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

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

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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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,
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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).

IEC 2042/10

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;

- porosity or penetration resistance of the housing;
- resistance of the housing and sealing system regarding transportation and handling damage.

6.4 Mechanism M3 – Acid generated inside the core

This mechanism is characterized by acid present or generated inside the FRP core material (excess of hardener or trapped humidity) with the acid being finally the root cause for SCC of the FRP core material and the resulting brittle fracture of the FRP core [4] and [5].

Acids generated by excess of hardener are in general weak organic acids. Acids generated by partial discharges and trapped humidity may be inorganic or organic acids. Both processes require moisture. Therefore the penetration path of moisture to the core is also a very critical criterion also for 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 damages and housing porosity. The moisture penetration can occur in the form of molecular diffusion due to the moisture permeability of the housing. 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.

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

- chemical (acid) resistance of the FRP core material;
- quality of the matrix system used for the core material in regard to the content of excessive anhydride hardener;
- long-term tightness of the sealing system;
- quality of the macroscopic interface between housing and FRP core material regarding voids that may lead to internal partial discharges;
- quality of the FRP core material regarding internal voids that may lead to internal partial discharges;
- porosity or penetration resistance of the housing;
- resistance of the housing and sealing system regarding transportation and handling damage.

7 Risk assessment

7.1 FMEA approach

The risks associated with brittle fracture of polymer suspension insulators were evaluated using FMEA (similar to the method given in IEC 60812 [1]). The Ishikawa procedure was used to identify the principle mechanisms of failure. It was then repeated for each mechanism to identify the modes that could initiate the mechanism.

FMEA was then used to take into account the risk of appearance (probability) of the different modes for each failure mechanism and included factors for the severity of the mode and for ease of avoidance and identification of the failure or damage. These were combined to create a Risk Potential Number (RPN) which is scaled from 1 to 1000 according to the risk severity. The relation is:

RPN = **P** (probability of occurrence) × **S** (severity) × **D** (difficulty of avoidance or detection)

7.2 Results

A risk assessment performed by means of the FMEA method leads to the following risk potentials for the individual modes of the respective failure mechanisms. Table 1 shows the definition of the risk potential and Table 2 the results of the risk assessment.

Table 1 – Risk potential number (RPN) and standardized risk potential of brittle fracture failure modes

RPN	Risk potential
750 – 1 000	Very high
500 – 750	High
300 – 500	Medium – High
150 – 300	Medium
100 – 150	Low – Medium
75 – 100	Low
<75	Very low

Table 2 – Risk assessment of the identified brittle fracture failure modes

Risk potential (RPN)	Mechanism	Mode	Root cause and description of failure mode
Very high (1000)	M1	1	***Sealing damage:*** acid and moisture penetration caused by loss of sealing. The sealing was damaged during transport, installation or handling
Very high (800)	M1	2	***Sealing damage:*** acid and moisture penetration caused by loss of sealing. The sealing function was degraded by ageing mechanism(s)
Very high (800)	M3	1	***Sealing damage***: moisture penetration caused by loss of sealing. The sealing was damaged during transport, installation or handling
High (681)	M1	3	***Corona ring design:*** improper design and application of corona rings, absence of rings when required
High (622)	M1	4	***Sealing damage***: acid and moisture penetration caused by loss of sealing. The sealing was degraded by erosion
High (622)	M2	1	***Sealing damage***: acid and moisture penetration caused by loss of sealing. The sealing was degraded by erosion
High (600)	M2	2	***Sealing damage***: acid and moisture penetration caused by loss of sealing. The sealing was degraded by ageing mechanism(s)
High (600)	M3	2	***Sealing damage***: moisture penetration caused by loss of sealing. The sealing was degraded by ageing mechanism(s)
High (556)	M1	5	***Housing damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by a manufacturing process problem
High (556)	M1	6	***Internal partial discharges:*** partial discharges are active in voids of the composite material or within the interface(s). Acid is generated by these internal partial discharges in combination with moisture and is in direct contact to the FRP core materials
High (533)	M1	7	***Sealing damage***: moisture penetration caused by loss of sealing. The sealing loss was caused by poor design
Medium – High (467)	M3	3	***Sealing damage***: moisture penetration caused by loss of sealing. The sealing was degraded by erosion

Risk potential (RPN)	Mechanism	Mode	Root cause and description of failure mode
Medium – High (467)	M1	8	***Sealing damage:*** acid and moisture penetration caused by sealing damage. The sealing damage is caused by a manufacturing process problem
Medium – High (444)	M3	4	***Sealing damage***: moisture penetration caused by loss of sealing. The sealing loss was caused by poor design
Medium – High (400)	M1	9	***Sealing damage:*** acid and moisture penetration caused by sealing damage. The sealing damage is caused by hot pressure washing
Medium – High (400)	M2	3	***Sealing damage:*** acid and moisture penetration caused by loss of sealing. The sealing was damaged during transport, installation or handling
Medium – High (311)	M3	5	***Sealing damage:*** moisture penetration caused by sealing damage. The sealing damage is caused by a manufacturing process problem
Medium – High (311)	M2	4	***Sealing damage:*** moisture penetration caused by sealing damage. The sealing damage is caused by a manufacturing process problem
Medium (292)	M1	10	***Housing Damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by installation, handling or transportation
Medium (278)	M3	6	***Housing damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by a manufacturing process problem
Medium (278)	M3	7	***Internal partial discharges:*** partial discharges are active in voids of the composite material or within the interface(s). Acid is generated by these internal partial discharges in combination with moisture and is in direct contact to the FRP core materials
Medium (278)	M2	5	***Housing damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by a manufacturing process problem
Medium (250)	M3	8	***Moisture diffusion:*** moisture diffusion through sound housing and accumulation of mositure at the FRP core material
Medium (200)	M3	9	***Sealing damage:*** moisture penetration caused by sealing damage. The sealing damage is caused by hot pressure washing
Medium (200)	M2	6	***Sealing damage:*** acid and moisture penetration caused by sealing damage. The sealing damage is caused by hot pressure acid and washing
Medium (178)	M2	7	***Sealing damage***: acid and moisture penetration caused by loss of sealing. The sealing loss was caused by poor design
Medium (175)	M3	10	***FRP core material:*** change of FRP material properties caused by certain production technologies which apply high temperature processes
Medium (175)	M3	11	***FRP core material:*** water bath cleaning of FRP rods for preparation of housing application
Medium (156)	M3	12	***Partial discharges in FRP core material:*** PD: acid generation caused by any voids within the material (process, manufacturing), moisture is required to form the acid
Medium (156)	M1	11	***Partial discharges in FRP core material:*** PD: acid generation caused by any voids within the material (process, manufacturing), moisture is required to form the acid
Low – Medium (133)	M1	12	***Sealing damage***: acid and moisture penetration caused by loss of sealing. The sealing loss was damaged by power arc affection
Low – Medium (125)	M2	8	***Housing damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by handling, installation or transportation
Low – Medium (125)	M3	13	***Housing damage:*** moisture penetration caused by housing damage. The housing damage is caused by handling, installation or transportation

Risk potential (RPN)	Mechanism	Mode	Root cause and description of failure mode
Low – Medium (117)	M1	13	***Corona ring installation***: corona rings are improperly installed, desired field grading and corona protection fail
Low – Medium (111)	M1	14	***Housing damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by bird attack
Low (89)	M2	9	***Sealing damage***: acid and moisture penetration caused by loss of sealing. The sealing loss was damaged by power arc affection
Low (89)	M3	14	***Sealing damage***: moisture penetration caused by loss of sealing. The sealing loss was damaged by power arc affection
Very low (56)	M3	15	***Housing damage:*** moisture penetration caused by housing damage. The housing damage is caused by bird attack
Very low (56)	M2	10	***Housing damage:*** acid and moisture penetration caused by housing damage. The housing damage is caused by bird attack

7.3 Discussions

The highest RPNs are associated with sealing damage. The modes associated with sealing damage are also the most frequent. Improper design and application of corona rings with a RPN of 681 already indicates a high risk. If this mode is combined with any of the other modes, the risk of that mode is significantly increased notably for the modes of mechanism 1. The guidance given hereafter is aimed to reduce the risk of occurrence of the major modes brought to light by the FMEA.

8 Guidance for material selection and production

8.1 Rod materials and production process

8.1.1 Fibreglass

There are two main types or classes of fibreglass used in rods for polymer insulators; they are "E" (Electrical) glass and "ECR" (Electrical corrosion resistant) glass. In the past it has been stated that using ECR glass was all that was necessary to prevent brittle fracture. However, E and ECR types actually include a huge range of different glasses with varying performances.

More recently it has been proposed that "boron-free" glass was the optimum type of ECR glass; however very few glasses are actually totally resistant. Reduced boron glasses do indeed show a better resistance to acid attack and can form the basis of an acid-resistant rod. Some ECR glass fibres can exhibit a much higher proportion of hollow fibres which can be deleterious to performance.

The glass fibres used for manufacturing insulator rods are coated with a surface agent called "sizing". Glass fibre sizing is not a single chemical compound, but a mixture of several complex chemistries, each of which contributes to the sizing's overall performance. The primary components are the film former and the coupling agent. The film former is designed to protect and lubricate the fibre and hold fibres together prior to molding, yet also to promote their separation when in contact with resin, ensuring wetting of all the filaments.

The coupling agent, almost always an alkoxysilane compound, serves primarily to bond the fibre to the matrix resin.

Beyond these two major components, sizing's may also include additional lubricating agents, as well as antistatic agents that keep static electricity from building up on the nonconductive fibres as they are formed and converted. Including additives for specialized, proprietary functions, a sizing formulation might contain eight to ten or more components. The interaction of these components with each other, with the matrix resin, and within a particular converting/fabricating environment is quite complex, yet reasonably well understood by sizing chemists.

It is therefore important that the sizing is compatible with the resin used for the matrix in order to ensure that the resin totally wets the fibres. It is also important that the sizing itself is neither porous nor subject to hydrolysis. An inappropriate sizing can increase the risk of longitudinal propagation of moisture or acids.

The storage conditions of glass fibre rovings can also influence the wetting of the fibre by the resin; hence attention should be paid to cleanliness, temperature and humidity both in storage and production areas.

8.1.2 Resins

It has been shown that excess resin hardener in the rod matrix can be hydrolyzed to produce carboxylic acid; crystals of acid anhydride (used as hardener agents) can also be included in the rod during manufacture. Carboxylic acids have been found with both resin systems (epoxy/polyester and vinyl ester) commonly used for composite insulator FRP cores [4], [5] and [6].

Both these cases can be avoided if a correct resin/hardener ratio is used. Furthermore frequent cleaning of manufacturing equipment (resin vats, storage and mixing equipment, etc.) can greatly reduce the risk of acid inclusion and incorrect mixing. To avoid mixing errors automated dosing units are beneficial. Presently there are other curing systems in development for matrix resins which avoid the usage of carbon anhydride hardeners. For the time being, these chemicals solve the problem of excess hardener but do not give satisfactory performance regarding other properties, e.g. hydrolysis resistance.

Since the microscopic interface between glass fibres and resin matrix is very important for all core properties, the adaption between fibres and the specific resin matrix must be realised using specific coupling agents (normally integrated in the sizing) without affecting the other important properties, e.g. hydrolysis resistance, mechanical performance, etc.

8.1.3 Rod production

Further to the precautions taken for the components of the rod, it is clear that a precise control of temperatures, pressures, speeds, etc., during the rod production process can only help to improve the quality of the rod and ensure a constant level of fibre wetting and resin hardening. The same applies for overall cleanliness and climatic control. Control of the dies between pultrusion campaigns for erosion and corrosion is also very important to avoid contamination of the FRP rod surface.

Regular inspections of pultrusion lots – including glass content, capillarity, water diffusion test, dye penetration test, chemical analysis and interlaminar shear strength test – can be included in the manufacturers quality program.

One point of note is that the surface state of sanded rod can influence the behaviour of the rod in a nitric acid test; however it is not known if this is of influence in service.

8.2 Housing and sealing

Since the ingress of moisture and acids are at the root of brittle fracture mechanisms particular attention should be paid to the housing and sealing products and processes.

The insulator housing is generally of elastomeric material and as such ensures the necessary protection of the rod from the elements. However some elastomeric materials, notably certain silicone rubbers, allow gradual diffusion of gases and liquids through their bulk. It is therefore important to ensure that interfaces are exempt of voids and defects.

The interfaces, or seals, between the housing and the rod and fittings are the main ingress points and are among the highest RPN in the FMEA analysis. Therefore particular attention should be paid to their materials, composition and process. The points that can influence interface performance and longevity are:

- Surface state of the rod and fittings: if surfaces are washed, sanded or shot-blasted the equipment and products should be kept clean and checked regularly for effectiveness. Furthermore cleaned or prepared components should be stored and handled in a manner to avoid pollution by grease, dust, etc.
- Surface bonding agents: often bonding agents are used to enable the housing to form a strong seal with fittings or rod. As for surface treatments, components that have had a bonding agent applied should be stored and handled in a manner to avoid pollution by grease, dust, etc. Furthermore care should be taken with the use and storage of the chemicals used for bonding, paying attention to shelf and pot life and avoiding pollution of the products.
- Sealing products: where sealing is ensured by the application of a jointing material (e.g. silicone mastic) similar attention should be paid to cleanliness and shelf and pot life of the products. The curing conditions of the products can also have an influence on their behaviour in service, so this phase should be carefully controlled.
- Design and composition: sealing systems for composite insulators should be designed to operate in a wide temperature range, e.g. –40 °C to +80 °C. The performance of the sealing depends on its position, shape, adherence to components and elasticity during temperature changes for the whole life of the insulator.

9 Preventive methods

9.1 Sealing

It is known that poor sealing is one of the major causes of brittle fracture failure in service [10] and [11]. This has also been confirmed by the FMEA in this technical report. In this sense, sealing is an essential function for composite insulators in order to avoid acid and moisture penetration. In general, the following methods for sealing are available:

- bonding
- mechanical contact
- sealant sealing (mastic)
- compression.

To obtain maximum sealing performance, multiple countermeasures might be preferable. Also, since the sealing performance is also related to the production quality, it is necessary to verify the performance by sample tests at least per the requirements of IEC 61109. At present, there are no other simple or reproducible tests available to verify sealing technique and material.

9.2 Corona rings

Corona rings are hardware devices designed to relieve the electrical stress concentration around metal fittings and the housing of composite insulators. Improper installation of corona ring(s) or incorrect corona ring(s) causes corona discharge around high electric field stress areas resulting in the generation of acid due to corona discharge (see 6.2). In the worst case, housing material or sealing of composite insulators might be damaged by corona and/or acid and then acid might reach the core. Historically, for higher system voltages such as above 145 kV, corona ring(s) have been fitted on the line end or on both ends. In addition to this, based on recent research works, the installation of corona rings may be indicated even for 100 kV-145 kV voltage class transmission lines, especially for high pollution, high altitude or