INFLUENCE OF NANOSILICA ON THE PERFORMANCE OF HTV SILICONE RUBBER FOR OUTDOOR INSULATION

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Abstract: The present work investigates the effects of the substitution of standard grade alumina tri-hydrate (ATH) for nanoscale silica as well as the addition of the latter to ATH filled HTV silicone rubber. The resulting material properties are evaluated with respect to the resistance to high voltage arcing, resistance to tracking and erosion and the degree and retention of hydrophobicity. Ten compositions were studied, consisting of one hydrophilic and one hydrophobic nanosilica in different amounts (0, 1 and 3%wt) added both to pure HTV silicone rubber and a standard grade ATH filled base material. The addition of the nanofillers improved the resistance of materials in the high voltage arc discharge test, and higher filler loadings imparted better performance. Surface treatment of silica didn't seem to affect the performance of materials in this test. Tracking and erosion resistance of hydrophobic silica was 18% higher to that of the hydrophilic one; 1%wt filler level imparted better resistance than 3%wt. Compositions containing ATH and hydrophilic silica enhanced the retention of hydrophobicity by 35% (1%wt) and 200% (3%wt). The receding contact angle showed a higher correlation factor to DDT results than the static and advancing contact angles.

1 INTRODUCTION

Electrical insulators perform an essential role in energy systems, providing both electrical insulation and mechanical support; thus, directly influencing the efficiency and reliability of these systems. Historically, electrical insulators have been traditionally composed of glass or porcelain; nevertheless, in the last few decades, polymeric insulators are being increasingly adopted.

The main advantages of polymeric insulators over their predecessors are the lower susceptibility to contamination and vandalism, as well as light weight, easy handling and reduced installation and maintenance costs [1-3]. On the other hand, limitations include high material cost and relatively low mechanical strength and erosion performance [4-6]. Moreover, the ability of polymeric insulators to resist physical and chemical degradation due to voltage stress, heat, rain, salt fog, pollution and ultraviolet radiation is still the focus of a great deal of research [3].

Adequate material development and compound formulations can provide higher general performance to polymeric insulators [7]. Fillers and additives are blended with the basic polymer not only to enhance performance, but also to reduce costs and facilitate processing [6, 8]. As such, alumina tri-hydrate (ATH) is a flame retardant extensively used to impart tracking and erosion resistance to silicone rubber.

Standard grade fillers and additives usually need to be added in high amounts to improve a desired property (up to 80% by weight of the formulation, according to [4]). This might, on the other hand, affect other properties negatively (e.g., ATH is knowingly detrimental to mechanical properties).

The application of nanoscale fillers has been widely researched in the last couple of decades [9-13]. These fillers present themselves as a viable alternative to the standard ones, reaching the desired improvements in polymer performance with comparatively low amounts (less than 10%wt) and generally avoiding the usual drawbacks of microfillers [9-11, 14].

In this context, the present work proposes to investigate the effects of the substitution of standard grade fillers for nanoscale silica, as well as the addition of the latter to ATH filled HTV silicone rubber. Materials are to be characterized through a wide range of electrical and physical tests, such as resistance to high voltage arcing, tracking and erosion, dynamic drop test and measurement of the static, advancing and receding contact angles.

2 EXPERIMENTAL

2.1 Material

Ten different HTV silicone rubber compositions were studied, containing one of two nanoscale silicon dioxide sorts, described in Table 1. These fillers were used in amounts of 0, 1%wt and 3%wt and were mixed to two HTV compounds: one pure and another containing standard grade ATH at 110 pph.

Table 1: Description of the nanoscale fillers used.

Filler	Description
S1	Hydrophilic fumed silica with specific surface area (BET) of 380 m^2/g
S2	Hydrophobic fumed silica, octylsilane treated, with specific surface area (BET) of 150 m^2/g

2.2 Methods

Resistance to high voltage arcing was determined according to IEC 61621 [15]. In this test arcs are ignited on the surface of a sample, which is said to fail if and when the surface becomes conductive or the sample caches fire. Samples were rinsed using isopropanol followed by distilled water, and conditioned for at least 24 h before the test in a controlled environment with temperature of (23 ± 2)°C and humidity of (50 ± 5)%. Twenty samples of each composition were tested, measuring 15 mm x 30 mm x 6 mm.

Resistance to tracking and erosion was tested following IEC 60587 procedure [16] at constant tracking voltage of 2,5 kV, 3,5 kV and 4,5 kV, and in each test the eroded mass was determined. Five samples of each material were tested, measuring 120 mm x 50 mm x 6 mm. Before testing they were cleaned with isopropanol followed by distilled water.

The retention of hydrophobicity was evaluated by the dynamic drop test (DDT). This test is not yet standardized, but experience shows that the DDT is one of the most promising test methods to achieve reproducible results for testing the retention of hydrophobicity [17].

The test setup consists of flat material samples tilted by 60° to the horizontal plane with two electrodes separated by 50 mm. A fluid with conductivity of 1,5 mS/cm drips over the sample at the rate of 12 drops/minute until the maximum current of 2 mA rms is reached. The test was executed following the procedure suggested in [17], with 8 samples of each material at a.c. voltage levels of 4 kV and 5 kV (rms).

Finally, measurements of wettability were performed according to IEC/TS 62073 [18] for determination of the static, advancing and receding contact angles with a Dataphysics OCA 20 instrument. Eight samples of each material were tested. The dynamic contact angle measurements were not performed on an inclined plane, but on a horizontal plane, by adding and withdrawing water from a droplet [18].

3 RESULTS AND DISCUSSION

Data contained in each graphic represent the mean value of all measurements and their respective 95% confidence interval (CI).

3.1 High voltage arcing

Test duration for each one of the ten compositions is divided in two classes: compositions without standard grade ATH (Figure 1) and compositions containing the mentioned filler (Figure 2).

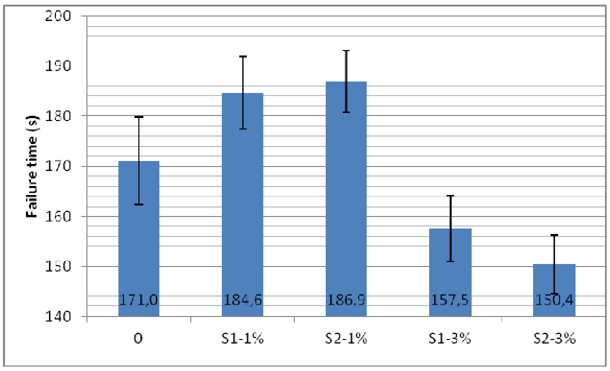

Figure 1: Failure time in the high voltage arcing test of compositions without standard grade ATH (mean values and 95% CI of n = 20 samples).

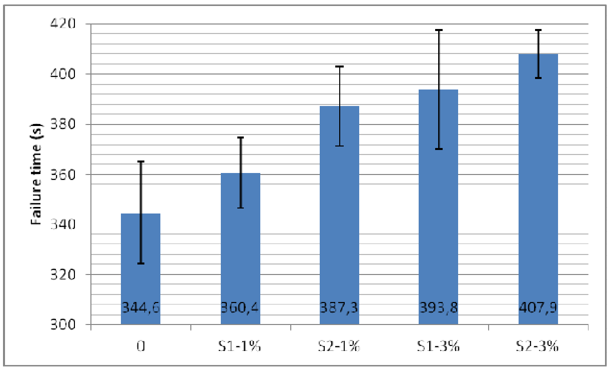

Figure 2: Failure times the high voltage arcing test of compositions containing standard grade ATH (mean values and 95% CI of n = 20 samples).

The first noticeable conclusion from the data is that compositions without standard grade ATH have an average failing time 55% shorter than the filled ones, performing considerably poorer. Comparison of the nanofillers shows that filler S2 has a failing time on average 4% longer than S1, an insignificant value considering the confidence interval. The addition of 1%wt nanosilica improved arcing time in 9% equally for compositions with and without ATH; 3%wt nanosilica improved arcing time in 16% for compositions containing ATH. On the other hand, the same amount of filler made arcing time 10% shorter for compositions without ATH.

3.2 Tracking and erosion

According to the standard [16], the five materials without ATH were classified *1B 2,5*, meaning in each case the 5 samples survived 6 h at 2,5 kV but at least one specimen fails at 3,5 kV. Eroded mass mean values for the 2,5 kV tests are presented in Figure 3. Materials containing standard grade ATH on the other hand were classified *1B 3,5* and eroded mass values are likewise presented in Table 4.

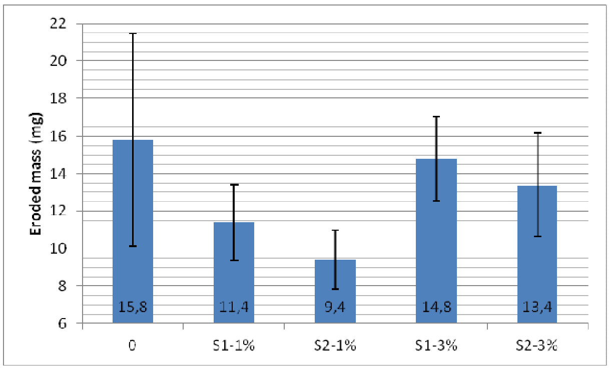

Figure 3: Eroded mass in the tracking and erosion test at 2,5 kV for compositions without standard grade ATH (mean values and 95% CI of n = 5 samples).

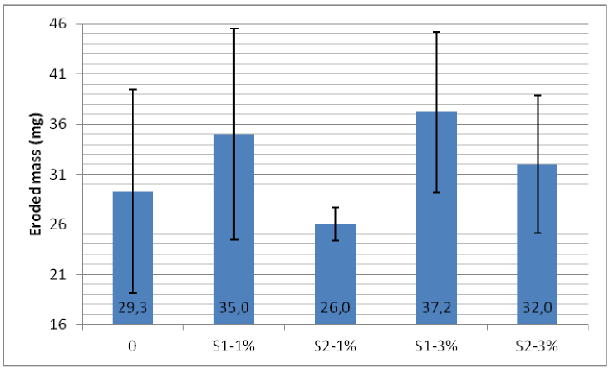

Figure 4: Eroded mass in the tracking and erosion test at 3,5 kV for compositions containing standard grade ATH (mean values and 95% CI of n = 5 samples).

Comparison of different fillers S1 and S2 with reference material '0' without standard grade ATH shows that the addition of hydrophobic silica S2 leads to an average erosion mass 28% lower, while for hydrophilic silica S1 it is only 17% lower. Figure 3 also shows an average reduction of eroded mass by 34% for compositions containing 1%wt filler when compared to '0', although that reduction was smaller for 3%wt (11%). In the case of samples containing standard grade ATH an improvement in T&E resistance could only be observed in composition S2-1%. When compared to the reference material '0', materials S1-1%, S1-3% and S2-3%, displayed erosion masses which were higher by 20%, 27% and 9%, respectively.

3.3 Retention of hydrophobicity

Initial trials were performed for all compositions at the same voltage level (4 kV), in which all samples without ATH withstood the stress for 24 h, hinting the necessity of an increase in the test voltage. On the other hand, in the second round of tests at 5 kV compositions containing standard grade ATH failed in the first minutes of test, making it impossible to accurately compare each composition. Therefore, two different voltage levels were adopted: samples without standard grade ATH were tested at 5 kV, while samples containing said filler were tested at 4 kV.

The previous observation in itself show that compositions without standard grade ATH have a higher retention of hydrophobicity than those with ATH, but because of the different voltage levels adopted, the amount can obviously not be quantified. Moreover, that is not the focus of this work, since the influence of standard grade ATH was previously documented by [19-20]. Results of the dynamic drop test (DDT) are shown in Figure 5 and Figure 6.

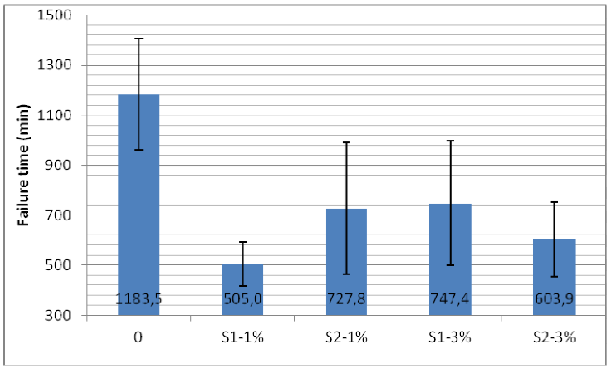

Figure 5: Failure time in the DDT at 5 kV for compositions without standard grade ATH (mean values and 95% CI of n = 8 samples).

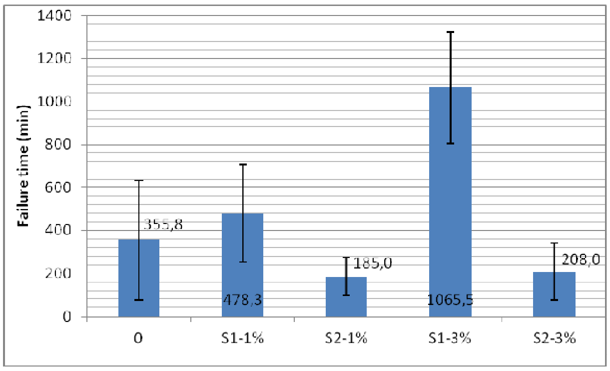

Figure 6: Failure time in the DDT at 4 kV for compositions containing standard grade ATH (mean values and 95% CI of n = 8 samples).

Literature shows that although the addition of fillers imparts better tracking and erosion resistance, it usually happens at the expense of hydrophobicity [20-23]. Figure 5 shows a decrease in DDT duration of 57% for filler S1 at 1%wt and a smaller reduction (37%) at 3%wt. Filler S2 on the other hand reduced DDT duration by 39% at 1%wt but a higher filler loading level reduced it even further (49%). Regarding the ATH filled samples, S2 decreased DDT duration by 48% and 42% for 1%wt and 3%wt, respectively while filler S1 actually improved DDT duration by 35% (S1-1%) and 200% (S1-3%).

3.4 Contact angle measurements

The receding, advancing and static contact angles are shown in Figure 7, Figure 8 and Figure 9, respectively. Correlation analyses were performed between each of these results and the failure time in DDT; the Pearson coefficient between each set of contact angles and the equivalent DDT result is presented in Table 2. This standardized coefficient varies between –1 and +1 if the variables are inversely or directly proportional, respectively, getting close to zero if variables are unrelated.

According to Table 2 the receding contact angle values hold a higher correlation to DDT results than the static and the advancing contact angles. Comparison of data in Figure 7 with Figure 6 also confirms the better performance of composition S1-3% against composition ‘0’. The contact angle of composition S1-1%, on the other hand, is still smaller than that of composition ‘0’.

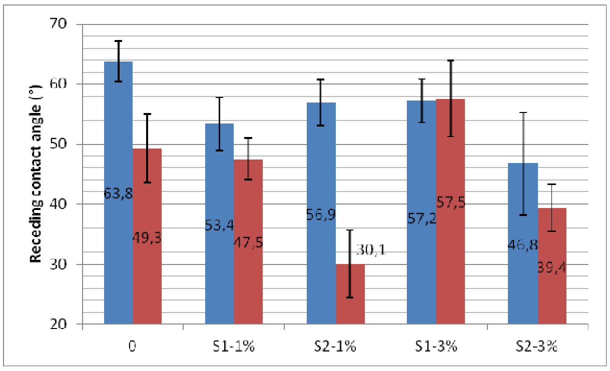

Figure 7: Receding contact angles of compositions without ATH (left) and compositions containing ATH (right); (mean values and 95% CI of n = 8 samples).

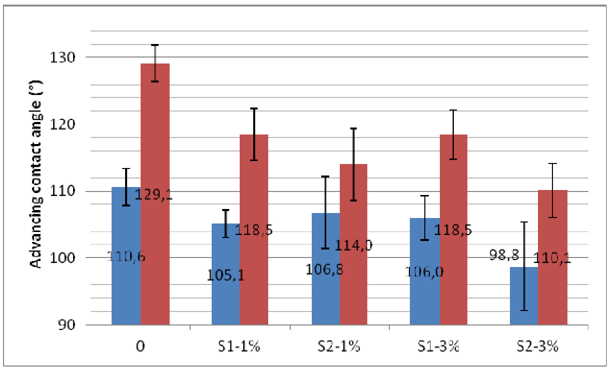

Figure 8: Advancing contact angles of compositions without ATH (left) and compositions containing ATH (right); (mean values and 95% CI of n = 8 samples).

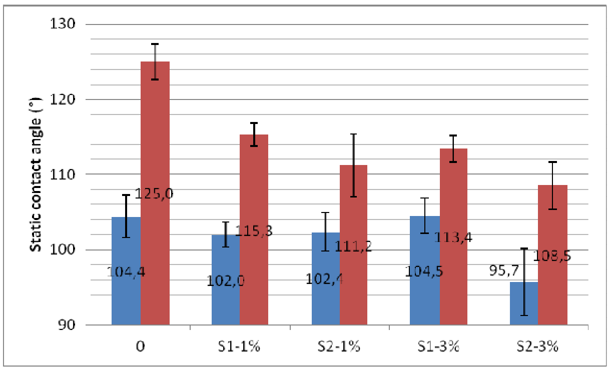

Figure 9: Static contact angles of compositions without ATH (left) and compositions containing ATH (right); (mean values and 95% CI of n = 8 samples).

Table 2: Correlation factors between contact angle (CA) measurements and DDT failure time.

Formulation / Correlation factor	Receding CA	Advancing CA	Static CA
Without standard grade ATH	0,830	0,734	0,522
With standard grade ATH	0,846	0,220	0,075

4 CONCLUSION

In this paper the influence of two nanoscale silica fillers in HTV silicone rubber was investigated. The addition of the nanofillers generally improved the resistance of materials in the high voltage arc discharge test, and higher filler loadings imparted better performance. Surface treatment of silica didn’t seem to affect the performance of materials in this specific test.

Tracking and erosion resistance of compositions filled with hydrophobic silica was in average 18% higher than that of hydrophilic silica filled ones. The lower filler level (1%wt) imparted better resistance than the higher level of 3%wt.

Retention of hydrophobicity was evaluated by the dynamic drop test (DDT). Hydrophilic silica filled compositions performance was particularly remarkable: in compositions containing standard grade ATH, DDT duration was actually improved by 35% (S1-1%) and 200% (S1-3%). In compositions without ATH, nevertheless, the same result was not observed and DDT duration was reduced, even though the reduction was less pronounced for the higher filler level.

Static, advancing and receding contact angle measurements were performed, and correlation tests showed that the receding contact angle is the one that has a higher degree of correlation to the retention of hydrophobicity evaluated by the dynamic drop test. Receding contact angle data also ratified the better performance of composition with hydrophobic nanosilica.

5 ACKNOWLEDGMENTS

The present work was accomplished with support from CNPq, an entity from the Brazilian government dedicated to scientific and technological development.

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