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Behavioral Studies of Insulators with Silicones Housing with Different Loads Quantities under Wheel Electric Tracking Test

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Abstract — **The development of the electric networks of high and medium voltage requires the changes in many constituent factors of the lines, for example, the change of insulating materials like ceramic to polymers in insulators and surge arresters. Currently, it is known that silicone compounds are more suited to work under high pollution environmental conditions. The better performance of the silicone in contaminated environments is mainly due to its chemical structure and chemical nature, ensuring a high hydrophobicity, a photodegradación resistance and electrical and chemical degradation resistance to its compounds. The practice and use with silicone compounds insulators in polluted atmospheres has shown that some insulators are inferior in performance when compared to others, presenting many times a performance much below the expectations. One of the most common misunderstandings in the design of a silicone compound for insulators is the amount of inorganic load used in their formulation. This paper attempts to clarify through the wheel electric traking test how the change in the amount of inorganic load is capable of changing the properties of resistance to electrical and chemical degradation of silicone compounds, decreasing the life expectancy of a polymer insulator and their performance in areas of high contamination.**

Key Words — **Polymeric Insulators, Silicon Rubber, Aging, Wheel Electric Tracking Test.**

I. INTRODUCTION

Many investigative techniques are used to evaluate the performance of electrical insulators [1]. International standards such as IEC 61109 [2] are available to ensure trials that determine the minimum requirements for acceptance and performance of an insulator. However, even taking all care, the selection of insulators for airlines under contaminated and coastal environments is a complex task and difficult to perform due to the divergence of information and lack of technical work that lead engineers to secure decisions.

The most classic test for assessing the performance of insulators on severe environmental conditions and polluted areas is very expensive and long, i.e. it takes 5000 hours [2]. But a new test, IEC 62217 [3], was accepted in 2004 to replace this one, which was an essay apparently cheaper and more brief that the test of 5000 hours. Despite of its emphasis on electrochemical properties of the material, the rolls of electrical routing essay did not care about the effect of UV radiation.

Essays seeking to assess the strength and performance of the insulators on pollution, especially polymeric insulators, usually evaluated two main characteristics, the project team and the polymeric material involved.

Being a relatively new test, the rolls of electrical routing is not totally understood, and his trial results deserve attention and careful evaluation. However, this test allows to compare the performance of different insulators keeping the same material or to evaluate different polymeric compounds keeping the same project.

This paper proposes the investigation of various silicone compounds with different concentrations of inorganic loads through a simple methodology of aging in rolls of electrical routing. The electrochemical, mechanical and morphological properties were used as a guide to indicate the best materials to be used to get insulators with good performance of the teams in the wheel.

II. Materials and Methods

Materials

• Compounds:

1. (S1) - silicone rubber compound with HTV fumed silica and alumina trihydrate zero parts (ATH);
2. (S2) - S1 + 25 parties fumed silica and alumina trihydrate (ATH);
3. (S3) - S1 + 50 parties fumed silica and alumina trihydrate (ATH);
4. (S4) - S1 + 75 parties fumed silica and alumina trihydrate (ATH);
5. (S5) - S1 + 100 parties fumed silica and alumina trihydrate (ATH).

All compounds were produced by "Bluestar Silicones".

Methods

• Wheel of electric tracking

The IEC 62217 standard, which cites two or four insulators of same compound with crepage distance between 500 mm and 800 mm, were tested simultaneously in the stem routing. Before starting the test, insulators were cleaned with deionized water. Then, the samples were arranged in four positions in each cycle (Figure 1). Each sample will be stopped at each one of four positions for about 40 s. The rotation of 90 ˚ a position till the next takes about 8 s.

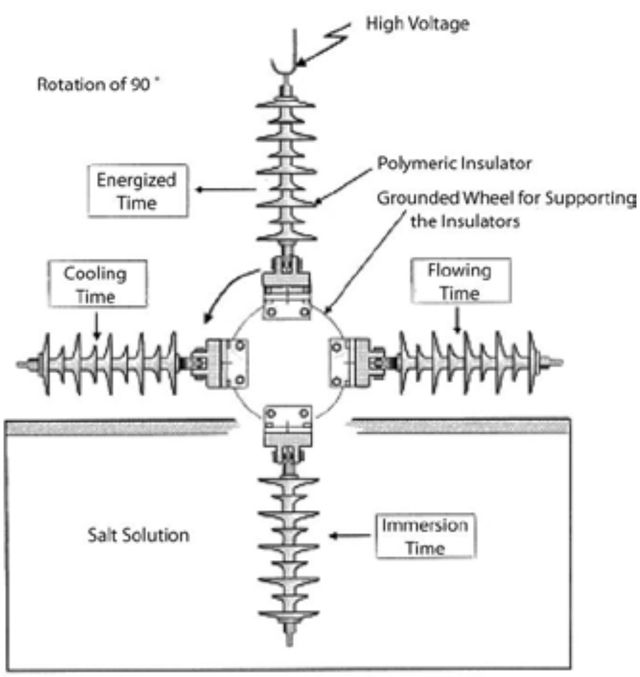

Figure 1. Schematic illustration of the electric tracking wheel.

In the first part of the cycle, samples must be immersed in a saline solution. The next cycle allow the samples to receive an excess of saline flow ensuring that slight moisture on the surface causes discharges across the dry bands that will be formed during the third cycle.

The third part of the cycle the sample is energized with voltage of industrial frequency.

The last part of the cycle allows cooling the surface that was heated by discharges into the track drought before the starting of the next cycle.

The saline solution must be replaced weekly during the weekly interruptions of the tests for inspection, not exceeding 1 hour. Periods of interruption will not be computed on the duration of the trial. One more grade interruption, lasting until 60 min, is permitted. In this case, it must be added in the duration of the trial, in a value of three times the length of the interruption.

The voltage of this trial, often in an industrial scale (kV), must be calculated by dividing the leakage distance measure in the insulator by 28.6 mm. The amounts of NaCl in deionized water were 2.80 kg/m³ ± 0.06 kg/m³. The chamber temperature was 20 ± 5 ˚C and the duration of the trial was 15000 cycles (800 h) as maximum.

The IEC 62217 [3] determines that the amount of NaCl in the solution must be of 1.4 kg/m³ and duration of the trial should be 30000 cycles. But the time for completion of this work is not allowed to time with the term suggested by the rule, it was divided by the amount of cycles in the middle and the amount of salt was doubled. There is no proven correlation between the techniques of standard and this work, since the goal was to compare the performance of the insulators composed solely for this study.

The bearings used in routing were manufactured by Balestro Electromechanical Industry.

• Density

The test to determine the density was done in triples. The mass and volume of three pycnometers were measured in an analytical balance, using thermometer and deionized water.

It was introduced in each pycnometer approximately 20 g of well minced silicone rubber and the pycnometer volume was filled with a liquid of well-defined density.

They removed the micro air bubbles in the material with the aid of a vacuum pump and a dessecador for few hours.

The pycnometer volume was again adjusted with the same liquid and the temperature of the system was fixed at 25 °C.

With an analytical balance it was measured the total mass of the pycnometer filled with rubber and fluid. Calculating the difference in the masses of pycnometer with rubber and vacuum, and the mass of rubber and fluid, the bulk density of the liquid was determined precisely the rubber density.

• Hardness

The hardness measures were undertaken with a durometer type Shore A, model Kori KR 14A in triplicate. The specimens were 6mm thick and vulcanized at 180 ºC for 10 min.

• Maximum elongation and tensile strength

This trial was conducted under the determinations of the ASTM D 412 standard [4]. The plates produced for trial removed the specimens were 2 mm thick and was vulcanized at 180 ºC for a period of 10 min.

Seven specimens were obtained using "Die C" form according to the standard [4]; after that, they were tested in a universal testing machine Kratos, model K2001. The load cell used in the test was 200 kgf and the speed was 500 mm /min.

To register very low elongation values, it was used a strength gage from Kratos, docked in the equipment.

• Tear

This trial was conducted under the determinations of the ASTM D 624 standard [5]. The plates produced for trial removed the bodies were 2 mm thick and was vulcanized at 180 ºC for a period of 10 min.

Seven specimens were obtained using "Die C" form according to the standard [5] and were likely tested on a machine testing mechanical Kratos model K200, using the same conditions used before.

• Electrical tracking and erosion

The equipment used for this test was manufactured in Balestro. The specimens were 6mm thick and were vulcanized at 180 ºC for a period of 10 min.

The specimens was sanded and tested according to NBR 10296 standard [6], methodology 2 and evaluation criterion A (steps test).

The pollutant solution, with a resistivity of 4.05 Ω.m, was prepared at a concentration of 0.1% of ammonium chloride (NH_4Cl) and 0.02% of wetting agent isooctil phenoxypolietoxietanol. The flow of this pollutant solution changed according to the imposition of the rule.

The test started with a tension of 1 kV and was increased 0.25 kV each hour [6]. The weights of the specimens were measured before and after tests.

• Infrared (FTIR)

The spectra were carried out in an infrared spectrophotometer Nicolet, model Magna-560, scanning range of 400 to 4000 cm^{-1} (infrared middle) and resolution of 4 cm^{-1}. The measures were conducted by diffuse reflectance (DRIFT) on the surface of the polymer. The best definition was obtained with 128 scans.

• Scanning electronic microscopy (SEM)

The morphology of the new and the aged rubber insulators was tested using a Leica scanning electronic microscope (SEM), model is LEO 440i. The top surface and the surface of cryogenic fracture of the insulators (fracture caused by immersion in liquid nitrogen) were observed. It was also used the accessory to analyze the presence of elements in the insulators´ samples by EDX (energy dispersive spectroscopy X-ray).

III. Results and Discussion

• Wheel of electric tracking

One way to assess electric tracking in an insulator is to submit it to a number of cycles to failure (Table I). It is assumed in this test that the device wills not failure until the end of 15000 cycles. However, the methodology of the IEC 62217 standard [3] do not apply to this work since it was created to essay commercial materials. Obviously aimed to decouple the results and failures that demonstrate a greater or lesser performance of the material.

TABLE I
ELECTRIC TRACKING WHEEL TEST OF COMPOUNDS – NUMBER OF FAILURES.

S1 (Cycles)	**S2 (Cycles)**	**S3 (Cycles)**	**S4 (Cycles)**	**S5 (Cycles)**
898	4.639	3.058	—	—
2.171	5.351	5.532	—	—
4.327	7.250	6.756	—	—
5.600	9.658	9.230	—	—
6.498	10.370	12.288	—	—
6.498	15.009	12.288	—	—

By the results in Table 1 it is possible to see that the only formulation which supported 15000 cycles test was the S2 containing 25 ppb of ATH in its composition. The second better result came from formulation S3 which reached 12300 cycles. The results of this test are incomplete because until now it was not possible to test all compounds due to the long duration of these trials. In other words, the formulations S4 and S5 are being carried out.

• Density

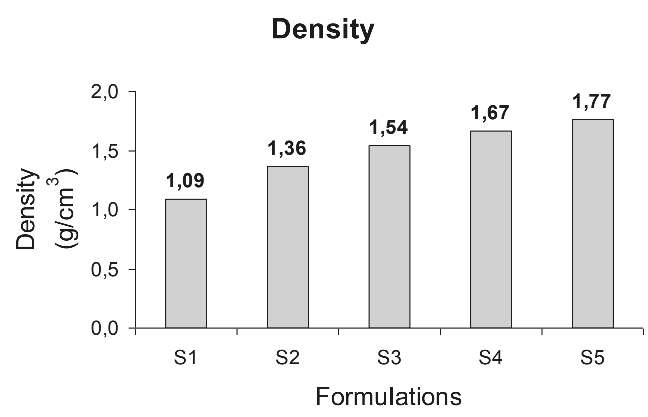

Figure 2. Density values of silicone compounds insulators in this study.

In Figure 2 is observed that the bulk density actual samples of silicone or increases with increasing the amount of charges in the compound.

This behavior is expected since the ATH density is much larger than the Polydimethylsiloxane (PDMS) which is the main constituent the silicone rubber. Thus, it is natural that increasing the amount of denser material in the compound, the bulk density of the resulting material will be larger too.

• Hardness

Figure 3 show the results of Shore A hardness test for silicone compounds with different ATH quantities.

These results indicate that the more load on the compound greater the hardness of the material. This behavior is expected for polymer composites.

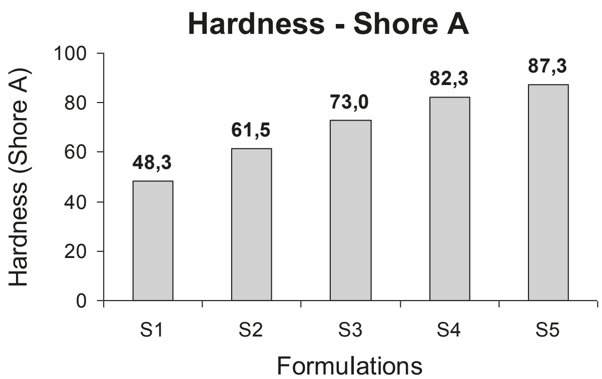

Figure 3. Values Shore A hardness of rubber with different concentrations of ATH.

• Maximum elongation

The elongation of silicone compounds with different loads is shown in Figure 4. It is observed that the elongation varies inversely to the amount of filler in the composite. It was expected, the interaction of filler with the rubber produces a largest hardness, on the other hand the same interaction difficult the molecule rubber elongation.

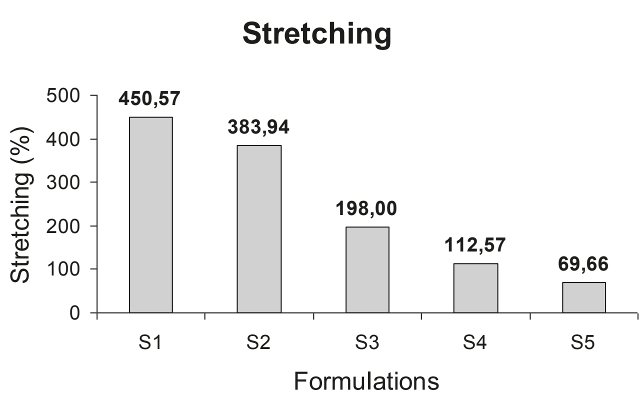

Figure 4. Maximum elongation of rubbers with different ATH concentrations.

• Tensile strength

Another important mechanical property of polymer composites is their tensile strength that is observed in Figure 5. It is visible that this property does not have a linear behavior with the filler concentrations.

With small additions of fillers, the composite exhibited greater tension values, which decreased when more filler were added, to a value smaller than that for the compound without ATH filler.

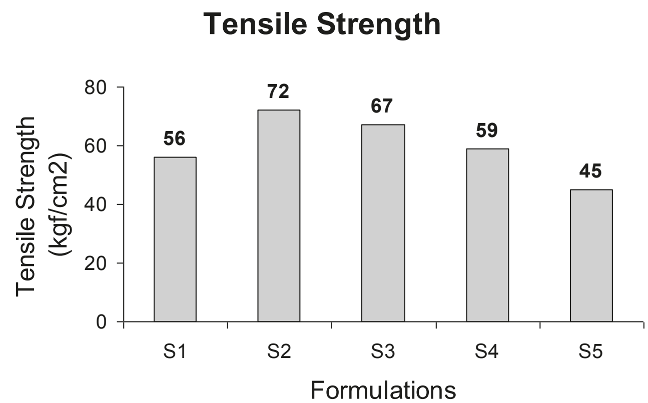

Figure 5. Tensile strength variation with ATH filler concentration for composites rubber based.

• Tear

The tear resistance is one of the most important properties of the composites to be used as insulator. This property impacts especially in the processability of insulators. In Figure 6 is shown the behavior of tear depending with the addition of ATH in compounds. In the same for maximum elongation behavior seen in Figure 4, the resistance of tear decreases with increasing ATH in the formulation.

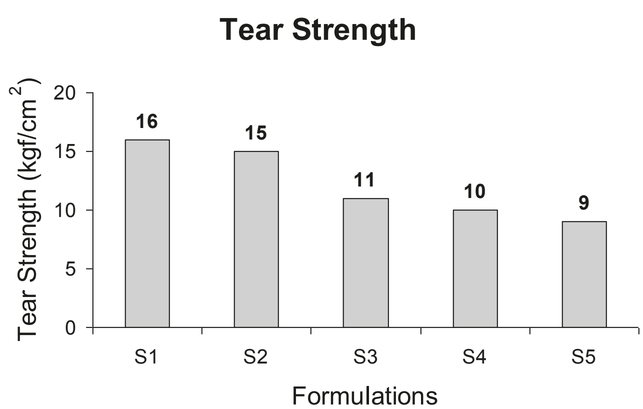

Figure 6. Resistance to tear of rubbers with different ATH concentrations.

• Electrical tracking and erosion.

The trials of electrical routing and short period of erosion in inclined plane provided many details regarding the formulations studied in this work.

The voltage for each compound *versus* its electrical routing resistance can be observed in Figure 7. These results show that the greater the amount of ATH in the compound, the greater the resistance to the electrical tracking. Gonzales et al. [7] had already observed this behavior in a similar test by varying the concentrations of ATH fillers and silica in silicone. The difference between this work was the standard methodology used, i.e. the NBR 10296 [6], whereas Gonzales et al. used ASTM 2303[9]; however, they are much similar.

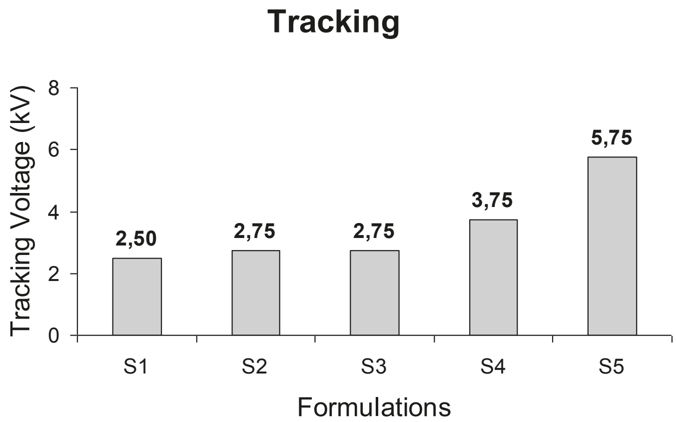

Figure 7. Values of electrical tracking voltage and erosion according to NBR 10296 standard.

The maximum and minimum values, seen in Figure 8, for each compound studied, show that the largest variation in the results is observed for formulation S3, while the more homogeneous results was that of the S5 formulation.

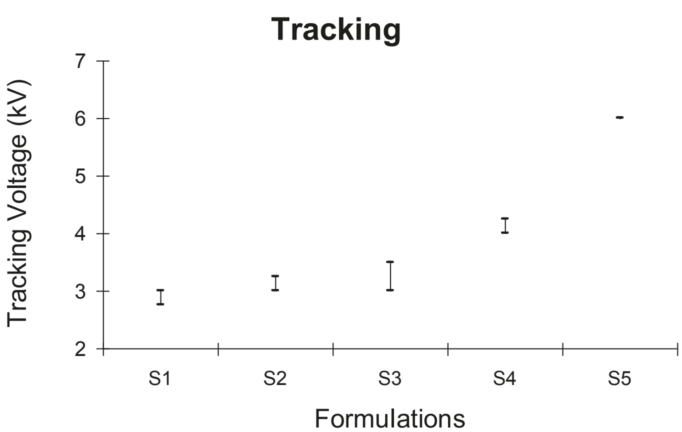

Figure 8. Minimum and maximum electrical tracking voltage.

Figure 9 illustrates the value of the average masse lost at the maximum and minimum erosion, for each compound.

It's easy to see that generally the average mass lost is almost close to the average value between the extremes of maximum and minimum, except for the compound S5.

The compound S5 presented a deviation of the measure for the minimum mass loss, what demonstrates that the mass loss was not homogeneous for the five specimens tested. In fact, one specimen of S5 series presented more severe erosion, the reason to the deviation observed.

According to Figure 10, the loss of volume by material erosion was similar to the mass loss (Figure 9).

This behavior was expected and can be explained by the same argument used to explain the mass loss. These last two results show that only the voltage discharge (when it occurs routing) is not a parameter for estimating the final best-performing of the material.

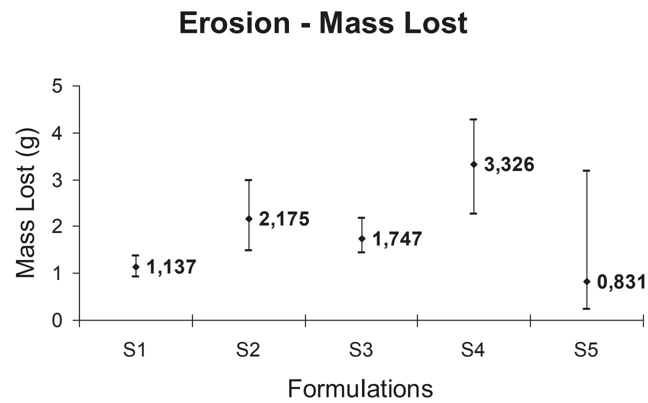

Figure 9. Mass lost by erosion in the test of electrical tracking.

The volume or mass erosion may be much more critical parameter in this trial and, for silicone compounds this may be more important.

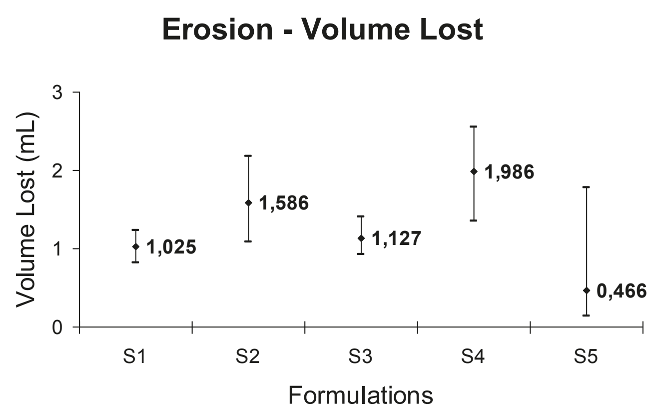

Figure 10. Volume lost by erosion in the test of electrical tracking.

• Infrared (FTIR)

The infrared results are shown in Figure 11, in all spectra are present typical bands of this material.

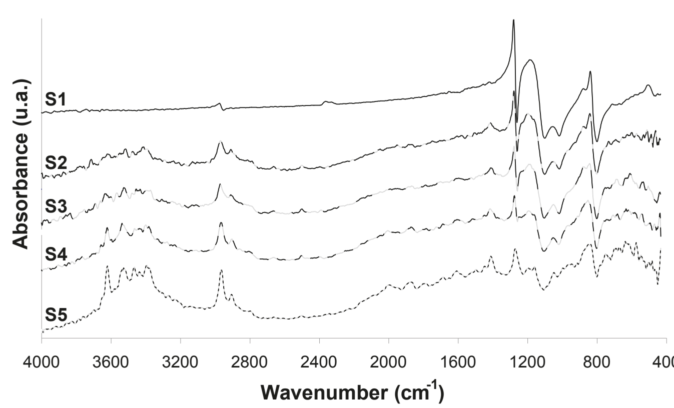

Figure 11. Infrared spectra of rubbers with different ATH concentrations.

Inone et al [9] allocated bands composed of silicone observed in commercial insulators. The absorption bands in 2960 and 1270 cm^{-1}, resulting from C-H and Si-CH_3 stretching, respectively, which are associated with CH_3 side groups, while the absorption band in 1020 cm^{-1} is attributed to the Si-O-Si group of the polymer main chain.

The absorption bands between 3700 and 3200 cm^{-1}, resulting from OH groups, belong to the alumina trihydrate filler (ATH).

It is observed in this work that the absorption bands between 3700 and 3200 cm^{-1} are more intense when the compound has more ATH filler in its formulation and also the absorption bands at 1270 cm^{-1} and 1002 cm^{-1} are more intense in the compound with less ATH filler.

These findings are important because demonstrate a semi-quantitative nature of the infrared technique.

• Scanning electronic microscopy (SEM)

The micrographs of the insulators´ surface before the aging at the wheel of routing are seen in Figure 12. It is observed in these micrographs that the distribution of inorganic fillers (white points) is more abundant in compounds formulated with higher concentrations of ATH, as expected.

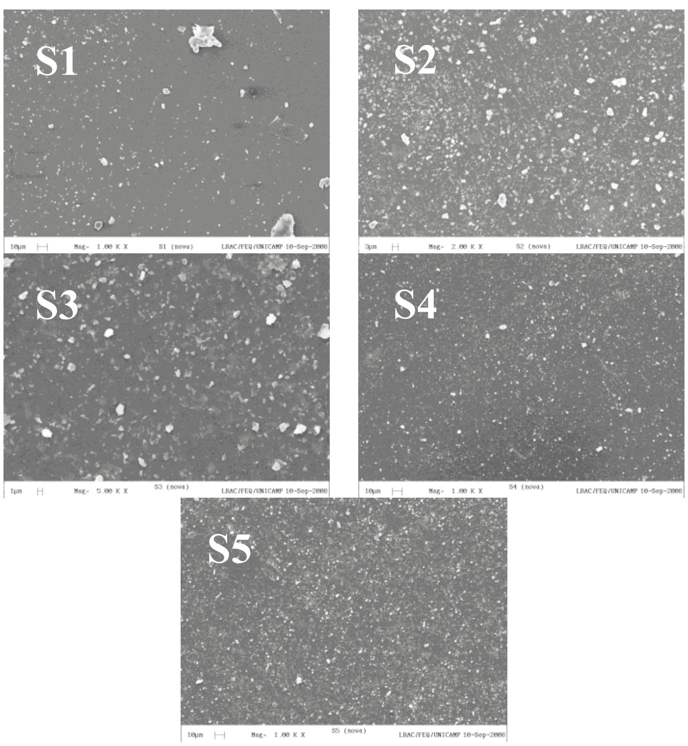

Figure 12. SEM micrographs of the compounds´ surface, (extension 1000 X).

Figure 13 show the micrographs of the surfaces resulting from the cryogenic fracture of the insulators before aging at the wheel of routing.

It was observed the same behavior as that of the normal surface, but in these micrographs the fillers dispersion is more defined.

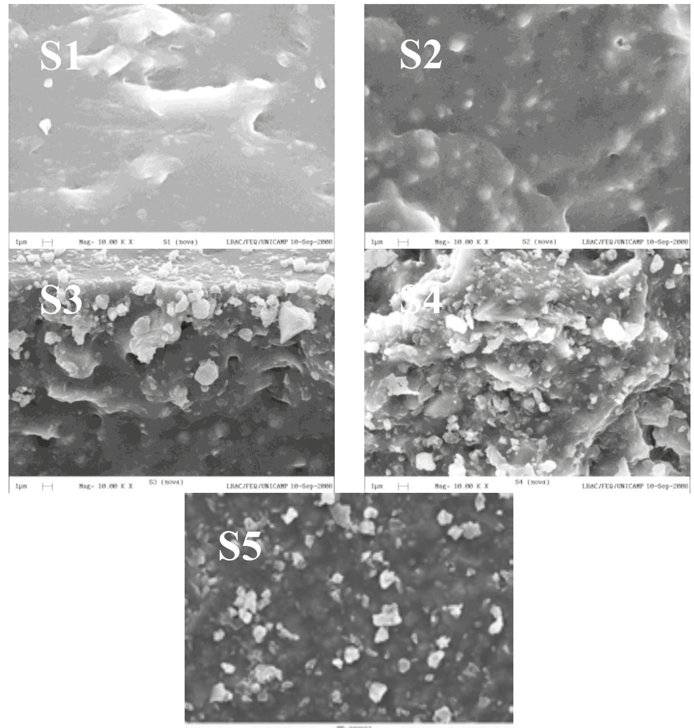

Figure 13. SEM micrographs of the cryogenic fracture of the compounds´ surface (extension 10000 X).

The micrographs´ surface of the compounds S1, S2 and S3 after aging by tracking wheel are observed in Figure 14.

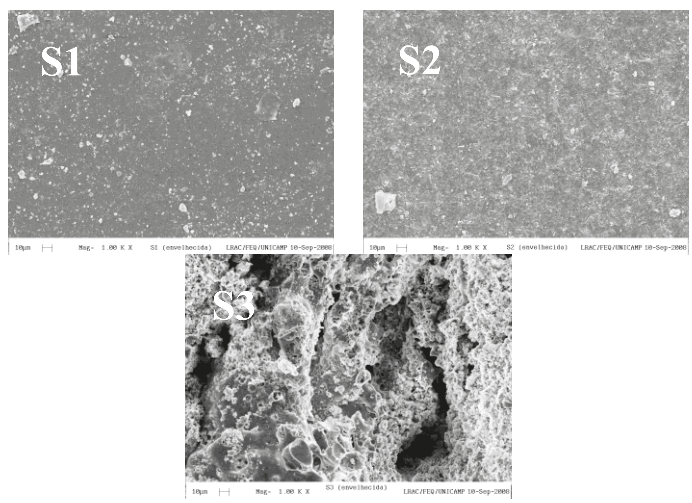

Figure 14. SEM micrographs of the surface of aging compounds in tracking wheel, (extension 1000 X).

Apparently there is not much difference between the new and aged materials´ micrographs of the surfaces, except for micrographs of the S3 compound. This is because the aged S3 compound was degraded by the action of electric shocks generated by the partial formation of dry bands during the testing of the wheel. This information permit to say that there is no degradation in regions that do not occurred electric discharges and that are not perceived changes in the morphological structure of the compound.

In the micrographs observed in Figure 15 it is observed the surfaces of the cryogenic fracture of the insulators aged by the tracking wheel and demonstrate the same behavior as seen in Figure 14 for S3 compound. It was possible to detect a region where a deep degradation show the inorganic loads totally exposed, demonstrating the degradation of the polymer matrix in this region.

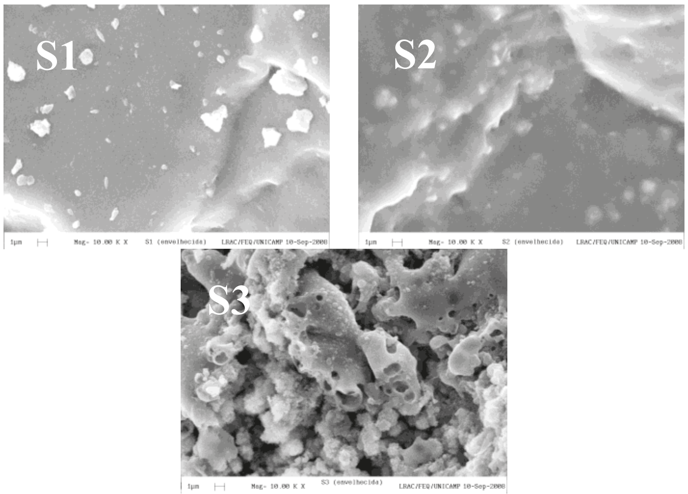

Figure 15. SEM micrographs of the cryogenic fracture of the aging compounds´ surface in tracking wheel, (extension 10000 X).

Figure 16 illustrate the EDX spectra of the non-aging compounds, which put in evidence the presence of Si atoms in the compounds, which are in great amount as expected.

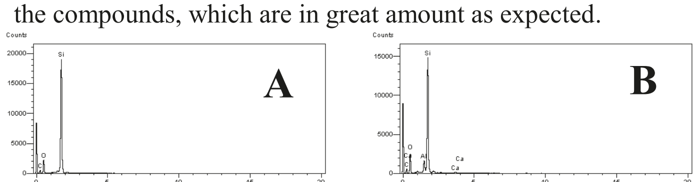

Figure 16. (A) EDX of S1 compound, (B) EDX of S2, S3, S4 and S5 compounds.

The EDX spectra of the aging compounds in Figure 17 put in evidence the atoms in the material after tracking test.

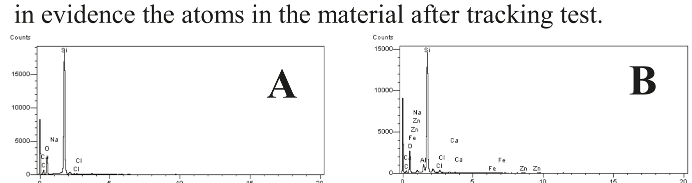

Figure 17. (A) EDX of S1 aging compound, (B) EDX of S2, S3, S4 and S5 aging compounds.

The spectra A of the figures 15 and 16 show atoms of Si, O, C in the compound S1before and Si, O, Ca, C, Na and Cl after the wheel. The main difference between these two spectra is the presence of sodium, calcium and chlorine atoms that are only observed after the ageing, and this is easily explained knowing that happens contamination by sodium chloride due to the trial itself from the wheel.

In the B spectra of the figures 15 and 16 are observed the atoms in the compositions S2, S3, S4 and S5. These spectra have differences more pronounced when compared with each other and between the spectra A.

When compared the spectra A and B of the new materials (Figure 16), they show the presence of aluminum and calcium (Al and Ca) in B compositions, there are not present in A spectra. This behavior was expected since the S1 composition had no ATH filler added what means that no aluminum atoms should be detected. Also, it was not observed atoms of calcium in the formulation S1. The atoms of calcium are common in formulations that have calcium carbonate between in the fillers with the main function of completion. As calcium was not observed in S1 composition, it was concluded that no calcium carbonate was present in S1.

By comparing the spectra B of the figures 15 and 16, after the ageing, it is evident the presence of sodium chloride as was expected, and others atoms as iron and zinc (Fe and Zn). The presence of these two other atoms can be explained by the deterioration of the terminal fittings insulators during the trial of ageing because the test exigency. Zinc came probably from the electroplating and iron from the steel.

IV. Conclusion

Through this paper concludes that:

- The analyses of density, hardness and mechanical tests were efficient to characterize the different compositions of silicone rubber and that we can supply details about the quality of the compounds;
- The density will be greater for inorganic compounds with more filler;
- The hardness will be higher as the amount of ATH in the compound increases;
- For higher quantities of fillers, the elongation will decrease;
- The resistance to tensile does not have a linear behavior with the filler concentration, as seen for intermediary quantities of fillers which showed the best results;
- Rip resistance is greater for compositions with less filler;
- The infrared demonstrated itself an efficient technique to determine silicone rubber as well as semi-quantitative technique for determination of the amount of ATH fillers;
- The test of electric tracking presented good performance to qualify formulations with better resistance to tracking and erosion; according to this test, the more fillers present in the rubbers, better will be their performance in general;
- The results of tracking wheel, despite partial results, show divergence of the results for electric tracking; i.e. it showed that the performance of insulators is not due to the rubber characteristic only, but also is due to the project;
- The SEM micrographs of the surface and the cryogenic fracture surface of the compounds were effective to observe the morphology and degradation regions of the compounds after aging;
- The EDX results showed that this analysis can determine qualitatively the presence of fillers and also the presence of

contaminants such as salt (sodium chloride) and metals waste from the degradation of the polymers supported by metal accessories during the test;

• This study suggests that the selection of polymeric materials depends on many factors, such as the environment in which this material will be subjected to mechanical, chemical, electrical properties and the project.

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