The use of nano fillers in silicone rubber composites for high voltage insulators

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ABSTRACT

Since some years ago, polymer compositions have been used for outdoor electrical insulation applications as an alternative to inorganic materials such as porcelain and glass. The organic compositions are based on silicone rubber and fillers. Various micro fillers such as alumina trihydrate and various silicas, natural and synthetic are used to improve erosion and tracking resistance under dry band arcing to these composites, when they are used for outdoor electrical insulation. This paper discusses the benefit of the addition of inorganic nano fillers into silicone composites. Two types of fillers were used in this study micro silica and a synthetic nano filler (nano fumed silica) were used to reinforce these silicone rubber composites. In order to evaluate the tracking and erosion resistance of the micro-nano filled composites, the inclined plane test and tracking wheel test were used. Several insulators were manufactured and installed on distribution lines in order to compare versus silicone rubber commercial formulations.

Keywords: fillers, composites, tracking, polymer, compound.

1 INTRODUCTION

Nano technology is growing up exponentially in the last years and some applications are: self-cleaning windows, high performance paints, anti-aging products, sunscreens, etc. Resins with nano fillers are used for the manufacture of composite panels for the production of automobiles. Other products include automotive coatings, scratch resistant and polycarbonate headlight covers. Carbon nano tubes (CNT) embedded in resin, have been used in high performance composite materials for making rackets, baseball bats and hockey sticks. The nano technology solutions are also to address environmental challenges such as water purification and air purification. In the electricity sector, energy storage is a very active area where the large surface area of nano materials provides a benefit with the new materials being developed for high-speed battery charging, supercapacitors and solid state hydrogen storage. Also of great interest is the generation of hydrogen by catalysis of the water and the development of improved membranes for fuel cells [1].

In the field of electrical insulation, for the manufacture of polymer insulation, micro fillers and silicone rubber are used as the main materials. The main functions of the fillers are: to reduce the cost of the insulator because the base silicone matrix is more expensive than fillers, to increase the thermal conductivity of the compound, to reduce the amount of organic material exposed to the surface, and to increase the resistance to carbonization and erosion of the compound. If materials more resistant to electrical discharges are implemented, it could be possible to avoid excessive maintenance in the polymer insulation. Consequently, the benefits for the energy companies can be a saving in periodical preventive maintenance in the outdoor insulation of transmission and distribution lines and lower power outages due to pollution. Also, the lifetime of the insulators could be extended.

In this work it is analyzed the effect of nano particles on improving the electrical properties of nano composites for electrical insulation. The results of the research indicate that nano fumed silica imparts better tracking resistance to silicone ruber (SiR) composites than only silica micro filler.

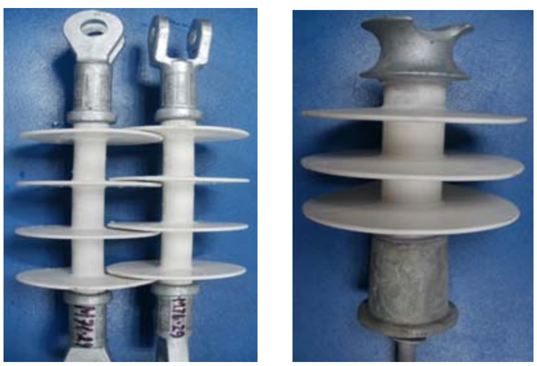
2 METHODOLOGY

One of the main problems of nano particles is to obtain an optimal dispersion, otherwise large particle aggregates or large regions in the matrix that are devoid of nano particles can be achieved. Nano composites were prepared by several mixing process in order to reduce agglomeration of nano particles. Initially, composites with HTV (high temperature vulcanizing) silicone rubber, micro particles with/without nano particles were prepared using a two-roll mill from the manufacturer Rescaldina. These composites were manufactured to assess the tracking, erosion, and electron microscopy tests. Subsequently, more compounds were prepared in a larger two- roll mill to improve the nano particle mixing. Additionally, materials were sent abroad to two companies to make preliminary mixing by using the Pressmixer and the Planetary mixer type. Further, composites were made using a Double Sigma mixer with a chamber of two liters and a working capacity of one liter. These compounds were evaluated using the scanning electron microscopy (SEM), salt fog test, tracking wheel tests, and inclined plane test, in order to demonstrate if the addition of nano particles improve the performance of the developed composites compared to commercial ready to use formulations.

Development of prototypes using industrial mixing methodology

Several batches of compound were prepared with the small double sigma mixer; with this compound various post type insulators with polymer concrete core were manufactured. These prototypes were tested in salt fog test chamber and failed. Several problems were faced to manufacture these prototypes. These prototypes, because of the polymer concrete core, were vulcanized at 150 °C and with this temperature; the core become brittle due to the high temperature used in the vulcanization. The polymer concrete core can endure up to around 140 °C before degradation can take place.

Therefore, suspension insulator prototypes with fiberglass core were manufactured. In this time, the materials of the formulation were mixed in an industrial double sigma mixer with a capacity of 35 liters. The suspension insulator prototypes were vulcanized at 170 °C and they are shown in Figure 1(a). Also a second batch were prepared in the same industrial double sigma mixer; further, post insulator prototypes were manufactured, which are shown in Figure 1(b).



(a) (b)

Figure 1: Prototype insulators manufactured with the developed formulation (a) Suspension, and (b) Post type insulators.

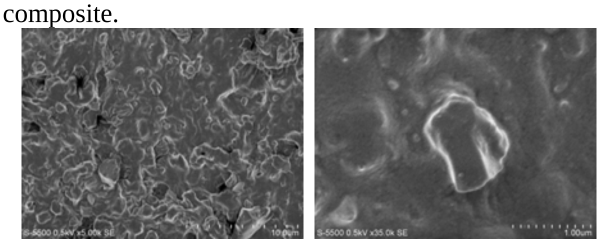
In order to scale-up the mixing process, an industrial double sigma mixer with a capacity of 600 litres and a working capacity of 300 litres was used. 350 post type insulators were manufactured from the compound using a Desma vertical rubber molding machine. Table 1 contains the description of the micro and nano fillers used to prepare the used composites.

Filler	**Average particle size (nm)**	**Surface area (m^2/g, BET)**	**Density (g/cm^3) @ 25 ºC**
Nano fumed silica	7	390±40	2.2
Micro silica	5000	5	0.58

Table 1: Characteristics of the nano and micro fillers.

2.1 Scanning Electron Microscopy (SEM) Observations

To verify dispersion of the nano filler in the compound, a FE-SEM (Field Emission Scanning Electron Microscope) Hitachi S-5500 was used to analyze the morphology of the composites. The S-5500 is an in-lens field-emission gun scanning electron microscope. In order to reduce charge accumulation on the insulating sample during observation, a very thin gold film was deposited by sputtering on each composite. Figures 2 and 3 shown the dispersion, by using two different magnifications, of the particles in the composite.



5000 x 35000 x

Figure 2: Scanning electron microscopy of the developed composite containing micro particles and nano particles.

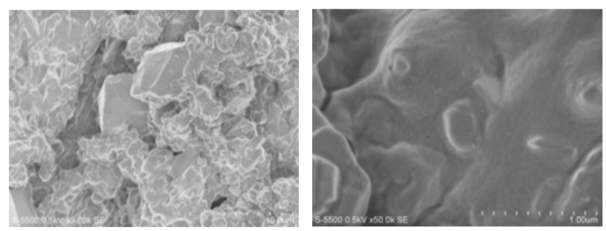


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Figure 3: Scanning electron microscopy of a composite containing micro particles but without nano particles.

2.2 Salt Fog Testing

A salt fog test was performed to evaluate the nano reinforced suspension insulators simultaneously with the commercial suspension type insulators. As recommended in the IEC standard [2], vertical and horizontal insulators were installed and tested. The commercial suspension type insulators after the salt fog test are shown in Figure 4 and the nano reinforced suspension type insulators after the salt fog test are shown in Figure 5.

(a) Insulator 3H (b) Insulator 3V

Figure 4: Commercial suspension type insulators after the salt fog test.

(a) Insulator 4V (b) Insulator 4H

Figure 5: Nano reinforced suspension type insulators after the salt fog test.

At the end of the salt fog evaluation, all the suspension type insulators passed the test without any problem. Contact angle measurements, at the end of the salt fog test, showed that the nano reinforced prototypes have good hydrophobicity compared with the commercial insulators that were evaluated simultaneously. Moreover, the measured level of contaminant accumulated on the insulators was measured as well at the end of the test; the results of the measurements are shown in Table 2.

Insulator/position in the test	**ESDD (mg/cm^2)**	**NSDD (mg/cm^2)**	**Static contact angle (°)**
3H / horizontal	0.51	15.27	97.0
3V / vertical	0.48	13.82	98.8
4H / horizontal	0.32	15.34	103.5
4V / vertical	0.45	14.21	105.9

Table 2: Hydrophobicity measurements and contaminant level at the end of 1000 hours of salt fog test on suspension type insulators.

It is important to mention that all the suspension type insulators did not fail the salt fog test, but by visual inspection, the commercial suspension insulators present a little bit more erosion on their surface than the nano reinforced suspension insulators.

2.3 Tracking Wheel Test

The developed prototype insulator and a commercial insulator, of the same profile and dimensions, were evaluated on a tracking wheel (Figure 6) following the recommendation in IEC/TR 62730 [3].

Prior to testing on the tracking wheel, the insulators were thoroughly cleaned with deionized water. In the test, each insulator remained stationary for 40 seconds in each of the four wheel positions and the travel time between positions was 8 seconds. The concentration of the saline solution was 1.4 kg/m^3 of NaCl which was changed weekly.

Two insulators from each type were tested on a tracking wheel and the test continued up to failure of the insulators. The main characteristics of the evaluated post type insulators are shown in Table 3. These insulators are designed for a nominal voltage of 13 kV.

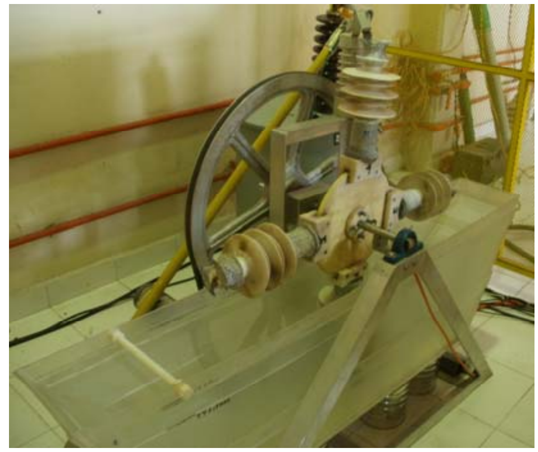

Figure 6: Nano reinforced suspension type insulators during the tracking wheel test.

During evaluation, tracking and puncture were developed in each of the two insulator types, that is the commercial type and also in the nano reinforced insulator. The average number of cycles to failure was measured and the maximum average was normalized using a value of 100, giving 100 cycles for the nano reinforced insulator, and 75 cycles for commercial insulator type.

Material	**Dry Arcing distance (mm)**	**Leakage distance (mm)**	**Major/Minor Shed diameter (mm)**
HTV Silicone rubber reinforced with nano particles	195	500	130/105
Commercial HTV Silicone rubber	195	500	130/105

Table 3: Basic parameters of the tested insulators.

From the obtained results, the nano reinforced compound withstood the highest number of cycles on the tracking wheel and the commercial insulator endured 25% fewer cycles than the nano reinforced insulators.

2.4 Inclined Plane Test

To compare the relative performance of the silicone materials in the ASTM inclined plane test, and to ensure that the materials are representative of the tested insulators, composites of the required dimensions were cut from the sheds of the commercial and nano reinforced insulators and tested at 4-4.75 kV with a flow rate of 0.9 ml/min [4]. As the same mold for manufacturing commercial type and nano reinforced insulators was used, the shape and dimensions of the tested composites are the same. The results of these evaluations are shown in Table 4.

Commercial type composites failed the inclined plane test, however; nano reinforced composites passed the test as shown in Figures 7 and 8.

Figure 7: Semi circular sheds from nano reinforced type insulator.

Figure 8: Semi circular sheds from commercial type insulator.

Material	**Number of failed samples**	**Average time to failure (min)**
HTV Silicone rubber reinforced with nano particles	0	No failure
Commercial HTV silicone rubber	4	52

Table 4: Summary of inclined plane test on insulator sheds.

Finally, 315 prototype insulators reinforced with nano particles and 300 commercial insulators were installed in distribution power lines in two different industrial-sea polluted areas as shown in Figures 9 and 10.

Figure 9: Commercial and nano reinforced insulators in the CRISA circuit of the Nogalar substation.

Figure 10: Commercial and nano reinforced insulators in the LCD 4055 Lázaro Cárdenas circuit.

After 26 months of succesful operation in 13 kV circuits with industrial-sea pollution, the nano reinforced insulators are in good condition.

3 CONCLUSION

In the study, distribution type insulators manufactured using a nano reinforced silicone rubber compound and a commercial formulation were evaluated on tracking wheel and inclined plane tests. In terms of both tests, the insulators manufactured with the nano reinforced silicone rubber exhibited the best performance when compared to identically commercial insulators from conventional silicone rubber compound.

Because of the obtained results a patent has been filed for the developed insulating micro nano composite. This composite, with greater resistance to erosion and tracking, is applicable in highly contaminated environments, and can be able to reduce preventive maintenance of the insulation to avoid pollution outages.

Also the developed formulation can be used as insulating cover for various electrical equipments.

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