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Selection guide for polymeric materials for outdoor use under HV stress

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SELECTION GUIDE FOR POLYMERIC MATERIALS FOR OUTDOOR USE UNDER HV STRESS

FOREWORD

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IEC 62039, which is a technical report, has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
112/34/DTR	112/54/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn;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

A bilingual version of this publication may be issued at a later date.

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 which is today part of IEC TC 112. As a consequence, in the year 2001, CIGRE formed the WG D1.14 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, a state-of-the-art report was issued by CIGRE in the brochure 255. 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 still need to be defined. This will be the future task of WG D1. This IEC Technical Report presents – as conclusion of the CIGRE-report – the important material properties for polymeric materials used in outdoor insulation and where they are applicable, and lists the standardised test methods including the minimum requirements. If no standardised tests are available, then test methods reported in literature are summarised.

SELECTION GUIDE FOR POLYMERIC MATERIALS FOR OUTDOOR USE UNDER HV STRESS

1 Scope

This IEC Technical Report presents the important material properties for polymeric materials used in outdoor insulation and, where applicable, lists the standardised test methods including the minimum requirements. If no standardised tests are available, then test methods reported in literature are summarised.

This report is valid for insulating materials used in outdoor high voltage electrical applications with a system voltage greater than 1000 V a.c. having polymeric insulation including also such applications where the housing is an integral part of the devices e.g. in surge arrestors and cable terminations. The scope of this report 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.

2 Normative references

The following referenced documents are indispensable for the application 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 60093, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials*

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

IEC 60250, *Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including metre wavelengths*

IEC 60455-2:1998, *Resin based reactive compounds used for electrical insulation – Part 2: Methods of test*

IEC 60587, *Test method for evaluating resistance to tracking and erosion of electrical insulating materials used under severe ambient conditions*

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

IEC 61006, *Electrical insulating materials – Methods of test for the determination of the glass transition temperature*

IEC 61109, *Composite insulators for a.c. overhead lines with a nominal voltage greater than 1000 V – Definitions, test methods and acceptance criteria*
Amendment 1 (1995)

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

IEC 62217, *Polymeric insulators for indoor and outdoor use with a nominal voltage greater than 1 000 V – General definitions, test methods and acceptance criteria*

ISO 62, *Plastics – Determination of water absorption*

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

ISO 4892-3, *Plastics – Methods of exposure to laboratory light sources – Part 3: Fluorescent UV lamps*

ISO 4892-4:2004, *Plastics – Methods of exposure to laboratory light sources – Part 4: Open-flame carbon-arc lamps*

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

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

3 Important material properties

3.1 General

This report 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 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 experience of performance of non-ceramic insulators in service.

3.2 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.

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

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

3.3 Resistance to corona and ozone

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 standard procedures for testing corona (e.g. IEC 60270) and ozone resistance of materials. With regard to the ozone test standards, they seem to be using unrealistically high ozone concentrations. 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. Appropriate test methods are therefore under consideration by CIGRE WG D1.14. 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. The resistance against ozone may possibly be covered by a corona test.

3.4 Resistance to chemical and physical degradation by water

A suitable test method to verify the resistance of housing, core and structural materials to chemical degradation is the “water diffusion test” (100-h boiling test) according to IEC 62217. Even though this standard is focused on core material, the procedure appears to be applicable to both housing and structural materials. The minimum requirement is a 12 kV withstand voltage at a duration of 1 min.

The resistance to physical degradation (dielectric properties after water immersion) can be verified by evaluating the loss factor according to IEC 60250 of materials during a long-term water immersion test. In that case, 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. Such a test can be performed as an optional test to gain experience.

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.

Concerning the material property “water absorption”, it is to be noted that 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 % by weight (according to ISO 62; 10 days at 23 °C). Silicones may absorb up to 2 % by weight. Nevertheless they are good insulating materials. Therefore, testing the water absorption and defining a minimum requirement does not appear to be necessary.

3.5 Tear strength

The preferred standard for testing the tear strength of elastomeric housing materials is ISO 34-1.

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 34-1.

3.6 Volume resistivity

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 volume resistivity parameter is also sensitive to incorrect curing processes of some resin systems.

The preferred test method is IEC 60093. The test method is applicable to core, housing and structural materials.

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

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

For verifying a given breakdown field strength (proof test) in the range of up to about 20 kV/mm, IEC 60243-1 is the preferred test method. Using a 3 mm specimen the breakdown field strength should be greater than 10 kV/mm.

Insulating materials usually have higher 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 breakdown field strength of insulation materials tested according to IEC 60455-2 should be greater than 40 kV/mm.

The different test arrangements in IEC 60243-1 and IEC 60455-2 result in different levels of the breakdown strength, therefore a general minimum requirement for non-ceramic outdoor insulation material cannot be specified.

3.8 Resistance to chemical attack

Core materials may be susceptible to acid attack which may be associated 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 a good sealing system can prevent composite insulators from causing brittle fracture regardless of the kind of glass fibre and resin matrix.

If a core material is to 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 resistance test shall apply. The test arrangement shall be according to the mechanical load time test (type test) of IEC 61109 with simultaneous application of 1 mol/l nitric acid HNO_3 directly in contact with the FRP core with a length of not less than 40 mm. The material shall withstand a tensile stress of 340 MPa for 96 h.

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 (see 3.3) or chemical degradation tests (see 3.4).

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.

3.9 Resistance to weathering and UV

Up to now the Xenon arc test (ISO 4892-2) has been widely used and many references are available. Also the carbon arc test (ISO 4892-4:2004) has been used mainly in some countries. The fluorescent UV test (ISO 4892-3) has promising features with respect to cost effectiveness and reproducibility. The definition of the parameters of the UV test (time of testing, rain, cycle, sample temperature, lamp type) is under consideration in order to calibrate the three methods.

3.10 Resistance to flammability

The resistance to flammability is determined by intrinsic material properties and the design of the insulation. As a material test (design test), the existing IEC 61109 (Amendment 1 of 1995) requires the flammability classification V0 according to IEC 60695-11-10. Nevertheless, in certain applications, e.g. medium voltage distribution line insulators, materials show acceptable performance even though they do not meet this criterion. The new standard IEC 62217 reflects to IEC 60695-11-10 and demands category HB 40 and V0. However, V0 and HB40 are not comparable but if a scaling of materials is done, materials passing V0 will pass HB 40 as well, but not vice versa. This step towards reduced requirements needs to be revalidated especially for transmission line level.

The minimum requirement shall be based on the fact that the insulation material will not continue burning after ignition e.g. by 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 (limiting oxygen index).

3.11 Arc resistance

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

3.12 Glass transition temperature

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

3.13 Hydrophobicity

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 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 and the comparability to other methods is under consideration.

Several test methods have been used to evaluate the ability of hydrophobicity transfer. The definition and evaluation of a test method with the potential to gain general acceptance is under consideration.

4 Summary

The important material properties identified above are listed in Annex A. The properties are specified for housing, core and/or structural materials. For some properties, several standardised test procedures are available. In such cases, Annex A lists the recommended method. If available and applicable, the minimum requirements have been listed.

Annex A
(normative)

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

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

	Property	Applicability and minimum requirements [a]			Tests standard
		Housing	Core	Structural	
See 3.2	Resistance to tracking and erosion	1A3,5 [b]	—	1A3,5	IEC 60587
See 3.3	Resistance to corona and ozone	X		X	Under consideration
See 3.4	Resistance to chemical and physical degradation by water [c]	"Voltage test" withstand voltage (no breakdown, no flashover) of 12 kV required for 1 min, current during test shall not exceed 1 mA (r.m.s.)			IEC 62217, water diffusion test
		Optional test to gather additional information, e.g. for material development: "Dielectric properties after water immersion" tan δ < 0,2 after 50 days of water immersion at 50 °C			IEC 60250 (tan δ)
See 3.5	Tear strength	>6 N/mm	—	—	ISO 34-1
See 3.6	Volume resistivity	$>10^{10}$ Ωm			IEC 60093
See 3.7	Breakdown field strength	40 kV/mm	(Covered by boiling test)	40 kV/mm	IEC 60455-2 (1998)
		10 kV/mm		10 kV/mm	IEC 60243-1; IEC 60455-2 (1977, withdrawn edition, see Bibliography)
See 3.8	Resistance to chemical attack [d]	—	No failure in the acid resistance test for FRP core		See text
See 3.9	Resistance to weathering and UV	X	—	X	ISO 4892-2 ISO 4892-3
See 3.10	Resistance to flammability	X	—	X	IEC 60695-11-10
See 3.11	Arc resistance	>180 s	—	>180 s	IEC 61621
See 3.12	Glass transition temperature	—	$T_g > T_{max} + 15$ K	$T_g > T_{max} + 15$ K	IEC 61006
See 3.13	Hydrophobicity [e] stability transfer	X	—	X	Under consideration