Specifying RTV Silicone Coating for Overhead Transmission Lines

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Silicone coatings have been largely used for decades in substation for mitigation of contamination problems but also for now more than 25 years at large scale for overhead lines. Progressively the use of coatings on overhead lines went from application in the field to a more consistent and reliable process where insulators are coated in factories taking advantage of industrial working environments and cleanliness more difficult to achieve in the field.

Two sets of parameters are being discussed in this paper both of equal interest to ensure long term performance of the desired property of pollution mitigation. Selecting the most appropriate material is key for ensuring a long lasting hydrophobicity as well as a resistance to erosion under severe pollution and corona related activity. The second major point to focus on is the application process itself which needs to be carefully considered to prevent an accelerated degradation of the performance of the insulators.

While CIGRE is currently working on providing a technical brochure offering detailed guidelines for coatings and coated applications through B2 69 activities, Sediver from its own experience based on decades of monitoring and supply of coated insulators, can contribute to the debate. Various materials have been screened in our Research Center in Saint Yorre, France and permanent monitoring of coated insulators installed around the world provide and excellent validation of the choices which are being made in our development programs.

1. Material selection

Numerous supplier offer their chemistry for the make up of their silicone coating. Today most silicone coatings are classified as RTV2 meaning that a curing agent is added to the chemistry to oppose to RTV1 where only moisture exposure was promoting the curing. Sediver took a position based on more than 40 years of field experience, research and testing on polymer housing materials used in the polymer industry in which Sediver was a major actor. Some will argue that there are other options than those presented hereafter and we surely respect that. Our approach is based on a unique approach where field performance is continuously challenging research and laboratory testing.

In this context we believe that silicone coatings need to be selected based on physico chemical parameters associated to ageing tests. Some of these tests should be type tests others need to be considered as type tests and sample tests.

An obvious first test is to verify the hydrophobicity of the silicone being used. IEC TS 62073 should be the reference with an expected HC1 level being expected.

The basics are described in CIGRE Technical Brochure 595. This document explains how to establish the fingerprint of the silicone and contains similar requirements as those for polymer housings. This finger-print shall include at least the following data:
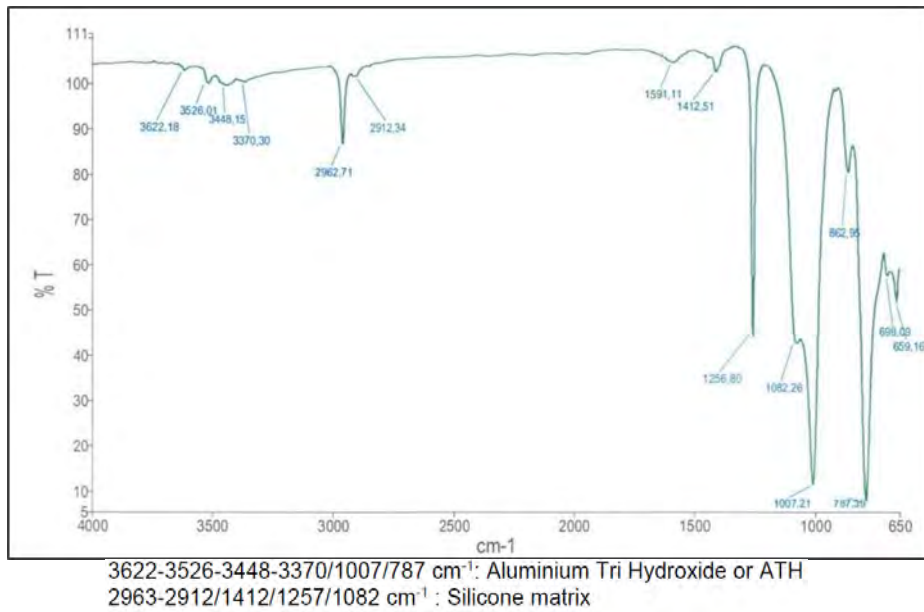
- Thermal Gravimetric Analysis (TGA)
- FTIR analysis (Fourier Transformed Infra-Red analysis)
- Density

TGA is intended to demonstrate the existence and ratio of ATH (Alumina Tri Hydrate) contained in the silicone. While coatings exist without ATH or with substitutes, Sediver strongly believes in the inherent benefit of using such a filler to reduce the risk and speed of erosion in very harsh environments. This is supported by multistress ageing tests procedures as descibed later in this section. An example of TGA test is shown in figure 1.
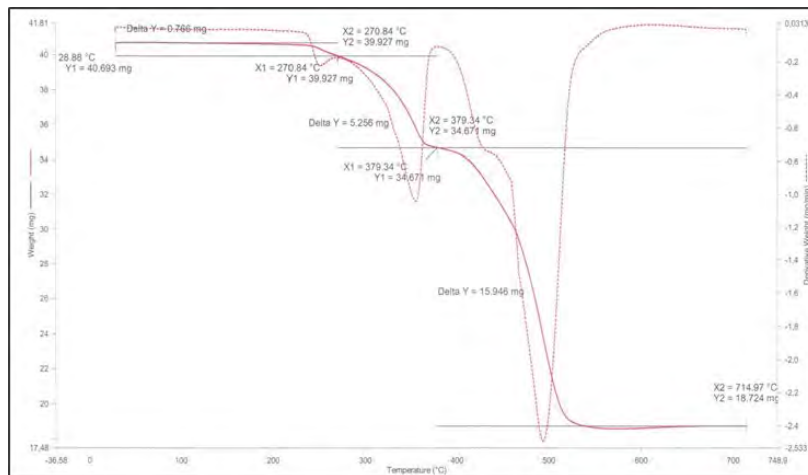
Figure 1: Typical TGA test result showing the ATH content in a silicone coating.

FTIR analysis will provide a spectrum as shown in figure 2 where the various key components are idenfiied at their absoprtion bands in a spectrum aimed at scanning all molecular species. FTIR as well as TGA are procedures capable to validate the consistency between approved materials through type tests and regular supplies through sample tests. Specific gravity is one more very useful indicator which should be used the same way as the two previously described parameters.

3622-3526-3448-3370/1007/787 cm⁻¹: Aluminium Tri Hydroxide or ATH
2963-2912/1412/1257/1082 cm⁻¹ : Silicone matrix

Figure 2: Typical FTIR spectrum helping the identification of the constituants of the silicone polymer.

Additional physico chemical parameters should be considered in an effort to establish reference properties of the silicone used in the coating among which the following shown in figure 3 and 4 are very common to the electrical applications of silicone:

| Physical property	Reference applicable Standard
Dissipation factor Tan δ	IEC 60250
Permittivity ε	IEC 60250
Resistivity ρ	IEC 62631-3-1
Dielectric strength	IEC 60243-1
Arc Resistance	IEC 61621

Figure 3: Physical properties describing the electrical intrinsic properties of silicone coatings
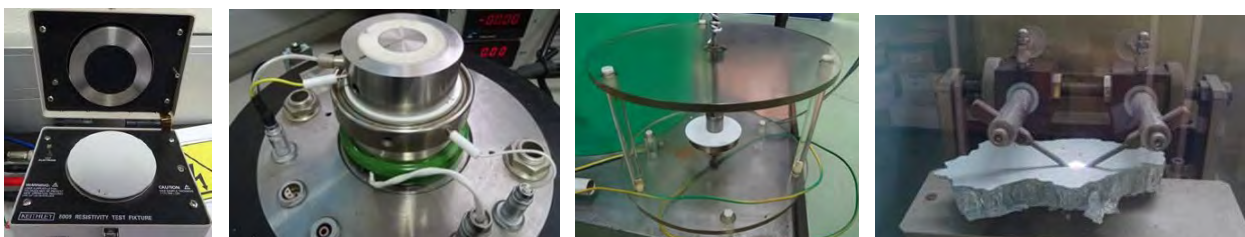
Figure 4: From left to right resistivity, permittivity and dissipation factor, dielectric strength and arc resistance tests

Once this physico chemical parameters are established there is a need for evaluating the electrical performance of the coating. From an electrical point of view the most interesting performance is the ability of the coating to sustain electric arcs without excessive erosion damage. Several tests should be considered besides the arc resistance already listed above:

A relatively well known test is described in IEC 60587 so called the inclined plan test. The test arrangement and typical results are shown in figure 5. Usually silicone coatings will meet the requirement of 1°3,5 (figure 6.1) when using the method 1 with 6h voltage steps. The test itself is easier to perform on silicone rubbers such as the LSR or HTV compounds which can be molded in larger section relatively easily. For coatings however this test is more challenging and offers less consistency given the higher difficulty for pouring such silicone in an appropriate mold. Another approach is to apply the coating over a ceramic tile. Figure 6.1 and 6.2 show the results for the same coating testing with different preparation procedures. Flucutations in the test can show withstand results at 1A4.5 but with a questionable consistency.
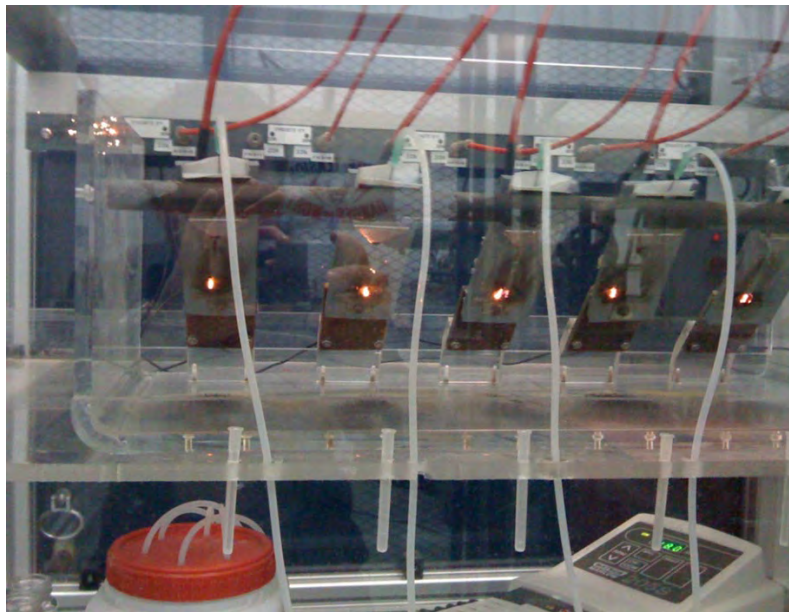
Figure 5: typical set up of the inclined plan test as per IEC 60587


Figure 6.1: typical coating sample after a 1A4,5 succesful test

Figure 6.2: the same coating but with a different sample preparation procedure. Sample failed the same stress as the one applied in 6.1

Referencing this test in a specification requires a clear description of the protocol by which the samples are being prepared.

A more pragmatic approach is the evaluation of the erosion resistance of the coating when applied on an insulator. Various tests such as 1000h salt fog or for polymers a 5000h mulitstress test exist but are typically designed to test for erosion resistance of larger thicknesses than the typical coating thicknesses which range in within an average of 300μm versus a minmum of 3mm for classical polymer insulators. Another test adopted for many years by a major European utility, TERNA, Italy, has shown an excellent capacity to discriminate among different chemistries of coatings and is used by many utilities today in their specifications. Figure 7 shows the test protocol. The acceptance criteria ask for the coating to not be eroded down to the surface of the glass or the porcelain, not more than 3 flashovers during the test.
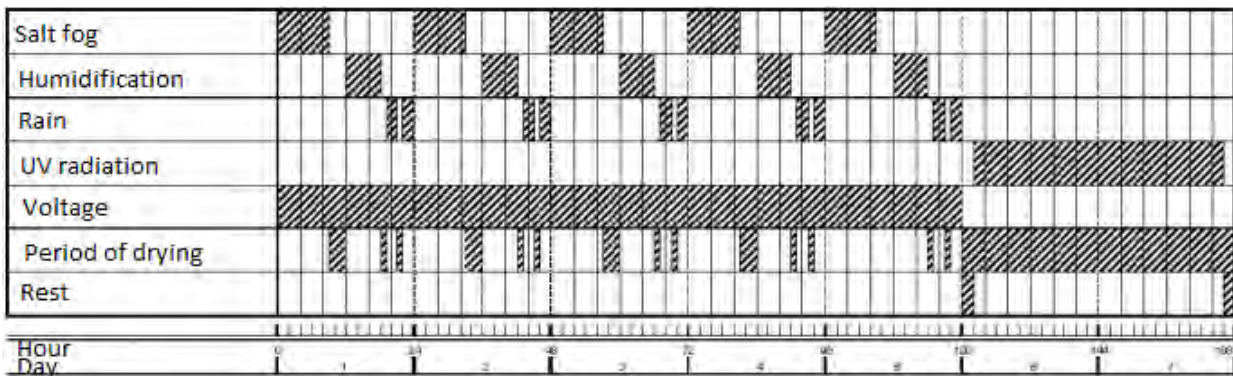
Figure 7: Test procedure and set up for the TERNA 2000h multistress ageing test

This test is performed on a given type of insulator, and can be requested for any given shape. Typcial electric stress level for this test is with a USCD= 37mm/kV and a 40g/l salinity. The flow is 1.33 dl/h/m^3 of the test chamber. The preparation of the salt fog shall comply with the specification IEC EN 60507 §7 and 8.

Each period of wetting lasts 6 hours. The vapour shall be produced by evaporation of a volume of water contained in a tank placed in the test chamber. The quantity of water evaporated shall be 33g/h/m^3 of the test chamber in a maximum time of 75 minutes at the beginning of the wetting period.

Each period of rain fall lasts 4 hours divided in two periods of 2 hours. The rain flow shall be 1.5 mm/min. Between the two periods of rain, a rest time of 1 hour shall be allowed. The rain characteristic shall comply with the IEC 60060-1 standard.

UV radiation at 0.5 kW/m² shall be applied for 48h with no voltage applied to the insulator strings. At the end of each radiation cycle the temperature on the surface of the insulators shall not be above 60°C.

Strings should be tested in both directions since the dry bands will not develop in similar conditions as the wetting will differ while under ribs of the insulators will play a role. Suspension units will usually show higher electric activity than tension strings in this test.An example of pass/fail results is shown in figure 8 in which the coating containing ATH shows a better erosion resistance.
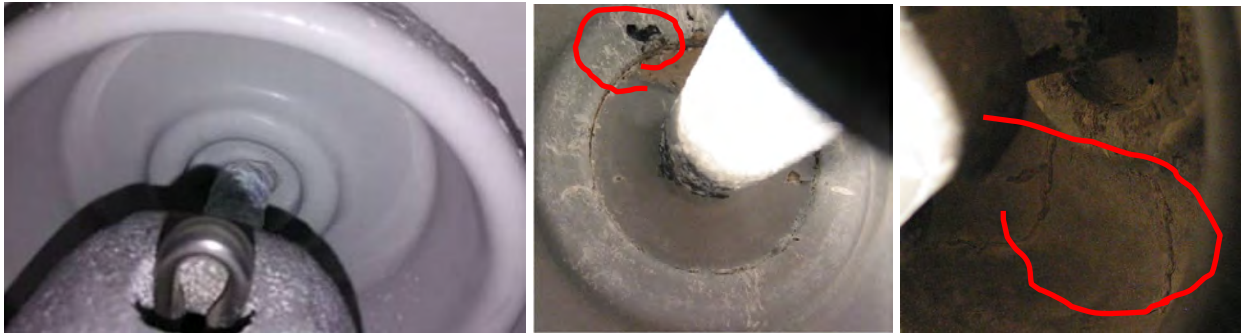
Figure 8: Results of the 2000h multistress ageing test (left) on a high performer coating made with ATH fillers (left) and lower performers using a different type of erosion resistant filler material (center and right).

2. Guidelines for application process control

The best coating might not last as long as expected if not correctly applied. In some cases the application will take place on site, either on the tower (not recommended since there is no possible control of the consistency of the thickness and cleanliness or adherence) or in the field near the line prior to installation of the insulators. In both cases additional parameters necessary for matching the material properties (among which viscosity) with the application tools (usually spray) should be defined. More and more utilities are looking at a different approach (initiated in Europe by TERNA, Italy) where the insulators are pre coated in a factory ensuring a clean surface preparation,and consistent controlled thicknesses and adherence. This demand has been growing ever since its introduction around the early years 2000.

Application of silicone coatings in a factory can be made by spray or dipping. Both methods work well provided properly developed in a combined approach of the physical properties of the silicone and the process.

Various inspection criteria can be used to verify that the coating is correctly applied evolving around the three following parameters:

- Visual aspect
- Adherence
- Thickness

2.a Visual aspect

More a cosmetic concern, the overall aspect is an indicator of potential problems with the consistency of the deposit. Figure 9 shows a few examples of unacceptable aspects among which runners and droplets, lack of coating in some areas.... Typical criteria include such visuals defects.

Figure 9: Examples of visual defects in the application. (left: uncoated areas, center: uneven coating, right: runners and droplets)

2.b Adherence

Adherence requires an appropriate preparation of the surface. Cleanless is better achieved when prepared in an industrial environment and figure10 shows what can happen when the coating is applied on site.

Figure 10: Example of poor adherence resulting from poor application on site and lack of cleanliness

Applicators may chose their own process but what matters to the end users is to have a test which can be used as a sample test to verify the consistency of the adherence all along the application process. Two main directions exist in this segment of properties:

- Scratch test as per EN-ISO 2409
- Water boiling test

The scratch test is a test easy to perform does not require any specific laboratory equipment but only a fork designed as per this standard and shown in figure 11. Adherence is considered as acceptable if the scratch does not peel the coating but cuts through the thickness. GO/NOGO examples are shown in figure 11;

Adherence satisfactory   Adherence not satisfactory

Figure 11: Scratch test as per ISO-EN2409. Left: testing fork. Center: acceptable adherence. Right: Bad adherence

Unlike for the scratch test, the water boiling test requires a laboratory and cannot be performed easily as a sample test, which is what really matters. The boiling test requires a 100h immersion in a boiling water tank. Adherence should be verified at the end of the test. This test is mentioned in IEEE 1523. Besides the fact that the document does not explain what is the time between the extraction from the water and the peeling test, it ignores the fact that silicone generally speaking is permeable to water and especially water vapor. While this test can make sense to test interfaces (seals) on composite insulators it does not make any consideration for the fact that the thickness of coatings will allow water to permeate below the coating itself. Therefore this test only makes sense if there is sufficient time to let the insulator dry. If the coating is well applied the adherence can be verified after a rest time of approximately 24h to 48h. Examples of temporary inhibition of the adherence are shown in figure 12 with samples from a variety of suppliers. This test which under these conditions could be used as a type test is not adapted to the needs of sample testing.

Figure 12: Various types of silicone coatings tested direclty after being extracted from the boiling tank after 100h of immersion.
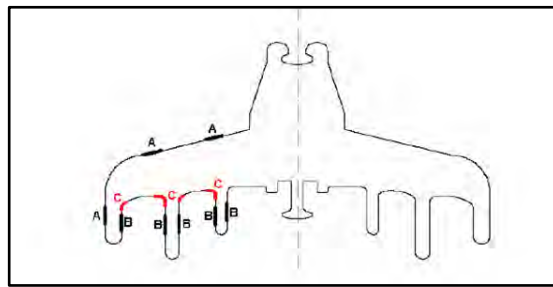
2.c <u>Thickness</u>

Excessive thickness does not necessarily go well along with good adherence. Not enough coating can end up with some spots easily uncoated. There is a general consensus around some typical values which are supported today with decades of good field experience. Therefore such values should be considered as a good reference.

Thickness cannot be measured accurately at the bottom of the insulators between the ribs, but guidelines can be recommended for the top surface or along the ribs themselves as shown in figure 13. Measures should be made on dry surface using a traditional caliper of an electronic reading from an electronic film thickness gage device as shown in figure 14. The measurement of the thickness shall be performed in 9 different positions **A** (3 x 3 points at 120 degrees apart) on the top surface

of the skirt and 15 positions **B** (3 x 5 points at 120 degrees apart) on the ribs. Area **C** is not practical for making measurements and will not be considered.

Figure 13: Typical thickness recommendations: A= 400µm+/-50µm, B=300µm +/- 50µm, C is not measured

Figure 14: Thickness readings

3. **Full or half coated insulators**

More than 20 years ago research was showing that expected pollution performance of under coated insulators (figure 15) could be an interesting alternative to fully coated insulators more difficult to pack ship and handle. This was not really transferred into large scale application until approximately 10 years ago when Sediver started to look closely at the expected performance of the under coated insulator. This option is currently extremely popular in utilities facing severe pollution conditions.

Figure 15: Fully coated (right) and under coated (left) glass insulators

Pollution performance tests performed on silicone requires special attention given the dynamic behaviour of the hydrophobic surface. Preconditioning can kill temporarily this property, therefore quick flashover or rapid flashover testing will be preferred with an additional withstand test for verification. In this context Sediver has performed extensive testing of silicone coated glass insulators comparing the results of fully and under coating. This tests have been cross checked in independant laboratories. Figure 16 shows a set of results in salt fog and solid layer pollution

conditions. It appears that the relative performance of both designs are comparable. Under coating appears to be an interesting alternative for highly polluted environments.

ESDD/NSDD 0.1/0.2 mg/cm²	Non coated	Under coated	Fully coated
Withstand (kV)	76	112.5	126
Gain	100%	148%	166%
40g/l salt fog	Non coated	Under coated	Fully coated
Withstand (kV)	15	18.6	17.6
Gain	100%	122%	117%
USCD (mm/kV p/gnd)	29	24	25

Figure 16: Set of test results comparing fully coated and under coated insulators

4. Recommendations

The various parameters described in this document provide a comprehensive set of information offered for consideration when selecting and testing silicone coated insulators. The following tables can be considered as guidelines for type tests and sample tests. Reference values are proposed as well based on a combined laboratory and field experience based on more than 20 years of testing and monitoring.

4.1 Type tests

The following elements can be considered as a reference for type tests:

Test	Reference	Comment
TGA	CIGRE TB 595	Only if ATH in the chemistry
FTIR	CIGRE TB 595	
Specific gravity	CIGRE TB 595	
Permittivity	IEC 60250	
Dissipation factor	IEC 60250	
Resistivity	IEC 62631-3-1	
Dielectric strength	IEC 60243-1	
Arc resistance	IEC 61621	
Inclined plan test	IEC 60587	For information only
Hydrophobicity	IEC TS 62073	
Thickness	See above section 2	
Adherence by scratch test	EN ISO 2409	
Adherence after 100h boiling water	IEEE 1523	Only after 24h of rest time
Multi stress erosion test	See above section 1	

4.2 Sample tests

The following tests can be used as sample tests with sampling size E1+E2 as per IEC 60383, with similar retesting conditions.

Tests	Reference	Comments
Visual inspection	See above section 2	
Hydrophobicity	IEC TS 62073	
TGA	CIGRE TB 595	
FTIR	CIGRE TB 595	
Specific gravity	CIGRE TB 595	
Adherence	See above section 2	Scratch test only
Thickness	See above section 2	

4.3 Reference values

Parameter	Recommended value
ATH content	At least 27%
Specific gravity	>1.2
Thickness	A= 400µm+/-50µm, B=300µm +/- 50µm
Hydrophobicity	HC1
Permittivity	>2.5
Inclined plan test performance	Min 1A3.5
Resistivity Ω.m	$0,8.10^{14}$
Dielectric strength kV/mm	>14
Dissipation factor (Tg Delta)	>50.10-4
Arc resistance (sec)	>180