IEC/TR 62662

Edition 1.0 2010-08

TECHNICAL REPORT

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Guidance for production, testing and diagnostics of polymer insulators with respect to brittle fracture of core materials

IEC/TR 62662:2010(E)

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TECHNICAL REPORT

Guidance for production, testing and diagnostics of polymer insulators with respect to brittle fracture of core materials

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE Q

ICS 29.080.10

ISBN 978-2-88912-172-4

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

GUIDANCE FOR PRODUCTION, TESTING AND DIAGNOSTICS OF POLYMER INSULATORS WITH RESPECT TO BRITTLE FRACTURE OF CORE MATERIALS

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IEC 62662, which is a technical report, has been prepared by IEC technical committee 36: Insulators.

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

Enquiry draft	Report on voting
36/294/DTR	36/297/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 stability 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- withdrawn,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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication 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 an urgent need within utilities and industry for material standards, which define the physical properties of the polymers applied for outdoor insulation. As a first step, a state-of-the-art report was issued by CIGRE which led to the publication of IEC 62039. This IEC technical report presents – as a conclusion of the CIGRE-report – the important material properties for polymeric materials used in outdoor insulation and, where applicable, lists the standardized test methods including the minimum requirements. The acid (brittle fracture) resistance of FRP core materials (see 3.7) was recognized as an important property for suspension/tension composite insulators. This technical report presents more detailed guidance on this subject taking into account different insulator designs and production techniques. The risk of occurrence and the influencing parameters were evaluated by failure mode effect analysis (FMEA). Brittle fracture is not the only failure mechanism for insulators in service and is generally less frequently observed than other modes, such as failure due to tracking and erosion. However, this subject is not yet covered by any IEC test procedures specifically designed to detect or prevent brittle fracture.

GUIDANCE FOR PRODUCTION, TESTING AND DIAGNOSTICS OF POLYMER INSULATORS WITH RESPECT TO BRITTLE FRACTURE OF CORE MATERIALS

1 Scope

This technical report presents an analysis of the risk of influencing factors for brittle fracture of composite insulators that are mostly loaded in the tensile mode (suspension and tension insulators). Guidance is given to reduce the risk of in-service brittle fractures.

This phenomenon is limited to tension and suspension insulators. However, the general information given concerning the importance of various parameters can be used as a guideline for the design and production of any kind of composite insulator.

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 61109, *Insulators for overhead lines – Composite suspension and tension insulators for a.c. systems with a nominal voltage greater than 1 000 V – Definitions, test methods and acceptance criteria.*

IEC/TR 62039, *Selection guide for polymeric materials for outdoor use under HV stress*

3 Terms and definitions

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

3.1
fibre reinforced plastic material
FRP
composite material consisting of reinforcing components e.g. glass or synthetic fibres that are embedded in a polymer matrix e.g. epoxy or polyester. The FRP core is the integral load-carrying part of a composite insulator

3.2
stress corrosion cracking
SCC
failure of material subjected to a constant tensile stress in a corrosive environment

3.3
brittle fracture
abnormal and sudden breakage of FRP core materials with well-defined characteristic fracture patterns

NOTE Before brittle fracture, no apparent plastic deformation takes place. In the case of FRP core materials, brittle fracture is caused by SCC.

3.4
failure mechanism
principal and fundamental process that leads to a characteristic failure, e.g. brittle fracture

NOTE A failure mechanism may have several modes of final failure.

3.5
failure mode
specific failure scenario or optional path of a failure mechanism

3.6
sealing system
technical arrangement to prevent the ingress of moisture, gases, etc., at a material transition point exposed to the environment

3.7
failure mode effect analysis
FMEA
standardized risk assessment tool generally used for failure prevention

3.8
damage
degradation of a component leading to penetration by acid or moisture

4 Description of brittle fracture

Brittle fracture is the commonly used term for stress corrosion-induced failure of insulator core rods manufactured from resin bonded glass fibre material (RBGF, commonly known as fibre reinforced plastic FRP). This failure mechanism results in a complete mechanical separation of the core (normally near the energized end fitting), and can occur at tensile loads well below the rated mechanical strength of the insulators. In addition to a (minimum) tensile stress of approximately 50 MPa, the brittle fracture mechanism requires the presence of acid from either external or internal sources. The chemical process of stress corrosion is an ion exchange mechanism whereby ions in the glass fibres are replaced by hydrogen ions from the acid (see IEC/TR 62039).

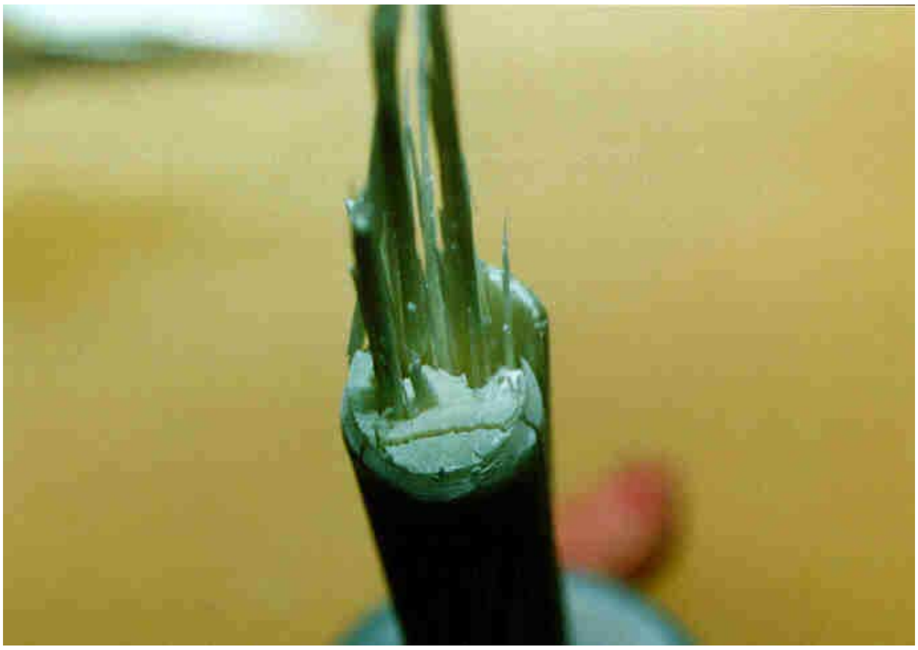

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Figure 1 – Typical brittle fracture

5 Identification of brittle fracture

The macroscopic features associated with the brittle fracture of an FRP core rod have been described by CIGRE [2] [1]. A typical brittle fracture is shown in Figure 1. The fracture surfaces typically have the following characteristics:

- a smooth, clean, planar surface perpendicular to the core axis, comprising a portion of the rod cross-section. Multiple failure planes separated by axial delamination may be present;
- normal tensile fracture (fibrous) in the remaining rod cross-section.

In addition to these macroscopic features, confirmation of the brittle fracture mechanism is possible through the identification of several distinctive features of the fracture surface of the individual glass fibres using scanning electron microscopy [3].

- The mirror zone is a smooth region perpendicular to the fibre axis that includes the stress corrosion initiation site for the individual fibre and may cover from <10% to >90% of the fibre cross-section.
- The hackle zone is a rough region on the fibre fracture surface that failed mainly due to mechanical stresses.
- The mist zone is a transition zone between the mirror and hackle zones and is intermediate in roughness.

Chemical analysis techniques to show the change in the glass chemistry due to the ion exchange mechanism may also be used as confirmation of the brittle fracture mechanism, see [2], [4], [5], and [6].

6 Failure mechanisms

6.1 Description of identified failure mechanisms

For the time being, three failure mechanisms have been identified and are well described in recent literature [7], [8], and [9]. The final physical-chemical mechanism is stress corrosion cracking (SCC) which leads to “brittle fracture” of the FRP core. The initiation of SCC requires the presence of acid in direct contact with the FRP core material for all mechanisms. The way in which this acid appears on or inside the FRP core material can be differentiated into the following three mechanisms.

NOTE Other mechanisms are currently under study, for example, crevice corrosion. The mechanisms are not yet sufficiently investigated to be included in this technical report. However, all require the presence of water (moisture).

6.2 Mechanism M1 – Acid generated by electrical activity

This mechanism is characterized by acid generation by internal and/or external electrical discharges with the acid being finally the root cause for stress corrosion of the FRP core material and the resulting brittle fracture of the FRP core.

Acid (nitrogenous acids) is generated by electrical discharges (corona) on the insulating material (external), at the metal fittings (external) or by internal partial discharges within internal voids. Electrical discharges in air generate radicals, ozone and nitrogen oxides which form acids when combined with water (e.g. moisture from the air). Internal partial discharges within voids of the FRP core material or at the interface between FRP core and housing may lead to acid generation. In some cases moisture vapour transmission in a hot wet environment followed by a cold cycle will cause condensation inside voids. The acid is then in direct contact with the FRP core material. Moisture is required for all modes of this mechanism to generate acid. Therefore the penetration path to the FRP core is a very critical criterion for

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1 Figures in square brackets refer to the Bibliography.

this mechanism. Moisture penetration may be possible if the sealing system is defective or insufficient. Other paths for moisture penetration to the FRP core may be housing damage or housing porosity. The moisture penetration can occur in the form of molecular diffusion due to the moisture permeability of the housing. Acids generated by electrical discharges are in general strong inorganic acids. The main chemical structures are HNO_2 and HNO_3. Polymeric compounds show in general a high resistance to HNO_3 and are often resistant to other acids. The same applies to the sealing systems at the end fitting (triple) point realized with such material compounds. Two main grades of FRP core materials exist:

- acid resistant core materials that pass the chemical resistance test in accordance with IEC 62039;
- non-acid resistant core materials that do not pass the chemical resistance test.

Acid resistant rods can resist acid for a much longer time period than non-resistant materials (see Clause 8).

The critical design features of composite insulators regarding this mechanism are:

- chemical (acid) resistance of the FRP core material;
- quality of the FRP core material regarding internal voids that may lead to internal partial discharges;
- quality of the macroscopic interface between housing and FRP core material regarding voids that may lead to internal partial discharges;
- long-term tightness of the sealing system;
- corona protection and field grading to reduce the appearance of acid-producing corona or partial discharges;
- resistance of the housing and sealing system regarding transportation and handling damage.

6.3 Mechanism M2 – Acid ingress from environment

This mechanism is characterized by acid ingress from the environment (e.g. pollution) with the acid being finally the root cause for SCC of the FRP core material and the resulting brittle fracture of the FRP core.

Acid or its anhydrides are present in the environment of the insulator installation. To obtain an acidic solution moisture is also necessary. Therefore the penetration path to the core is also a very critical criterion for this mechanism. Acid penetration may be possible if the sealing system is defective or insufficient. Other paths for acid penetration to the FRP core may be housing damages or housing porosity. Acids in the environment may be weak to strong acids depending on the kind of pollution. Inorganic polymeric compounds show in general a high resistance against such acids. Silicone or EPDM housing materials are sufficiently resistant to most acids but also may exhibit porosity. The same applies to the sealing systems realised with such material compounds. Two grades of FRP core materials exist:

- acid resistant core materials that pass the chemical resistance test in accordance with IEC 62039;
- non-acid resistant core materials that do not pass the chemical resistance test.

Acid resistant rods can resist acid for a much longer time period than non-resistant materials (see Clause 8).

The critical design features of composite insulators regarding this mechanism are:

- chemical (acid) resistance of the FRP core material;
- long-term tightness of the sealing system;