nominal voltage greater than 1000 V – Definitions, test methods and acceptance criteria", 1995.

[4] DIN VDE 0441, part 1, Tests on polymeric composite insulators for a.c. voltage greater than 1000 V, Tests on materials for outdoor insulators", 1985.

[5] Draft Publication IEC 62217 Ed. 1, Polymeric indoor and outdoor use with a nominal voltage greater than 1000 V – General definitions, test methods and acceptance criteria" (Common Clauses), March 2000

[6] "Service Experience Report – Polymeric Insulator Performance in a 20 kV OHTL on Nordstrand Island" (in German), ETZ Report No. 30, AK 451.0.2, 1998 (DKE AK 451.0.2, Betriebserfahrungen und Untersuchungen an Kunststoffisolatoren in einer 20 kV-Leitung auf der Insel Nordstrand, VDE-Verlag, ISBN 3-8007-2361-1, 1998)

[7] Stietzel,U., Untersuchungen zum Einfluss von Feuchtigkeit auf die elektrischen Eigenschaften organischer Isolierstoffe für Freiluft-Hochspannungsanwendung, Thesis, University of Braunschweig, Germany, 1984

[8] Krämer, A., Kärner, H. C., Hubler, E., Munk, K. A., Improvement of Ageing Resistivity of Cycloaliphatic Epoxy Resin, ISH Braunschweig, Germany, Proceedings, Paper 52.03, 1987

[9] van der Huir,R., Untersuchung oberflächenspezifischer Eigenschaften polymerer Isolierstoffe für den Hochspannungs-Freilufteinsatz, Thesis, University of Braunschweig, Germany, 1991

[10] van de Huir, R., Kärner, H.C., Evaluation of Polymeric Insulation Materials for HV Outdoor Application, 6th ISH, New Orleans, USA, Proceedings, Paper 30.02, 1989

[11] van de Huir, R., Kärner, H. C., Aus der Au, H. R., Hubler, E., Munk, K., Krämer, A., Long-term weather resistance of different high voltage insulation materials, 6th ISH, New Orleans, USA, Proceedings, Paper 21.03, 1989

[12] Kärner,H. C., Cycloaliphatics as Insulation Materials, Symposium on Non-Ceramic Insulator Technology, Singapore, Paper 12, 1996

[13] Massen,U., Worldwide Outdoor Experiences with Cycloaliphatic Epoxy Insulators over 30 Years, Symposium on Non-Ceramic Insulator Technology, Singapore, Proceedings, Paper 14, 1996

[14] Massen, U., Beisele,C., Cycloaliphatic Epoxy Insulators - Experiences over 30 Years, ETG-Fachtagung, Bad Nauheim, Germany, ETG-Fachbericht 76, 99-108, 1999

[15] Beisele, C., Kultzow,R., Experiences with new Hydrophobic Cycloaliphatic Epoxy Outdoor Insulation Systems, IEEE Electrical Insulation Magazine, Vol. 17, No., 33 – 39, 2001

[16] Schrijver, C., Optimierung der elektrischen Eigenschaften glasfaserverstärkter Kunststoffe, Thesis, University of Braunschweig, Germany, 64 – 66, 1998

[17] Kindersberger, J., Kuhl, M., Bärsch, R., Evaluation of the conditions of non-ceramic insulators after long-term operation under service conditions, paper No. 3193, 9th International Symposium on High Voltage Engineering, August 28 – September 1, Graz, Austria, 1995

5 TEAR STRENGTH

5.1 INTRODUCTION

The tear strength parameter is the maximum force, which a specified test piece with a cut inserted, can withstand, before rupture. It is related to the sample thickness. This property is only applicable to the elastomeric housing materials like silicone rubber and EPDM. In general elastomers can be defined as "any material of a macromolecular nature that can be stretched at room temperature to more than twice it's length and return to approximately it's original shape when the stress is released".

The first generation of silicone composite insulators, manufactured with condensation curing RTV-2 silicone rubber sheds were easily attacked by birds, since the material had a low mechanical strength, (i.e. tear strength < 5 N/mm, ASTM D 624 B).

Since the introduction of the higher strength HTV silicone rubber as an insulator shed material, the potential damage caused by transportation, handling and bird attacks has been significantly reduced to few, specific cases.

5.2 AVAILABLE TESTS

To evaluate the tearing strength of elastomers, different standards are available, which utilise various die shapes:

- DIN 53507 A (Testing rubber and elastomers; Determination of the tear strength of elastomers; Trouser test piece)
- DIN 53515 (Determination of tear strength of rubber elastomers and plastic film using Graves angle test piece with nick)
- ASTM D 624 B (Standard Test Method for Tear Strength of Conventional Vulcanised Rubber and Thermoplastic Elastomers)
- ISO 34 / JIS K6252 (Rubber, vulcanised or thermoplastic—Determination of tear strength—Part 1: Trouser, angle and crescent test piece)

5.3 DISCUSSION OF AVAILABLE TESTS AND MINIMUM REQUIREMENTS

The shape of the test specimens is shown in figure 5.1. For ASTM D 624 B and ISO 34 (identical to JIS K 6252) the shape of test specimen is the same.

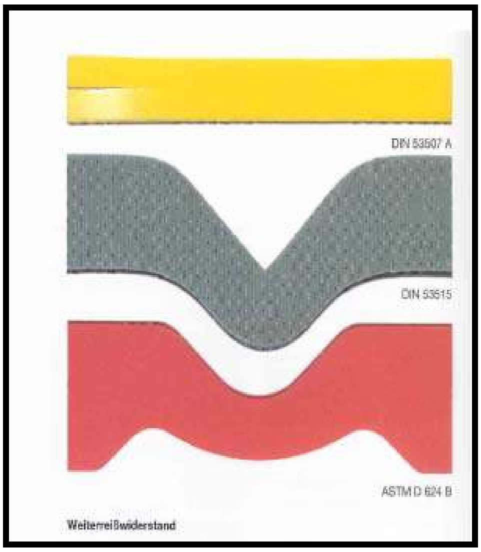


Figure 5.1 The shape of the test specimens

The Trousers-Test (DIN 53507 A, see figure 5.2) might have a more realistic correlation to some situations in service, but this test can't be carried out in automatic manner.

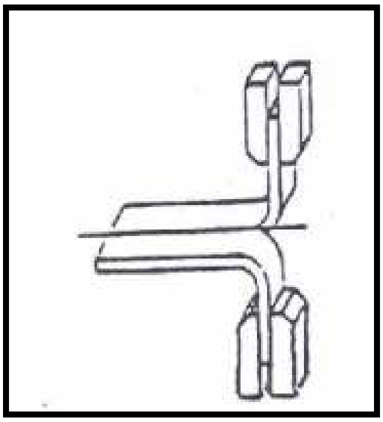


Figure 5.2 The Trousers-test

For elastomers the most often utilized Tear Strength test method is ASTM D 624 B, due to the higher consistency in these results.

The thickness of the samples is usually 2mm ± 0,5 mm and at least three (preferably five) specimens per insulator shall be tested. The cutting of the nick has a strong influence on the test results for all rubbers. Therefore, the sharpness of the razor blade must be controlled frequently and the cut has to be adjusted to the hardness of the rubber in order to secure the right depth (see figure 5.3).

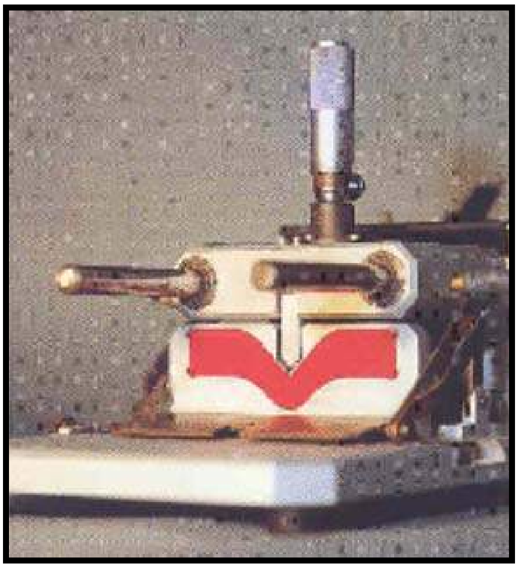


Figure 5.3 Apparatus for cutting the nick in Crescent sample

In ASTM D 624 B the cut shall be 0.5 mm ± 0.05 mm in depth. In ISO 34 and JIS K6252 the depth of the nick is 1.0 mm ± 0.1 mm. Use of a microscope giving at least a 10 X magnification can check the depth of the nick.

A deeper cut according to ISO 34 will cause lower values (approx.60%) of the tear strength in comparison to ASTM D 624 B. So a tear strength of > 10 N/mm in ASTM D 624 B is corresponding to > 6 N/mm in ISO 34.

Because of a specific ″blocking“ effect of silicone rubbers in the tear strength test the results can show a large variation depending if the “blocking” effect happens or not.

5.4 CONCLUSION

Even when ASTM D 624 B seems to be a suitable test procedure for the tear strength of elastomeric housing materials and much data is available, the international standard ISO 34 should be the preferred test standard.

Based on the experience with the first generation silicone composite insulators and the more than 20 years experience with the HTV silicone rubber shed material the tear strength should be > 6 N/mm according to ISO 34.

6 VOLUME RESISTIVITY

6.1 INTRODUCTION

Volume resistivity can be used as an aid in the selection of an insulating material for a specific application. The change in the resistivity with temperature and humidity may be significant and must be known when designing for specific operating conditions. Volume resistivity measurements are often used to check the uniformity of an insulating material, either with regard to the processing, or to detect conductive impurities that affect the quality of the material and that may not be readily detectable by other means.

6.2 AVAILABLE TESTS

The tests are described in IEC 60093:1980 (Test methods for volume resistivity and surface resistivity of solid electrical insulation materials) and various other international standards i.e.

- ASTM D 257:1999 (Standard test methods for DC resistance or conductance of insulating materials)

- DIN IEC 60093:1993 (see the above-mentioned IEC standard; which has replaced the former DIN 53482)

- JIS K 6249:1997 (Test methods for uncured and cured silicone rubber)

- JIS K6911:1995 (Test methods for thermosetting plastics)

6.3 DISCUSSION OF AVAILABLE TESTS AND MINIMUM REQUIREMENTS

Scope of IEC 60093:

The test methods include procedures for the determination of volume resistivity and calculations for the determination of volume resistivity of solid electrical insulating materials. The test methods are applicable for core, housing and structural materials.

Test description:

Volume resistivity (ρ) is determined by the measurement of the resistance to electrical conductivity provided by a unit cube of a material at a given temperature and relative humidity (after reaching a steady state current between the electrodes placed on opposite faces of a specimen under d.c. voltage).

A typical specimen consists of a sheet of the insulating material with a defined thickness (h) covered on opposite sides by electrodes with a defined effective area. The type of electrode (guard ring) makes it possible to ignore the surface resistance. The standards describe possible sample geometries, as well as, different types of electrodes and instruments together with circuits typically used to measure volume resistivity, which are based on the calculation of volume resistivity (ρ) according to following equation:

$\rho = R_x . A/h$ (Ωm)

R_x=Volume resistance (Ohm)

A= effective area (m^2)

h=average thickness (m)

Recommendations are given for values of voltage, time of application, nature and the geometry of the electrodes, temperature and humidity of the atmosphere and the test specimens and the conditioning of the test specimens.

In a standard set-up the specimen is 2 mm thick and a voltage of 1000 V DC is applied. The electrodes are preferably applied by means of a silver lacquer. If this is not possible due to adhesion problems other electrode materials like conductive rubber, metal foil or sprayed metal can be used. A steady state is normally reached after between 10 seconds to 100 minutes. If exact values are required, the steady state has to be reached. For acceptance tests, however, the value after 1 min can be used. This will lead to results that are slightly lower than the true volume resistivity values.

The volume resistivity of the most commonly used electrical insulation materials is between 10^6 Ωm and 10^{15} Ωm.

The lifetime of polymeric insulators does not depend on the volume resistivity at a level greater than 10^{10} Ωm. In reality, leakage currents do not flow through the bulk of the insulator material but remain on the surface. Their magnitude is predominantly influenced by surface properties (i.e. surface resistivity).

The standardized test methods for volume resistivity are well established and there is no need for further development.

6.4 CONCLUSIONS

Volume resistivity measurements can show the presence of conductive contaminants in insulation materials. This property may have some importance in the assessment of additives that are often used (e.g. fillers containing different levels of ionic impurities). The test method is applicable to core, housing and structural materials. The volume resistivity parameter is also sensitive to incorrect curing processes of some resin systems.

As a minimum requirement, the volume resistivity should be greater than 10^{10} Ωm.

7 BREAKDOWN FIELD STRENGTH

7.1 INTRODUCTION

The electrical strength is one of the most important properties of an insulation system.

If the electrical stress is higher than the electrical strength of the insulation material then the material will break down. So the polymeric materials used for insulators need to have sufficient electric breakdown field strength.

7.2 AVAILABLE TESTS

The international standards for breakdown field strength are

- IEC 60243 (Electric strength of insulating materials – Test methods)

- Part 1: Test at power frequencies
- Part 2: Additional requirements for tests using direct voltage
- Part 3: Additional requirements for impulse test

The test procedures are described in

- IEC 60455 (Resin based reactive compounds used for electrical insulation)

- Part 1: Definitions and general requirements and
- Part 2: Methods of test“ IEC 60455-3 „Specification for solventless polymerizable resinous compounds used for electrical insulation
- Part 3: Specifications for individual materials“

7.3 DISCUSSION ON AVAILABLE TEST AND MINIMUM REQUIREMENTS

The breakdown field strength was tested until 1998 according to IEC 60243-1, which refers to IEC 60455-2, on 3 mm plates with cylindrical electrodes of 25/75 mm diameter (figure 7.6). IEC 60243 and IEC 60455 were revised in 1998. For hard resin insulation materials (e.g. epoxy resins) a test arrangement with an incorporated electrode was introduced (figure 7.1). The distance is 1 mm.

Soft resin reactive compounds (e.g. silicone rubbers) should be tested in the form of sheets with a maximum thickness of 3 mm (figure 7.2). With reference to experience in many laboratories and to several publications [1-3] it is known, that attached electrodes immersed in an insulation fluid cannot be used to determine the breakdown strength of high voltage insulation materials. Because of the lower electric strength of the fluid a “side-breakdown“ occurs, as a result of, the “surface-gliding-discharges“. Under such test conditions the break down does not take place in the (small) area of the homogenous electric field. Therefore this test method can only be applied to detect cracks or defects in the test sample but not to measure the intrinsic electric strength of the polymeric insulation material.

The influence of the test arrangement and the design of the electrodes on the value of the breakdown strength can be demonstrated by comparison of the following illustrations (figures 7.3 – 7.6):

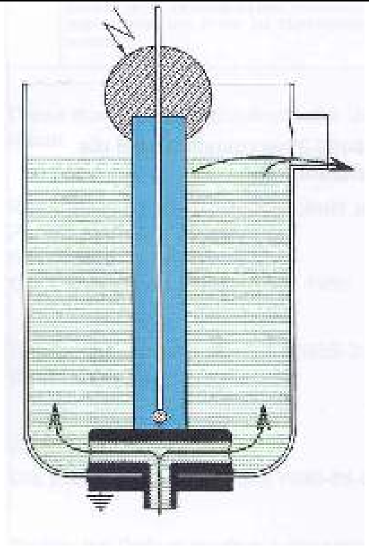


Figure 7.1

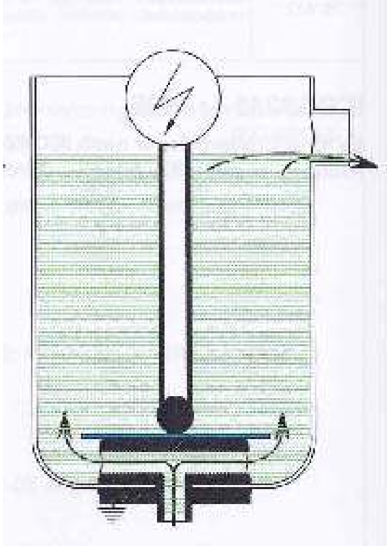


Figure 7.2

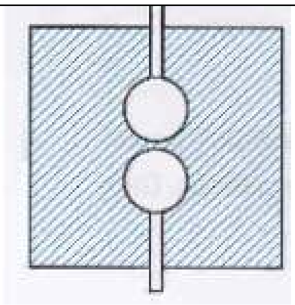


Figure 7.3

Material	Epoxy resin [1]	Silicone rubber [4]
Electrode distance	0.5 mm	1 mm
E_d	139 kV/mm	100 kV/mm

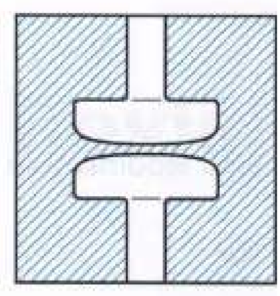


Figure 7.4

Material	Epoxy resin [1]	Silicone rubber [5]
Electrode distance	2 mm	0,9 mm
E_d	72 kV/mm	120 kV/mm

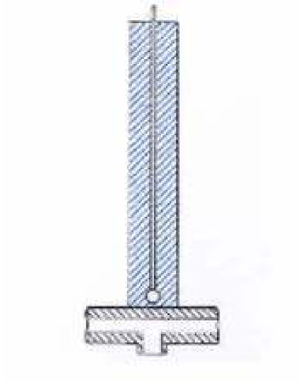


Figure 7.5

Material	Epoxy resin [1]
Electrode distance	1 mm
E_d	50 kV/mm

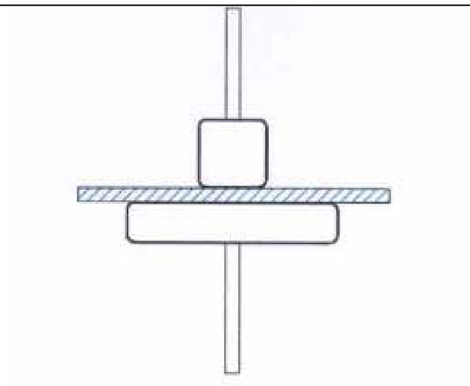


Figure 7.6

IEC 60243 –1 / DIN VDE 0303-21

Material	Epoxy resin [1]	Silicone rubber [6]
Electrode distance	3 mm	1 – 3 mm
E_d	22 – 28 kV/mm	26 – 15 kV/mm

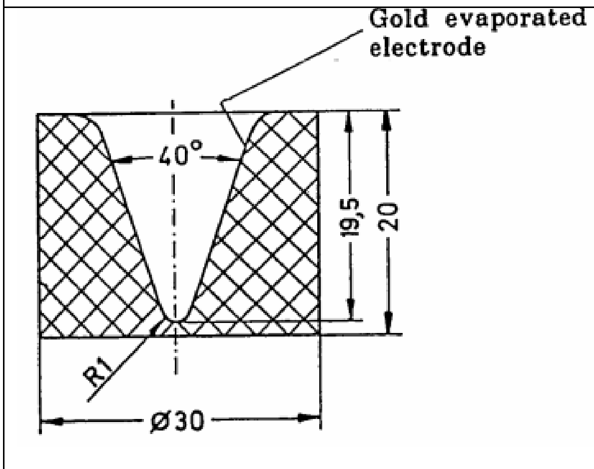


Figure 7.7

Material	Epoxy resin [2]
Electrode distance	0,5 mm
E_d	140 kV/mm

It is difficult to source information regarding the breakdown field strength of other insulation materials in literature. Results obtained at FH Zittau show that the breakdown strength of EVA (heat shrink tube) at a 1 mm sheet (ball/disc-electrode 10/60 mm similar to IEC 60243-1) is 28 kV/mm. For an EPDM material, as used in cable accessories, the breakdown field strength, as measured in a butylester insulation fluid (relative permittivity of approximately 5) was 50 – 75 kV/mm.

A new test sample design (figure 7.7) as proposed in [2] could be used. By using a conductive coating inside, the disadvantage of attached electrodes can be avoided, and the determination of an intrinsic dielectric strength of the material becomes possible. The preparation of the samples is difficult for some materials.

7.4 CONCLUSIONS AND MINIMUM REQUIREMENTS

The electrical breakdown strength is an important property of insulation materials and should be verified for housing and structural materials. The breakdown strength of the core material is evaluated during the test, which measures the resistance against chemical and physical degradation, by water.

Due to the different test arrangements presented in IEC 60455-2 for hard resin based insulation materials (e.g. epoxy resin) and soft resin based reactive compounds (e.g. silicone rubber), which results in different levels in the breakdown strength, a general minimum requirement for non-ceramic outdoor insulation material cannot be specified.

The breakdown field strength of hard resin insulation materials tested according to IEC 60455-2 (figure 7.1) should be greater than 40 kV/mm.

For testing according to IEC 60243-1 (figure 7.6) using a 3 mm specimen the breakdown field strength should be greater than 10 kV/mm.

7.5 REFERENCES

[1] Wittker, Kritische Betrachtungen der Normenentwicklung für Gießharze am Beispiel der Durchschlagsfestigkeit, VANTICO

[2] Seifert, J., Grenzflächen- und Verbundprobleme in mineralisch gefüllten Epoxidharzformstoffen, Thesis TU Braunschweig, 1998

[3] Beyer, M., Boeck, W., Möller, K., Zaengl, W., Hochspannungstechnik, Theoretische und praktische Grundlagen, Springer-Verlag, 1986

[4] Osterheld, J., Dielektrisches Verhalten von Silikonelastomer-Isolierungen bei hohen elektrischen Feldstärken, Thesis TU Dresden, 1995

[5] Zelenyánski, E., Dielectric Strength of Silicone Elastomers, 8th ISH, Yokohama, 1993

[6] Winter, H-J., Dielektrische Eigen-schaften von Silikonelastomeren als Isolierstoffe, ETG-Fachbericht 93, 2003

8 RESISTANCE TO CHEMICAL ATTACK

8.1 INTRODUCTION

Polymeric materials may be attacked by chemicals. In particular, acids may cause damage to FRP rods. This may reduce the mechanical strength significantly and eventually the damage can lead to a complete fracture of an insulator. Compared to other possible effects of chemical attack, e.g. to housing materials and structural materials, a possible breakage of the core of an insulator is dominating with respect to the integrity of an insulator. Thus, the general term "chemical resistance" shall concentrate on acid and chemical resistance of core materials. The term "chemical resistant" should be regarded under the aspect of the chemical nature or environment where insulators for overhead lines or substations shall be applied or already are in operation, also considering that acid generation is possible by corona effects and moisture (nitric acid). In this section, a summary of the state of the art of research on brittle fracture is introduced.

Due to the specific fracture pattern the phenomenon of a breakage of a FRP rod under mechanical load and the simultaneous exposure to acids is called "brittle fracture" of a FRP rod. The mechanism that leads to "brittle fracture" of glass fibre reinforced polymeric materials (GFRP) is a kind of "stress corrosion" of the composite material mainly influenced by the chemical nature (composition) of the FRP material. The major factor of influence for this mechanism of stress corrosion turned out to be the acid resistance of the reinforcing glass fibres. The first appearance of the phenomenon can be dated back to the mid 1970s [1].

Stress corrosion involves an ion exchange mechanism. Sodium ions with a big ion radius are replaced by hydrogen ions with a small ion radius, resulting in an increase of stress in the glass surface of the filaments. Glass fibre filaments that are not acid resistant build up spiral flaws on their surfaces after immersion in diluted acids. The flaws in the filaments lead to a nearly complete loss of the fibre's mechanical strength and initiate the failure of the composite material, which can be described by the mechanism of fracture mechanics [1]. From the aspect of material science, brittle fracture should be better declared as chemically induced or affected stress corrosion.

Brittle fracture appearance of core materials requires for the following 3 conditions that have to be active simultaneously:

a) A mechanical tension/bending load must be applied to the FRP rod that leads to tensile stresses which exceed 50 MPa ("damage limit" for stress corrosion mechanism [1]). It should be noted that these mechanical stresses are not only generated by the external load(s) but may also be induced from internal tensile stresses in the FRP coming from the way of end fitting attachment or any other production process.

b) Acid and / or water from any (internal or external) source that comes into direct contact with the FRP core material

c) Sufficient time of affection

Although research is still going on in this field (WG B2.03 [2] and IEEE TF on Brittle Fracture [4]), publications and sufficient scientific knowledge regarding the fundamental mechanism of brittle fracture as well as material choice and insulator design are available so that this failure can be prevented for complete composite insulator FRP rods [1], [2], [3], [4], [5], [13], [15].

Brittle fracture is limited to a group of FRP core materials used in specific types of composite insulator products, namely composite long-rod and line post insulators. Up to now, only solid FRP rods (cores) with unidirectional reinforced glass fibres stressed with tensile [2], [3] and in very few cases also with bending loads [13] have been affected. Brittle fractures of FRP tubes or of structural materials have not yet been reported.

Brittle fracture of suspension or tension long-rod and line post composite insulator types can cause severe failures such as line dropping [2], [3], [4]. A guideline for the identification of brittle fracture is given in [7]. Figure 8.1 shows typical appearances of FRP rod brittle fractures from line service and from laboratory testing with organic and inorganic acids [1], [2], [3], [5].

A: brittle fracture of FRP rod near end fitting after 3 years of service (420 kV OHTL).

B: brittle fracture of FRP rod on free length caused by organic acid during an artificial acid resistance test.

C: brittle fracture of FRP rod on free length caused by inorganic acid during an artificial acid resistance test.

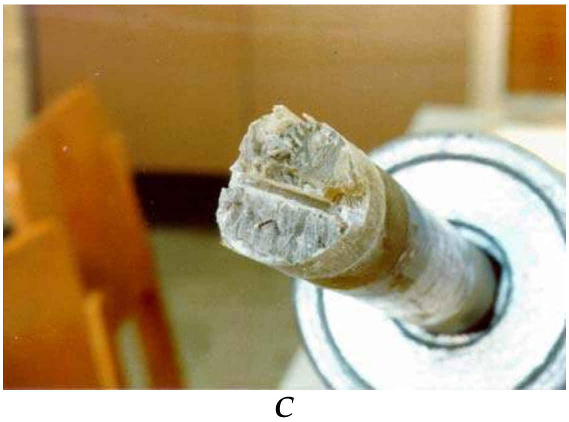


Figure 8.1 Typical appearance of brittle fractures

Brittle fracture can be simulated in laboratory tests. The application of strong inorganic acids such as HNO_3, H_2SO_4, $HClO_4$, HCl to a FRP rod under simultaneous mechanical loading leads to brittle fracture if the stress parameters, i.e. acid concentration, mechanical stress are sufficiently high. HNO_3 (nitric acid) plays an important role in the testing because one process that produces HNO_3 is electrical corona activity in combination with H_2O. So, HNO_3 , can always be present when corona discharges occur in humid air.

Recent studies shows that weak organic acids can also initiate brittle fractures of FRP rods [2], [3]. This process involves the formation of organic acid by hydrolysis of excess anhydride hardener, esters or vinyl esters. The excess hardener may be present in FRP rods due to incorrect formulation and/or manufacturing processes. If moisture finds its way to acid crystals or residual hardener on or near the surface of the finished rod, it will act as a carrier for the acid allowing it to seep into cracks and reach the surface of the fibres, thereby starting the brittle fracture process. A Round Robin Test performed by CIGRE WG B2.03 just finished, the results will be published in Electra 2004.

In either case, the mechanism of brittle fracture requires that the FRP rod is exposed directly or indirectly to the environment for damage to occur, since both processes require the presence of H_2O. The studies by Gorur et al. [13], [14] made with samples from commercially available FRP rods for composite insulators show that even pure water can initiate brittle fractures (pure water contains H_3O^+ and OH^- ions from the equilibrium reaction at pH=7). Beside the glass fibre type, also the resin matrix type influences the brittle fracture resistance. Acids are confirmed but may be not the only cause or initiator for brittle fractures [14].

Due to the fact that moisture or water plays a major role in all processes under discussion, any design feature that prevents the FRP rod in HV insulators from water should be considered as very important and essential (sealing system at the end fitting, covering the FRP core with elastomeric sheath of sufficient thickness, good quality of interfaces between materials). Hence, for composite insulators which consist of FRP rods as load carrying elements, brittle fracture of the core may also be avoided by a proper design and quality of the housing and the sealing between metal fittings and insulating body. Therefore, even FRP rods, which are susceptible to stress corrosion by acids, do not necessarily lead to brittle fractures of insulators caused by strong inorganic acids from external source. Sealing and interface qualities are verified in the product relevant type and design tests. Under the aspect of defining a pure material property, an acid resistance test of the core is necessary to verify that a core material is resistant to the mechanism of stress corrosion within the technical lifetime of an insulator [1]. Because the acid source can be from internal or external source such test of the core material shall be taken into consideration to verify that a core material is brittle fracture proof.

If “chemical resistance” is required for housing materials (which is extremely rare in technical user specifications and is mostly covered by the term “shall withstand all environmental conditions”), most user specifications for Silicone, EVA, EPR and EPDM housings require ozone and NO_x resistance as “chemical” resistance. It is proposed that ozone and NO_X resistance (including resistance against nitrogenous acid derivatives) should be covered by “corona resistance” and should be verified by an adequate corona resistance test method. Excepting SO_2 resistance, all relevant items of the term “acid and chemical resistance” are then covered by the term “corona resistance”.

8.2 AVAILABLE TESTS FOR CORE MATERIALS

The aim of a suitable test is to classify core material with respect to their susceptibility to the mechanism of brittle fracture, i.e. stress corrosion, under the conditions given in service. The test methods given below are for reference purpose to identify the type of core material.

A Test for organic acids

CIGRE WG B2.03 is currently investigating a simple test to check for the presence of organic acid resulting from hydrolysis of the resin mix (due to incorrect hardener ratio or insufficient curing). This test consists in soaking samples of FRP rod in water and measuring the pH over time. The final procedures and acceptance criteria are still under consideration.

Note that this test verifies whether acid can be generated within the rod without additional acid supplied from outside. The test would not give any indication about the resistance of a core material against brittle fracture.

B Chemical composition

The resistance of FRP rod to acid depends principally on the formulation of the glass. Standard electrical grade glass has low resistance whereas chemical resistant glass has high acid resistance but is unsuitable for electro-mechanical applications. Glass manufacturers have been producing "corrosion-resistant" electrical grade glass for many years now and all such glasses are characterised by a very low boron ($B_2O_3<0.01\%$ by weight) and fluorine (<0,005% by weight) content [1], [6]. Therefore a primary test would be to proceed with a chemical analysis of the glass fibres.

For the time being it is not possible to state a particular level of boron and/or fluorine that is related to acid resistance. So, an additional test is necessary.

C Acid resistance test

Since acid resistance is regarded as a material property of the core the FRP rods under test are directly exposed to acids, irrespective of any protection provided by the housing of a real insulator.

This acid resistance test with strong inorganic acids could be performed as a mechanical type test (in addition to the standard 96 h mechanical load-time test) in accordance with IEC 61109, Annex A.3, with an acid container applied according to figure 8.3. The test is performed at a temperature between 15°C and 20°C to confirm the mechanical resistance to stress corrosion of the FRP core. It is to be noted that this test applies a set of stresses (tensile load equivalent to 340 MPa, in nitric acid, 96 hours) that are known to evaluate FRP materials regarding acid resistance. There is no direct correlation between these test stresses and those applied in service. Both horizontal and vertical set-up position of the specimen is acceptable.

C1 Test Specimen:

One insulator from the production line or one specimen is used. The specimen shall have a length L_1 between end fittings of least 10 times the core diameter D_1, but not less than L_2=600 mm. Suitable end fittings shall be used. An example is given in figure 8.2.

The visible core surface has to be smoothed by means of a fine abrasive cloth (grain size 180). An acid container, made of polyethylene shall be arranged surrounding the visible core surface in such a way that the liquid can simply be poured into the container and no acid come into contact with the end fittings. The size of the acid container shall be adapted in such a way that the FRP core is surrounded of a liquid thickness not less than 1 cm and along a length of not less than 4 cm. The container shall be covered and/or sealed to prevent evaporation and break through of the liquid more than 5 % of its volume during the test period.

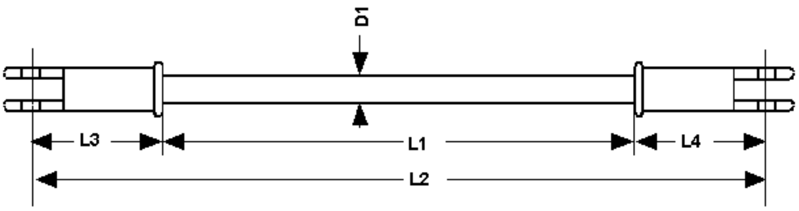


Figure 8.2 Example of a test specimen for acid resistance ("brittle fracture resistance") test for solid core FRP materials, for example, used as a load carrying part of a long rod composite insulator.

C2 Performance of the test:

The specimen is subjected to a tensile load applied between the metal parts. The tensile load shall be increased rapidly but smoothly from zero to a load at which a tensile stress of 340 MPa in the FRP core is achieved. This tensile load shall be maintained for 96 h. Immediately after applying the load, nitric acid of a concentration of 1n (n = normal) shall be poured into the acid container (1n = 63 g HNO_3 plus 937 g H_2O). The acid must not come into contact with the end fittings. Both horizontal and vertical set-up position of the specimen is acceptable.

Figure 8.4 shows one example of a vertical test set-up for a long-duration tensile test (without excluding other test set-ups).

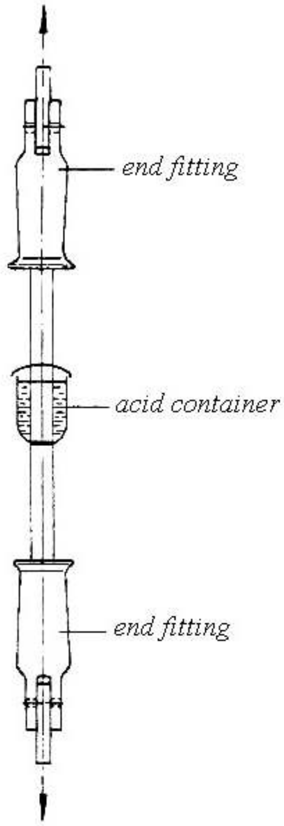


Figure 8.3 Acid resistance test combined with 96 h mechanical type test in accordance with IEC 61109, Annex A.3.

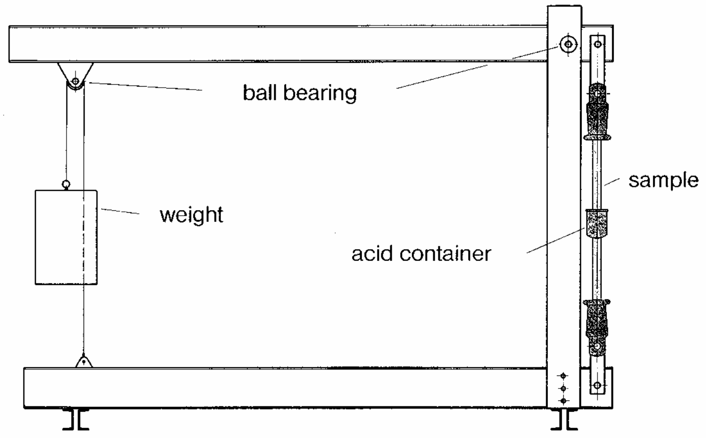


Figure 8.4 Example for permanent load application in a test set-up for 96 h acid resistant test. The sample is subjected to pure tensile stress. The container with 1n-HNO_3 is applied at the middle of the free FRP rod length.

C4 Evaluation of the test:

If a failure occurs before 96 hours, the time to failure shall be recorded.

If no failure occurs until 96 hours the specimen is regarded as acid resistant core.

8.3 CONCLUSION

Core materials may be susceptible to acid attack which may come along with water penetration and lead to stress corrosion when mechanical loads are applied simultaneously. As a result brittle fracture may occur.

The integrity of the housing is important for the performance of the composite insulator. It should also be noted that proper insulator design or good sealing system could prevent composite insulators from causing brittle fracture regardless of the kind of glass fibre and resin matrix.

If a core material shall be evaluated regarding its acid proof, for example, a core material used for composite longrod or composite linepost insulators (excluding hollow core insulators) then an acid test according to test method C shall apply. Tests according to method A and B give useful information.

For structural materials chemical resistance tests are not required according to the current knowledge. No failures of the “brittle fracture” type are reported from structural materials. Other tests that evaluate the resistance of chemical attack to structural material surfaces may be applicable or are already covered by other procedures, e.g. corona resistance tests.

For housing materials no supplementary tests are necessary since the effects of acid and chemical attack are already covered by tests proposed in other parts of this report.

8.4 REFERENCES

[1] Kuhl, M., FRP Rods for Brittle Fracture Resistant Composite Insulators”, Transaction on Dielectrics and Electrical Insulation, Vol. 8, No.2, April 2001, pp. 182-190.

[2] CIGRE WG B2.03, Brittle fractures of Composite Insulators – Field Experience, Occurrence and Risk Assessment, submitted for publication in ELECTRA

[3] CIGRE WG B2.03, Brittle fractures of Composite Insulators – Failure Mode Chemistry, Influence of Resin Variations and Search for a Simple Insulator Core Evaluation Test Method, submitted for publication in ELECTRA

[4] IEEE Brittle Fracture Task Force, Brittle Fracture in Non-Ceramic Insulators, to be published

[5] de Tourreil, C., Pargamin, L., Thévenet, G., Prat, S., Siampiringue, N., Brittle fracture of composite insulators: the new explanation and a field case study", ISH 2001 paper 5-25

[6] T. L. Wagner: "The New Wave of Boron-Free Glass Fibers", Composites 2001, Paper MA-302

[7] CIGRE WG 22-03: “Guide for the Identification of Brittle Fracture of Composite Insulators FRP rod“, ELECTRA No. 143, 1992, pp. 61-69.

[8] Lapp Insulators GmbH & Co. KG: “Test on composite insulators and FRP rod materials - 96 h ´brittle fracture´ test”, type test template document no. 82240, version 06/ 2000.

[9] J. Aveston, J.M. Sillwood: “Long Term Strength of Glass Reinforced Plastics in Dilute Sulphuric Acid“, Journal Mat. Sci., 17 (1982) pp. 3491-3498.

[10] IEC Publication 61109: „Composite insulators for a.c. overhead lines with a nominal voltage greater than 1000 V – Definitions, test methods and acceptance criteria“, 1995.

[11] ASTM D-1149: ”Standard Test Method for Rubber Deterioration – Surface Ozone Cracking in a Chamber”, 1999.

[12] DIN 50018: ”Testing in saturated atmosphere in the presence of sulphur dioxide”, 06.97.

[13] Montesinos, J.; Gorur, R.S.; Mobasher, B.; Kingsburry, D.: “Mechanism of Brittle Fracture in Nonceramic Insulators”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 9, No. 2, April 2002.

[14] Montesinos, J.; Gorur, R.S.; Mobasher, B.; Kingsburry, D.: “Brittle Fracture in Nonceramic Insulators: Aspects of Microscopic Flaws in Glass reinforced Plastic (GRP) Rods”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 9, No. 2, April 2002.

[15] M. Kumosa, H. Shankara, Narayan, Q. Qiu and A. Bansal, "Brittle Fracture of Non-Ceramic Suspension Insulators with Epoxy Cone End-Fittings", Composite Science and Technology, Vol. 57, (1997), pp. 739-751.

9 RESISTANCE TO WEATHERING AND UV

9.1 INTRODUCTION

Outdoor HV line insulators are exposed to weather and sun. Organic materials are affected by weathering. This requires implementing relevant testing. It is impossible to cover the various weather conditions all over the world with one test. A pragmatic test with good reproducibility, high acceleration factor and reasonable costs is needed.

9.2 AVAILABLE TESTS

- ISO 4892-1: 1999 Methods of exposure to laboratory light sources – Part 1: General guidance
- ISO 4892-2: 1994 Methods of exposure to laboratory light sources – Part 2: Xenon-arc sources.
  Devices using those spectra are often called Weather-O-Meter (WOM)
- ISO 4892-3: 1994 Methods of exposure to laboratory light sources – Part 3: Fluorescent UV lamps. Spectra generated by this method (lamp type 1, sunlight) are also known in the literature as Global UV (GUV)
- ISO 4892-4: 1994 Methods of exposure to laboratory light sources – Part 4: Open-flame carbon-arc
- NF C 32-062: This test uses high pressure mercury vapour lamps (4 X 100 W/m2) (Atlas chamber) according to the French standard NF C 32-062 generating spectra with discrete lines.

9.3 DISCUSSION ON AVAILABLE TEST AND MINIMUM REQUIREMENTS

ISO 4892-2: 1994

Xenon arc produces high IR radiation resulting in high sample temperature (up to 80 °C black panel temperature). The lamp will loose intensity during a 1000h test. Due to these drawbacks alternatives should be investigated.

ISO 4892-3: 1994

The scope of the method is to test the exposure to UV-light with dry climate interrupted by rain cycles. The test can be applied on solid organic materials for outdoor applications both for housing and structural materials.

ISO 4892-3: 1994 has good reproducibility under standardised conditions, but has to be improved by quantitative irradiation specifications. The following parameters of the test are recommended:

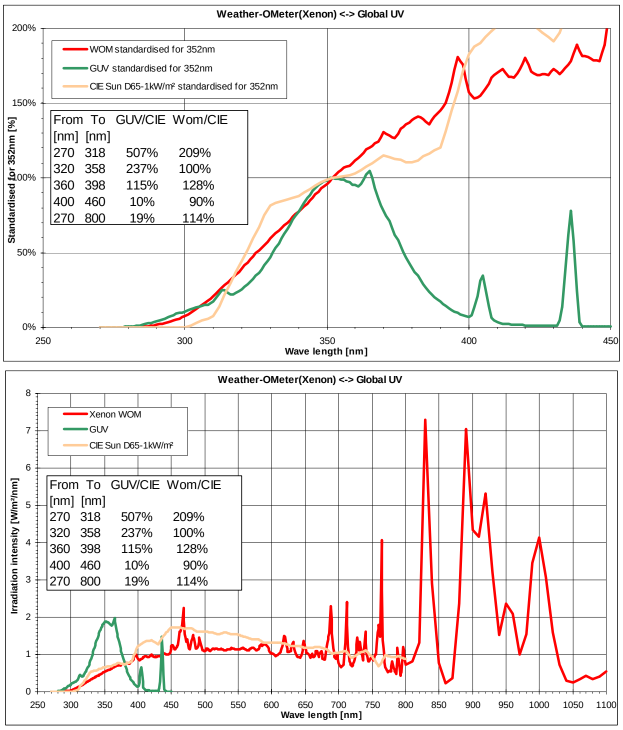
- Procedure, set up: ISO 4892-3: 1994, Exposure mode 2.
- Samples: Flat specimen 40*40*4 mm
- UV irradiation: Sun spectra in the range of 270 nm to 360 nm; 100 % duty ratio (24 h per day).
- Dry heat: 5 h with 50 °C ± 3 K and 10 ± 5 %rh.

- Rain: 1 h of water spray at 20 °C ± 3 K (Vantico 50 °C ± 3 K).
- Inspection interval: 500 h to 2000 h.
- Spectrum <270 nm 0 %; 270 nm to 300 nm 2 %; 300 nm to 320 nm 8 %; 320 nm to 360 nm 53 % and 360 nm to 400 nm 37 %. These values may vary by 20 % of this specification.
- Irradiation intensity 85 ± 20 W/m² in the range 270 nm to 400 nm.
- Irradiation dose 1.5 GJ/m² in the range 270 nm to 400 nm.
- An irradiation intensity with 85 W/m² in the range 270 nm to 400 nm over a test period of 5000 h would result in an irradiation dose of 1.5 GJ/m².

The parameters should be understood as target values. It is, for example, not possible to restore a dry climate immediately after the rain phase (wet test chamber). The acceleration factor is that 1000 h Fluorescent lamp UV is roughly equivalent to 1 year natural weathering in Central Europe [1].

Comparison between the Fluorescent lamp UV (ISO 4892-3) and Xenon arc (ISO 4892-2):

Fluorescent lamp UV uses only UV radiation in order to accelerate aging whereas Xenon Arc uses UV and visible light with a large infrared part (figure 9.1).



From [nm]	To [nm]	GUV/CIE	Wom/CIE
270	318	507%	209%
320	358	237%	100%
360	398	115%	128%
400	460	10%	90%
270	800	19%	114%

From [nm]	To [nm]	GUV/CIE	Wom/CIE
270	318	507%	209%
320	358	237%	100%
360	398	115%	128%
400	460	10%	90%
270	800	19%	114%

Figure 9.1 Comparison of Xenon spectra and Global UV spectra with CIE D65- 1kW/m² standard sun spectra

The Fluorescent lamp UV test can be operated at 30 - 50 % of the costs of Xenon Arc test due to lower initial equipment and lamp cost. Lamp life: Fluorescent lamp UV 2000 h until 30 % loss of intensity; Xenon Arc: 1000 h to 2000 h until complete loss of intensity.

Lamp power: Fluorescent lamp UV: 1 kW. Xenon Arc: 6 kW.

A comparison between the fluorescent lamp C-UV and Xenon arc on materials like EPDM, HTV silicone and EPM is given in [3]. The fluorescent lamp used in [3] had a different spectra compared to the spectra recommended above.

ISO 4892-4: 1994

This standard is practically not in use anymore.

NF C 32-062:

Industry partly uses a SEPAP 12-24 chamber (Atlas chamber) with high pressure mercury vapour lamps (4 X 100 W/m2) to check the materials UV resistance. The lamps present a UV line spectrum above 290nm and the test temperature (60°C) is directly measured on the sample surface by means of a Pt 1000 sensor.

A comparison test with natural aging on identical EPDM samples has shown by FTIR analysis that 400 hours in this test chamber is equivalent to one year in natural aging.

A second comparison test with a Xenon arc test chamber was performed. Using actinometer polyethylene films which UV aging is well known by mean of FTIR spectrometry analysis, this test has shown that the SEPAP chamber has a 2.5 acceleration factor compared to the Xenon arc test.

This test method is standardised for communication cables (NF C 32-062).

This test method generates spectra with discrete lines; it is the least comparable to the sunlight. Calibration effort is huge, risk of erroneous results cannot be excluded.

9.3.1 Criteria to determine ageing due to weathering

The following tests are used to determine the progress of ageing at each inspection interval.

a) **Visual inspection of sample surface**

Visual inspection without magnifying glass on occurrence and density of cracks.

b) **Determination of roughness**

ISO 4287: 1997 Geometrical Product Specifications (GPS) -- Surface texture: Profile method - Terms, definitions and surface texture parameters.

Parameters

- Measurement: R_a-Value (where R_a is the arithmetical mean deviation of the profile).
- Tests: 5 each specimen.

- Min. requirement: Roughness < 100 µm after 1.5 GJ/m² Fluorescent lamp UV as defined above.

No cracks. A surface texture is considered to be a crack, if it is longer then 4 mm and wider then 100 µm.

9.4 CONCLUSION

Up to now Xenon arc test (ISO 4892-2) has been widely used and many references are available. The flourescent UV test (ISO 4892-3) has promising features with respect to cost effectiveness and reproducibility. It will be the task of the future work to define the parameters of UV test (time of testing, rain cycle, sample temperature, lamp type) and test criteria in order to calibrate the two test methods.

9.5 REFERENCES

[1] Beisele, C., "Hydrophobic Cycloaliphatic Epoxy - Latest Findings and Future Developments", Proc. of the 2001 World Insulator Congress, Shanghai China, November 2001, pp. 141 – 153

[2] Schubert, H., Interfacial Climates on Irradiated Surfaces, Kunststoffe plast Europe, translated from Kunststoffe 84 (1994) 12

[3] de Mattos Mehl, Toureil, C, Multiple Stress Aging of HV Polymeric Insulation, IEEE Transactions on Electrical Insulation,

10 RESISTANCE TO FLAMMABILITY

10.1 INTRODUCTION

In this chapter it is only focussed onto the combustion/fire performance of polymeric housing materials or structural materials with combined function of housing and support.

From the service point of view it will be differentiated between applications for distribution, transmission network as well as railway.

Possible fire events can be initiated by failures of the electrical system or the fire cases of the environment. Examples for both are:

- power arc initiated by lightning strike or pollution
- internal breakdown of (oil-filled) apparatus
- pole fires in the case of wood poles
- fire events in relatively closed atmospheres such as tunnel systems
- fires in the landscape (fields, forests)

Polymeric materials show different resistance to flammability due to the intrinsic strength (basic structure) and added fillers, components. This requires selection procedures to fulfil minimum requirements. The material tests do not consider the design influence of the complete arrangement (string, apparatus). The complete arrangement is influenced by further factors and in-situ conditions such as:

- manufacturing method (mould line, adhesives/sealings for modular housings)
- heat dissipation effects
- guidance of power arc
- ignition source
- heat exposure duration

A positive superposition of these factors can lead to a successful performance of weaker materials, but would require the knowledge of the overall in-situ scenario. Flammability has probably played a limited role for many applications in the past, but is substantially in applications with fire load restrictions (e. g. tunnels) and might become more important by the rules of the de-regulated energy markets.

10.2 AVAILABLE STANDARDS FOR POLYMERIC INSULATORS (WITHOUT RAILWAY INSULATORS)

This matter is considered in the existing IEC 61109 [1], which refers to IEC 60707-1st Edition (flammability test) [2]. In the near future, IEC 62217 [3] will describe properties as harmonizing standard and is referring to IEC 60695-11-10 [4]. The main differences between both are as follows:

Previous standards, which referred to IEC 60707 has required FV0 as value for the design test. This means vertical method and evaluation of the after-flame and afterglow times as well as the detection of down-dropping burning particles. The first edition was also defining a specimen thickness of 3 mm.

In contrast to, the IEC 60695-11-10 leads to the following changes: The specimen should pass HB 40 (method A) or V 0 (method B). The set-up of the test arrangements can be seen in figure 10.1 – 10.2

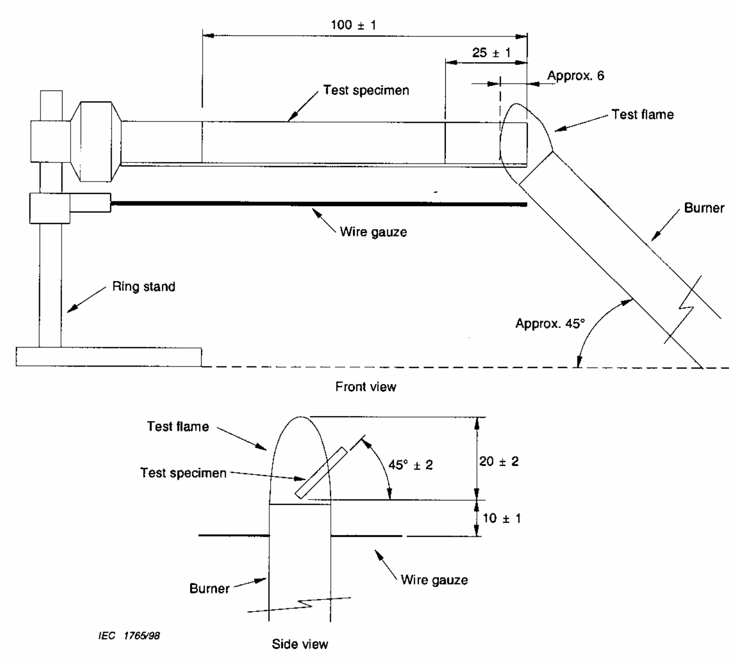


Figure 10.1 Set-up of HB-test

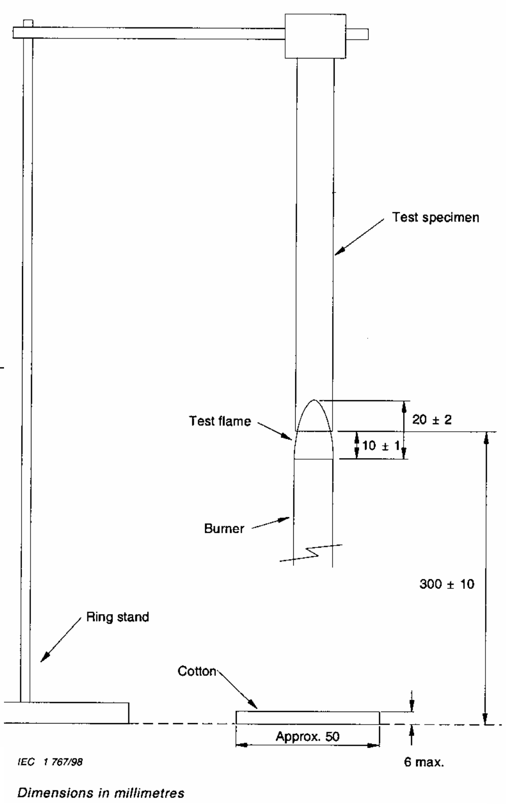


Figure 10.2 Set-up of VB-test

Both are not comparable in their objectives. HB is a horizontal procedure and permits burning of the material, hence it aims more on the evaluation of the linear burning rate, but provides almost no information about the after-flame, afterglow performance and dripping of flaming particles.

The acceptance criteria for HB 40 consist of 3 paragraphs, which have weaker requirements going from *a)* to *c)*:

A material classified HB40 shall present one of the following criteria:

a) it shall not visibly burn with a flame after the ignition source is removed;

b) if the test specimens continue to burn with a flame after removal of the ignition source, it shall not have the flame front pass the 100 mm mark;

c) if the flame front passes the 100 mm mark, it shall not have a linear burning rate exceeding 40 mm/min.

Taking the VB procedure, the flame touches both sides of the specimen in the contact area. The acceptance criteria are more defined and strict in this procedure:

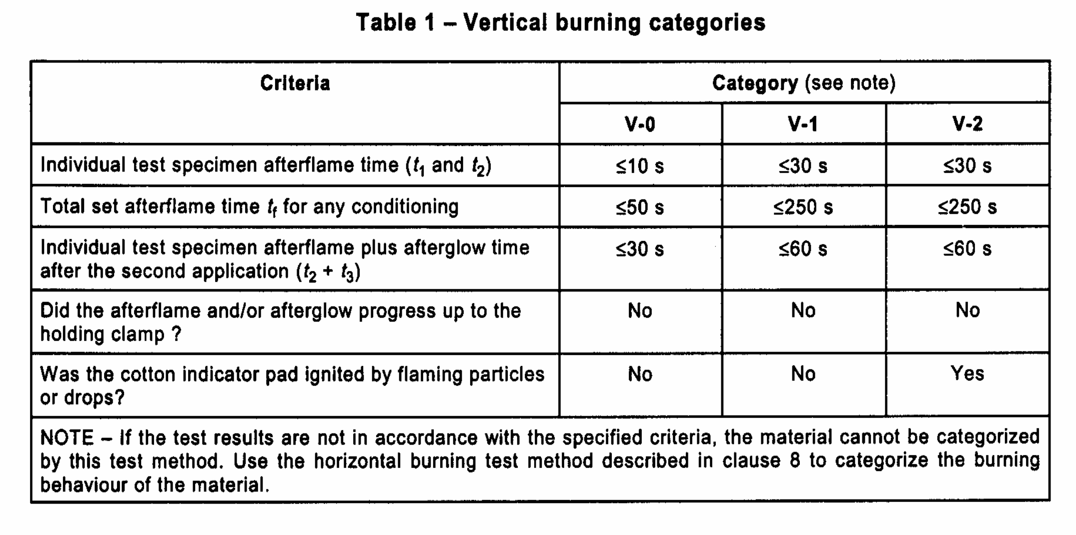


Table 1 – Vertical burning categories

Criteria	**Category** (see note)		
	V-0	**V-1**	**V-2**
Individual test specimen afterflame time (t_1 and t_2)	≤10 s	≤30 s	≤30 s
Total set afterflame time t_f for any conditioning	≤50 s	≤250 s	≤250 s
Individual test specimen afterflame plus afterglow time after the second application (t_2 + t_3)	≤30 s	≤60 s	≤60 s
Did the afterflame and/or afterglow progress up to the holding clamp ?	No	No	No
Was the cotton indicator pad ignited by flaming particles or drops?	No	No	Yes
NOTE – If the test results are not in accordance with the specified criteria, the material cannot be categorized by this test method. Use the horizontal burning test method described in clause 8 to categorize the burning behaviour of the material.			

Table 10.1 Criteria and categories of the V-method

From this point of view, the vertical method B provides more information and is recognized to be more difficult to pass.

Tests performed on specimen with typical and comparable shed thickness have shown that a material passing the HB40 test, does not necessarily meet V0 but V2.

The IEC 60695-11-10 permits a thickness of specimen up to 13 mm. In IEC 62217 CDV, the thickness is defined to be 3 mm, which corresponds to a typical shed thickness of elastomeric housings and minimum thickness of the (cylindrical) housing across the shank.

10.3 AVAILABLE STANDARDS FOR POLYMERIC INSULATORS FOR RAILWAY APPLICATIONS

Due to recent fire accidents in tunnels and the stronger requirements for railway applications, the minimum requirements for composite insulators have been extended in prEN 50151 [5]. This preliminary standard refers to further standards in respect to the behaviour in fire situations. These standards are mostly known from cable applications and are as follows:

- IEC 60332 fire propagation test [6]
- IEC 61034 smoke emission test [7]
- IEC 60754 toxicity test [8]

It has been shown that these tests cannot be directly applied to polymeric insulators. This is for the reason that the tests have been developed in respect to fire propagation of cables.

Further standardization work is ongoing in EN 45545 Part 2 [9], which will refer to ISO5659-2 [10] to investigate the smoke generation.

10.4 LIMITING OXYGEN INDEX

Limiting Oxygen Index might be used as additional criterion and/or as an alternative material test (described in ASTM 2863 [11]). In this procedure the sample is placed vertically in a flowing atmosphere of nitrogen and oxygen and ignited at the top. LOI is the percentage oxygen in the mixture, which leads to a maintained burning of the sample. It gives an indication about the overall risk for fire propagation in dependence on the required oxygen percentage. The measured value can be related to the oxygen content of the natural atmosphere (21%).

LOI may typically range from less than 20% up to 40%. Examples of LOI-values of commercially used polymeric materials are HTV silicone rubber (ATH-enriched) 44,5%, EVA 20,5% and cyclo aliphatic resin less than 20%. The LOI depends on type and amount of filler in the material.

10.5 SERVICE EXPERIENCE

10.5.1 Distribution and Railway

In the distribution network considered up to and including 36 kV, materials such as Cycloaliphatic Epoxy resin or EVA have been used in the past without passing the V0 criterion for a material thickness of 3 mm as required by IEC 61109. This confirms the influence of further parameters as shown in the introduction. In the case of specific requirements such as high values and long duration of short circuit, the use of V0 housing materials appears as more appropriate.

10.5.2 Transmission

As shown in a survey of CIGRE WG 22-03 [12], the dominating percentage of housing materials is made from Silicone Rubber and EPDM for transmission level insulators. These materials do pass the V0 criterion in general.

10.6 STATE-OF-THE-ART CONSIDERATIONS

In the new standard IEC 62217, the flammability is defined as additional value to other ageing-relevant properties such as tracking and erosion resistance. Despite the fact that the standard will cover "all" polymeric materials, the selection criterion as per procedure A (HB) or B (VB) should be more precisely, as example distinguishing for voltage levels. Taking the outdoor experience, the requirements appear as sufficient. The use of the LOI-measurement could be considered as supplement.

The positive experience in the past can be attributed to the fact that for distribution level materials have been used, which would pass V2 and HB40. For transmission level, V0 was the dominating requirement.

With the new scenario, the risk is given that alternative materials could be recognized to be sufficient with a HB40 (criterion c) and no V-classification. This would ignore the existing experience with the introduced materials and bear the risk for extended fire damages.

In the case of railway insulators in tunnel systems the technical requirements might be more severe. It has been shown that the simple use of existing cable standards is not suitable for the differentiation of various materials. In this respect, the deduction of specific test methods is necessary.

10.7 CONCLUSIONS

The resistance to flammability is determined by intrinsic material properties and the design of the insulation. As material (design) test, the existing IEC 61109 requires V0. Nevertheless, materials are in service mostly for distribution line insulators, which do not pass this criterion. The new standard IEC 62217 (Common Clauses) reflects to IEC 60695-11-10 and demands category HB 40 or V0. However, V0 and HB40 are not comparable to each other but if a scaling of materials is done, materials passing V0 will pass HB40 as well, but not vice versa. This step towards reduced requirements should be revalidated especially for transmission line level.

The minimum requirement shall be based on the fact that the insulator will not continue burning after power arc or due to electrical discharges. It is known that this requirement is met by category V0. But still it is unclear if this is the minimum requirement. Alternatively, the minimum requirement could be expressed in terms of suitable level of LOI. Details have to be investigated. Further investigation is necessary to give correlation to V0 and HB-categories.

10.8 REFERENCES

[1] IEC 61109: Composite Insulators for a. c. overhead lines with a nominal voltage greater than 1000 V, 1st Edition 1992

[2] IEC 60707: Methods of test for the determination of the flammability of solid electrical insulating materials when exposed to an igniting source. 1st Edition 1990

[3] IEC 62217: Polymeric insulators for indoor and outdoor use with a nominal voltage greater than 1000V – general definitions, test methods and acceptance criteria. CD 2002

[4] IEC 60695: Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods. 1st Edition 1999

[5] prEN 50151: Railway applications, fixed installations, electric traction, special requirements for composite insulators. March 1999

[6] IEC 60332: Test on electric cables under fire conditions. 3rd Edition 1993

[7] IEC 61034: Measurement of smoke density of cables – burning under defined conditions. 2nd Edition 1997

[8] IEC 60754: Test on gases evolved during combustion of electric cables. 1st Edition 1991

[9] EN 45545-2: Railway Applications

[10] 5659-2: Smoke generation, Edition August 1998

[11] ASTM 2863: Standard test method for measuring the minimum oxygen concentration to support candle-like combustion of plastics. Year 2000

[12] Composite Insulators. Survey from WG 22-03 published in ELECTRA 191, 8/2000

11 ARC RESISTANCE

11.1 INTRODUCTION

Insulators used in polluted environment are often exposed at their surface by electric discharges, e.g. dry band arcs. This dry band arcs could be the beginning of flashovers due to pollution [1]. In order to show no fast deterioration under this conditions there is also a need for the housing and structural materials of composite insulators for a minimum arc resistance of the polymeric material as well as a resistance against tracking and erosion (see 2.1). Recent investigations at FH Zittau demonstrate this correlation for silicone rubbers [2]. Many experiences with salt fog tests (IEC 62217) and also field tests (e.g. at Koeberg Insulator Pollution Test Station) show, that an improved arc resistance for housing materials is essential to pass this tests. This can be achieved for silicone and EPDM rubber for example by a special filler (ATH) or by special additives (silicone rubber).

11.2 AVAILABLE TESTS

Following standards exist for testing of the arc resistance of polymeric insulating materials (housing and structural):

- ASTM D-495 (High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation)
- DIN VDE 0441, Part 1 (Prüfung von Kunststoff-Isolatoren für Betriebswechselspannungen über 1kV – Prüfung von Werkstoffen für Freiluftisolatoren – Hochspannungs-Lichtbogenfestigkeit)
- IEC 61621 (Resistance test to high-voltage, low-current arc discharges)
- VDE 0303 Teil 71 (identical to IEC 61621)

11.3 DISCUSSION ON AVAILABLE TEST AND MINIMUM REQUIREMENTS

In ASTM D-495 and IEC 61621 at least 5 samples has to be tested. The thickness has to be approx. 3mm and the electrodes have to be at least 6mm from the edge of the sample. The use of thicker samples has to be noted in the test report.

In DIN VDE 0441, part 1 the number of tested samples is 10 and the dimensions are 30 x 15 x 10 mm.

The test should be made with Tungsten rod electrodes with a diameter of 2,4mm with a length of at least 20mm. The tips electrodes should have a polished elliptical face with a surface inclined at 30° to the axis of the electrode. The arrangement of the electrodes is shown in the figure 11.1. According to IEC 61621 the test will be made in 1 min-current steps according to the sequence in table below:

Step	Current [mA]	Time Cycle	Total Time [s]
1/8	10	1/8 s on 7/8 s off	60
1/4	10	1/4 s on 3/4 s off	120
1/2	10	1/4 s on 1/4 s off	180
10	10	60s (cont.)	240
20	20	60s (cont.)	300
30	30	60s (cont.)	360
40	40	60s (cont.)	420

The end point in this test, that is „failure", is usually quite definite for the materials under discussion here. At rather sharply defined time a conducting path is formed across the dielectric and the arc disappears into the material. At the same time a noticeable change in sound takes place. For many polymeric insulation materials with a high percentage of carbon in the molecular chains, the failure is easy to detect by the extinction of the arc, caused by the high carbon-containing path between the electrodes. Because of the inorganic backbone structure of silicone elastomers the arc can still exist, although the material surface is visibly eroded, which makes the identification of the failure more difficult [3].

For more details please see the standard IEC 61621.

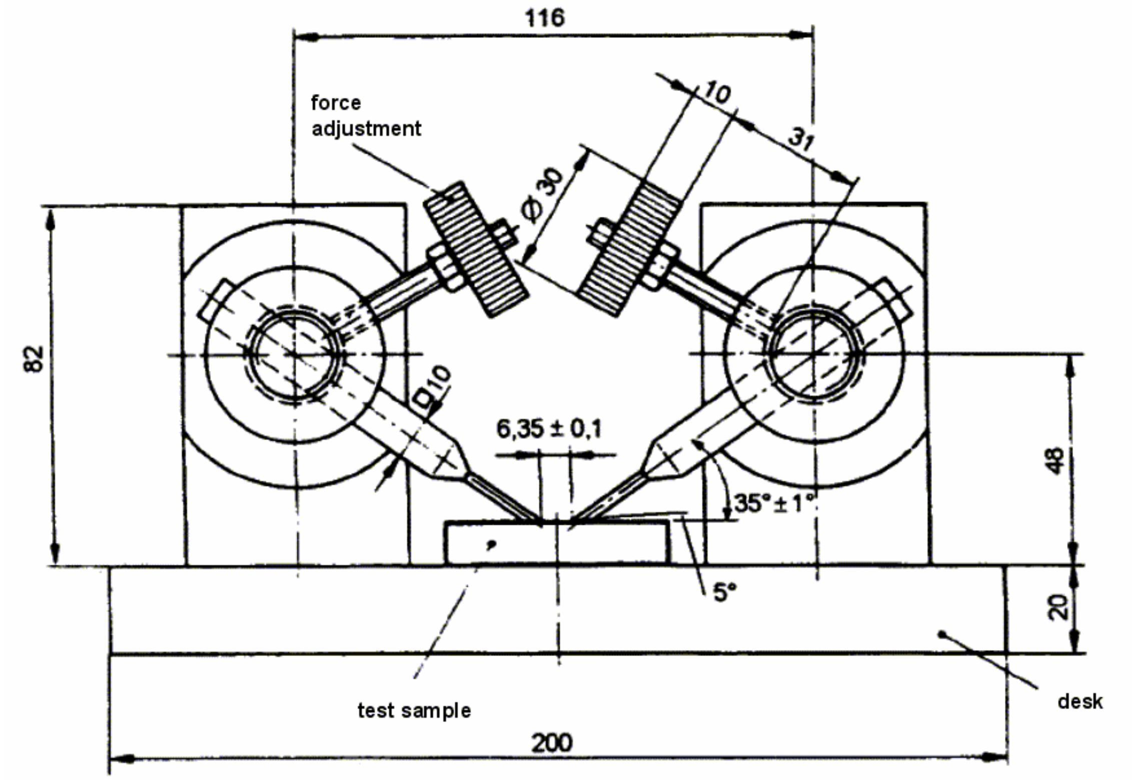


Figure 11.1 Apparatus for arc resistance test

In ASTM D 495 (at least 5 samples, 3mm thickness) there is a slightly longer „on"-time during the first steps and in the report the median and minimum arc resistance time shall be noted.

In DIN VDE 0441,1 (10 samples, 15mm thickness) the result will be reported by a Classification (HL class) according to the arc resistance time:

HL class	Arc resistance time
0	0 – 180
1	180 – 240
2	240 – 300
3	300 – 360
4	360 - 420

In IEC 61621 (5 samples, 3mm thickness) the median, minimum and maximum arc resistance time shall be noted in the report.

This test should be applied for the housing (silicone rubber, EPDM) and structural material (epoxy resin) but not for the core (FRP). Because of evaporation this test can't be applied on PTFE.

The reproducibility of the test results is quite good in all standards and this is a quick test in comparison e.g. to the related tracking and erosion test.

11.4 CONCLUSION

IEC 61621 is preferred for testing for the arc resistance of housing and structural materials. The test can be carried out quickly and reproducible. According to service experience with polymeric composite insulators [4] the minimum arc resistance time for the outdoor insulation material should be greater than 180 s.

11.5 REFERENCES

[1] R.Gorur, E.Cherney, J.Burnham, "Outdoor Insulators", 1999, p.148,149

[2] Hochschule Zittau/Görlitz (FH), Versuchsbericht 31/02

[3] R.Bärsch, H.Jahn, J.Lambrecht, F.Schmuck, "Test Methods for Polymeric Insulating Materials for Outdoor HV Insulation", IEEE Transactions on Dielectrics and Electrical Insulation, Vol.6, No.5, October 1999, pp.668-675

[4] AK 451.0.2, Kunststoff-Isolatoren DKE, etz-Report „Betriebserfahrungen und Untersuchungen an Kunststoff-Isolatoren in einer 20-kV-Leitung auf der Insel Nordstrand

12 GLASS TRANSITION TEMPERATURE

12.1 INTRODUCTION

Polymer Science Definition of Glass Transition Temperature, T_g:

The temperature at which a polymer changes from a hard glassy state into a rubbery / leathery state, due to a change in the free volume of the polymer. The glass transition is a second order transition. The transition process and the defined glass transition temperature are dependent on the analytical technique of measurement and the rate of measurement (temperature and time or frequency).

IEC 61006 Definition of T_g:

Glass transition: "A physical change in an amorphous polymeric material or in the amorphous regions of a partially crystalline polymeric material from (or to) a viscous or rubbery condition to (or from) a hard one."

Glass Transition Temperature: "The midpoint of the temperature range over which the glass transition takes place."

The following gives a simplified description for the main mechanisms: By decreasing the temperature each liquid solidifies. Due to the lower energy, the intermolecular forces change (note: glass transitions are not based on chemical reactions). The molecular chains loose their mobility, the molecule motion itself is reduced significantly. Enthalpy and volume decrease (figure 12.1).

Homopolymers and random copolymers have a single (α) glass transition temperature and possible lower temperature (β and γ) transitions related to vibrational, rotational and translational motions of the molecular chains and pendant groups. The thermal history of the material, the molecular structure and impurities have a strong influence.

12.2 AVAILABLE TESTS

There are four potential test methods available to measure the T_g value: always a temperature increase is applied to the samples.

1 DTA: Differential Thermal Analysis

2 DSC: Differential Scanning Calorimetry

3 TMA: Thermo-Mechanical Analysis

4 DMA: Dynamic Mechanical Analysis

IEC 61006, ISO 11357-2 or ISO 11359-2 describes in detail how to determine T_g by these methods. However, experience with the measurement indicates that results of different laboratories generally show a deviation, even when the same type of instrument is used. The results depend on the sample preparation, the procedure and the interpretation.

The following procedures are recommended to ensure consistent, high quality comparable results:

- A competent thermal analysis operator should perform the analysis.
- A low heating rate of maximum 10 °C per minute should be programmed.
- The sample weight should be 20 to 25 mg.
- The instrument should be calibrated regularly.

For DTA / DSC:

- The sample should be cut such that one surface is flat on the DSC / DTA pan.
- The midpoint of the transition should be obtained by using the derivative of the enthalpy curve.

12.3 DISCUSSION ON AVAILABLE TESTS AND MINIMUM REQUIREMENTS

12.3.1 Applicability

The requirement on T_g is applicable for core and structural materials. It does not apply to electrical apparatus where the mechanical stresses on the structural insulating materials are not significant, e.g. cast instrument transformers.

DTA and DSC are simple methods as well as time and cost effective techniques. Energy (temperature or enthalpy) differences are investigated during the measurement. Both are good methods to determine the curing status of the composite material. When the analysis is conducted at a slow heating rate i.e. 5 degrees a minute then there should be less than 2 degrees variation in repeated analysis, assuming the sample is homogeneous.

With TMA and DMA, mechanical material parameters and the T_g are measured. Especially in the case of fibre reinforced polymers, the fibre orientation as well as the samples geometry influence the result. Therefore, TMA and DMA can give some information about the mechanical behaviour. These specialised instruments are generally less available than DSC and DTA instruments.

The various methods for determination of T_g rely on the measurement of the change in different physical properties of the polymer as it is heated through the glass transition temperature. Thus, different methods can lead to different values of the glass transition temperature. To compare T_g-values from non ceramic insulator (NCI) materials measured by different laboratories, the values must be obtained by the same test method and comparable test procedures.

12.3.2 T_g as a Quality Indicator

During the curing process of amorphous or partially crystalline polymers, generally a 3-dimensional network is created from mostly linear molecules by cross-linking. Molecule motions as well as mobility are reduced. Consequently, the value of T_g increases continuously. Reaching the actual hardening temperature, the glass state is formed but the curing reaction is not finished. The speed of the dynamic cross-linking process strongly slows down.

To close the cross-linking reaction further energy input - amount and time are depending from the polymer system - is necessary. Because the polymer is already in the glass status and therefore hard, misinterpretation is possible when it is allowed to stop the curing process. For the case it was too early, the T_g measurement would show a difference to the specified value. Therefore T_g is a quality indicator for the curing process of the polymeric material.

12.3.3 Operating security:

The importance of the T_g for NCI core and structural materials is explained; the changes in the molecular energy, mobility and motion as well as structure during the glass transition influence the mechanical, dielectric and electrical properties. Figure 2.11-2 shows an example with shear modulus G as the mechanical property and tan δ as the electrical property. Here, for the minimum material requirements to be defined, the correlation between T_g and mechanical properties is discussed. The description of electrical and dielectric properties is shown better and more accurately by other parameters.

12.3.4 Correlation between T_g and mechanical properties

Within the temperature range around the T_g, the mechanical material properties change significantly because of the physical change from a hard to a rubbery material. Per definition the core and structural materials carry a mechanical load, and generally the polymeric materials used for outdoor insulation are amorphous or partly crystalline. Therefore, to guarantee constant mechanical values regarding the glass transition during long-term service, the maximum allowable temperature stress for an insulator made from polymers is limited.

This document does not define an absolute temperature value, but a minimum temperature difference of 15K, which is necessary between T_g and the maximum temperature allowed continuously during operation, T_{max}:

$$(T_g - 15K) = T_{max}$$

All long-term temperature stresses T_{long} must be kept below T_{max}:

$T_{long} < T_{max} = (T_g - 15K)$

or,

$T_g > (T_{long} + 15K)$.

The glass transition is a time-dependant process. In the short term temperatures T_{short} may be allowed in the range of or higher than T_{max}, for example during a curing process of the housing material applied on the core. This is within the responsibility of the insulator manufacturer applying structural or core materials. Users of the finished non-ceramic insulator, for example apparatus manufacturer, have to coordinate short-time temperatures $T_{short} > T_{max}$ during their production process with the insulator manufacturer.

12.4 CONCLUSION

Based on practical experience and the physical mechanism of glass transition, a safety margin of 15 K is defined between T_g and maximum allowed, continuously operating temperature T_{max}. T_g measurements shall be performed according to IEC 61006, ISO 11357-2 or ISO 11359-2. Special view shall be taken for the complete test report as described in the standard. Detailed description of sample geometry and preparation, test method and parameter as well as analyse of the test results is necessary.

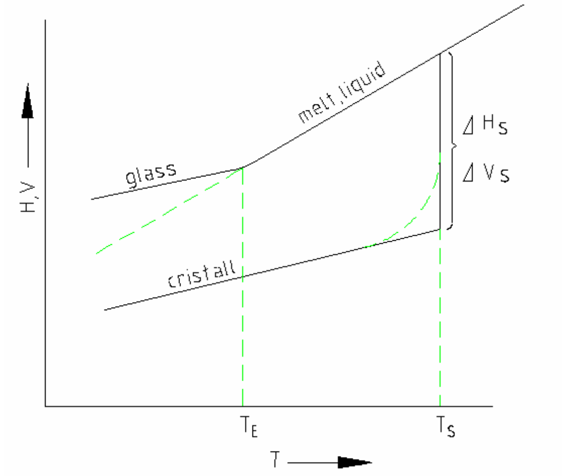
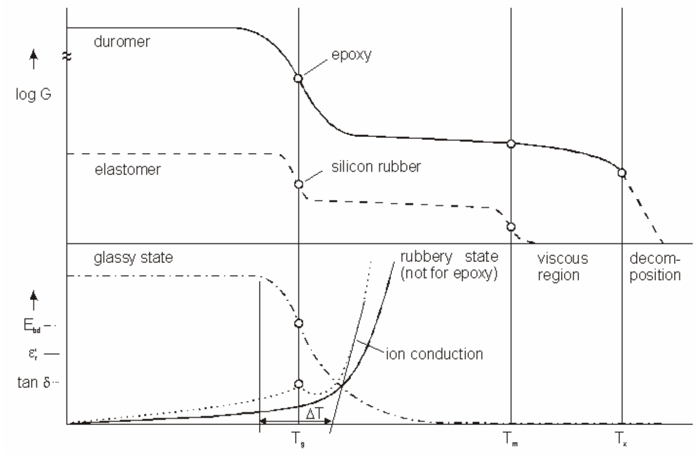
	

Figure 12.1 *Enthalpy and volume versus temperature in liquid, crystal and glassy state. T_E = Freezing Temperature, T_S = Melting Temperature.*	*Figure 12.2* *Mechanical (log G) and Electrical Behaviour versus Temperature for an epoxy resin and a silicone elastomer. [1]*

12.5 REFERENCES

[1] Seifert, J.M.: Interfacial and microscopic bonding problems in minerally filled epoxy casting products for high voltage insulation", PhD Thesis, TU Braunschweig, 1998

[2] Menges, G.: "Werkstoffkunde Kunststoffe", Hansa Verlag, 1990

[3] IEC International Standard 61006: "Methods of test for the determination of the glass transition temperature of electrical insulating materials", 1991

[4] Nitsche/Wolf: "Kunststoffe. Erster Band", Springer-Verlag 1962

[5] Bittmann, E., Ehrenstein, G.W.: "Bestimmung der Glasübergangstemperatzur bei Duroplasten", Hanser-Verlag, Materialprüfung 39 (1997) 4

[6] Ngai, K.L.: "Dynamic and thermodynamic properties of glass-forming substances", Journal of Non-crystal solids, Vol. 275, pp 7-51, 2000

[7] ISO 11357-2: "Plastics -- Differential scanning calorimetry (DSC) -- Part 2: Determination of glass transition temperature", 1999

[8] ISO 11359-2: "Plastics -- Thermomechanical analysis (TMA) -- Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature", 1999

13 HYDROPHOBICITY

13.1 INTRODUCTION

Three properties of hydrophobic materials describe the wetting behavior of insulating materials (figure 13.1) [1].

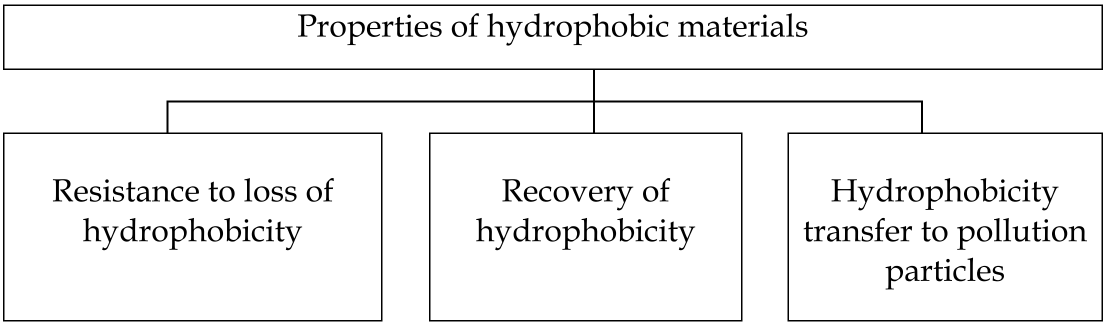


Figure 13.1 Properties of hydrophobic materials according to [1]

Hydrophobic surfaces don’t show surface film layers when sprayed with water. This may lead to:

a) suppression of the insulator leakage current,

b) higher inception voltages of electrical discharges in wet pollution layers,

c) higher specific flashover voltages than hydrophilic insulators,

In consequence the surface erosion is less intensive.

Especially the leakage current suppression ability (LCSA) of hydrophobic materials is under investigation and was discussed intensively in CIGRE WG 15.04 [6].

In regard to insulating materials the LCSA is a secondary property, caused by the hydrophobicity. It was agreed in the group, that the primary property hydrophobicity should be evaluated.

If it were possible to compare the hydrophobicity properties of different insulating materials in a laboratory, this would help to develop and to rank materials

Tests for the evaluation of the hydrophobicity are applicable to housing and structural materials if the material is claiming to have permanent intrinsic hydrophobic properties.

13.2 TESTING OF THE HYDROPHOBIC PROPERTIES

Based on the current experiences it makes sense to look for feasible ways to evaluate the “loss of the hydrophobicity” and the “hydrophobicity transfer”.

a) loss of the hydrophobicity

Methods for the evaluation of the “loss of the hydrophobicity” give information about the *stability of the hydrophobicity* under certain stresses.

It turned out that the hydrophobicity of insulating materials might become reduced under such main stresses like water immersion, exposure to UV or intense electrical discharges.

There are no standardised test arrangements for the evaluation of the influence of electrical discharges in the hydrophobicity available. That is why there several equipments are in use.

A needle-plane arrangement has been used for checking the loss and recovery of the hydrophobicity [11]. The needle electrode is positioned 10 mm over test specimens which is positioned on a grounded plane. 18 kV ac (r.m.s) voltage is applied for 150 min.

A multiple needle arrangement, has recently been used when studying the mechanism of hydrophobicity loss and recovery on Polydimethylsiloxane (PDMS) materials [12]. This corona electrode is equipped with 31 needles, which tips had a radius of 56 µm. The treated sample was placed on circular glass plates on the grounded plane electrode at a distance of 40 mm from the needle tips. The applied voltage was 20 kV_{max} ac (r.m.s). The electrodes are mounted in a desiccator to provide a controlled atmosphere.

Other stresses showed a minor influence on the hydrophobicity. Nevertheless, changes of the hydrophobicity are proposed to be used to determine the influence of UV-radiation in polymeric insulating materials. The standard EN 828: 1998 (Adhesives, Wettability, Determination of contact angle and critical surface tension of solid surfaces) recommends the measurement according to the "dynamic advancing drop method".

In service the surface of insulating materials may become stressed simultaneously by moisture and electrical discharges. The stability of materials against such simultaneous stresses is important for their performance.

b) hydrophobicity transfer

The hydrophobicity transfer to pollution particles is easy to evaluate. Some sort of dry artificial pollution layers are used to evaluate the changes of their wetting behaviour in dependence on the time [3], [4], [5]. The evaluation can be done either by measuring wetting angles or by using a drop-roll-of method like it was proposed in [4]. It is also possible to evaluate the leakage current of a pollution layer as a function of hydrophobicity transfer [5], [10].

It is not recommended to work on a method for the recovery of the hydrophobicity. Any comparative evaluation method has to start at the same low level of the hydrophobicity. To reach the same level requires *different pre-stressing* of different materials. This is questionable from the point of view of the comparison of the results. A material, which shows a good and stable hydrophobicity would become pre-stressed much more intensively than a weak material to destroy the hydrophobicity – a comparison of the recovery is not possible.

Besides this, the technically most important recovery process, the migration of low molecular weight parts becomes evaluated with the described transfer tests as well.

The degree of hydrophobicity can be quantified by different methods (IEC TR 62073):

- contact angle method,
- surface tension method,
- the spray method (STRI).

In comparison to the electrical performance it turned out that the receding angle of water correlates best to the electrical performance of the wet surface [9].

13.3 TESTS FOR STABILITY OF HYDROPHOBICITY

There are no standard methods for quantifying and comparing the hydrophobicity processes of different materials.

In regard to service conditions the following tests can be used to evaluate the stability of the hydrophobicity under multi-stress conditions:

a) salt-fog-test [6],
b) modified rotating wheel test [5], or
c) dynamic-drop-test [7], [8].

13.3.1 Salt-fog test

- test specimens, test procedure, test conditions

The test specimens, the test procedure and the test conditions may be the same like proposed in [6] by CIGRE WG 15.04 for the evaluation of the "Leakage Current Suppression Ability". Samples in any test run shall be of the same material in order to prevent contamination.

- measuring and data acquisition

The leakage current flowing across each specimen shall be monitored.

- Evaluation of the test results

A test criterion may be the mean value of the cumulative charge of the individual samples after 50 cycles. The charge can be used to rank different materials with respect to their ability to suppress leakage current under high voltage and low conductivity salt fog conditions by showing a stable hydrophobicity.

At present, it is not possible to indicate minimum requirements for materials.

Advantages of a salt-fog-procedure are the availability of the test equipment and the fact that a salt-fog test could be used at the same time to evaluate the ability of a material to suppress the leakage current.

The large scatter of the results, the long test duration and the special measuring equipment, which is needed to measure the charges or the peak-like currents, are disadvantages of this procedure.

13.3.2 Modified Rotating-Wheel-Dip-Test

- test specimens, test procedure, test conditions

Cylindrically shaped test specimens of about 30 mm diameter and 100 mm in length are used. 4 specimens are mounted as shown below on a wheel, which moves 90 degrees after 60 s each [5]. A conductivity of the NaCl-solution 1,5 mS/cm was proposed for silicone elastomers [5], a recommendable specific electrical stress is 0,6 kV/cm. Samples in any test run shall be of the same material to prevent contamination.

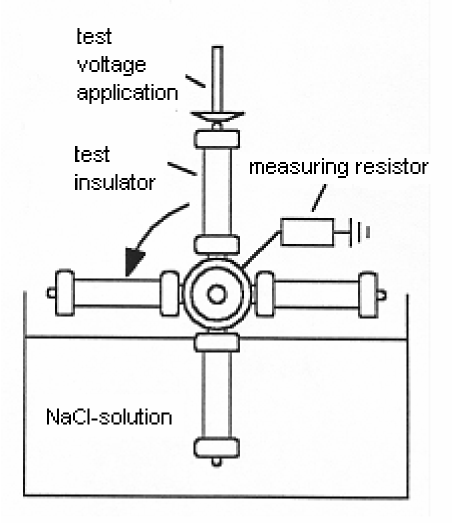


Figure 13.2 Modified Rotating-Wheel-Dip-Test (in principle)

- measuring and data acquisition

The leakage current flowing across each specimen shall be monitored during the energized phase. The measured data can be used for a differentiation between different materials.

- Evaluation of the test results

In [5] a 1 mA-criterion was used to determine a time of the partial loss of the hydrophobicity.

Minimum requirements for materials do not exist so far.

The advantage of a wheel-procedure is the shorter test cycle in comparison to the fog-procedure. Unfortunately the test equipment is complicated and not easy to adjust for reproducible results. Furthermore the test specimens are not easy to produce.

The large scatter of the results requires the test of a bigger number of specimens.

13.3.3 Dynamic-Drop-Test

Both, with the salt-fog- as well with the rotating wheel-dip-test it can be observed that electrical discharges occur at the ground electrode when moving drops contact the electrode. Further, it turned out that the stability of the hydrophobicity is reduced with the number of drop-initiated discharges. The accidental rolling down of water drops is subject for significant variation of test results. This explains a large observed statistical scatter.

In order to get more reproducible results the number and frequency of water drop initiated discharges must be controlled. This is the basic idea of the dynamic-drop-test.

- test specimens, test procedure, test conditions

A plate shaped test specimen is used. The specimen is inclined 60 degree from the horizontal position. About 1 ml/min of a NaCl-solution with specific conductivity of 1,5 mS/cm is pumped continuously through the high voltage electrode (figure 13.3). The NaCl-solution drains through cavities inside the HV electrode. The adjustment of the pumping process and the HV electrode leads to about 16 moving droplets per minute. After adjusting the flow rate the test voltage is applied. The specific electric stress should be in the range of (0,6 ... 1) kV/cm [7].

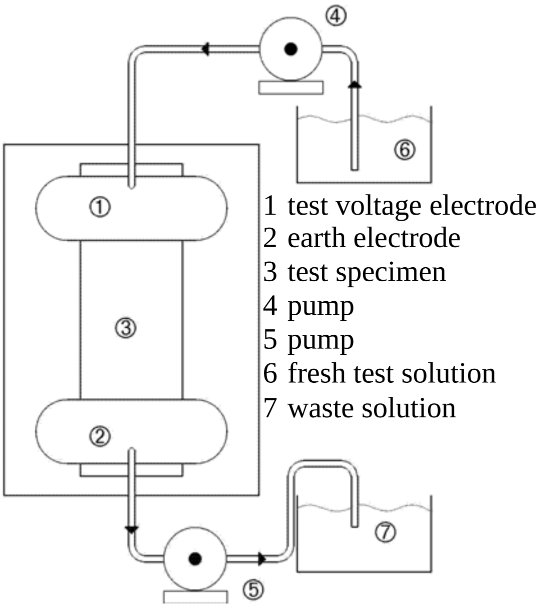


Figure 13.3 Dynamic-drop-test (in principle)

- measuring and data acquisition

Current-time-relays are used to evaluate the leakage current. By reaching a certain leakage current the partial loss of the hydrophobicity can be detected reliably.

- Evaluation of the test results

The surface of the specimens of the insulating material becomes stressed by moisture and electrical discharges. In dependence on the stability against these stresses the hydrophobicity gets lost (figure 13.4). The left figure shows a sample with still existing hydrophobicity, the right figure shows a partially lost hydrophobicity.

A 5 mA-criterion was found to be useful to indicate the loss of the hydrophobicity electrically when the proposed test parameters are used. End of test is reached when leakage current is higher than 5 mA for more than 2 seconds.

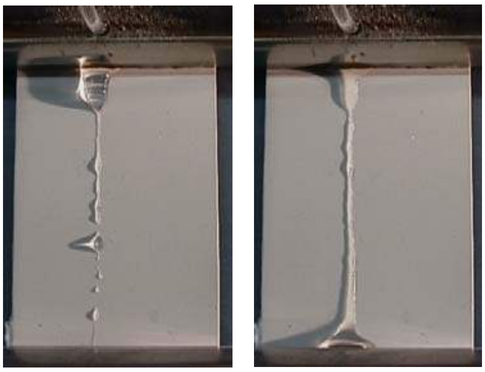


Figure 13.4 specimens in the dynamic-drop-test

A differentiation between insulating materials is possible. A liquid silicone rubber, which is partly filled with a non-treated ATH, shows much less stability of the hydrophobicity than a non-filled one.

Minimum requirements for materials do not exist so far. Further experience with this test is needed especially regarding the influence of the surface roughness on the test results.

The advantage of the dynamic-drop-test is the very short test cycle in comparison to all other available tests. The test is easy to install and easy to handle. So far good experiences on the reproducibility are available.

13.4 TESTS FOR HYDROPHOBICITY TRANSFER

The comparative evaluation of the hydrophobicity transfer ability of insulating materials can be done by applying an artificial pollution layer and by evaluating the changes of the wettability in dependence on time.

In the past several artificial layers like fumed silica, kaolin powder, treated and non-treated quartz powder and different application technologies were used.

Reliable results were found using silane-treated quartz powder 600 which is applied as a powder-water suspension. Based on the available data the following procedure is proposed:

- test specimens

Test specimens for the evaluation of the hydrophobicity transfer into the pollution layer shall be plate-shaped (50 x 50 mm^2) with a thickness of 6 mm. Specimens have to be cleaned by using Isopropanol and distilled water. The application of the artificial layer should start 24 h after cleaning.

- test procedure

Silane treated quartz powder 600 is used to pollute the specimens. The powder becomes suspended in water (7,5 g powder, 3 ml of distilled water) by mixing for about 2 minutes.

The suspension is applied into a mask of 30 mm x 30 mm and a thickness of 0,6 mm. Surplus suspension is removed by using a glassy stick. The prepared specimens are stored under normal lab conditions for about 24 h prior the measurements start.

- data acquisition

During the storage of the specimens under controlled temperature and humidity the wetting behaviour becomes evaluated in dependence on the time.

Evaluation methods can be:

a) measurement of the dynamic wetting angles

b) hydrophobicity classification using the HC-classes according to STRI (in dependence on the time)

It is recommended to use the dynamic wetting angles for evaluation to avoid subjective results. The receding angle is the preferred measure.

A method proposed in [4] combines the sucking behaviour of the pollution layer and the moving behaviour of droplets on the surface of the pollution layer to evaluate the hydrophobicity transfer.

It is also possible to evaluate the influence of hydrophobicity transfer on the electrical behaviour of the pollution layer as described in [7].

The most preferable evaluation method has to be found by doing round robin tests.

13.5 CONCLUSION

It seems that the dynamic hydrophobicity properties of insulating materials can be covered by

- a test to evaluate the stability of the hydrophobicity and
- a test to evaluate the hydrophobicity transfer ability.

So far, the stability of hydrophobicity has been tested mainly by the salt-fog test and the modified rotating wheel dip test. A newly developed dynamic drop test offers promising features with respect to reproducibility and cost effectiveness. Further, it uses flat samples, which are easy to manufacture. The future work should evaluate the applicability of this method and compare it to other methods.

Several different test methods have been used to test the ability to transfer hydrophobicity. The results are not comparable to each other. Future work should concentrate on defining and evaluate a test method with the potential to gain general acceptance.

13.6 REFERENCES

[1] CIGRE Task Force 33.04.07, Natural and Artificial Ageing and Pollution Testing on Polymeric Insulators, CIGRE report 142, June 1999

[2] Lange, G., Bärsch, R., Lambrecht, J., Liebermann, H., Winter, H-J., Wolters, H, Erste Betriebserfahrungen mit einem Silikoncoating auf Porzellanstützern unter Fremdschichtbedingungen, Elektrizitätswirtschaft, Jg. 97 (1998), Heft 23, S. 34 – 41

[3] Kindersberger, J., Kuhl, M, Effect of Hydrophobicity on Insulator Performance, 6th International Symposium on High Voltage Engineering, New Orleans, August 1989, paper 12.01

[4] Janssen, H., Ursache und Lebensdauer der Hydrophobie polymerer Werkstoffe für Hochspannungs-Freiluftisolatoren, PhD_Thesis, University of Braunschweig/Germany, 1999

[5] Lambrecht, J., Über Verfahren zur Bewertung der Hydrophobieeigen-schaften von Silikonelastomer-Formstoffen, PhD-Thesis, Technical University of Dresden/Germany, 2001

[6] CIGRE SC 15, WG 15.04 ”Outdoor Insulation”, Report on Development of a Test Technique to Assess a Polymer's Long Term Ability to Suppress Leakage Currents under High Voltage and Low Conductivity Salt Fog Conditions, September 2000

[7] Jahn, H., On the evaluation of material-specific and technological influence factors on the hydrophobicity and erosion behaviour of silicone rubber surfaces, Dissertation, TU Dresden, 2003 (in german)

[8] Bärsch, R., Bewertung der Hydrophobie sowie des Kriechstromverhaltens von Silikonelastomeren für Hochspannungs-Freiluftisolatoren, ETG-Tagung, Silikonelastomere, Berlin, March 2003 (in german)

[9] Hofmann, J., Elektische TE- und Ableitstrommessungen mit Impulsspannung an polymeren Isolierstoffoberflächen mit Ropfenbelägen zur Diagnose des Oberflächenzustandes am Beispiel von Elastomeren, Diss., TH Zittau, 1995

[10] Jahn, H.; Bärsch, R.: On the influence of different stress factors on the hydrophobicity and the electrical behaviour of silicone rubber surfaces. Int. Conf. On

Advances in Processing, Testing and Application of Dielectric Materials, Wrocław, September 2001, proceedings, pp.363-366

[11] Beisele C. ”Hydrophobic Cycloaliphatic Epoxy – Latest Findings and Future Developments”, Proc. of the 2001 World Insulator Congress, Shanghai China, November 2001, pp. 141-153

[12] Hillborg H.C. ”Loss and Recovery of Hydrophobicity of Polydimethyl-siloxane after Exposure to Electrical Discharges”, PhD thesis, Dept. of Polymer Technology, Royal Institute of Technology, Stockholm Sweden, 2001, ISBN 91-7283-029-8

14 SUMMARY

The important material properties identified in the survey by the WG are listed in table 14-1. The properties are specified for housing, core and / or structural materials. For some properties several standardised test procedures are available. In such cases Table 14-1 lists the most widely used. If available and applicable, the minimum requirements have been listed.

Twelve properties have been identified. Standardised test methods and minimum requirements where available for eight of them. For the remaining four properties, test methods and minimum requirements need to be defined. This is the future task of WG D1-14.

Table 14-1 Important properties and minimum requirements of polymeric materials for non-ceramic outdoor insulation

				Applicability and Minimum requirements			**Tests standard**	**Suggestion for future work**
Chap	**Property**	**Symbol**	**Units**	**Housing**	**Core**	**Structural**		
2	Resistance to tracking and erosion			1A3,5[1]	–	1A3,5	IEC60587	
3	Resistance to corona and ozone			X	–	X		The resistance to corona should refer to the mechanical integrity of the materials. Therefore, corona test should be combined with mechanical stress. Suitable corona test arrangement needs to be defined. The correlation between corona test and service performance need to be investigated further. The corona test also covers the resistance to ozone.
4	Resistance to chemical and physical degradation by water[2]			"voltage test" withstand voltage (no breakdown, no flashover) of 12 kV required for 1 minute, current during test shall not exceed 1 mA (r.m.s.)			IEC 61109, 62217, water diffusion test	
				Optional test "Dielectric properties after water immersion" $\tan \delta<0.2$ after 50 days of water immersion at 50C			$\tan\delta$ (IEC 60250)	
5	Tear strength	F	N/mm	>6	–	–	ISO 34	
6	Volume resistivity	ρ	Ωm	$>10^{10}$			IEC 60093	
7	Breakdown field strength	E	kV/mm	40	(covered by boiling test)	40	IEC 60455-2	

---

[1] Insulating materials for special medium voltage applications, e.g. termination materials for XLPE cables, show a stability of class 1A2,5 and show satisfying performance in service

[2] Water diffusion test gives all necessary information about suitability of materials for outdoor insulation. The water immersion test gives additional information about the mechanism of aging and is useful to rank materials

				Applicability and Minimum requirements			Tests standard	Suggestion for future work
Chap	**Property**	**Symbol**	**Units**	**Housing**	**Core**	**Structural**		
				10		10	IEC 60243-1	
8	Resistance to chemical attack[3]			–	No failure in the acid resistance test for FRP rods	–		
9	Resistance to weathering and UV			X	–	X	ISO4892-2:1994 ISO4892-3:1994	Evaluate Xenon arc and fluorescent UV methods with respect to duration of testing and minimum requirements
10	Resistance to flammability			X	–	X	IEC 60695-11-10 ASTM 2863	Consensus should be achieved for the minimum requirement, i.e. vertical or horizontal burning test. Alternatively, a test measuring the limiting oxygen index (LOI) should be evaluated. Further investigation is necessary to give correlation to VB and HB-categories
11	Arc resistance	T	s	>180	–	>180	IEC 61621	
12	Glass transition temperature	T_g	C	–	$T_g > T_{max} + 15K$	$T_g > T_{max} + 15K$	IEC 61006	
13	Hydrophobicity[4] - Stability - Transfer			X	–	X		Several test methods exists. Evaluation with respect to reproducibility is necessary.

---

[3] This property is applicable only to rod materials claiming to be acid resistant

[4] This property is only applicable to materials claiming to have permanent intrinsic dynamic hydrophobic properties

APPENDIX A WATER ABSORPTION

A.1 Introduction

The following descriptions of relevant terms are based on references [1] and [2].

Diffusion:

This is the spreading of a liquid or a gas from a source. It is a physical phenomenon in which matter is transported under the influence of a concentration gradient. The electrons, ions, atoms or molecules change position as a result of their kinetic potential from a region, in which they occur at a higher concentration to one of a lower concentration. According to Fick's 1st law of molecular diffusion, the rate of diffusion is proportional to the concentration gradient. The coefficient is called the "Diffusion Coefficient", and has the dimension $m^2 \cdot s^{-1}$.

In the case of an initially dry material exposed to a wet environment, there exists a concentration gradient for the moisture, leading to a potential diffusion process of the water from the outside to the inside of the material.

Absorption:

Absorption occurs when one substance is assimilated into the interior of another. An example of absorption is the swelling of a polymer by water. This term should not to be confused with the process of adsorption, which is entirely a surface effect.

Transmission:

The process of allowing a substance or energy source to pass through another medium. This term is normally used in spectroscopy and is not really applicable to water absorption.

Permeation:

This is the process by which a chemical (e.g. water) moves through a protective material (e.g. an NCI housing material) on a molecular level. Permeation involves the following:

1. Sorption of the molecules of the chemical in contact with the outside surface of a material.
2. Diffusion of the sorbed molecules into the material, and
3. Desorption of the molecules from the opposite (inside) surface of the material, through to the bulk of the collecting medium.

In the case of an initially dry housing; when the material is exposed to a wet environment, there is a concentration gradient with regard to water, leading to a possible *diffusion* process of water vapor from the outside into the bulk of the material. The water may be absorbed by the housing-material. If the water passes through the housing-material and then further diffuses into the next layer (i.e. into the FRP-rod), one can regard this as a *permeation* process.

The materials used for outdoor insulators may be exposed to environmental conditions such as rain, dew, fog and humid air. Such sources of moisture may lead to the diffusion of water into the polymer, depending on the length of the exposure time, the temperature and the permeability of the polymeric insulator material.

The diffusion of water could influence many properties of the polymer, which are relevant to its application as an insulator. Examples are; the Tan δ, the mechanical strength, the breakdown strength and changes in dimensions, etc.

The water may even diffuse through the housing material into the core of a composite insulator. In this case the water may be transmitted through the housing. This might be important for hollow insulators in specific applications as the water may further proceed through the insulator. However, such a phenomenon can be corrected by optimised design and may not require specific material characteristics.

Water may possibly also diffuse into the bulk material and dissolve or water-soluble components or leach non-soluble components of the polymer formulation. If a sample weighs less after water storage and subsequent re-drying, it indicates that it contains water-soluble components showing weaknesses in the polymer formulation, such as an unsuitable filler or improper curing. Water diffusion could possibly therefore be used as an indicator to assess the integrity of the housing and core materials.

A.2 Available tests

- ISO 62:1999 (Plastics -- Determination of water absorption) is a widely used standard to measure the water absorption of plastics.
- DIN VDE 0441 / Part 2 provides another available standardized test method, which classifies the resistance of an insulation material against thermal breakdown after water diffusion. As an intermediate result this method also yields the amount of water absorbed after boiling the test samples for 100 hours in a saline solution.
- Additional standards relating to diffusion processes were sourced; however, they are not regarded as being applicable to insulation materials:
    - ISO 2556:1974 (Plastics -- Determination of the gas transmission rate of films and thin sheets under atmospheric pressure -- Manometric method)
    - ISO 7783-2:1999 (Paints and varnishes -- Coating materials and coating systems for exterior masonry and concrete -- Part 2: Determination and classification of water-vapour transmission rate (permeability))
    - ISO 8308:1993 (Rubber and plastics hoses and tubing -- Determination of transmission of liquids through hose and tubing walls)

- ASTM F1249-01 (Standard Test Method for Water Vapour Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor). This test method covers a procedure for determining the rate of water vapour transmission through flexible barrier materials. The method is applicable to sheets and films up to 3 mm in thickness, consisting of single or multi-layer synthetic or natural polymers and foils, including coated materials. It provides for the determination of water vapor transmission rate (WVTR), the permeability of the film to water vapor, and for homogeneous materials, water vapor permeability coefficient. As this standard does not measure the water absorption but only the permeation data, it is not applicable.

A.3 Discussion of available tests and the minimum requirements

The following statements refer only to the proposed test method ISO 62:1999

The scope and subject is to measure the weight gain after water storage. It is applicable to all polymeric NCI and all parts of the NCI i.e. core, housing and structural components.

ISO 62 suggests a) storage at 23 °C and b) storage in boiling water. Boiling accelerates the water diffusion, however it might also change the reaction mechanism and could even result in hydrolysis reactions. Therefore storage at 23 °C is more similar to the natural in-service conditions and should be preferred.

Test procedure:

1. Samples: 50 x 50 x 4 mm
2. Drying (24 h / 50 °C) / measuring weight ($m1$) / immersion into water (24 hour at 23 °C) / measuring weight ($m2$)
3. Test criteria: $C = (m2 - m1) / m1$

The reproducibility of the test method is good and it is time and cost effective.

With regards to the "Resistance against chemical and physical degradation by water"; the suggested test (DIN VDE 0441 / Part 2) considers the effect of the water absorption and the potential hydrolysis on the breakdown voltage. In principle this test could also yield a value for the weight gain. The most important difference is the temperature (100 °C), which may lead to hydrolysis phenomena and thus a potential change in the mechanism. The measured change in weight might not reflect only the water uptake and it is therefore representative of the in-service conditions.

With regards to the "Dielectrical properties after water immersion": This test considers the dependence of the loss factor on the water absorption at 50 °C and yields also the water absorption values. Storage in water at 50 °C does not usually lead to hydrolysis [4]. Therefore this test might be sufficient and an additional water absorption test at 23 °C might not be necessary. However, water absorption values for many materials at 23 °C are typically available, which makes pre-selection and comparisons simpler.

A.4 Conclusion

There is no correlation between the amount of water absorbed and the degree of degradation of polymeric materials.

Well proven, long term experience with outdoor epoxy insulation systems typically shows water absorption values of the magnitude of 0.05 % to 0.3 % water (according to ISO 62; 10 days at 23 °C).

Silicones may absorb up to 2% water [3]. Nevertheless they are good materials for insulators [4].

Therefore, testing the water absorption and defining a minimum requirement appears to not be necessary.

A.5 References

[1] Römpp Online, Georg Thieme Verlag, (based on 10th edition for chemistry and 2nd edition for environment). http://www.roempp.com/prod/

[2] A. D. McNaught and A. Wilkinson, Compendium of Chemical Terminology, "The Gold Book", Second Edition, Blackwell Science, 1997 [ISBN 0865426848] http://iupac.chemsoc.org/ publications/compendium/index.html

[3] H. C. Kärner, "Cycloaliphatics as Insulating Materials", Symposium on Non-Ceramic Insulator Technology, Singapore, June 12 - 14, 1996

[4] U. Stietzel, "Untersuchungen zum Einfluss von Feuchtigkeit auf die elektrischen Eigenschaften organischer Isolierstoffe für Freiluft-Hochspannungs-Anwendung", PhD thesis, Braunschweig, 1984