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TECHNICAL REPORT

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Selection guidelines for polymeric materials for outdoor use under HV stress

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INTERNATIONAL
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SELECTION GUIDELINES FOR POLYMERIC MATERIALS FOR OUTDOOR USE UNDER HV STRESS

FOREWORD

IEC TR 62039 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2007. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition of hydrophobicity definitions and hydrophobicity transfer test;

b) addition of stress corrosion test.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
112/526/DTR	112/535/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

There is a need within utilities and industry for material standards that define the physical properties of the polymers applied for outdoor insulation. This requirement was identified during discussions in IEC TC 36 and IEC TC 112. As a consequence, in 2001, CIGRE formed the working group D1.14 and later on working groups D1.27, C4.303 and D1.58 with the specific task of defining the physical parameters which are important for the polymeric materials applied in outdoor insulation and developing the relevant test methods, where necessary. As a first step, a state-of-the-art report was issued by CIGRE in Technical Brochure 255. Thirteen properties were identified; standardized test methods and minimum requirements were available for eleven of them. For the remaining property of hydrophobicity retention and recovery, test methods and minimum requirements still need to be defined. This will be the future task of SC D1. This document presents, as a conclusion of the CIGRE report, the important material properties for polymeric materials used in outdoor insulation, where they are applicable, and lists standardized test methods including minimum requirements. If no standardized tests are available, then test methods reported in literature (references in the bibliography) are summarized.

SELECTION GUIDELINES FOR POLYMERIC MATERIALS FOR OUTDOOR USE UNDER HV STRESS

1 Scope

This document presents the important material properties of polymeric materials used in outdoor insulation and, where applicable, lists standardized test methods including minimum requirements. If no standardized tests are available, the test methods reported in literature are summarized.

This document is valid for insulating materials having polymeric insulation, which are used in outdoor high voltage electrical applications with a system voltage greater than 1 000 V AC and 1 500 V DC (several tests are only defined for alternating current, which are not applicable for direct current). Such applications are relevant where the housing is an integral part of the device, for example in surge arresters and cable terminations. The scope of this document is limited to the insulation materials only and is not generally intended for coating materials (coating materials are, for example, thin layers applied on toughened glass and ceramic). Some tests mentioned in this document are applicable for coating and are under consideration by CIGRE. The performance of insulators in service depends on several factors such as the type of material, the design and environmental conditions. Consequently, the choice of materials that fulfil the requirements listed in Table 1 is a necessary condition but does not guarantee satisfactory performance when used in outdoor insulation.

In Annex A and Annex B different test methods for testing additional properties are given, which are not standardized.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60243-1, *Electric strength of insulating materials – Test methods – Part 1: Tests at power frequencies*

IEC 60243-2, *Electric strength of insulating materials – Test methods – Part 2: Additional requirements for tests using direct voltage*

IEC 60455-2, *Resin based reactive compounds used for electrical insulation – Part 2: Methods of test*

IEC 60587, *Electrical insulating materials used under severe ambient conditions – Test methods for evaluating resistance to tracking and erosion*

IEC 60695-11-10, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 61621, *Dry, solid insulating materials – Resistance test to high-voltage, low-current arc discharges*

IEC TS 62073, *Guidance on the measurement of hydrophobicity of insulator surfaces*

IEC 62631-3-1, *Dielectric and resistive properties of solid insulating materials – Part 3-1: Determination of resistive properties (DC methods) – Volume resistance and volume resistivity – General method*

ISO 34-1, *Rubber, vulcanized or thermoplastic – Determination of tear strength – Part 1: Trouser, angle and crescent test pieces*

ISO 483, *Plastics – Small enclosures for conditioning and testing using aqueous solutions to maintain the humidity at a constant value*

ISO 4892-2, *Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps*

ISO 6721-11, *Plastics – Determination of dynamic mechanical properties – Part 11: Glass transition temperature*

ISO 11357-2, *Plastics – Differential scanning calorimetry (DSC) – Part 2: Determination of glass transition temperature and step height*

ISO 11359-2, *Plastics – Thermomechanical analysis (TMA) – Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
hydrophobicity
surface of a solid insulating material characterized by its capacity to repel water or aqueous electrolyte solutions

Note 1 to entry: Hydrophobicity of a polymeric insulating material is, in general, a volume property by means of the chemical composition of a material at its surface.

Note 2 to entry: Nonetheless, hydrophobicity is strongly affected by surface effects such as:

- surface structure (i.e. roughness);
- chemical interaction between water and the solid surface (adsorption, absorption, swelling of the solid material in contact with water);
- an accumulated pollution layer.

Note 3 to entry: Furthermore, the conditions during an evaluation of hydrophobicity (climatic (temperature, pressure, humidity), and the method for cleaning or electrostatic charges can affect the measured degree of hydrophobicity.

3.2
hydrophobicity class
HC
specific level of the scale used in the spray method (Method C)

Note 1 to entry: Seven classes, HC1 to HC7, have been defined. HC1 corresponds to the most hydrophobic surface and HC7 to the most hydrophilic surface.

[SOURCE: IEC TS 62073:2016, 2.6]

3.3
hydrophobicity transfer
phenomenon of a transfer of hydrophobicity from the bulk of the housing material onto the pollution layer on its surface

[SOURCE: CIGRE TB 442:2010, Clause 4]

3.4
hydrophobicity transfer material
HTM
polymeric material which exhibits hydrophobicity and the capability to transfer hydrophobicity onto the layer of pollution, which is a combined dynamic behaviour of retention and transfer of hydrophobicity specific to different insulator materials

[SOURCE: IEC TS 60815-4:2016, 3.1.4. modified – The text after "pollution" has been added and the Note to entry has been deleted.]

4 Important material properties

4.1 General

This document defines 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, electrical and chemical properties of the materials have been considered.

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

- housing materials (in general a silicone rubber, EPDM, EVA, etc.);
- core materials (FRP, etc.);
- structural materials (epoxy, etc.).

The minimum requirements are, as far as possible, based on the performance of polymeric insulators in service.

4.2 Resistance to tracking and erosion

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. The thickness of the test specimens should be 6 mm ± 0,5 mm.

The minimum requirements are given in Table 1.

NOTE IEC 60587 covers only alternating current. A tracking and erosion test for direct current is still under consideration by CIGRE (see also CIGRE TB 611).

4.3 Arc resistance

The test for the arc resistance capability of housing and structural materials is carried out according to IEC 61621.

The minimum requirements are given in Table 1.

NOTE IEC 61621 covers only alternating current. An arc resistance test for direct current is still under consideration by CIGRE.

4.4 Water diffusion test (resistance of material to chemical and physical degradation by water)

4.4.1 General

The following procedure is primarily intended to evaluate the core material for resistance to water attack. It can be also used to evaluate the resistance to water attack of housing materials, if suitable.

4.4.2 Test specimens

At least six material samples are cut approximately 90° to the long axis of the insulating core with a diamond-coated circular saw blade under running cold water. The length of the samples h should be 30 mm ± 0,5 mm. The cut surfaces are smoothed by means of a fine abrasive cloth (grain size 180). The cut ends should be clean and parallel. Detailed requirements for the dimension of the specimen under test (e.g. circumstance, persistent) are defined in the related products standards.

If the samples cannot be cut from the insulator or other components, they are to be tested. Samples are prepared separately by using a similar manufacturing process and parameters as intended for the production of the insulating parts.

4.4.3 Test procedure

4.4.3.1 Pre-stressing

The surfaces of the specimens are cleaned with ethanol and filter-paper immediately before boiling. The specimens are boiled in a suitable container (e.g. made of glass or stainless steel) for 100 h ± 0,5 h in deionized water with 0,1 % by weight of NaCl.

Specimens of only one core material are boiled together in the same container. An example of such a container is shown in Figure 1.

After boiling, the specimens are removed from the boiling container and placed in another container (e.g. made of glass or stainless steel) filled with tap water at ambient temperature for at least 15 min. The voltage test is carried out within the next 3 h after the removal of the specimens from the boiling container.

Dimensions in millimetres

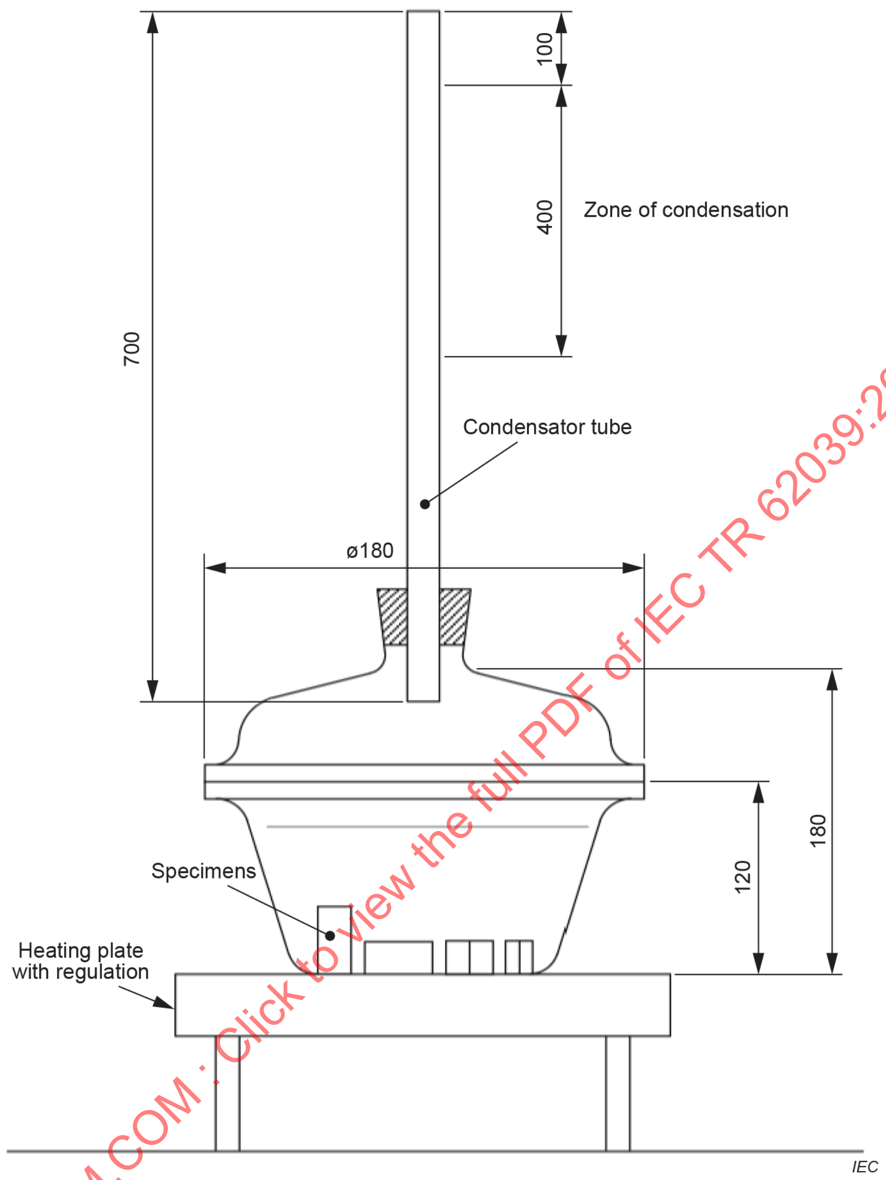


Figure 1 – Example of boiling container for water diffusion test

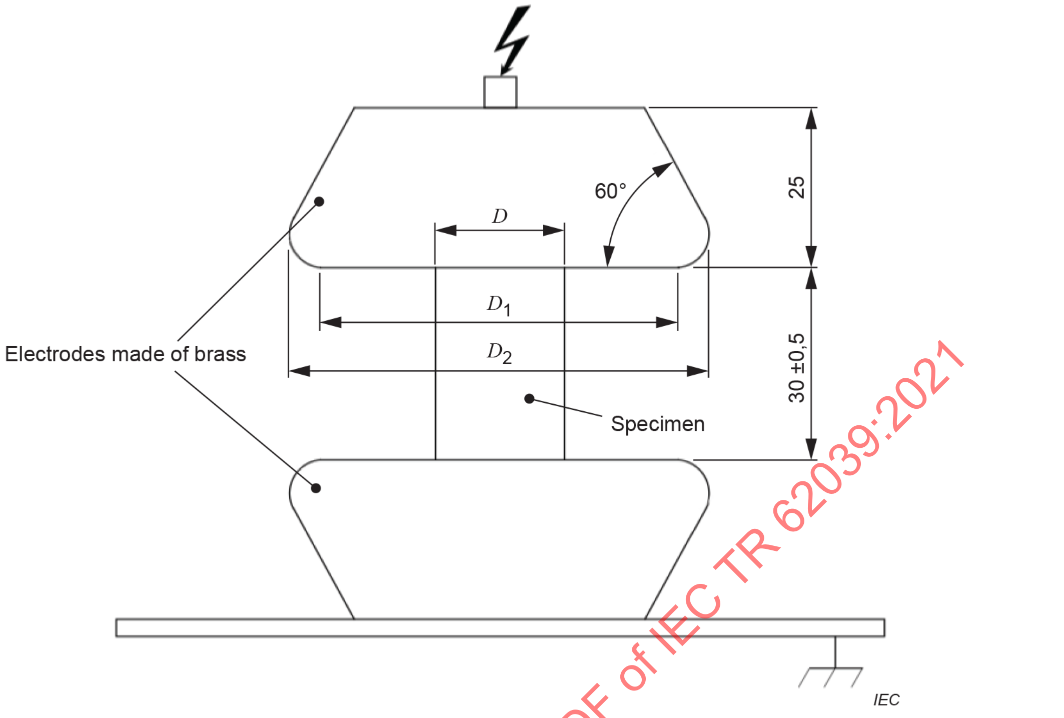
4.4.3.2 Voltage test

The voltage test is carried out with the assembly shown in Figure 2. A typical high-voltage circuit for the test is shown in Figure 3.

Immediately before the voltage test, the specimens are removed from the container and their surfaces dried with filter paper.

Each specimen is placed between the electrodes. The test voltage is increased at approximately 1 kV/s up to 12 kV. The voltage is kept constant at 12 kV for 1 min and then decreased to zero. The RMS value of the current is measured during the whole voltage test.

Dimensions in millimetres

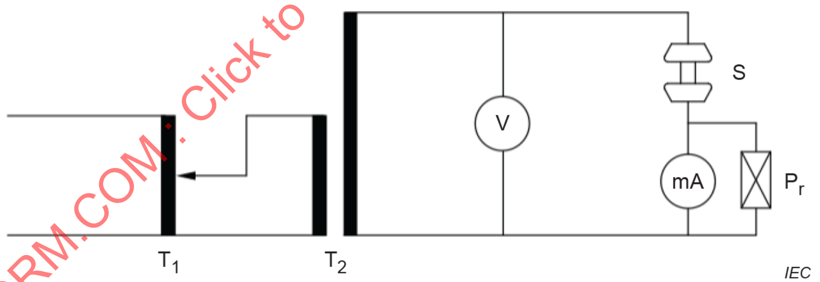


Key

$D_1 \geq (D + 25\ \text{mm})$

$D_2 \geq (D_1 + 14\ \text{mm})$

Figure 2 – Electrodes for voltage test



Key

T_1 regulator

T_2 high-voltage test transformer

V high-voltage measurement

mA milliamperemeter

P_r protection for the milliamperemeter

S electrode with test-specimen

Figure 3 – Voltage test circuit

4.4.4 Minimum requirements

The minimum requirements are given in Table 1.

The maximum RMS current value depends on the sample cross-section. If other sample sizes are used by product standards, these should be considered.

4.5 Tear strength

The standard for testing the tear strength of elastomeric housing materials is ISO 34-1 (method B, procedure (a) – without nick).

The minimum requirements are given in Table 1.

4.6 Volume resistivity

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

The test method is in accordance with IEC 62631-3-1. The test method is applicable to core, housing and structural materials.

The minimum requirements are given in Table 1.

NOTE The applicability for coating materials is also under consideration by CIGRE.

4.7 Breakdown field strength

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 does not need to be measured separately because it is evaluated during the test that measures the resistance to chemical and physical degradation by water (see 3.4).

Sheet test samples are given in IEC 60243-1 for alternating current and IEC 60243-2 for direct current.

Insulating materials usually have high intrinsic electrical strength. In order to evaluate that, a different test arrangement is necessary. Such an arrangement is presented in IEC 60455-2 for rigid insulation materials (e.g. epoxy resin) and flexible insulation materials (e.g. silicone rubber). The different test arrangements in IEC 60243-1, IEC 60243-2 and IEC 60455-2 result in different levels of the breakdown strength.

The minimum requirements are given in Table 1.

NOTE The applicability for coating materials is also under consideration by CIGRE.

4.8 Stress corrosion test (resistance to chemical attack)

4.8.1 General

Core materials can be susceptible to acid attack that can be associated with water penetration. When significant tensile mechanical loads are applied to the core simultaneously, stress corrosion can occur. As a result, brittle fracture can occur.

If a core material is to be evaluated regarding its acid resistance, for example a core material used for outdoor insulators that are predominantly subjected to tensile stress, an acid resistance test can apply.

The test is performed under ambient temperature to confirm the mechanical resistance of the core material to stress corrosion.

4.8.2 Test specimens

Three specimens prepared in accordance with the normal production process are selected. The specimens have a length of insulation between end fittings of at least 10 times the core diameter, and not less than 800 mm. Suitable end fittings are used. To avoid any latent damage to the core by the difficult removal of the housing it is permissible to prepare bare rod samples for this test.

4.8.3 Procedure

The visible core surface should be smoothed by means of a fine abrasive cloth (grain size 180). A non-transparent acid container should be placed to surround the visible core surface and be sealed at the base to prevent any leaking acid. The size of the acid container should ensure that the core material is surrounded by the liquid radius of not less than 1 cm and along a length of not less than 4 cm. Following the filling of the container with the acid, it should be covered and/or sealed to prevent evaporation of the acid by more than 5 % of its volume during the test period.

The specimen is subjected to a tensile load applied between the metal fittings. The tensile load is increased rapidly but smoothly from zero to the full load. The full load for unidirectional glass fibre composites should be 340 MPa (for other materials different mechanical loads can be used) and maintained for 96 h. Immediately after applying the load, nitric acid of a concentration of 1 N (N = normal) is poured into the acid container (1 N = 63 g HNO_3 plus 937 g H_2O). Both horizontal and vertical set-up positions of the specimen are acceptable.

Figure 4 shows an example of a vertical test set-up

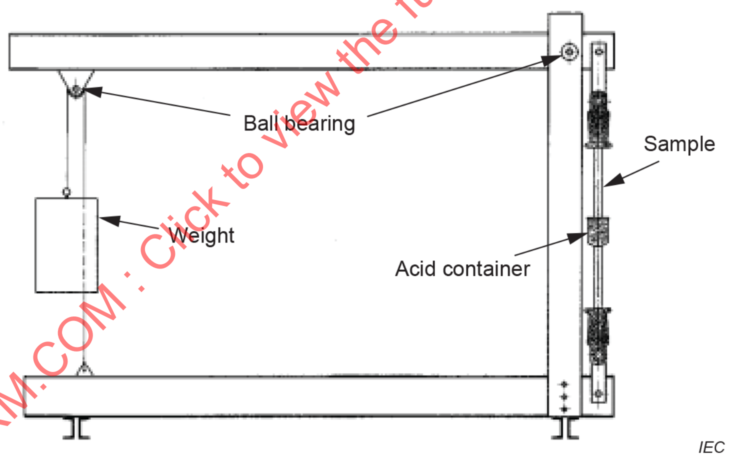


Figure 4 – Example of permanent load application for stress corrosion test

4.8.4 Acceptance criteria

The test is passed if no mechanical failures of any specimen occur within 96 h.

4.9 Resistance to weathering and UV procedure

Three specimens should be taken from the housing of insulators (with markings included, if applicable). If the specimen shape or thickness is inappropriate, then samples may be made separately using the same manufacturing process and parameters.

The insulator housing material should be subjected to a 1 000 h UV light test using the following test method. Markings on the housing, if any, are directly exposed to UV light:

Xenon-arc methods: see ISO 4892-2, using cycle 1 with one dark period of 8 h per 24 h.

NOTE 1 More information on accelerated weathering tests can be found in CIGRE TB 488.

The minimum requirements are given in Table 1.

NOTE 2 The applicability for coating materials is also under consideration by CIGRE.

4.10 Resistance to flammability procedure

This test is intended to check the housing material for ignition and self-extinguishing properties.

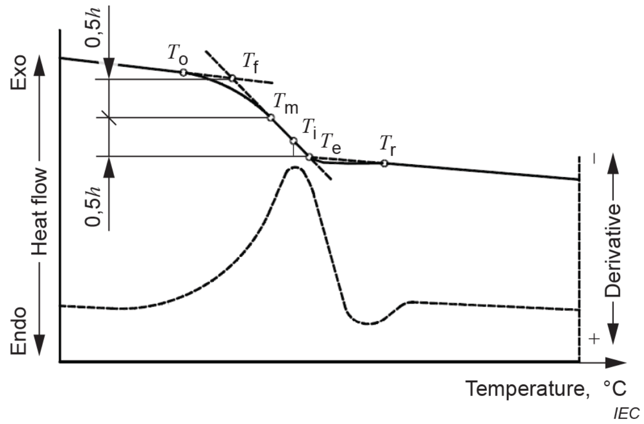
The test specimen and procedure are in accordance with IEC 60695-11-10. Sample thickness should be 3 mm.

The minimum requirements are given in Table 1.

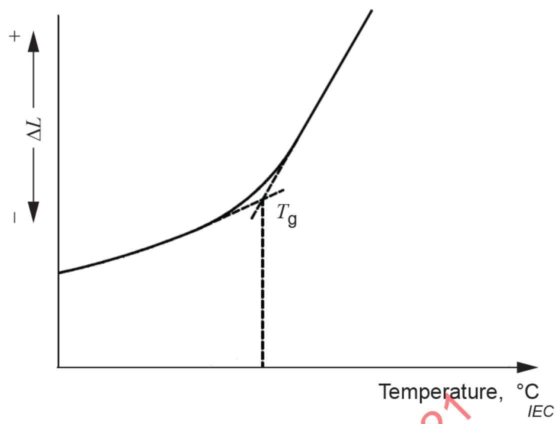
NOTE More information on the test of resistance to flammability can be found in CIGRE TB 489.

4.11 Glass transition temperature

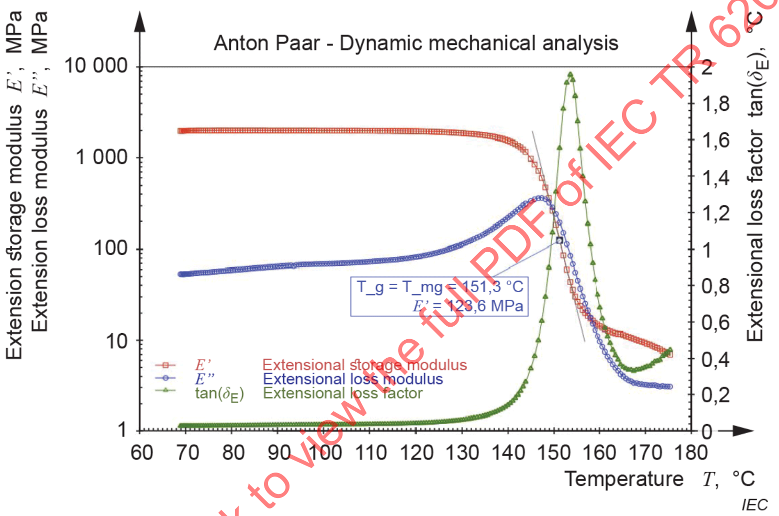
The glass transition of a polymeric material occurs in a temperature region in which a significant change in specific electrical, mechanical, thermal, or other physical properties takes place. Therefore, the observed glass transition temperature can vary significantly depending on the property chosen for observation and on details of the experimental technique (e.g. heating rate, frequency of test). Therefore, the observed T_g (defined as midpoint temperature T_m of the DSC curve at which the curve is intersected by a line that is equidistant between the two extrapolated baselines or, respectively the point of intersection of the tangents to the TMA curve – shown as T_g before and after the transition (Figure 5)) should be considered only as an approximate value, valid only for that particular technique and test conditions.. Full information is only given by means of a complete test report as described in the relevant standard giving a detailed description of sample geometry and preparation, test method and parameter as well as analysis of the test results. Measurements of the glass transition temperature T_g are performed according to ISO 11357-2 (DSC), ISO 11359-2 (TMA) or ISO 6721-11 (DMA).



a) Example of measurement by differential scanning calorimetry (DSC) according to ISO 11357-2



b) Example of measurement by thermomechanical analysis (TMA)



c) Example of measurement by dynamic mechanical analysis (DMA)

Key

T_o temperature of first deviation

T_f extrapolated onset temperature

T_m midpoint temperature

T_i inflection temperature

T_e extrapolated endset temperature

T_r temperature of return to baseline

NOTE This figure is taken from IEC 61006[1].

Figure 5 – Definition of glass transition temperature T_g

Based on practical experience and the physical mechanism of glass transition, for structural, core and adhesive materials (like glue) the glass transition temperature T_g should be at least higher than 15 K above the maximum continuous operating temperature T_{max}. If this margin is less than 15 K, further special investigation for proving the necessary properties should be done.

CIGRE Working Group B2.03 investigated the effect of high temperature conductors on the temperature of fittings on conventional and composite insulators. These tests were able to demonstrate that, at a conductor temperature of 200 °C and higher, the temperature of the

1 This publication has been withdrawn.

composite insulator fittings rises by only 30 K when compared with the ambient temperature. The smaller shed diameter of composite insulators in comparison to cap and pin insulators, and the longer length of the crimped end fitting, counteract large increases in temperature. Since the wide range of string designs did not have to be simulated in this test, a corresponding check is recommended when using high temperature conductors. This recommendation applies to conventional and composite insulators.

4.12 Hydrophobicity

4.12.1 General

The hydrophobicity of polymeric insulating materials is known to be a dynamic property and is an important property if the materials are used in outdoor applications. It comprises

- the retention of hydrophobicity against certain stresses like partial discharges under wet conditions (water droplet corona),
- the recovery of hydrophobicity after a resting period, and
- the transfer of hydrophobicity onto an accumulated pollution layer.

If a polymeric insulating material has the ability to transfer its hydrophobicity onto an accumulated pollution layer, it is expected also to have the ability for recovery after a reduction or loss of hydrophobicity. Therefore, the term hydrophobicity transfer material (HTM) represents the dynamic hydrophobicity properties altogether. Examples of polymeric, hydrophobic but non-HTM are epoxy resins, EPDM or EVA. Silicone rubber is service proven as HTM, however, the individual recipe, including treatment of fillers can play a vital role for the HTM dynamics.

For an entire characterization of dynamic hydrophobicity properties of insulating materials, which is important for service performance of HTM, the following test methods seem to be applicable:

- a test to evaluate the hydrophobicity transfer ability, and
- a test to evaluate the retention and recovery of hydrophobicity.

4.12.2 Transfer of hydrophobicity

4.12.2.1 General

For the evaluation of the transfer of the hydrophobicity either Method A (4.12.2.2) or Method B (4.12.2.3) should be used.

NOTE The improvement of both methods is still under consideration and the aim is to specify only one method in a future revision of this document. The applicability for coating materials is also under consideration by CIGRE.

4.12.2.2 Method A

4.12.2.2.1 Specimens

The specimens are plain plates with the dimensions ($L \times W$) 50 mm × 50 mm. The thickness is 6 mm. The samples are produced with a foil between material and mould to avoid the use of a mould release agent.

4.12.2.2.2 Test procedure

4.12.2.2.2.1 Specimen preparation

Measurement is performed with five samples.

In order to achieve a clean and smooth surface, first the specimens are cleaned with isopropyl alcohol and then rinsed with deionized water. The specimens are then dried for at least 24 h under normal laboratory conditions. Samples of different material are stored separately from each other in order to avoid cross-influence of different materials.

The method tests the intrinsic properties of hydrophobicity, and effects of materials on the surface should be excluded by proper pre-treatment of the materials.

The specimens are covered with adhesive foil so that a window of the dimensions ($L \times W$) 30 mm × 30 mm is obtained (Figure 6). The thickness of the adhesive foils defines the thickness of the pollution layer. A thickness of adhesive foil of 0,36 mm should be used.

NOTE 1 If, for example, the thickness of a single foil is 0,12 mm, a thickness of 0,36 mm can be achieved by putting three foils on top of each other.

Dimensions in millimetres

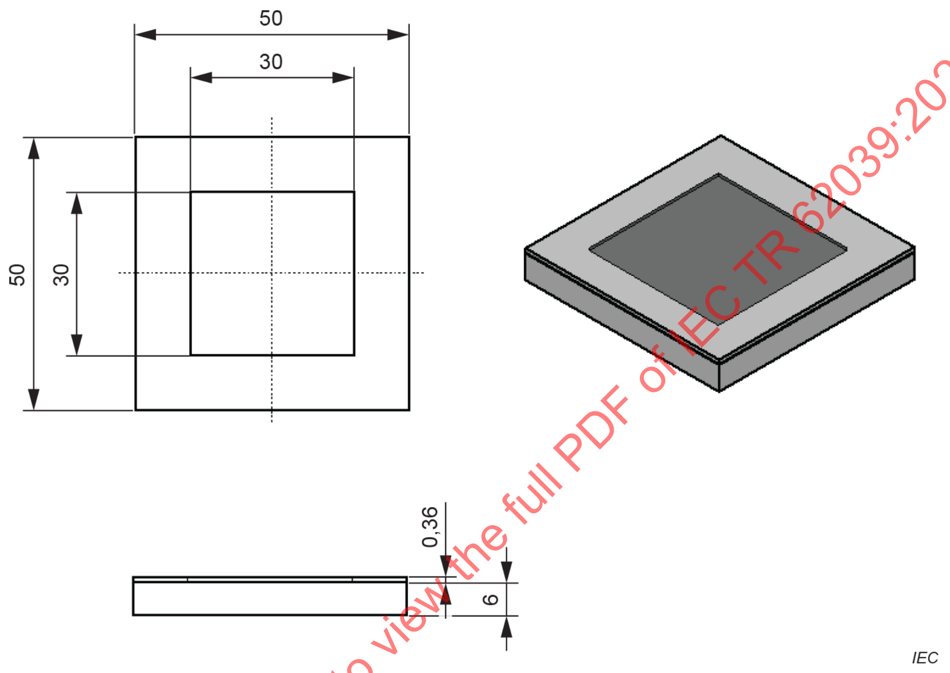


Figure 6 – Specimen with adhesive foil

Inside the area marked by the window of the foil the specimens are then coated by applying a slurry. The slurry is made of 7,5 g silica powder (untreated, i.e., not silanized, medium grain size of approximately 3 µm) and approximately 3,5 ml of a mixture of water and isopropanol (a volume fraction of 65 % water and a volume fraction of 35 % isopropanol) and is homogenized by stirring. A clean doctor blade is used to wipe off the excess slurry. As isopropanol tends to evaporate, the slurry shall be used within 5 min after preparation. This results in a smooth and even surface (Figure 7).

NOTE 2 Slurry stirred for approximately 2 min is usually sufficient to avoid clots.

NOTE 3 The shape and material of the stick can influence the thickness of the pollution layer. To evaluate possible effects it is suggested that details of the stick (i.e. shape and material) are recorded in the test report.

NOTE 4 After drying of the slurry the thickness of the remaining layer will be less than the thickness of the foils, i.e. 0,36 mm. The results of this test refer to the nominal thickness of the slurry applied to the sample which is the thickness of the foils.

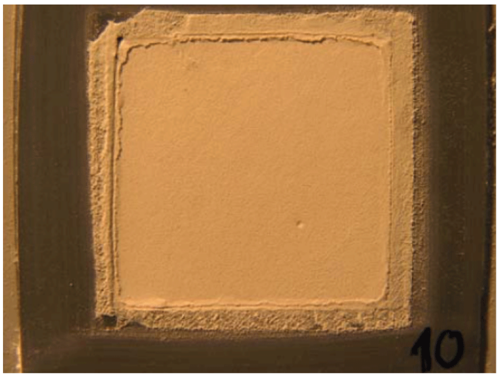


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Figure 7 – Specimen with pollution layer

4.12.2.2.2.2 Storage of the specimen

After the application of the slurry the samples are stored in desiccators under controlled humidity of 53 % ± 10 % relative humidity and at a temperature of 23 °C ± 2 °C (e.g. by using a saturated solution with magnesium nitrate or a climate chamber) for 96 h. The desiccators should meet the requirements given in ISO 483. The humidity and the temperature in the desiccators are recorded. Samples to be tested at different times are stored in a separate desiccator. Alternatively, each sample can be stored in a separate desiccator. The desiccator should not be overloaded with samples so that the target relative humidity is reached within a relatively short time, for example within less than about 2 h. During the period of time between the application of the slurry on the samples and the insertion of the samples into the desiccator, uncontrolled drying of the applied slurry should not occur. The relative humidity in the desiccators should be monitored and recorded.

4.12.2.3 Method B

4.12.2.3.1 Test specimens

Five test specimens are taken from the housing of insulators to be tested. If the shed and sheath are made of different materials or manufacturing processes, they are tested separately. If the test specimens are inappropriate for purpose of the test, then samples may be made separately using the same manufacturing process and parameters.

The area of the test specimens should be around 30 cm^2 to 50 cm^2 and their thickness between 3 mm to 6 mm. It is not permitted to polish test specimens before the test.

4.12.2.3.2 Procedure

4.12.2.3.2.1 Specimen preparation

Clean the specimen surfaces with ethanol and rinse with deionized water, dry in a dust-proof container and keep them for at least 24 h under standard laboratory ambient conditions (40 % to 70 % relative humidity, 20 °C to 25 °C).

Before polluting the specimen, use a dry sponge or soft brush to slightly paste an even layer of dry kieselguhr on the surface of the specimen. Then use a blower-like device to eliminate excess kieselguhr to enable the attachment of a very thin layer of hydrophilic substance to the surface. This layer of kieselguhr is extremely thin and therefore does not influence the desired amount of pollution. Pollution application should be completed within 1 h after the preconditioning.

4.12.2.3.2.2 Pollution application

Kieselguhr in accordance with IEC 60507:2013, Table 2, and NaCl are used as the pollutants. Kieselguhr is weighed and put on the surface of the specimen. The NaCl solution is dropped on the kieselguhr using a pipette or syringe. The kieselguhr and NaCl solution are mixed and then evenly applied on the specimen using a small paintbrush.

The desired amounts of kieselguhr and NaCl are 0,5 mg/cm^2 and 0,1 mg/cm^2 respectively. The mass of kieselguhr is calculated according to the area of the test samples. The volume of NaCl solution is chosen according to the mass of kieselguhr to form a slurry that can be easily applied. The mass of NaCl is calculated according to the area of the test samples.

NOTE In practice, the ratio of NaCl solution to kieselguhr for the slurry that can be easily applied might be around 0,025 ml/mg. For example, if the test area of the specimen is 50 cm^2, the applied kieselguhr and NaCl are 25 mg and 5 mg respectively. A 0,625 ml NaCl solution is used. Then the concentration of the prepared NaCl solution is 8 mg/ml.

4.12.2.3.2.3 Storage of the specimen

The five polluted specimens are then placed in the dust-proof container for 96 h under standard laboratory ambient conditions (40 % to 70 % relative humidity, 20 °C to 25 °C). The relative humidity in the container should be monitored and recorded.

4.12.2.4 Measurement of transfer of hydrophobicity

The measurement shall be done 96 h after application of the pollution layer.

The measurement of the static contact angle θ_s should be performed by applying a water droplet of a certain volume on the horizontal surface of a test specimen by using a pipette or a syringe with a scale.

Measured values of the static contact angle cannot be correlated with that of the receding angle (dynamic contact angle). If needed, the measurement of the dynamic contact angles is proposed in accordance with IEC TS 62073 (Method A).

It is recommended to keep the capillary pipette of the syringe immersed in the droplet during the entire measurement in order to avoid vibrations and distortions of the droplet that otherwise can affect the result.

The measurement of the contact angle should be finished within 1 min after the application of the drop to the surface. If a longer time is required, the actual time needed for the measurement should be documented in the test report. If the drop is sucked in the pollution layer within 3 min after its application, the contact angle is set to zero whatever the measured contact angle is.

The volume of each drop should be in the range of 5 µl to 10 µl. The drops are placed in the centre area of the sample (see Figure 8). This can alleviate the effects of an unequal pollution layer thickness. The drops should be distributed in this centre area, i.e. no measurements take place on the exact same location on the sample.

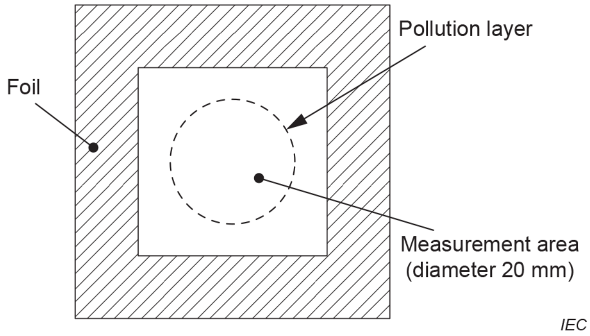

Figure 8 – Area for the drop application for measurement according to IEC TS 62073 (example for Method A)

For each specimen, the contact angle θ of three points is measured. The average of the total fifteen measurements on the five specimens is denoted in θ_{avg}, the minimum denoted in θ_{min}.

4.12.2.5 Minimum requirements

The minimum requirements are given in Table 1.

4.12.2.6 Test report

The test report should include the following:

- specimen description;
- specimen preparation and storage conditions (temperature [°C] and relative humidity [%] in the desiccator);
- documentation of the method used (A or B);
- each measured static contact angle, median of static contact angle for all samples at the times of measurement, and drop volume;
- temperature in laboratory [°C];
- relative humidity in laboratory [%].

4.12.3 Retention and recovery of hydrophobicity

So far, the retention of hydrophobicity has been investigated by means of several scientific projects, such as salt-fog testing and rotating wheel dip testing. 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 applicability of this method for evaluating the retention and recovery of hydrophobicity and the comparability to other methods is under consideration by CIGRE WG D1.58.

5 Important properties and minimum requirements of polymeric insulation materials for outdoor use under HV stress

Table 1 provides the minimum requirements for polymeric insulation materials for outdoor use under HV stress in general. Application committees (e.g. TC 36 in IEC 62217) define special application related acceptance criteria, which might be different from those given in Table 1.

Table 1 – Important properties and minimum requirements of polymeric insulation materials for outdoor use under HV stress

Subclause	Property	Applicability and minimum requirements [a]			Tests standard
		Housing	Core	Structural	
See 4.2	Resistance to tracking and erosion	1A3,5 [b]	—	1A3,5	IEC 60587
See 4.3	Arc resistance	> 180 s	—	> 180 s	IEC 61621
See 4.4	Resistance to chemical and physical degradation by water [c]	"Voltage test" withstand voltage (no breakdown, no flashover) of 12 kV required for 1 min. The (peak) current value depends on the sample cross-section. If other sample sizes are used by product standards, this should be considered. If nothing is specified a maximum RMS current value of 1 mA should not be exceeded.			See this document
See 4.5	Tear strength	> 10 N/mm [d]	—	—	ISO 34-1 (Method B, procedure (a) without nick)
See 4.6	Volume resistivity	> 10^{10} Ω · m			IEC 62631-3-1
See 4.7	Breakdown field strength	30 kV/mm	(Covered by boiling test)	30 kV/mm	IEC 60455-2
		20 kV/mm		20 kV/mm	For sheet materials at 1 mm IEC 60243-1; IEC 60243-2
		10 kV/mm		10 kV/mm	For sheet materials at 3 mm IEC 60243-1; IEC 60243-2
See 4.8	Resistance to chemical attack [e]	—	No failure in the acid resistance test for FRP core	—	See this document

Subclause	Property	Applicability and minimum requirements [a]			Tests standard
		Housing	Core	Structural	
See 4.9	Resistance to weathering and UV	X	—	X	After the test, markings on shed or housing material should be legible; surface degradations such as cracks and raised areas are not permitted. In case of doubt concerning such degradation, two surface roughness measurements should be made on each of the three specimens. The roughness, R_z as defined in ISO 4287, should be measured along a sampling length of at least 2,5 mm. R_z should not exceed 0,1 mm. NOTE ISO 3274 gives details of surface roughness measurement instruments.
See 4.10	Resistance to flammability	X	—	X	
	Overhead line insulators for $U_m \leq 72{,}5$ kV	HB40-25 mm		HB40-25 mm	IEC 60695-11-10
	Overhead line insulators for $U_m > 72{,}5$ kV	V0		V0	IEC 60695-11-10
	Other insulators for $U_m \leq 145$ kV	HB40-25 mm		HB40-25 mm	IEC 60695-11-10
	Other insulators for $U_m > 145$ kV	V1		V1	IEC 60695-11-10
See 4.11	Glass transition temperature [f]	—	$T_g > T_{max} + 15$ K	$T_g > T_{max} + 15$ K	ISO 11357-2 (DSC) ISO 11359-2 (TMA). ISO 6721-11 (DMA)
See 4.12.2	Hydrophobicity [g] transfer	$\Theta_{SAvg} \geq 90°$ $\Theta_{Smin} \geq 80°$	—	—	See this document
See 4.12.3	Hydrophobicity [g] retention	X	—	X	Under consideration
See 4.12.3	Hydrophobicity [g] recovery	X	—	X	Under consideration

Subclause	Property	Applicability and minimum requirements [a]			Tests standard
		Housing	Core	Structural	

[a] X: regarded as an important property (minimum requirements need to be evaluated)

—: not applicable or not regarded as an important property

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

[c] The 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 ageing and is useful to rank materials.

[d] For special materials (e.g. highly filled functional materials) other minimum requirements may be applicable.

[e] This property is applicable only to core materials claiming to be acid resistant.

[f] Based on practical experience and the physical mechanism of glass transition, for structural and core materials the glass transition temperature T_g should be at least higher than 15 K above the maximum continuous operating temperature T_{max}. If this margin is less than 15 K, further special investigation for proving the necessary properties shall be carried out.

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

Annex A
(informative)

Additional measuring methods

A.1 General

For the evaluation of additional properties several other non-standardized methods are available to users. In Annex A and Annex B different test methods about the performance against several stresses are given:

- resistance to corona and ozone;
- water immersion test;
- resistance to acid attack generated by partial discharge under wet, contaminated, and energization condition.

A.2 Resistance to corona and ozone

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

The resistance against ozone may possibly be covered by a corona test, which is described in CIGRE TB 255 and in Bi *et al*..

A.3 Resistance to acid attack generated by partial discharge under wet, contaminated, and energization condition

Appropriate test methods such as an acid water immersion test are therefore under consideration by CIGRE WG D1.62.