Manufacturing & Qualifying RTV Coated C8-2550 Ceramic Post Insulator for HVDC Air-Core Dry-Type Reactors

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Abstract

Global Energy Transition is increasing the need for HVDC-links everywhere, this means new substations with modern VSC (voltage sourced) HVDC-converters, using IGBT/IGCT semiconductor switching elements, converter reactors, etc. The ionization of the airborne particles, that results from the electric field between the poles, aggravate the pollution challenges in this application. The ionized particles are drawn by the electric and magnetic field and are depositing a quickly growing pollution layer on the insulators.

At the same time the increasing HVDC voltages, power ratings and loss evaluation makes that equipment bigger and heavier, increasing the mechanical strength required from support insulators. Insulators must support high compression forces, combined by increased flexural stresses coming from seismic requirements and/or high wind-load or short circuit forces due to the magnetic coupling between reactors and at the same time have a minimum flexion.

T&D industry is solving these challenges by combining high strength ceramic porcelain insulators with RTV-coating to improve the pollution resistance in DC-applications. The RTV coating has been slowly moving from in field executed ad hoc coating to coating in controlled industrial conditions by the insulator manufacturers. The new IEC TS 63432: "*RTV silicone rubber coated insulators for AC and DC high-voltage applications - definitions, test methods and acceptance criteria",* recently circulated for comments, will further accelerate this tendency.

This paper describes the design, manufacturing, and homologation steps of RTV coated C8-2550 ceramic post insulators for a 500 kV HVDC air-core dry-type reactor support as a part of real HVDC-link project using sub-sea cable connections between the converter stations

KEYWORDS: HVDC, Air-Core Dry-Type reactor, RTV coating, isostatic, ceramic post insulators, PPC Insulators, Trench

1. Introduction

The global Energy Transition is increasing the need for HVDC-links everywhere in world. First element is the need for energy efficiency, which turn HVDC transmission lines to a more economical solution if it comes to overhead lines longer than about 600-800 km or about 50 to 70 km cable connections. The integration of bulk offshore wind energy without modern VSC converter technology is often not feasible.

DC-links are as well an excellent way to interconnect local or national grids because HVDC allows power exchange between asynchronous grids. This gives better control of power flow and helps stabilize grids and avoid cascading failures. DC-links are as well essential to integrate renewable energy sources, like offshore wind parks or solar power generation from remote areas to the load centers. Additionally, HVDC back-bone systems are planned and integrated for the same purpose.

This tendency requires more substations (converter stations) with adapted equipment for the AC/DC conversions, converter transformers, IGBT/IGCT valves, air-core dry-type converter reactors and sometimes smoothing reactors just to mention some major heavy equipment. This heavy equipment requires insulation solutions both for mechanical strength and increased creepage distances on a challenging pollution environment.

RTV-coated ceramic insulators can combine high strength and low flexion with enhanced pollution performance with HTM silicone-coating.

2. Isostatic ceramic post Insulators Design and manufacturing process

The isostatic manufacturing process was developed in the 70'ties for the needs of powder metallurgy. The isostatic process allowed manufacturing metal alloys or ceramics, which were not possible to manufacture by any other technology. On the isostatic process, a rubber-mold is filled by dry powder, pressed with a very high-pressure (up to 1100) bar to give the wanted shape to the product. On Hot Isostatic Pressing (HIP), the temperature is raised to several hundreds of degrees of Celsius to complete the sintering on same operation. On Cold Isostatic Pressing (CIP), the pressing is done by an hydraulic process at room temperature.

On the isostatic insulator manufacturing process, the raw material base, Kaolin, Clays, Alumina, and Feldspar, is the same as in the plastic process. The particle size distribution and recipe are optimized for the spray dryer process where the mixed slurry is dried to a fine and homogenous powder. The PPC CAB spray drying process scheme is presented in Figure 1 below.

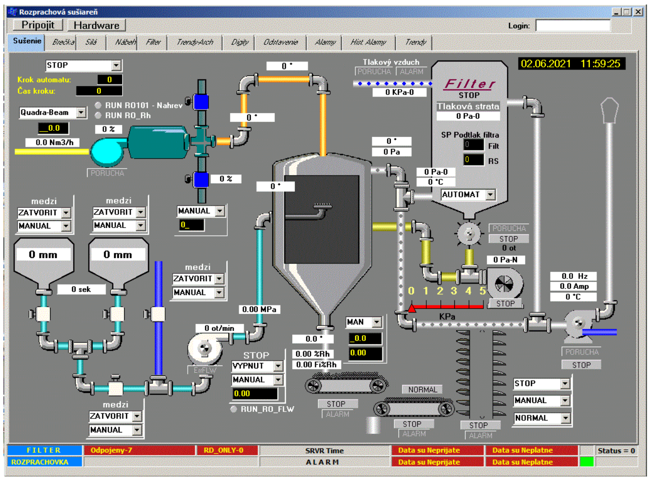

Figure 1. The spray drying process scheme.

Figure 2: the CAB spray dryer, the manufactured powder is transported with conveyor belts to silos.

From the silos the powder is moved to the filling area where a rubber-cannister inside a steel-cylinder is filled. The filled cylinder is transported by a carousel crane to the press itself. See Figure 3.

Figure 3: In the front we can see the steel-cylinder with a rubber-cannister inside. Behind we can see the blue structure of the press itself.

The pressure cycle takes a couple of minutes, where the pressure is increased up to 1050 bars. After the pressure cycle the body is now a solid machinable ceramic cylinder and ready for turning.

Figure 4. Pressed cylinders for turning process.

After pressing the cylinders are moved directly to the turning, glazing, and sanding operations before being loaded onto the kiln car for the firing cycle. After firing the manufacturing steps are identical with the conventional plastic process: visual inspection, cutting and grinding, assembly and final testing.

The isostatic manufacturing process results in a higher strength for the C-130 grade compared to the conventional manufacturing process. This makes the isostatic ceramic post insulators very suitable for support insulators for demanding equipment.

3. Application of Room Temperature Vulcanization (RTV-1) Silicone

The spray coating is executed in an industrial painting chamber with a strong suction system to eliminate the free silicone particles from air.

Figure 5. RTV-Coating Process at CAB

RTV-Coating is done in tree layers with a curing period in between. The layers are approximately 125 µm – 150 µm thick (DFT – dry film thickness), this three steps process results a very good primary adhesion and homogenous RTV-coating thickness. If necessary, a 4th layer can be applied for specific designs.

4. Qualifying Process of RTV coated post insulators

Both the mechanical and electrical type tests of the insulator were done according to IEC 60168 and as these type tests are state-of-art, this paper focuses on RTV coated insulator qualification requirements.

The RTV coated post insulators homologation consists of type tests for RTV silicone characterization and tests on the applied RTV on the insulator.

4.1 Type Tests for silicone characterization

The type tests for silicone characterization were done on molded/cast silicone slabs, and the tracking and erosion test was performed on RTV-1 coated ceramic tiles.

1. RTV Silicone Coating Thermogravimetric Analysis (TGA) - EN ISO 11358-1:2022
2. RTV Silicone coating differential scanning calorimetry (DSC) - EN ISO 11357-2:2022
3. RTV Silicone coating Fourier Transform Infrared Spectroscopy (FTIR) – EN 1767:1999
4. RTV Silicone coating density Measurements – ISO 2781:2018 Method A
5. RTV Silicone Tracking and erosion test – IEC 60587:2022

The tests 1 to 4 were executed in an external accredited laboratory. The test report doesn't state if the results are passing or failing, as pass criteria are not defined. The report gives only the FTIR spectrum, the TGA-graph shows three material degradations between + 300°C and + 600 °C with residual mass of about 40 %, the DSC diagram shows that the RTV was thermally stable throughout most of the temperature range from -60°C to + 200°C and the measured mass density is 1.383 g/cm^3. The report doesn't give any interpretation of the results.

It was not simple to find an accredited laboratory for the tracking and erosion test according to IEC 60587:2022 with adequate test equipment. Therefore, it was finally executed Trench Austria's material laboratory with calibrated equipment.

PPC Cab manufactured five C-130 ceramic plates (120 mm x 50 mm x 6 mm), which were coated with RTV-1 silicone with the factory coating equipment.

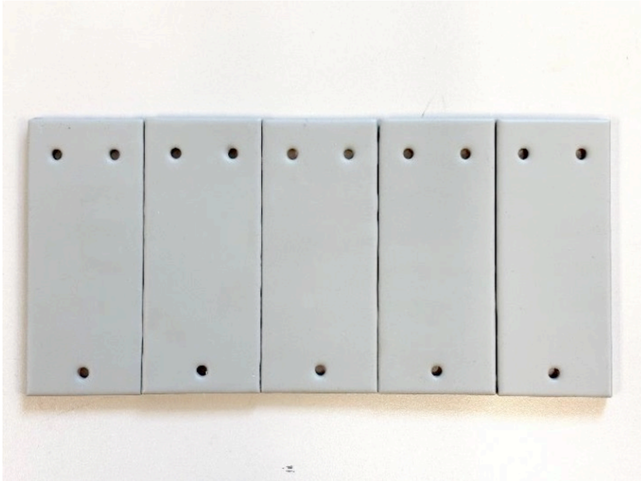

Figure 6: Cleaned samples for Tracking and Erosion test according to IEC 60587:2022

The test parameters were:

• Test voltage	AC 4,5 kV
• Test frequency	50 Hz
• Series Resistance	33 kOhm
• Flow rate	0,6 ml/min
• Contaminant	2,53 S/m
• Test duration	6 hours

All samples passed the test. The maximum measured erosion depth was 0,65 mm, none of the samples punctured or ignited.

Figure 7: Cleaned samples after the tracking and erosion test.

The material wear of the RTV at the lower electrode is typical behavior in this test for RTV-1 silicone material.

4.2 Type Tests for Coated Insulator

These tests are done as Factory Acceptance Test (FAT) for finished coated ceramic insulators.

1. Visual Examination after RTV coating – Customer Specification.
2. Silicone coating thickness measurement – Customer Specification.
3. Silicone coating adhesion test – EN ISO 2409
4. Silicone coating hydrophobicity test - IEC TS 62073
5. RTV Silicone coating homogeneity test – Customer Specification

Visual Examination

The project specification calls for:
"The coating material must have a uniform surface both in appearance and color. There must be no diffuse drops, excessive roughness, or accumulation of material."

Three samples were examined. All selected insulators passed.

Figure 8: Visual Examination of RTV-coated post insulators.

Silicone coating thickness measurement (DFT)

Small rectangular coating samples were taken as follows:
First (top) shed, shed in the middle and bottom shed. At each location the sample was taken from both shed sides - top side and from underneath. The samples were measured by a handheld micrometer caliper.

Figure 9: RTV-Silicone coating thickness measurement.

The RTV dry-film coating thickness was specified as 400 µm on upper side of the shed and 320 µm underneath.

Measured values:

Upper Shed	average 547 µm, minimum 447 µm.
Underneath	average 421 µm, minimum 360 µm.

Silicone coating adhesion test

The RTV-Coating adhesion test was executed according to clause 5.2.3.2 of ISO 2409, with a multiblade tool. With the tool a crosscut is created, the area is then covered with self-adhesive scotch tape. After removing the scotch tape, the crosscut surface is inspected for removed coating particles.

Figure 10: Scratching the coating with a multiblade tool.

Figure 11: the cross-cut area on the RTV-coating.

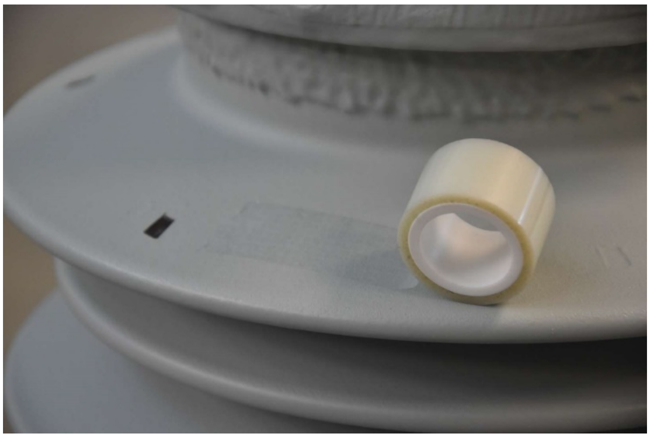

Figure 12: the cross-cut area covered by self-adhesive scotch tape.

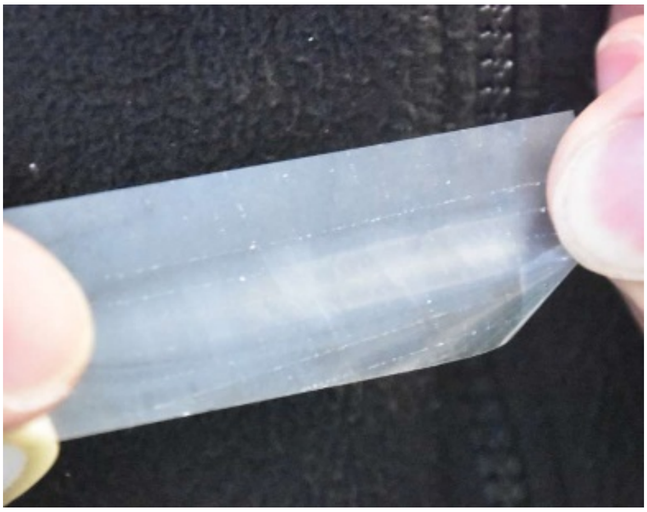

Figure 13: The scotch tape is examined for detached coating particles.

The result on all adhesions tests was class 0, as specified in ISO 2049:

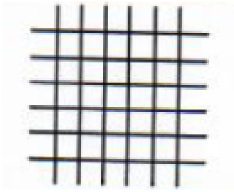

Figure 14: The edges of the cuts are completely smooth; none of the squares of the lattice is detached.

Silicone coating hydrophobicity test

The hydrophobicity evaluation was done according to IEC TS 62073.

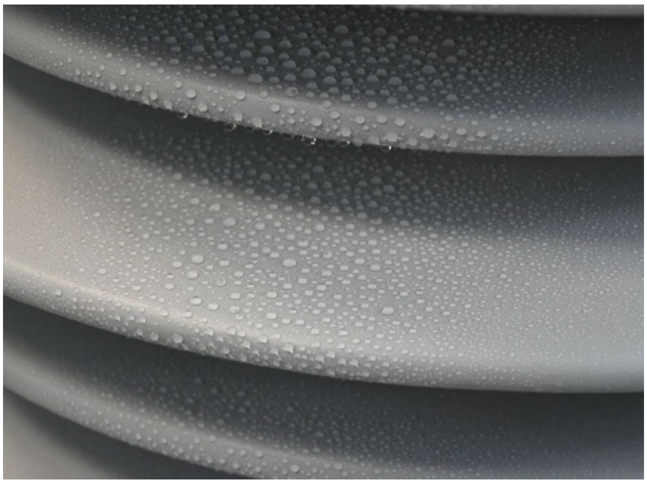

Figure 15: Hydrophobicity test by sprayed water.

The hydrophobicity class HC1 as per IEC TS 62073 was observed on all tested samples.

RTV silicone coating homogeneity test

In the customer specification it is specified that the homogeneity of the coating thickness is measured by 6 samples around one shed 60° apart from each other, and additionally 3 samples in line, starting one centimeter from shed tip to core, equally spaced. The variation of coating thickness shall not be higher than ±20 % from the mean value.

Homogeneity measurements:

Around the shed (6 x 60° apart): mean 455 µm +/- 11%
Line (shed tip to core): mean 466 µm +/- 1 %.

The RTV coating homogeneity passes the specified requirement.

5. Post insulators application as HVDC air-core dry-type reactors support

In modern VSC (voltage sourced) HVDC schemes, air-core dry-type reactors are placed in the converter arms of the rectifiers and are needed for:

- di/dt limitation for the converter modules during switching.
- Short circuit protection for the converter modules.
- Limiting the rate-of-rise of short circuit currents.
- Improving the controllability of the converter to balance the current between the converter arms.
- To provide sufficient reactance between the VSC converter and the ac network to allow a good controllability of the power and reactive power exchanges between the ac network and the converter.

They must be mechanically supported and electrically insulated from ground and other structures. This is where ceramic post insulators come in.

The insulation to ground of these reactors is typically provided by post insulators and most often by ceramic post insulators. Depending on the configuration of the HVDC scheme, these insulators are stressed by ac voltage, dc voltage or both, which imposes special requirements for these insulators regarding creepage distance and shed profiles and in case needed or specified, additional enhancement using RTV coating

These reactors are heavy, often couple of tens of tons and need to be designed for significant mechanical forces such as:

- Static dead load
- Dynamic electromagnetic forces between the reactors during faults or high current surges.
- Dynamic seismic loads.
- Dynamic wind load (if outdoor)
- Terminal loads

and load combinations of above

Typically, HVDC applications demand extra-long creepage distance and insulator length due to limited creepage factors for DC application. For such application an additional HTM RTV-1 coating can be used to optimize the design parameters of the ceramic post insulators.

In practice, each single phase HVDC air-core reactor is mounted on several tall post insulators arranged symmetrically around its base. The reactor and if needed the insulators are fitted with corona/grading rings to control electric field stresses.

The use of ceramic post insulators for HVDC air-core dry-type reactor applications is well proven and the utilization of RTV coating by design may further support the application under severe environmental conditions.

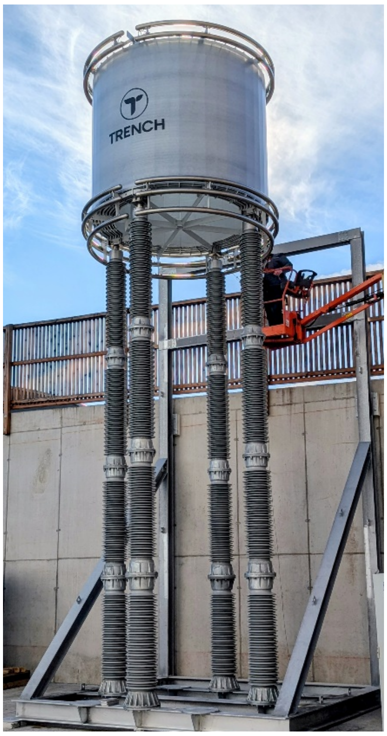

Figure 15: Trench Austria GmbH – 515 kV HVDC air-core dry-type converter reactor installed for factory testing. Photo curtesy of Trench Austria GmbH.

6 Discussion and Conclusions

The four first silicone characterization tests TGA, DSC, FTIR and silicone coating density, also called "fingerprint" test, were part of the customer specification. The test report basically states that: Yes, the RTV looks like RTV according to these tests.

When an external laboratory states that the FTIR spectra is supporting the identification of the sample as a cured RTV silicone resin is not really bringing an added value for the project. It is presumed that such requirements come from the period when RTV-coating was still a new technology and any kind of coating without clear traceability was proposed as solution.

Today, when RTV coating is state-of-the-art technology with known qualified and ISO-certified players with good traceability and solid references in last decades, it can be questioned if these fingerprint tests are really required. It should be noted that the repeatability of the TGA, DSC and FTIR is not evident and therefore the interpretation requires a lot of expertise and can be a source of confusion.

Following this logic the working group IEC TC/36 PT 63432 is now proposing on the circulated committee draft to move these tests to "for information only".

On this project the homologation of the RTV coated insulators was based on customer specification and joint agreements. There were also some discussions of the interpretations or the correct test parameters. This situation will be improved in future as the IEC TS 63432 will clarify the homologation process and type tests for all factory coated glass or ceramic insulators.

Further in this project the ceramic insulators were factory coated before delivery to the customer. The factory coating is done in controlled conditions which allows excellent adhesion and homogenous coating thickness and is a guarantee for long lifetime. These are significant advantages when compared to the on-site coating where the insulators need to be cleaned and then protected against dust and rain for the coating process itself. These critical working conditions will cause more variations on the coating thickness. The de-energization of the line or substation for the field coating will also make the whole process much more expensive.

Factory coated insulators will require adapted packaging to avoid any transport damage and special care during the installation. However, small damage can be touched up after the installation. The repair is very simple, and it is also used when the RTV-coating is restored after the dry-film thickness measurements, thickness homogeneity control and adhesion tests.

The new Technical Specification IEC TS 63432 will therefore reinforce the tendency to use RTV coated ceramic insulators for HVDC applications where high rigidity, compression strength and pollution performance are required.

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