The Effect of Micro-Eggshells and Aluminium Hydroxide on Tracking Resistance of Silicone Rubber Composite

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Abstract. Break down due to surface tracking is one of the critical insulation failures, especially in the polymeric insulation. It has made worse the reliability of the power transmission system. This present work attempts to solve the problem by observing the effect on tracking resistance of adding micro-eggshells and aluminum hydroxide into the silicone rubber. In order to fabricate the composite specimen, red eggshells (63 to 74 µm), aluminum hydroxide, and RTV silicone rubber were procured. The constant voltage test method, according to the IEC-60587 standard, was used to evaluate the tracking resistance; each specimen was applied by 4.5 kV for 1 hour, and the tracking length was declared as the inverse of tracking resistance.

Besides, the rule of mixtures was employed to estimate the thermal conductivity. The results show that the tracking resistance of the composite specimens was overall higher as compare to the pure rubber. Moreover, It was found that tracking resistance and thermal conductivity decreased when the eggshells increased. It was described that the rise of thermal accumulation on the insulator surface in the hybrid composite caused by lower thermal conductivity. Therefore, it could be concluded that the mixing of micro-eggshells and aluminum hydroxide should not be used as fillers for suppressing the tracking failures.

1. Introduction
Silicone rubber has been used as a high voltage outdoor insulator. In the transmission line system, with their advantages such as high dielectric breakdown, UV, and pollution resistance. They are mostly employed to be an external layer for suspension, dead-end, and inter-phase insulators. Even if they have numerous advantages, their surface can be destroyed by surface discharge or tracking, which produces much heat, then break their chemical bond and make the system failure. Thus, it is required to enhance their properties to make them more tracking resistance[1].

There are many efforts to study the problem, and most of them filled inorganic fillers such as silicon dioxide, aluminum oxide, and aluminum hydroxide into the rubber. Among the fillers, aluminum hydroxide is the popular filler. The ability of aluminium hydroxide to release water of hydration at high temperatures (about 220 degrees Celsius) is the crucial function to resist chemical bond breaking by take away heat from the rubber surface[2-4]. Also, there was a previous report which stated that alternative filler as eggshells could improve tracking resistance because it contains absolutely calcium carbonate(CaCO3)[5]. By the way, using only eggshells was seem unstable owning to its CaCO3 composition was vary with the source of the eggshells. Therefore, this study investigates the effect of eggshells and aluminium hydroxide on tracking resistance of silicone rubber composite.
2. Materials and methods
Test specimen consisted of 3 composites: room temperature vulcanizing silicone rubber (RTV), micro red eggshells, and aluminum hydroxide (AH). The RTV was supplied in two parts, liquid silicone rubber, and catalyst, by Super Silicone & Resin Art. Micron red eggshells, which contain 93 to 97% calcium carbonate[6], were obtained by grinding and sieving red eggshells until a size of them is in the range of 63 to 74 µm. The AH was supplied by Qchemical. The test specimen was initially fabricated by mixed the rubber with a dedicated amount of each composition, as mentioned in table 1. Then, the composite was stirred by hand for 5 mins to avoid agglomeration. After that, the mixture was stirred again for 2 mins; at the same time, the catalyst was carefully added. Finally, the composite was poured into a 50x120x6 mm. mould, and kept in the oven at room temperature for at least 6 hours.

Tracking resistance was obtained by the test, according to IEC 60587[7]. Tracking resistance defined as the length of a carbon path on the surface of material created by deterioration from the heat of arc discharges. The test is composed of 5 components, such as a 4.5 kV 50 Hz transformer, a 33 kΩ 200 W remitting current resistor, a contaminant feeder with a flow rate of 0.6 ml/min, electrodes, and a specimen mounting support, as shown on the schematic diagram in figure 1. The contaminant is a mixture of 0.1 wt% of NH4Cl, 0.02 wt% of Triton X-100, and distilled water. For the test procedures, a specimen was firstly mounted on the specimen mounting support at an angle of 45 degrees from the horizontal. Then, assembly the electrodes and eight filter papers. After that, the contaminant was fed to filter papers. While filter papers are full of the contaminant, the contaminant smoothly flows to the bottom electrode through the hole of the top electrode. Finally, the 4.5 kV was supplied for 60 mins to the electrodes. When the testing time reaches 60 mins, the test is done, then the specimen was cleaned by distilled water and measured the length of the deterioration area. Three specimens per material type were tested at the same time for repeatability of results.

Thermal conductivity is the ability of a material to conduct heat. In this work, the rule of mixtures equations is used to calculate the thermal conductivity, so the rule is represented by

\[ k_c = k_r V_r + k_{f1} V_{f1} + k_{f2} V_{f2} + k_{f3} V_{f3} + \ldots + k_{fn} V_{fn} \]  

(1)

In these expressions, \(k\) and \(V\) denote the thermal conductivity and volume fraction, respectively, whereas the subscripts c, r, and fn represent composite, rubber, and filler number n[8]. In order to calculate the thermal conductivity, the parameters in Table 2 are employed and the results are plotted in figure 4.

Table 1. Composition of test specimens.

| Specimen type | Composition (%wt) |
|---------------|-------------------|
|               | Silicone rubber   | Micro-eggshells  | Aluminium hydroxide |
| E0A0          | 100               | 0                | 0                  |
| E1A9          | 90                | 1                | 9                  |
| E3A7          | 90                | 3                | 7                  |
| E5A5          | 85                | 5                | 5                  |

Table 2. Physical properties of materials in use.

| Material type                        | Physical property | Sources |
|--------------------------------------|-------------------|---------|
| Silicone rubber                      | k (W/m·K)        | 0.27    | [9]     |
| Micro-eggshells (CaCO₃)              | Density (g/cm³)   | 2.26    | 2.77    | [9]     |
| Aluminium hydroxide                  |                   | 21.34   | 2.42    | [4]     |
3. Results and discussion

3.1. Tracking resistance

Figure 2 shows the physical development of carbonized tracking patterns on the surface of the test samples with various loadings. The measured physical development of tracking is charted in Figure 3. In general, it can be seen that the pure rubber (E0A0) is the lowest tracking resistance because it has the highest tracking development. Furthermore, it can be observed that tracking resistance is substantially lower in the micro-eggshells/aluminium-hydroxide filled composites with increasing the eggshells contents and decrease the other filler.

Figure 2. The physical development of tracking patterns after the test.

Figure 3. Average tracking length after the test.
3.2. Thermal conductivity

As described early, tracking begins due to temperature build-up on the surface of the composites during the test. Hence, the thermal conductivity of the composites extensively causes the tracking process as it could slow down the arc discharge mechanism and reduce the tracking failure possibilities. As shown in Figure 4, the thermal conductivity of hybrid composites is relatively higher as compared to the A0E0 specimen, but it decreases when the eggshells increase. With decreasing thermal conductivity, hybrid composites can conduct heat away less effectively in the discharge area during the test. Therefore, the tracking failure trends to growth on the composite specimens.

![Figure 4. Thermal conductivity of specimens.](image)

In order to explain the decrease in thermal conductivity of hybrid composites, the decomposition of aluminium hydroxide and calcium carbonate is engaged. When the arc discharge occurs, it generates the heat and transfers it to the fillers through the rubber. As a result, the chemical bonds of the fillers tend to break when the temperature reaches their melting point. The melting point of aluminium hydroxide is about 220°C; at this point, aluminium hydroxide will release water and form aluminium oxide, as shown in equation 2. The released water is considered as the primary function to take away the heat from the discharge region. Adding both aluminium hydroxide and micro-eggshells shows the result in a counter way. It is considered that calcium carbonate in the eggshells changes into calcium oxide at approximately 800°C [10] by arc discharge, as shown in equation 3. Calcium oxide absorbs the released water and forms calcium hydroxide, as shown in equation 4. At this stage, the amount of water decrease and thermal conductivity decrease[11].

\[
2\text{Al(OH)}_3 \rightarrow \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \quad (2)
\]

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \quad (3)
\]

\[
\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \quad (4)
\]
4. Conclusion
In this study, the effect of micro-eggshells and aluminium hydroxide on tracking resistance of silicone rubber composite has been investigated. Due to the water-absorbing of calcium oxide, the composites have lost their thermal conductivity and increase the chance of tracking failure. It could be observed that adding the micro-eggshells and aluminium hydroxide into silicone rubber may lead to lower the tracking resistance. Therefore, it is suggested that the mixing of micro-eggshells and aluminium hydroxide should be used at appropriate amount for the purpose of fillers for suppressing the tracking failures. However, further study on other properties of silicone rubber with the loading of micro-eggshells and aluminium hydroxide is needed.

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