Coating...of Course

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The title of this paper can appear slightly provocative, but, it describes extremely well the current trend worldwide whenever high pollution conditions require special care in the definition of an insulator string and the relevant specific creepage distance.
While originally this technique was used by maintenance for mitigating problems encountered in service, the use of RTV coating on glass and porcelain discs has jumped to a point where it can no longer be considered as a marginal approach for solving a local problem but clearly part of the design of new transmission lines.
The major push came from the decision taken more than 20 years ago to establish a product which performances were established through an industrial process where the insulators were coated in a factory [1], in controlled conditions rather than in the field where the difficulty of outdoor conditions can compromise the long-term performance of the product.

As an illustration of this growing demand figure 1 shows the actual trend seen by Sediver in the development of silicone coated glass insulators. These numbers are only from Sediver market share showing a growth of 30 times over a period of approximately 20 years.

Figure1: Evolution of the supply of silicone coated glass insulators starting at a base 100 in 2004 over an18 years period (Sediver).

As already mentioned, the big appetite for this type of product is the ability to give to glass insulators the pollution performance of polymer insulators without the risks inherent to polymers. But beyond this aspect, the real change came when insulator manufacturers like Sediver started to offer an industrial approach combined to stringent qualification methods and material specifications. The product is defined no longer as a coating but as a coated insulator resulting from the association of a silicone material, an application process and the insulator itself all of it under the responsibility of the insulator manufacturer.

The need for clear and well-defined material and testing specifications led to the effort currently materialized through the work being done in IEC 36 / 535 [2] where experts are drafting a standard for RTV coated insulators. Just recently CIGRE had published two very good base documents on coatings: Technical Brochure TB 837 [3] and TB 838 [4].

It is today relatively well understood that the ageing process of silicone material comes with several changes in the properties of the material. Loss of hydrophobicity (partial or complete) will progressively let the leakage current increase and subsequently start an erosion process. This has led to numerous attempts to define an erosion test. This paper will describe the various available options for evaluating the aging and electric degradation of silicone coatings for glass and porcelain insulators. The tests were performed at the Sediver Research Center in France.

1. The 1000h Test

This test which is described in IEC 61109 [5] depends largely on the USCD that is being used and the insulator profile. A test performed at 8g/l with a USCD= 34mm/kV does not show any damage to any coating while the same shape tested at USCD=25mm/kV will damage the coating whatever it is (figure 2). This test designed for polymer has one flaw if it is used for coatings: the thickness of the coatings is around 350µm while polymers are being tested to establish their resiliency with thicknesses at or above 3mm. This test is not adapted to the objective of selecting a coating.

Figure 2: Erosion on 2 different coatings in a 1000h salt fog test with a USCD=25mm/kV

2. The 5000h Multi Stress Test

Like for the previous test, this test was crafted for polymer insulators with housing thicknesses of 3mm minimum. The same conclusion can be made here. The test is not designed to discriminate the performance of coatings which are applied in thin layers while for polymers as soon as the core is exposed there is a major risk of failure which explains why the limit of acceptance in the depth of erosion is 3mm. Below figure 3 shows the evolution of the degradation of coated insulators in this test, which conclusions are totally irrelevant. It can be noted nevertheless that despite the erosion the insulator remains fully functional unlike a polymer in the case where the erosion would reach the core.

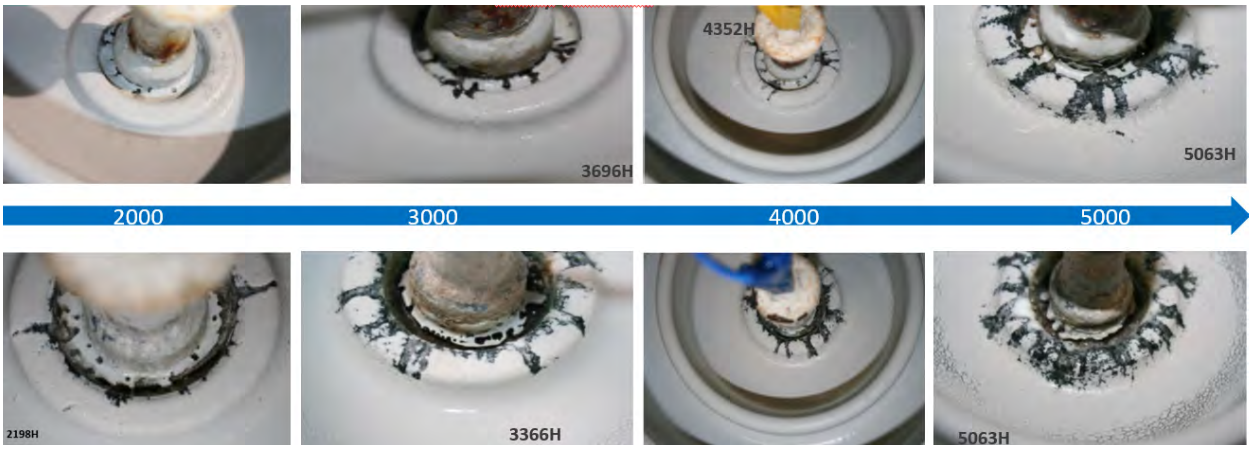


Figure 3: evolution of erosion of the coating on glass insulators in a 5000h multi stress test

3. The 2000h Multi Stress Test

This test is today by far the most frequently used and will most likely be included in the upcoming IEC standard. It is not a reduction of the 5000h test, but a different protocol as shown in figure 4.

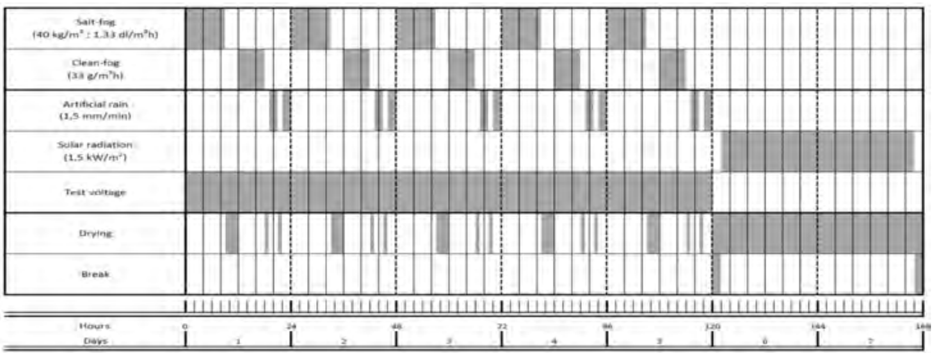


Figure 4: weekly cycle of the 2000h test procedure

The main settings include a salinity of 40g/l and a configuration of a vertical and a horizontal string energized at a voltage corresponding to:

$$Ut = 1.1 \times n \times Li / SSCD$$

Where n is the number of discs in the string under test,
Li the creepage distance of an individual disc
SSCD the specific creepage distance for the maximum operating voltage (phase to phase)

The acceptance criteria for this test are:

Not more than3 flashovers
No tracking paths (conductive paths)
The erosion shall not reach the underneath surface of the insulator (glass or porcelain)

Figure 5 shows the set up for this test and figure 6 shows different types of results as a function of the nature of the chemistry and application of the coating. This test has proven to be effective in discriminating coatings prone to erosion compared to good survivors under the given stress conditions.

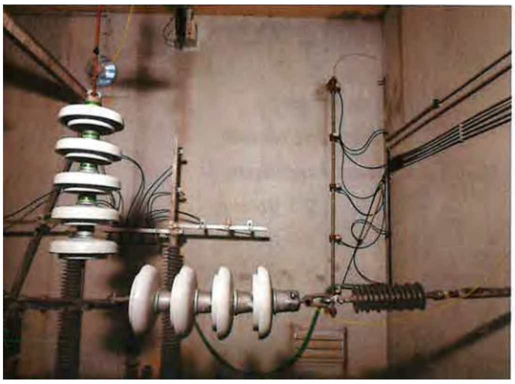


Figure 5 : Set up of the 2000h test

Figure 6 : Typical results showing discrimination among coating chemistries

4. Inclined Plane Test

This test is described in IEC 60587 [6] but the standard which was just updated recently does not cover coatings. The reason behind was the difficulty to prepare samples and as a result the only test so far for coating is described in a CIGRE brochure ref 478 [7]. It may be interesting to revisit this aspect and the tests results shown hereafter should bring some valuable light to this test.

a. CIGRE 478

The test method described in the brochure is using ceramic tiles on which the coating is applied as it would be on an insulator for a so-called better representativeness from the real product. It is not really the case because on an insulator the shape itself will induce particularities in the way the arc can establish itself and generate erosion. This test can only be a reference test for the sake of comparison between coatings but not a test describing the risk of erosion on an insulator.

To illustrate this point figures 7 and 8 show typical results which all are considered as acceptable since the only criteria in the protocol of CIGRE 478 is that the tile should not break…but erosion is not considered as a criterion by itself. In other words, given the fact that erosion will take place anyway the only difficulty in this test is to find a ceramic tile strong enough not to break. It is not testing the coating.

Figure 7 : Set up of the test

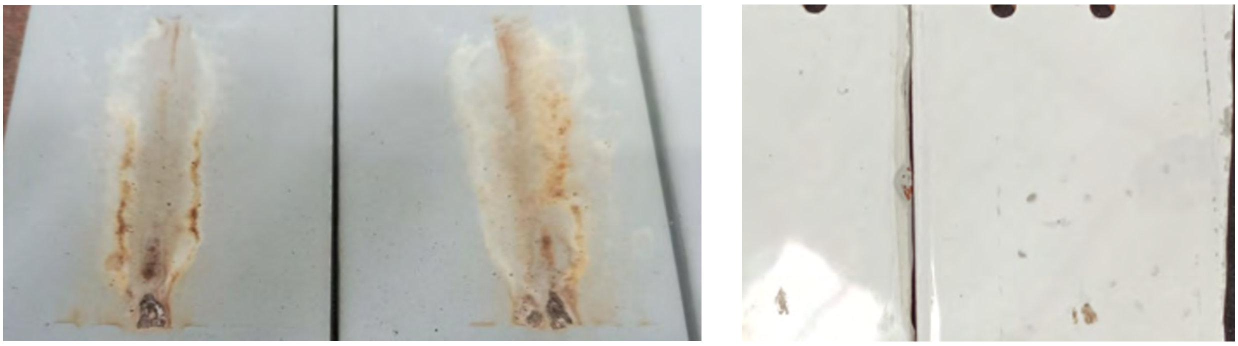


Figure 8 : Typical results of the inclined plan test at 3.5kV. All samples are eroded (left) through their thickness with a mark on the tile underneath but without a destruction of the tile itself (right)

For most commonly used coatings this test should be performed at 2.5kV if the criteria would be to accept erosion without puncturing the coating.

b. IEC 60587

In this version of the test slabs are required. There are two reasons why this test was not considered in the standard:

How to make slabs?
How representative is the result if it is not made like on a real insulator?

The answers are simple: slabs can be easily made by casting the silicone in a mold (figure 9) and the test anyway is not representative of a real insulator as already stated earlier. It can only be a test which result is a relative evaluation comparing different coatings. For polymer insulators this test is being used on slabs as well and is not any representative of the actual housing on insulators either since the shape of actual sheds does not easily allow this test to be produced on real sheds. In both cases this test can only give a relative result.

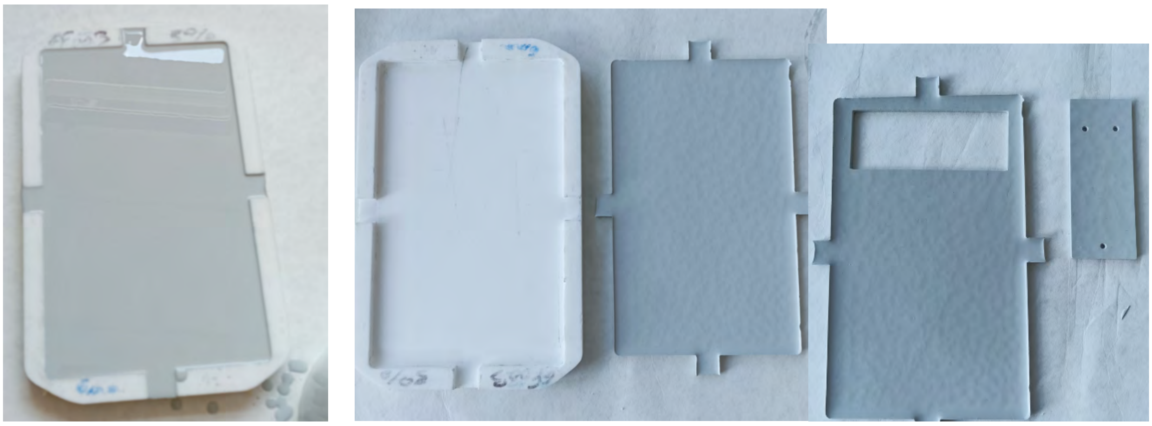


Figure 9: Casting of slabs in a dedicated mold

In this case the test can be easily performed with the usual acceptance criteria as shown in Figure 10 where slabs were tested at 3.5kV

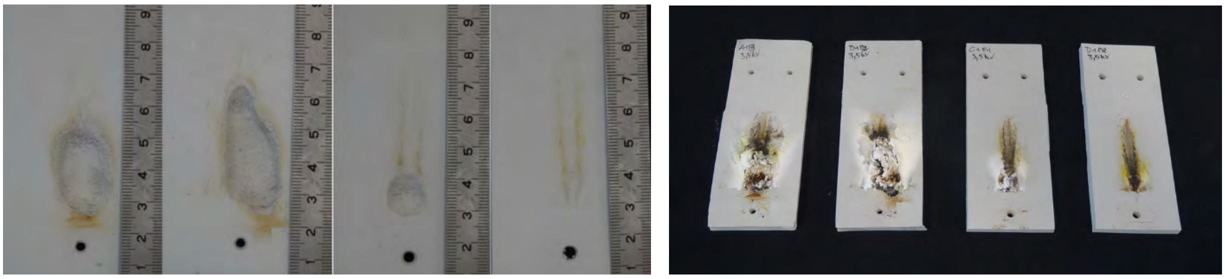


Figure 10: Result at 3.5kV showing a coating which pass (left) and one which failed (right)

Overall, the inclined plan test can be used to give an indication in relative performance provided the IEC 60587 method is being used with slabs. The CIGRE 478 method offers no indication of performance that could be valuable and test only the quality of the ceramic tile beneath the coating. It is therefore totally useless.

5. Tracking Wheel Test

This test initialy created in Canada has been used for polymer insulators. Here again the difficulty is to determine how to cope with thin coatings when for polymers the thickness of the rubber over the core is at least 3mm. This test was a classic for polymer insulators and is described in IEC 62217 [8]. It is not a test considered for ceramic or glass insulators because originally aimed at defining the ability of housing materials to sustain strong regular dry band arcing.
It consists of a wheel with 4 branches where the insulators are installed. The wheel turns and when reaching the lower position of the cycle the insulator finds itself in a tank of salt water. When reaching the upper position, the insulator is energized. The setup of the test is described in figure 11.

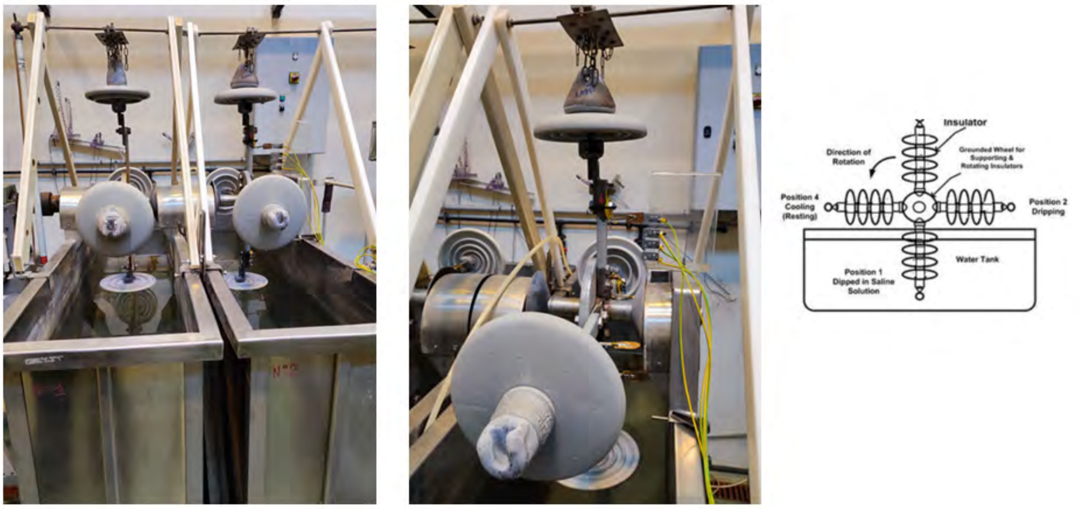


Figure 11: Set up of the tracking wheel test as per IEC 62217 (right) and actual arrangement in Sediver R&D laboratory with silicone coated glass and porcelain insulators

The success in this test is defined for polymer insulators as usual is that permanent tracking should not take place and erosion should not reach the core.

For investigation purposes silicone coated glass and porcelain insulators were tested. They were installed in parallel on two wheels. The insulators themselves, either glass or porcelain had the same mechanical rating, the same diameter, and the same leakage distance. Two different chemistries of coatings were tested as well on both glass and porcelain insulators. The salt water was set at 1.4 g/l and the voltage applied was set to reach a USCD=31mm/kV.

The test was performed several times and beyond the visual and erosion criteria, the leakage current was monitored along with the cycles. The test results appear to be very interesting and can be compared to the end of life of a silicone coated insulator including what appears to be a good correlation with known aging in field conditions. The evolution of the changes and degradations are also in line with the “Sediver aging index already published previously [9] and shown in appendix. The main comments are summarized hereafter:

a. Adherence of the coating on the dielectric is being challenged as it is always the case when a thin layer of silicone is immersed for some time in water. Some samples will display large bubbles some will not and not at the same time depending mostly on the nature of the silicone coating and the application process (figure 12).

b. For some samples the adherence is completely recovered after a rest time following the end of the test. Approximately 24h of rest time for the best candidates (Figure 13). It seems also that while all samples were coated with similar care of adhesion, porcelain is more inclined to lose adherence than glass.

	
Large loss of adherence of silicone type A on porcelain insulator (8000 cycles)	Better adherence of silicone type B on porcelain insulator (13000 cycles)
	
Areas with lack of adherence on glass insulator with silicone type A after 14000 cycles	Good adherence with silicone type B on glass after 24000 cycles.

Figure 12: Adherence of the coating for porcelain and glass insulators with silicone type A and type B

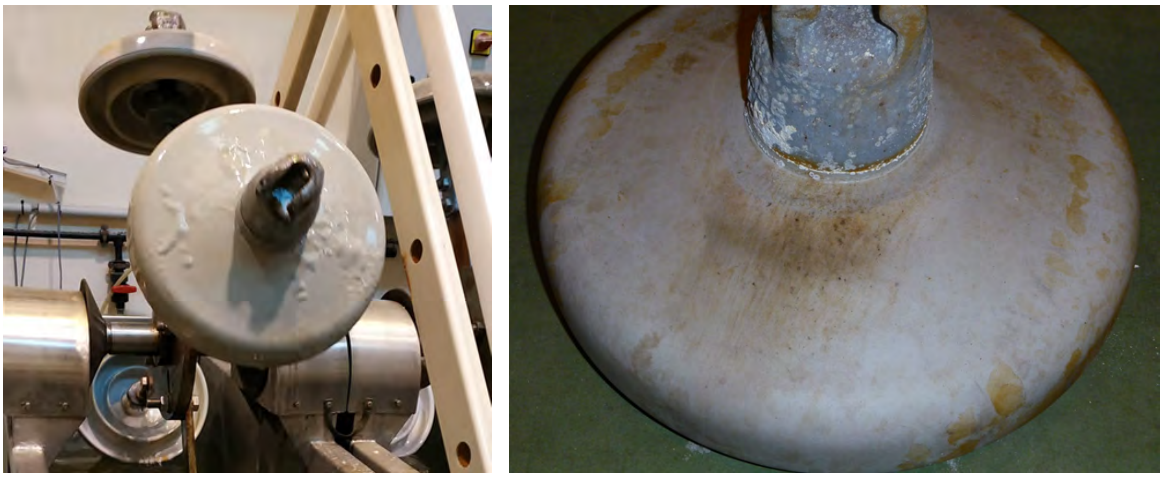


Figure 13: Loss of adherence of silicone type B after 28000 cycles on glass Insulator (left). The same Insulator 24h after the end of more than twice the test duration (65000 cycles)

c. The development of dry band arcing over time intensifies as hydrophobicity is being lost or reduced. This increase of electric activity is significantly more severe for the porcelain discs (figure 15), most probably due to the design of the porcelain ribs.

   The top behavior is strongly influenced by the assembly of the cap on the dielectric. A gap between the base of the cap and the upper surface of the disc will favor discharge activity leading progressively to severe erosion as shown in figure 14 disregarding the type of silicone.

   This is a phenomenon less prone to take place when the cap is sealed on the glass with a flock as per Sediver glass insulators design (Figure 15).

Figure 14 : Electric activity on porcelain after approximately 7000 cycles (left) and erosion as of approximately 13000 cycles on porcelain with type A silicone.

Figure 15: Comparison of dry band arcing activity at the base of the cap of Sediver glass having a flock at the base of the cap and a porcelain insulator. (Silicone type A at 10000 cycles).

d. The bottom sides of the insulators are typically more impacted given the concentration of activity around the pin. This is where the nature of the silicone itself can make a difference as shown in figure 16.

Figure 16: Glass insulator at approx. 20000 cycles. Left silicone coating type A, Right Silicone coating type B

e. Directly in line with the previous observations, the leakage currents were monitored and showed 2 interesting phenomena. There was always more leakage current on the porcelain units than the glass insulators despite their similarities in leakage distance (The shape of the ribs of the insulator is most likely an important factor). The second interesting observation is the difference in the current themselves as a function of the coating formulation combined with the type of insulator (figure 17).

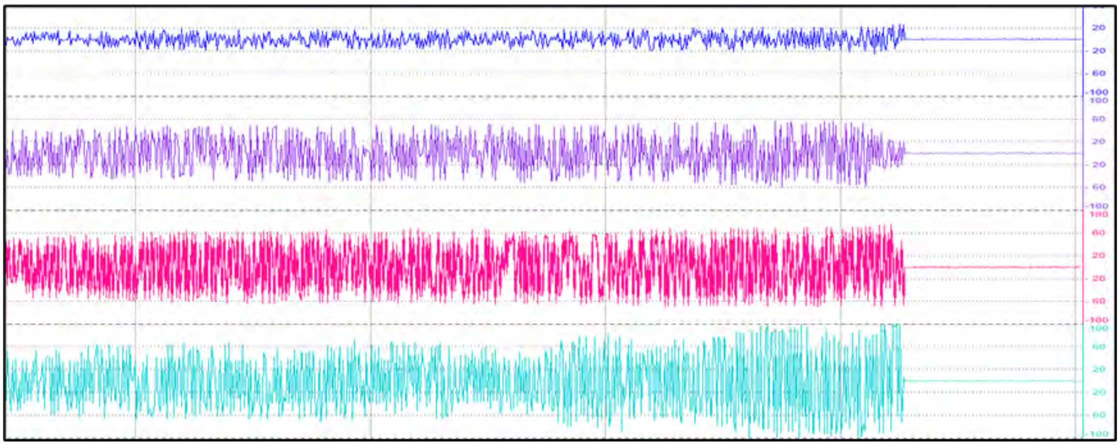


Figure 17 left: from top to bottom: Glass with silicone type B, Porcelain with silicone type B, Glass with silicone type A, Porcelain with silicone type A. Readings at approx. 7000 cycles.

f. Another interesting finding of the test is the possibility to reach an end-of-life situation over the course of the test. This test could be a good tool to select the best coated insulators for service since, as mentioned earlier, we have seen several situations which compare to field findings. The table below can summarize the test ultimate findings based on results obtained on 2 separate wheels running simultaneously and where consistent results were found.

Type and coating	Result	Nb of cycles	Erosion top	Erosion bottom
Glass coating A	1 shattered	28000	yes	yes
Glass coating B	OK	63000	no	no
Porcelain coating A	2 punctured	8000 / 14000	yes	yes
Porcelain coating B	OK	30000	yes	yes

Overall and while this test is not at this point used in any standard for silicone coated insulators the outcomes should be considered with interest and possibly added to the upcoming standard for silicone coated insulators. The test appears to provide the following elements:

- Ability to survive strong electric activity can be discriminated with the tracking wheel test
- Clear differences in leakage currents are identified with this test pointing towards the combined influence of type of coating and shape of the insulators.
- Ranking of coatings performance can be established with the tracking wheel test
- Adherence recovery can be demonstrated in this test. Likewise different dynamics in hydrophobicity were pointed out over the course of this test.

6. Conclusions

The various test results shown in this summary can provide good guidance in the selection of the most appropriate test protocol aimed at the determination of aging, end of life and erosion of silicone coated glass and porcelain insulators.

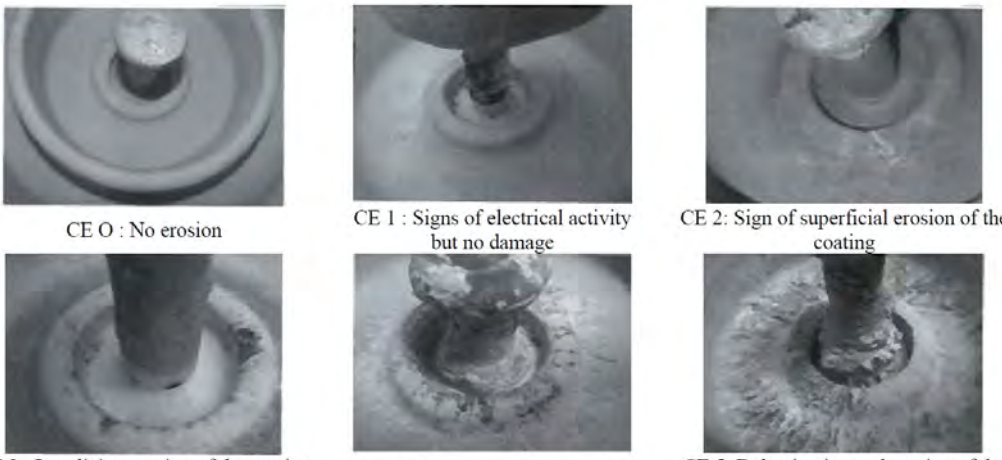
From a material point of view the inclined plan test can give some indication in relative terms comparing different silicone chemistries. The test makes only sense if slabs are being tested as per IEC 60587; Using CIGRE 478 is totally useless.

- o The 1000h and 5000h tests are not adapted to coatings since they were designed for polymer insulators which housing by nature have thicknesses at lest 3mm over the core. Coatings are in the range of 300µm.

- o The 2000h multi-stress test has been established and largely used by numerous utilities for more than 20 years providing good discrimination capabilities confirmed by more than 20 years of field experience including in very harsh environments.

- o The tracking and erosion wheel test is a very interesting test protocol providing valuable information on aging and end of life as a function of the insulator type (glass, porcelain, shape) and the silicone chemistry itself. If provides information on leakage current patterns and shows aging evolution all along which seems to fit with some field experience. The test is relatively rapid (30000 cycles as it is but cycles can be added) and not too complex to put in place. It can be an interesting addition to any standard or specification on RTV coatings.

Appendix : SEDIVER Classification of erosion of silicone coating



CE O : No erosion

CE 1 : Signs of electrical activity but no damage

CE 2: Sign of superficial erosion of the coating

CE 3 : Localizing erosion of the coating with spots where insulator surface is apparent

CE 4: Large erosion section of the coating

CE 5: Delamination and erosion of the coating on large areas with large insulator surface visible

SEDIVER **C**oating **E**rosion classification chart

References:

[1] : R. Rendina, M.R. Guarniere, A. Posati, J.M. George, S. Prat and G. De Simone, "First Experience With Factory-Coated Glass Insulators On The Italian Transmission Network" INMR World Conference & Exhibition on insulators, Rio de Janeiro, May, 2007.

[2] : IEC 36/535 - IEC TS 63432 ED1 - Room temperature vulcanizing (RTV) silicone rubber for outdoor insulators – 2025.

[3] : “Coating for improvement of electrical performance of outdoor insulators under pollution conditions” CIGRE Technical Brochure 837, 2021.

[4] : “Coatings for protecting overhead power networks against icing, corona noise, corrosion and reducing their visual impact” CIGRE Technical Brochure 838, 2021.

[5] : 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”, Edition 2.0, 2008.

[6] : IEC 60507, “Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems”, Edition 3.0, 2013.

[7] : CIGRE Technical Brochure 478, 2011.

[8] : IEC 62217, “Polymeric HV insulators for indoor and outdoor use - General definitions, test methods and acceptance criteria”, Edition 2.0, 2012.

[9] : J.M. George, S. Prat and F. Virlogeux, “Coating glass insulators for service in severe environments” INMR ; n°4, 2014 ; pp. 60-64