EVALUATION OF ELECTRICAL TRACKING OF POLYMERIC INSULATOR HOUSING

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Abstract: In this paper, an evaluation of the capacity of polymeric composite insulators, with silicone housing, to withstand electrical arc discharge activity that can cause a defect called electrical tracking is performed. This damage may exposure the insulator core to environmental and pollution conditions that can cause, depending on the crack depth, its breakage and can be considered as the most common cause of insulation failure. With this aim, silicone compounds with different formulations were evaluated to compare their resistance to electrical tracking. In addition, the measurement of volume resistivity and dielectric constant of each sample were performed to evaluate possible correlations.

1 INTRODUCTION

The development of new equipment and technologies is essential for improving the electrical system, increasing efficiency and reliability. In mid 1970, began studies with polymers involving a fiberglas core as an alternative to ceramic insulators. This new insulators which, among other advantages, are lighter, easier to install and more difficult to be damaged by vandalism, were named composite insulators. In addition, polymers facilitate a greater flexibility in insulator design, and also can provide improved electrical performance especially under heavy contaminated conditions. These advantages have been possible, principally because polymers can be formulated to make the insulators more resistant to damage from the numerous elements in nature, such as extreme temperatures, UV radiation from sun light, corona and electrical arc discharge activity.

The facility of producing polymer compounds for polymeric insulators housing makes it hard to know which polymer is best for determined application. So for each formulation is important know their resistance to damages from environmental agents and electrical aging stresses in service that may cause the deterioration of the insulator performance.

Electrical arc discharge activity caused by the flow of leakage current on the surface of polymeric composite insulators, under wet contaminated conditions, can cause a defect called electrical tracking. Arcs created from this discharge phenomenon burn the insulator housing and create carbonized tracks. This damage may exposure the insulator core to environmental and pollution conditions that can cause, depending on the crack depth, its breakage and can be considered as the most common cause of insulation failure. With this aim, silicone compounds with different formulations were evaluated to compare their resistance to electrical tracking. In addition, the measurement of volume resistivity and dielectric constant of each sample were performed to evaluate possible correlations.

Based on the test results, the ratio between the maximum leakage current and the voltage applied during the tracking test was obtained, allowing to evaluate the influence of the filler used in each formulation. It was also possible to assess trends to tracking withstand of each formulation as a function of both its resistivity and its dielectric constant. The information obtained allowed for a better assessment on the influence of the type and amount of filer used in the formulation of silicone compound for polymeric insulator housing, allowing the choice of insulator better suited to environmental applications where it will be installed, increasing the reliability of the selection process.

2 CHARACTERISTICS OF THE TESTED SAMPLES

The main material that makes up the samples under test is the vinyl methyl silicon. To this polymer were added the following fillers: fumed silica, ATH (alumina trihydrate) and quartz. The proportion of the filler in each test composition (TC) can be seen in Table 1. To perform the tests, 5 samples were prepared with each formulation and jointed to a TC group. Each sample were cast with 50 mm x 120 mm and a thickness of 6 mm.

3 TEST PROCEDURE

3.1 Measurement of volume resistivity

The measurements were performed following ABNT NBR 5403 standard [1] using a "Tettex" cell for solid (Figure 1) and a teraohmmeter (Figure 2). The volumetric resistivity was obtained by the following equation:

$$\rho_v = \frac{R_v \times A}{E}$$

where:

R_v volumetric resistance;

E sample thickness (measured with a micrometer as shown in Figure 3);

A area of the electrode of Tettex cell.

Table 1: Composition of the samples under test

Sample	Composition
TC 1	silicon without filler
TC 2	silicon with 10 phr of fumed silica
TC 3	silicon with 100 phr of ATH
TC 4	silicon with 50 phr of ATH and 50 phr of quartz
TC 5	silicon with 100 phr of quartz
TC 6	silicon with 70 phr of ATH and 30 phr of quartz

Note phr means parts per hundred of rubber (silicon)

Figure 1 – Tettex cell model 2914 for solid samples

Figure 2 – Teraohmmeter "Burster" model resistomat type - 2408

Figure 3 - Dead Weight micrometer made by Testing Machines Inc, model 553 mm

3.2 Measurement of dielectric constant

The measurements were performed following ASTM D150 [2] using a standard capacitor (Figure 4), a "Tettex" cell for solid, (Figure 2) and a RLC bridge (Figure 5). The dielectric constant (ε_r) was obtained by the following equation:

$$\varepsilon_r = \frac{C_x \times E}{\varepsilon_0 \times A}$$

where

C_x capacitance of test sample

E sample thickness (measured with a micrometer as shown in Figure 3);

A area of the electrode of Tettex cell;

ε_o vacuum permittivity (8.854 x 10^{-12} F/m).

Figure 4 - Standard Air capacitor type 1403-A, serial 6566 made by General Radio (1000pF ± 0.1%)

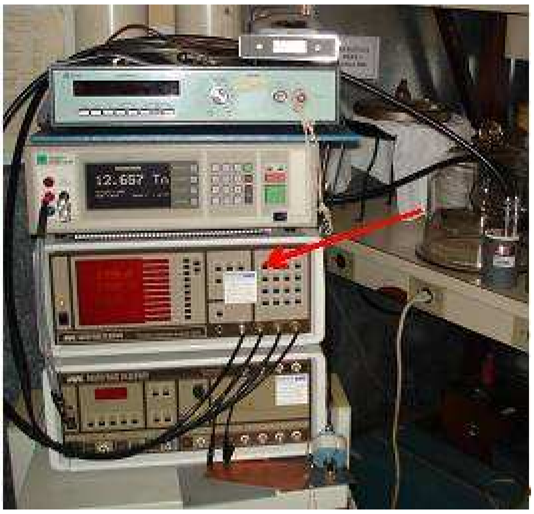

Figure 5 - RLC bridge made by Wayne Kerr model 3245

3.3 Tracking test

The test was performed following IEC 60587 [3], as can be seen in Figure 6. The method 2 of the IEC 60587 was used with the evaluation criterion A. The initial voltage used in the test method was 2 kV, rising in steps of 250 V until a failure occurs.

At the end of the test, the samples were classified as 2AX, where X indicates the highest value supported by the samples under test.

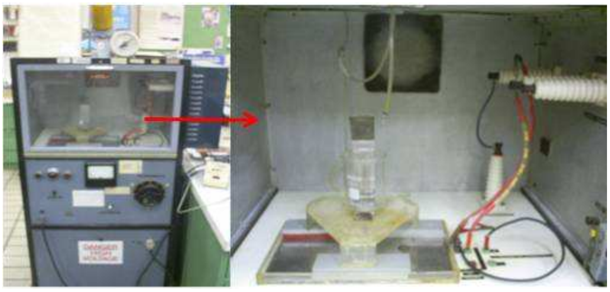

Figure 6 - Device for tracking test

4 TEST RESULTS [4]

The test results can be seen in Tables 2 to 7. As the size of the electrodes used to measure capacitance and volume resistivity is larger than the dimensions of the test samples there was necessity to perform simultaneous measurements of two samples, placed side by side, as can be seen in Figure 7. The value of the thickness showed in the tables is the medium value of ten measurements, with five measurements performed in each sample. Due to this test method, one sample was excluded in the measurements of each composition. The visual inspection performed before and after the tracking test can be seen in Figures 8 to 13.

Figure 7- Arrangement for the test cell

Table 2: Test results of composition TC 1

Sample	Thickness (mm)	Dielectric constant ε_r	Volume resistivity ρ_v (Ω.m)	Tracking test (kV)
1	-	-	-	3.00
2	6.19	4.19	3.54E+14	2.75
3	6.19	4.19	3.54E+14	2.75
4	6.18	4.13	5.47E+14	2.50
5	6.18	4.13	5.47E+14	2.50
Tracking class				2A2.50

Table 3: Test results of composition TC 2

Sample	Thickness (mm)	Dielectric constant ε_r	Volume resistivity ρ_v (Ω.m)	Tracking test (kV)
1	6.33	3.77	1.43E+14	2.75
2	6.33	3.77	1.43E+14	2.75
3	6.32	3.82	1.15E+14	2.75
4	6.32	3.82	1.15E+14	2.50
5	-	-	-	2.50
Tracking class				2A2.50

Figure 8 – TC 1 samples before and after tracking test

Figure 9 – TC 2 samples before and after tracking test

Figure 10 – TC 3 samples before and after tracking test

Figure 11 – TC 4 samples before and after tracking test

Table 4: Test results of composition TC 3

Sample	Thickness (mm)	Dielectric constant ε_r	Volume resistivity ρ_v (Ω.m)	Tracking test (kV)
1	6.30	4.41	4.02E+13	3.25
2	6.30	4.41	4.02E+13	3.50
3	6.28	4.45	4.02E+13	3.25
4	6.28	4.45	4.02E+13	3.50
5	-	-	-	3.50
Tracking class				2A3.25

Table 5: Test results of composition TC 4

Sample	Thickness (mm)	Dielectric constant ε_r	Volume resistivity ρ_v (Ω.m)	Tracking test (kV)
1	6.30	4.41	4.02E+13	3.50
2	6.30	4.41	4.02E+13	3.50
3	6.28	4.45	4.02E+13	3.50
4	6.28	4.45	4.02E+13	3.50
5	-	-	-	3.50
Tracking class				2A3.50

Table 6: Test results of composition TC 5

Sample	Thickness (mm)	Dielectric constant ε_r	Volume resistivity ρ_v (Ω.m)	Tracking test (kV)
1	6.30	4.10	6.78E+13	2.75
2	6.30	4.10	6.78E+13	3.25
3	6.32	4.17	5.98E+13	3.25
4	6.32	4.17	5.98E+13	3.25
5	-	-	-	3.25
Tracking class				2A2.75

Table 7: Test results of composition TC 6

Sample	Thickness (mm)	Dielectric constant ε_r	Volume resistivity ρ_v (Ω.m)	Tracking test (kV)
1	6.57	4.41	3.00E+13	3.25
2	6.57	4.41	3.00E+13	3.25
3	6.40	4.67	1.93E+13	3.25
4	6.40	4.67	1.93E+13	3.25
5	-	-	-	3.25
Tracking class				2A3.25

Figure 12 – TC 5 samples before and after tracking test

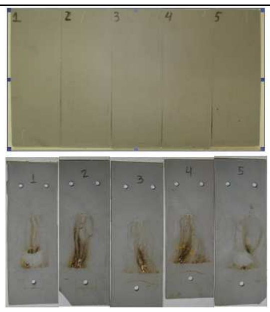

Figure 13 – TC 6 samples before and after tracking test

The mean value of the maximum current measured during tracking test in samples of each formulation, for each value of applied voltage, can be seen in Tables 8 and the values of the maximum current in each sample can be seen in Figures 14 to 19.

Table 8: Medium value of the maximum current

Voltage (kV)	TC 1 (mA)	TC 2 (mA)	TC 3 (mA)	TC 4 (mA)	TC 5 (mA)	TC 6 (mA)
2.00	21.6	15.8	21.2	20.0	19.2	20.8
2.25	29.6	22.0	27.2	26.0	27.6	28.0
2.50	43.6	32.0	34.0	32.8	36.0	35.2
2.75	53.2	39.6	40.8	39.6	41.4	40.8
3.00	58.7	60.0	46.8	47.2	51.2	48.0
3.25	60.0	-	51.2	51.2	56.0	55.2
3.50	-	-	56.8	56.4	60.0	60.0
3.75	-	-	60.0	60.0	-	-

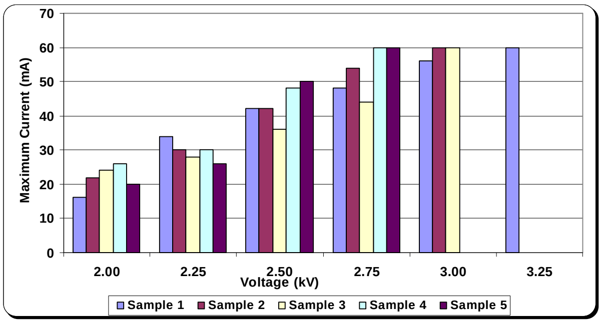

Figure 14 – Maximum current during tracking test in samples with test composition 1

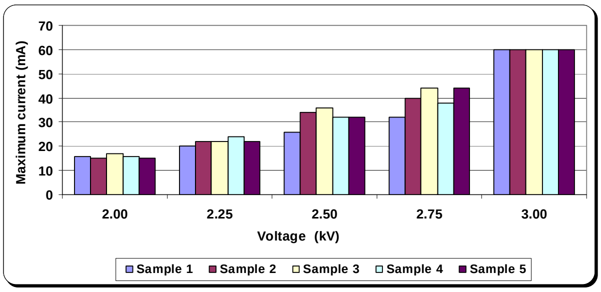

Figure 15 – Maximum current during tracking test in samples with test composition 2

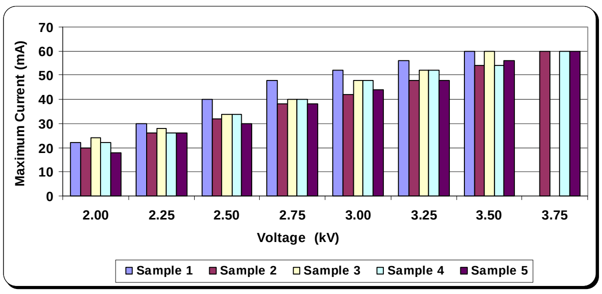

Figure 16 – Maximum current during tracking test in samples with test composition 3

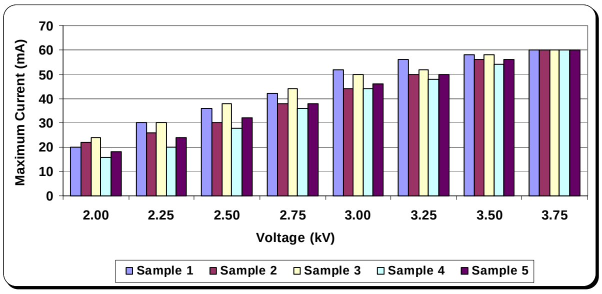

Figure 17 – Maximum current during tracking test in samples with test composition 4

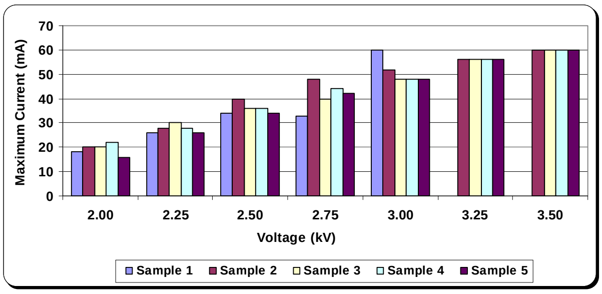

Figure 18 – Maximum current during tracking test in samples with test composition 5

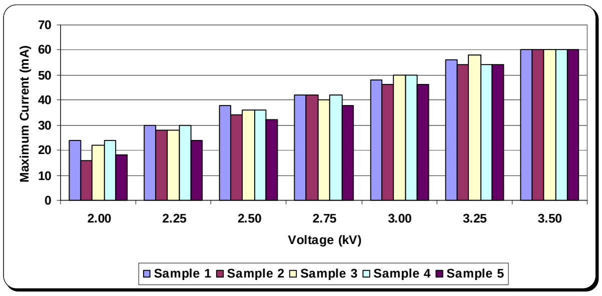

Figure 19 – Maximum current during tracking test in samples with test composition 6

5 TEST EVALUATION

The comparison of the test results, considering the medium values of the measurements of dielectric constant and volume resistivity, can be seen in Table 9 with the following observations:

- the use of fumed silica as filler causes a reduction in both dielectric constant and volume resistivity;
- the use of ATH as filler causes an increase in dielectric constant and a decrease in volume resistivity;
- the use of quartz as filler causes only a decrease in volume resistivity and the dielectric constant became the same;
- the combination of ATH and quartz as filler causes an increase in dielectric constant and a decrease in volume resistivity, although the change of these properties depends on the ratio of each filler component;

The relationship between the tracking voltage of each sample and its dielectric constant (ε_r), irrespective of the sample formulation, can be seen in Figure 20 and indicates a growing trend of voltage tracking with the growth of dielectric constant. The equation that represents this relationship is:

$$\text{Tracking voltage (kV)} = 0.795e^{0.3168\varepsilon_r}$$

The relationship between the tracking voltage of each sample and its volume resistivity (ρ_v), irrespective of the sample formulation, can be seen in Figure 21 and indicates a declining trend of voltage tracking with the growth of volume resistivity. The equation that represents this relationship is:

$$\text{Tracking voltage (kV)} = 3.7478e^{-0.1009\rho_v}$$

Note: The value of the volume resistivity to be used in the formula above should be a multiple of 10^{13}.

Table 9: Comparison between results

Composition number	Filler	$\Delta\varepsilon_r$ (%)	$\Delta\rho_v$ (%)	Reference
TC 2	10 phr of fumed silica	-8.74	-71.3	TC 1
TC 3	100 phr of ATH	+6.58	-91.1	TC 1
TC 4	50 phr of ATH and 50 phr of quartz	+7.03	-84.9	TC 1
		+4.29	+69.4	TC 3
TC 5	100 phr of quartz	-0.01	-85.8	TC 1
		-6.79	+58.7	TC 3
		-7.19	-6.31	TC 4
TC 6	70 phr of ATH and 30 phr of quartz	+9.20	-94.5	TC 1
		+2.46	-38.8	TC 3
		+2.02	-63.9	TC 4
		+9.93	-61.4	TC 5

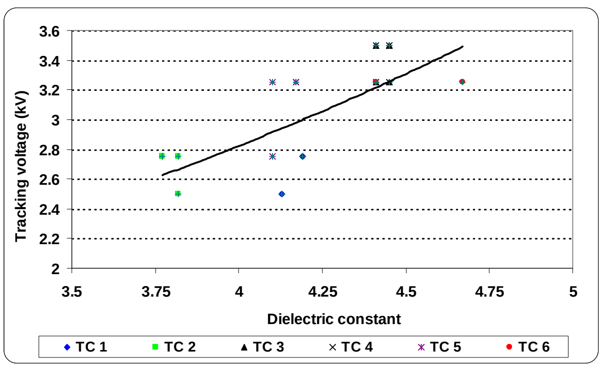

Figure 20 – Relationship between tracking voltage and dielectric constant

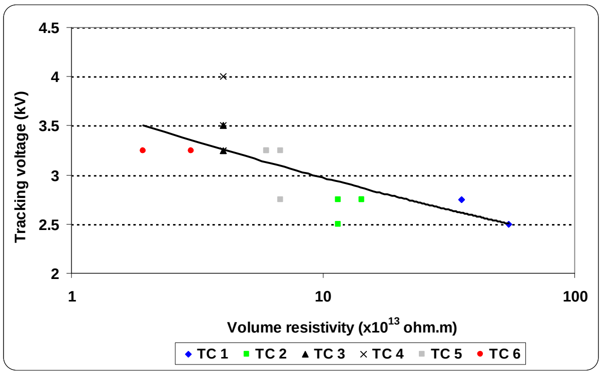

Figure 21 – Relationship between tracking voltage and volume resistivity

The analysis of the current values presented in Table 8 provides additional information about changing of the current values with the test voltage. The curves in Figure 22 show that some compositions have a faster degradation with the increase of the test voltage.

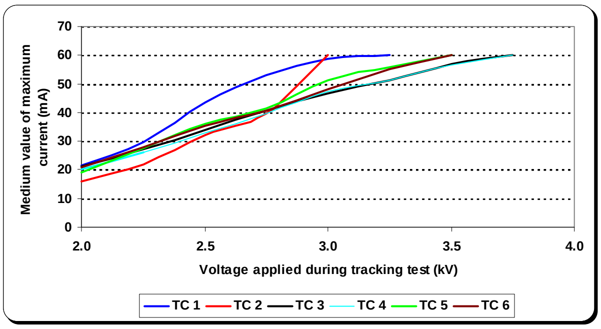

Figure 22 – Variation of the current during tracking test

6 CONCLUSION

The results presented show that, except the composition TC2, all the others compositions cause improvements in the value of tracking voltage but the additives included in the formulation of the compounds caused changes in the characteristics of the compositions.

Note: Consultation with the supplier of composition TC2, to verify the reason for poor performance in the tracking test, indicated that the additives were with nano dimension, then probably the spread of the additives should not have occurred homogeneously.

As the volume resistivity evaluates the leakage current flowing through the insulating compound, under the influence of a potential difference, and that the dielectric constant evaluates the electric flux density in the material for the same applied electric field, can be considered that great reduction in the value of volume resistivity and the increase of the dielectric constant increases the conductivity of the compounds.

Despite the increase in conductivity, the performance improvement of tracking withstand offsets the use of additives in the formulation of the compound. Furthermore, the increase in conductivity ensures reduced heating of the material and reduces the losses, under the action of electric fields.

Not considering the economic aspects but only the results of the tracking test, the composition TC 4 can be considered as the composition that presented the best performance.

The equations with the relation among the tracking voltage and the dielectric constant and among tracking voltage and the volume resistivity are useful to have an idea of the performance during the tracking tests but more tests with others samples must be performed to obtain a better statistical evaluation.

7 ACKNOWLEDGMENTS

To technical staff of CEPEL’s Electric and Magnetic Properties Laboratory for performing all the tests. To Momentive Performance Materials and Dinaflex by disposing of the samples for the tests.

8 REFERENCES

[1] ABNT NBR 5403, Solid electrical insulating materials - Determination of volume and surface resistivity: test method (in Portuguese).

[2] ASTM D150, Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation.

[3] IEC 60587, Electrical insulating materials used under severe ambient conditions – Test methods for evaluating resistance to tracking and erosion.

[4] Gonçalves, Pedro Paulo, Electrical tracking on the housing of polymeric insulators, Universidade Federal Fluminense, 2010 (in Portuguese).