Improvement of Tracking and Erosion Behavior of Outdoor Insulation with a New Polymeric Alloy

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Abstract

Tracking and erosion resistances of high temperature vulcanizing (HTV) silicone rubber, ethylene-propylene diene monomer (EPDM), blend of silicone-EPDM, and a new polymeric alloy were evaluated after being aged by the stress of water salinity and UV radiation. Silicone rubber insulators suffer from tracking and erosion resistance. New polymeric alloy shows an excellent resistance to electrical discharge on pollution environments in comparison to silicone rubber, EPDM, and blend of them. UV stress deteriorated the surface of EPDM, thereby reducing the tracking and erosion resistance of it. Water salinity reduced tracking and erosion resistance in silicone rubber. The losses of hydrophobicity of polymeric materials during UV aging have been also studied in this paper.

1 Introduction

The history of polymeric insulators began in the 1940s when organic insulating materials were used to manufacture high voltage indoor electrical insulators from epoxy resins [1]. These materials were light weight, impact resistance, and could be used to form large complex parts. Polymeric insulators for outdoor use were made feasible by the discovery in the 1950s that alumina trihydrate filler increases the tracking and erosion resistance of the polymeric materials. However, polymeric insulators for outdoor application on transmission lines were not developed until the late 1960s. In the late 1960s and early 1970s, manufactures introduced the first generation of commercial polymeric transmission line insulators [1]. At the beggning, non-ceramic insulators contained ethylene propylene rubbers (EPR) which were made by different companies such as Ceraver of France (1975), Ohio Brass of U.S.A. (1976), Sedivar of U.S.A (1977) and Lap of U.S.A (1980). At 1976, Rosenthal Co and Reliable Co of the U.S.A in 1983 presented silicone rubber (SIR) [1]. Silicone composite insulators were used in Germany in 1977 for up to 123 kV and in 1979 for up to 245 kV [2]. Early utility experimentation with the first generation of polymeric insulators led to mixed results. One insulator that featured silicone rubber housing, and construction that avoided joints in the housing, performed well electrically. However, because of low tear resistance of the sheds the room temperature vulcanized silicone rubber was replaced with high temperature vulcanized silicone rubber. Ethylene propylene diene monomer (EPDM) shed sections used in another insulator type provided good housing material performance. Shed bonds degraded in these early insulators when exposed to a coastal environment. The suppliers have developed an alloy consisting of EPDM with silicone rubber. Ohio Brass (1986) a blend of ethylene propylene (EPR) and silicone which was subsequently changed to ethylene propylene diene monomer (EPDM) and SIR compound in 1989. The alloy of EPDM and SIR may make it possible to combine the properties of two materials [3]. It was reported that one company has produced commercially with the alloys of EPDM and SIR over 2.5 million distribution, 0.1 million transmission class line post insulators and 0.4 million suspension insulators which are currently installed in power systems in different parts of the world [3]. This gives a clear indication of a wield acceptance of this blend of materials. This paper reports on experimental investigation on electrical and surface properties of silicone modified polymer (new component) compared with silicone rubber (SIR), ethylene-propylene–diene monomer (EPDM), and alloys of SIR-EPDM.

2 Sample Preparation

All the materials used for this work were commercial products and they were used without further treatments. Table 1 shows identification of raw materials. Several formulations containing silicone rubber and EPDM were prepared. Silicone rubber was blended with EPDM and other materials at 180 °C in a Haake internal mixer for 10 min at a rotor speed 100 rpm for preparation alloy of SIR-EPDM and new polymeric alloy. The individual elastomers and the blends were compound with peroxide in a roll mill at
room temperature. Vulcanization was done in hydraulically operated press at 170 °C and 15 bar for 10 min.

Table 1 Identification of material

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>HTV silicone rubber, peroxide cure</td>
</tr>
<tr>
<td>B</td>
<td>EPDM base, peroxide cure</td>
</tr>
<tr>
<td>C</td>
<td>Alloy of SIR-EPDM (50/50), peroxide cure</td>
</tr>
<tr>
<td>D</td>
<td>New polymeric alloy, peroxide cure</td>
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</table>

3 Test Apparatus and Test Procedure

3.1 Tracking

The tracking resistance is evaluated according to IEC 60587 [4]. The set-up according to IEC 60587 tracking and erosion test is shown in Figure 1.

![Figure 1](image)

The experimental set-up to tracking and erosion test

The contamination electrolyte used in this study was a 0.1% ammonium chloride solution (NH₄CL) and 0.02% Isooctyl-phenoxypolyethoxylol (a non-ionic wetting agent) in de-ionized water (Triton X-100). The conductivity of the contaminant was measured with a conductivity meter (Schott Geräte CG 858) and it was 2530 µs / cm at 23 °C. The samples were slab – shaped (12 cm x 5 cm x 6 mm). The distance between the top and the bottom electrodes was 5 cm. A voltage of 3 kV AC was supplied. Thus, voltage application of 3 kV created an average electric field strength of 600 V/cm. The flow rate of contaminant was obtained with a peristatic pump, and the chosen flow rate was 0.3 ml / min. The end of test (tracking time) was defined as the leakage current is over 60 mA for 2 sec.

3.2 Hydrophobicity

Hydrophobicity of a surface is intimately related to the so-called contact angle. Consider an ideal axisymmetric drop of water resting on an ideal flat homogenous horizontal solid surface. The contact angle is the angle θ which is formed by the air-water interface of the drop and the solid surface at the three–phase line of contact. The most commonly used method for contact angle measurements of surface hydrophobicity is the sessile drop technique. A droplet of a purified liquid (distillate water) is placed on a surface using a syringe. The resulting angle between the droplets is measured, generally using a goniometer or a charge coupled device (CCD) camera fitted onto a microscope. A drop shape analysis system G10 (Kruss-USA) was used for hydrophobicity studies.

4 Results and Discussion

4.1 Tracking and erosion resistance evaluation

When subjected to polluted atmospheres, insulators attain deposits of airborne solid contaminants, usually containing some ionic substances which form electrolytes and give rise to surface leakage currents under moist conditions such as fog, rain, dew or mist. In regions of high current density differential evaporation of the moisture from the surface layer produces local voltage gradients (electrical stresses) greater than the breakdown stresses for the surrounding atmosphere (air). The discharges propagate across dried regions, or bands. This mechanism is known as dry band formation. These types of electrical discharges may occur in service under the influence of dirt, moisture, and deposited conductive salts. Discharge inception under the above conditions is the consequence of several sequential processes:

a) The coating of the insulator with ionic deposits
b) Formation of an electrolyte by the absorption of moisture
c) Surface leakage currents and localized drying of the electrolyte (dry band formation).
Processes (a) and (b) are dependent on the environment, and may even be combined as in the case of salt storms in coastal regions, whereas (c) is dependent on the rate of formation of the ionic conduction on the surface. The degrading effect of these processes is simulated by the tracking test. Tracking and erosion are serious degradation modes for non-ceramic insulators that reduce their insulating properties and mechanical strength considerably. Surface electrical discharging ultimately results from build up of leakage current on insulating devices during wet contaminated conditions. In this situation, the polymer material can undergo various chemical reactions leading to deterioration of mechanical and electrical properties. One method of degradation is the formation of a carbonaceous conducting path on the surface of the insulation, due to heat generated by discharges. These start locally across the dry bands formed on the surface of a sample, when sufficient contamination is accumulated in the surface regions between the electrodes. The carbonized conduction path finally forms over the short circuited path. Another mode of damage is the progressive loss of material because of the formation of degradation products due to a localized reaction, resulting in erosion of the insulting surface. The mode of degradation may vary according to the chemical composition of the polymer, type of contamination, and the type of the discharge activity.

Table 2  Tracking test conditions

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<tr>
<td>Applied voltage</td>
<td>3.5 kV</td>
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<tr>
<td>Flow rate contamination</td>
<td>0.3 ml/min.</td>
</tr>
<tr>
<td>Type of contamination</td>
<td>NH₄Cl</td>
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<tr>
<td>Conductivity</td>
<td>2530 µs/cm</td>
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Table 3  Tracking time, weight loss and maximum erosion depth

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<tr>
<td>T (min)</td>
<td>1</td>
<td>20</td>
<td>120</td>
<td>30</td>
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<tr>
<td>Weight loss %</td>
<td>1</td>
<td>2.5</td>
<td>fire</td>
<td>0.3</td>
</tr>
<tr>
<td>Maximum erosion depth (mm)</td>
<td>1</td>
<td>3.3</td>
<td>-</td>
<td>1.5</td>
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<td></td>
<td>2</td>
<td>1.5</td>
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It can be seen from Table 4 that the tracking and erosion resistance have changed after water salinity aging in the case of silicone rubber. This can be the result of the absorption of water during water salinity aging. The reduction is clearly caused by an expansion force during the boiling of absorbed water. Furthermore, if water is injected into the bulk, ions or electrons in contaminated electrolyte can migrate into the interior via absorbed water, and a current develops through the bulk. The development of such current causes the boiling of absorbed water and, finally, promotes mechanical and chemical erosion. It seems that NaCl in salt water permeates into the samples and acts as ionic carrier, causing on increase in current density.

Table 4  Tracking time, weight loss and maximum erosion depth: 1) after water salinity and 2) after UV aging

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<td>1.5</td>
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<td>1</td>
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The tracking resistance of polymer insulating materials can be offered by environmental conditions such as UV radiation, moisture, and acid rain. The influence of water salinity and UV radiation on tracking resistance of samples also studied. Table 4 shows the tracking resistance and erosion parameters after UV and water salinity aging. The samples were immersed in water salinity (5% NaCl) for 1500 hrs. The polymers have also been exposed to UV for 1700 hrs at 30°C.

Table 4  Tracking time, weight loss and maximum erosion depth: 1) after water salinity and 2) after UV aging

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Table 4 shows the changes of the tracking and erosion resistance after UV aging (1700 hrs). The test results indicated that UV radiation has had no negative effect on tracking endurance for silicone rubber (A) and the new material (D). It can be the result of disappearing
of carbon and increasing of oxygen because of UV stress. This means that oxygen binds silicone polymers at the surface instead of carbon in methyl groups (CH₃) [5]. When carbon as a result of the formation of conductive path decreases, therefore, tracking resistance increases, special in silicone rubber. According to the results obtained by EDX and ATR-FTIR, it is adequate to define that C-H and Si-CH₃ bonds in PDMS are broken, and then the atomic rate of oxygen increases and OH bonds are formed at broken chain sites to form silanol groups because of UV aging [5-7].

Figures 2 to 4 show a comparison of tracking time and erosion parameters in different condition for sample A, B, C, and D. It can be seen that sample D has good tracking and erosion resistance compared to silicone rubber, EPDM and blend of silicone-EPDM. Although, tracking resistance for silicone rubber improved by UV aging, but it should be noted that the reduction of hydrophobicity during UV aging causes accumulation of pollution on the surface of polymer and flashover.

Gas Chromatography-Mass spectrometer (MS) shows the evolved gases during the thermal degradation of HTV-silicone rubber [8]. Silicone rubber subjected to thermal decomposition is known to form cyclic dimethylsiloxane (DMS) together with a small amount of linear DMS (∼1%wt). The molecular units of most formed cyclic DMS (∼90%wt) are D3 to D6 [8-11]. It has been shown already that electrical discharges increase the number of cyclic silicone oligomers of 4 to 6 unites (D4 to D6) on the surface of HTV silicone rubber [5]. Cyclic silicone oligomers of low unite would increase at the surface with the duration of the inclined plane tracking and erosion test. Those low unit silicone oligomers possess low boiling temperatures, with those of D4 to D6 ranging from 173 °C to 245 °C [5]. When dry-band arcing is concentrated in one point, formed the oligomers D4 to D6 are volatilized due to their low flash points.

4.2 Contact angle

Figure 5 shows the influence of UV aging on to the contact angle of samples. The test condition was maintained as 50 ± 5 % RH and 30 ± 3 °C, and
samples were subjected to UV light for 1700 h. It is well known that 200 hours of test period is equivalent to 1 year of actual outdoor exposure considering only the UV wave length (300-400 nm) that is mainly related to the deterioration of polymers [12].

Figure 5 Variation of contact angle with duration of UV aging

5 Conclusion

In this work surface properties and tracking resistance of silicone rubber, EPDM, blend of silicone and EPDM, and silicone modified polymer have been investigated. The hydrophobicity of polymers decreased with UV aging. This was attributed to the forming of polar groups such as carbonyl and damaging of hydrophobic groups such as methyl at the surface of polymers. Most organic materials used for electrical insulation may suffer from tracking. It is shown that the tracking resistance of silicone rubber decreased with water salinity stress. It can be the result of diffusion of water in silicone rubber. It is shown also that UV stress decreases the tracking resistance of EPDM. It can be the result of loss of hydrophobicity at surface of EPDM. The new polymeric alloy shows no influence of water salinity stress and UV stress on the tracking time and shows also a good behaviour concerning contact angels as function of UV ageing time.

6 Literature