INFLUENCE OF NANOFILLERS IN MECHANICAL AND ELECTRICAL PROPERTIES OF POLYMERIC INSULATION

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ABSTRACT

This work reports the role of nano fillers in enhancing the mechanical and electrical properties of silicone rubber insulation. Silica and Zinc oxide nano fillers were added to the base polymeric material and mechanical properties such as tensile strength, elongation and hardness and electrical tracking properties were investigated. Inclined plane test as per ICE 60587 was used to conduct tracking studies. Hydrophobicity analyses of the samples were also carried out. It was found that there was a significant improvement in the mechanical and erosion resistance properties of polymeric insulation due to the addition of nanofillers.

Keywords: Polymeric Nano composites, Nano fillers, Electrical Tracking, Hydrophobicity.

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1. INTRODUCTION

Outdoor insulation is subjected to various electrical, mechanical and thermal stresses that cause the degradation of the insulating material used in the transmission lines. Therefore, Ceramic and glass insulators are now being replaced by polymeric insulators such as RTV (room temperature vulcanised) Silicone rubbers, EPDM (Ethylene Propylene Diene Monomer), EPR (ethylene propylene rubber), Epoxy resins etc., These polymers are light in weight, exhibit better performance in contaminated environment, cost effective and maintenance free. However pure Silicone rubbers shows little tracking and erosion resistance. Incorporation of nano fillers in polymers results in Nanocomposites which helps in improving thermal conductivity, relative permittivity, tracking and erosion resistance [1]-[3].

Tracking is the peculiar problem which occurs on the surface of the insulator resulting from the contamination. In wet and polluted conditions, outdoor insulators are susceptible to dry band arcing. It is the phenomenon that occurs when an insulator gets wet a thin film is formed and a small leakage current starts to flow. On evaporation of the film due to rise in
temperature dry band is formed on the surface, current flow is interrupted and voltage gradient occurs across the band which causes minor arcing and it can lead to flashover.

The experiment has been carried out by preparing RTV Silicone rubber samples incorporated with nano fillers. Nano fillers has been added to the raw Silicone rubber by means of two roll mill technique. The nano fillers used are SiO2, ZnO and the combination of SiO2 and ZnO taken in the concentration of 5% by weight of the polymer and they are mixed with surfactant by means of magnetic stirrer to eliminate the agglomeration of nanoparticles. The morphology of the polymer are analysed by Scanning Electron Microscope.

The comparison of nano filled polymer with the virgin polymer without (nano filler) has been done by performing various tests such as hydrophobicity, breakdown strength, mechanical test such as hardness, tensile strength, elongation etc. To find its tracking resistance, inclined plane test has been carried out and results have been compared in parameters like erosion depth, tracked length, tracking time, percentage hydrophobicity retained, weight loss. From the analysis nano filled polymer showed better performance compared to polymer without nano filler[4]-[6].

2. SAMPLE PREPARATION:

The Base Polymer for the preparation of the sample is Light Grey Silicone Rubber- Methyl Vinyl Siloxane supplied from Dow Corning’s, Mumbai Pvt Ltd. The Shore hardness of the rubber is 65, Average molecular weight is 6000, Volume resistivity is \(2 \times 10^{14}\) mho-cm, Elongation of 280\%, Tensile strength of 747 psi, Relative dielectric constant of 3.67 and Viscosity of 100.

The nano fillers specifically inorganic oxide fillers are added to improve specific properties of the polymer and also to reduce the costs spent to avoid tracking problem by other means. The specific properties being thermal conductivity, electrical conductivity and surface hydrophobicity. Unlike the conventional polymers, this polymer nanocomposites is composed of nano sized fillers equally dispersed in the polymer matrix. The fillers incorporated in this study are zinc oxide (ZnO) and silica (SiO2).

The Silica nano filler is purchased from Avantika enterprises Pvt, ltd, Chennai. Zinc oxide nano filler is purchased from Sunkem industries Pvt, Ltd, Kanpur.

The Nano filler cannot be directly added to the silicone rubber. It is essential to facilitate bonding between the polymer matrix and the filler particles. Intermediate substance called the surfactant is required to ensure the proper dispersion of the filler in the raw material. Surfactants are compounds that lower the surface tension (or interfacial tension) between two liquids or between a liquid and a solid. Surfactant used in this study is Ethanol.

Two roll mill techniques were used to prepare silicone rubber samples. Initially raw silicone rubber is flattened between the rollers. Initial gap size is 2mm. The temperature around 40 degrees Celsius is set. Then the Rubber is added. It is masticated and becomes softer with the reduced viscosity. Gap size is increased to 3mm. Then the Curing agent Dicumyl peroxide (3g) is added. When the rubber is flattened along with the curing agent to an extent, nano fillers are added. Nano filler mixed with ethanol in the magnetic stirrer at an rpm of 500 for 1 hour and then is gently poured into the rubber. Each time the mixture is poured the rubber is made to pass between the rollers, to ensure uniform dispersion of the fillers in the rubber.

After the silicone rubber samples are made by the two roll mill technique, it is subjected to curing process. Curing helps to reduce stickiness, to increase rubber strength and durability and to retain the elasticity.
In pre curing the flattened rubber is cured at temperature of nearly 180 degree Celsius for 15-20 minutes. In post curing process the rubber is cured at temperature of nearly 200 degree Celsius for about 4 hours. The curing agent used is Dicumyl peroxide. After curing is done the flattened rubber is cut into the required shape using mould of specified thickness. Three samples with different fillers (ZnO, SiO$_2$ and ZnO+SiO$_2$) of 5% concentration by weight are prepared. The size of the sample prepared is 140mmX 140mm X 2 mm.

3. SCANNING ELECTRON MICROSCOPE ANALYSIS

The morphology of the nano particle distribution in the rubber matrix is investigated using scanning electron microscope (SEM). VEGA3 SEM instrument is used for the analysis. The nano filled and virgin samples (without nano filler) are analysed using SEM to ensure the dispersion of the fillers in the polymer matrix. The figures shown below demonstrate the morphology of the sample at different resolutions.

![SEM images of (a) 5% SiO$_2$ filled (b) 5% ZnO filled (c) 5% (SiO$_2$ + Zinc oxide filled) silicone rubber samples](image)

Figure 1 SEM images of (a) 5% SiO$_2$ filled (b) 5% ZnO filled (c) 5% (SiO$_2$ + Zinc oxide filled) silicone rubber samples

4. TRACKING EXPERIMENTAL TEST SETUP

The experimental arrangement consists of mounting support supported by a stand with the sample mounted over it clamped between the electrodes. A 100kV, 10 kVA test transformer is used to supply higher AC tracking voltage. 5kV constant tracking voltage was used during the study. The experimental work was carried out based on IEC 60587 standard.[8]-[9]. Figure 2 Shows the experimental arrangement of Inclined plane test as per standard.

Initially the leakage current starts to flow between the top and bottom electrodes through the contaminant which provides ions constituting the leakage current. Due to the current there is a raise in temperature which slowly evaporates the contaminant. Dry band is formed on the surface. When dry band is formed current flow gets interrupted and voltage gradient appears across the band. This voltage gradient exerts electrostatic stress cross the surface and causes further evaporation and an increase in the width of the dry band. This increase in width of the band causes a higher voltage gradient which causes minor arcing. During dry band current decreases almost to zero and voltage increases.
After dry band arcing intermittent contaminant flow will occur because of the instability due to contaminant flow, air.

Tracking is initiated by the complete dry band and it is marked with increased magnitude of leakage current. Tracks develop progressively from bottom to top electrode. A hotspot is formed just above the lower electrode which leads to the erosion of the sample.

5. LEAKAGE CURRENT-ANALYSIS

Figure 4 a) shows the initial leakage current pattern during the tracking studies. The leakage current increased the temperature of the surface and dry band was observed on the surface. During dry band formation the leakage current pattern collapsed and discontinuity in the waveform was observed as shown in Figure 4 b). After the onset of tracking, the current increased considerably and erosion of the sample was observed near the bottom of the electrode.
The leakage current starts building up through the film of contaminant initially, on the formation of dry band gradually the current slightly decreases due to the voltage gradient and in the final stage when there is a fine conducting path after the dry band, the leakage current rises to a greater magnitude rapidly and sample is tracked. The table below shows the leakage current values at different regions in four different samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initiation of dry band (mA)</th>
<th>Dry band formation (mA)</th>
<th>Tracked condition (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfilled silicone rubber</td>
<td>17.83</td>
<td>15.38</td>
<td>54</td>
</tr>
<tr>
<td>5% SiO$_2$ filled</td>
<td>9</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>5% ZnO filled</td>
<td>18.59</td>
<td>13.96</td>
<td>55</td>
</tr>
<tr>
<td>5% ZnO + SiO$_2$ filled</td>
<td>16.63</td>
<td>14.59</td>
<td>40</td>
</tr>
</tbody>
</table>

From the above table, the leakage current for the nano filled samples is considerably reduced compared to the unfilled sample.

6. TRACKED SAMPLE- ANALYSIS:
Figure 5 shows the images of the samples after tracking. The tracking length and the erosion depth was measured for different samples.

![Figure 5](image)

**Figure 5** (a) Unfilled sample (b) 5% SiO2 filled (c) 5% ZnO filled (d) 5% ZnO + SiO2 filled

Table 2 shows the values of erosion depth, track length and tracking time measured.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Erosion depth (mm)</th>
<th>Track length (mm)</th>
<th>End Point criterion time (Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfilled silicone rubber</td>
<td>0.7</td>
<td>35</td>
<td>3</td>
</tr>
<tr>
<td>5% SiO$_2$ filled</td>
<td>0.6</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>5% ZnO filled</td>
<td>0.6</td>
<td>37</td>
<td>4.5</td>
</tr>
<tr>
<td>5% ZnO + SiO$_2$ filled</td>
<td>0.4</td>
<td>34</td>
<td>4</td>
</tr>
</tbody>
</table>

It was found that erosion depth and tracking length was minimum for the samples prepared with 5% ZnO + SiO$_2$ filled samples.
7. ANALYSIS-HYDROPHOBICITY:
Hydrophobicity can be described using contact angle on the material surface that a liquid drop makes when it comes in contact with the solid material. Contact angle is also a measure of surface contamination and gives the information about surface roughness and heterogeneity. The shape of the liquid droplet depends on the type of the solid material and physical and chemical state of its surface. Smaller the contact angle, the more wettable is the surface and vice versa. Generally surfaces with less than 35 degree are hydrophilic and those with greater than 90 degree are hydrophobic.

Reduction in hydrophobicity will lead to an increase surface leakage current activity which will contribute to increased surface dryness.

Silicone rubber inherently is hydrophobic in nature. But tracking phenomenon is the aggravation of effect of pollutants on the surface. So for a polymeric insulator to impart tracking resistance, the retention of hydrophobicity place a significant role. To evaluate the above, contact angle was measured before and after the inclined plane tests for the samples.

From the above figure it is evidently clear that, the reduction in contact angle for unfilled, 5% silica filled, 5% zinc oxide filled and 5% zinc oxide+silica filled are 59.7º, 34.2º, 33.0º, 14.1º respectively.

Therefore the loss is hydrophobicity in 5%silica filled, 5% zinc oxide filled and 5% zinc oxide+silica filled are 25.5º, 26.7º, 45.6º less compared to the unfilled sample.

This lower reduction in hydrophobicity will deflect the increase in leakage current on composite insulator surface and increase the flash over voltage under the wet conditions. It can also be stated that hydrophobicity will be recovered in case of less reduction

8. ANALYSIS OF MECHANICAL STRENGTH:
Table 3 shows the comparison of mechanical properties of various samples. Mechanical properties such as Tensile strength, elongation at break and hardness was measured.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tensile strength Kg/sq.cm</th>
<th>Elongation at break %</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfilled silicone rubber</td>
<td>41.8</td>
<td>132.8</td>
<td>76</td>
</tr>
<tr>
<td>5% SiO₂ filled</td>
<td>42.3</td>
<td>136.32</td>
<td>76</td>
</tr>
<tr>
<td>5% ZnO filled</td>
<td>49.64</td>
<td>137.21</td>
<td>78</td>
</tr>
<tr>
<td>5% ZnO +SiO₂ filled</td>
<td>39.32</td>
<td>142.76</td>
<td>76</td>
</tr>
</tbody>
</table>
From the table and graphs, it is evident that Zinc oxide filled samples shows increased hardness and tensile strength. But Elongation at break was higher for the samples filled with 5% ZnO+ SiO$_2$.

**9. CONCLUSION:**

It was observed that the samples prepared without nano fillers showed considerable hardness and tensile strength. But with 5% SiO$_2$ filled samples, the tracking resistance is improved with respect to reduction in leakage current and the tracking time is extended compared with unfilled samples. For 5% ZnO filled samples significant improvement in mechanical strength has been observed. The tracking time is greatly extended compared to other samples. For the 5% ZnO+ SiO$_2$ filled samples much difference in the tracking length was not observed. But the erosion depth was reduced compared to other samples. The loss of hydrophobicity is also very low compared to other samples.
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REFERENCES


