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MICROSCOPIC STUDY OF A SOLID INSULATING MATERIAL AFTER BREAKDOWN UNDER DC and AC VOLTAGES

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Abstract- The monitoring of the state of the insulation and it's interpretation is an important and challenging task. In order to monitor the state of the insulation after application of various voltages under DC and AC conditions, the samples of the paper insulating material Leatherite paper was observed under Scanning Electron Microscope (SEM). The SEM (JEOL JSM-6480LV) was operated in low vacuum mode in order to observe the samples, which are difficult to view due to excessive surface charging. The experimental data were obtained by using a cylinder-plane electrode system with artificially created cavities punched at the centre of the sample. The SEM observations for the virgin samples of Leatherite paper (thickness of 0.13 mm) and the samples stressed with a voltage of 50%, 75% of breakdown voltage and on breakdown were taken under application of DC voltage. On comparison with a virgin sample, no indication of insulation deterioration was observed for the sample with the application of 50% of the breakdown voltage. However, at 75% of the breakdown voltage the center of the sample appears to be more whitish, indicating excessive charging of the sample. It indicates that the deterioration of sample has started. On breakdown, the sample clearly showed a puncture taking place right at the center as expected along with the whitish colour. The puncture was having an area of approximately 50 µm by 35 µm (1750 µm^2). The puncture also implies that the center of the sample was highly stressed and the breakdown is mainly due to PD in cavities of the sample. Similar procedure was also adopted for the insulating samples of Leatherite paper under power frequency AC conditions and it is observed that the PD activity is more prominent under AC rather than DC and the puncture area of 180 µm by 100 µm (18000 µm^2) was found.

Keywords: Insulation breakdown, Partial Discharge, Electron Microscopy

INTRODUCTION

PD has been an important topic of interest in the field of solid insulations over the last several decades, which is very much evident from the large number of literatures associated with it [1-6]. The PD studies can mainly be categorized but not limited to the following types; the physics of PD inception, the factors governing the breakdown voltage by PD in cavities, observation of the degradation process due to PD etc. It continues to evoke a lot of interest amongst the insulation researchers.

The physics of the PD inception for solid insulating materials has been described separately by Boggs [7] and Devins [8] wonderfully. It is well known that cavities within the solid insulating materials are the main sources of PD. These cavities are essentially gas-filled and can result from many causes. If the voltage between the electrodes is raised to the point that the field within the cavity goes above the breakdown strength for the gas within the cavity, a PD can take place that may ultimately lead to breakdown. The time taken for breakdown to occur depends on the applied voltage and the size of the cavity. At the end of the PD process, the field in the cavity can be reduced to zero. If the field in the cavity is reduced to zero, the electric field in the solid insulating sample is the same as if the cavity is filled with a conductor.

It is well understood from the existing literatures that the magnitude of the breakdown voltage due to PD in cavities for solid insulating materials is governed by many factors, such as, the thickness of the solid insulating material [9-10], void size and void diameter [11-13], void shape [14-15], nature of the applied voltage waveform [16-17], immersion medium [18-19], temperature [20], relative permittivity [9-10], void orientation [21], gas and gas pressure within the void [7]. In this paper the factors affecting the breakdown of Leatherite paper are its' thickness, the void depth and the void diameter. A SEM has been used to observe different stages of the PD degradation process occurring in Leatherite paper finally culminating in the breakdown of the material. Multiple voids are not considered as the other points in the samples of the insulating materials are lightly stressed by the developed field pattern. Section 2 of the paper describes the experimental set up and the procedure adopted for obtaining the experimental data on the breakdown voltages. Section 3 of the paper has presented the SEM observations and it's related discussion. Section 4 has provided the concluding remarks.

EXPERIMENTAL SET UP

Sample Preparation

The samples are prepared from commercially available insulation sheets of Leatherite Paper of 0.13 mm thickness. Before testing, the conditioning procedure was adopted to the test specimen in accordance with that laid in ASTM Handbook [22]. This ensured that the surfaces of the insulating sample were cleaned and dry, since the contamination on the insulating specimen or absorption of moisture may affect the breakdown voltage.

Creation of void

The voids of different sizes are artificially created by means of a spacer made up of Kapton film, with a circular punched hole at the centre. The diameter of the voids is 1.5 mm, 2 mm, 3 mm, 4 mm and 5 mm. The thickness of the Kapton spacer used is of 0.025 mm and 0.125 mm. Thus, the sizes of the void, that is, the volume of air space, depends on a typical diameter of the punched hole and thickness of the spacer.

Electrode Geometry

The cylinder-plane electrode system as shown in the Figure 1 is used for breakdown voltage measurements. The electrodes, both high voltage and ground, were made of brass. They were polished, buffed and cleaned with ethanol before the start of the experiment. Further, the electrodes contact surfaces are cleaned by ethanol between two consecutive applications of voltage to avoid contaminations that may arise due to application of voltage. Sufficient care had been taken to keep the electrode surfaces untouched and free from scratches, dust and other impurities. The insulation sample is sandwiched between the electrodes with the help of insulating supports.

Measurement of DC and AC Breakdown Voltage

The DC voltage applied to the insulating samples of Leatherite paper was obtained from a 40 kV AC/DC Series Hipot Tester (MODEL: HD 100) manufactured by Hipotronics, USA. The voltage is raised in steps of 500V and held constant for a period of 30 s in each level until the breakdown occurs. The total time from the application of voltage to the instant of breakdown were noted down. Nine data points were obtained for a particular type of sample and void condition. All the tests were carried out in air at room temperature and atmospheric pressure.

Also an AC voltage of 50 Hz is applied from the same Hipot Tester (Resolution: 200 V rms) to the insulating samples of Leatherite paper. The voltage is raised in steps of 200V (rms). Rest of the procedure is identical to that presented for DC conditions.

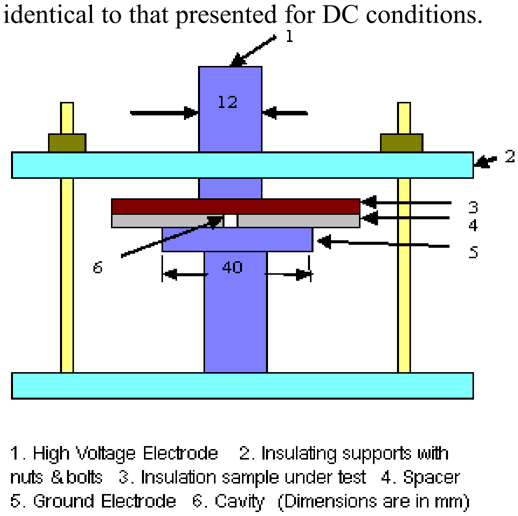
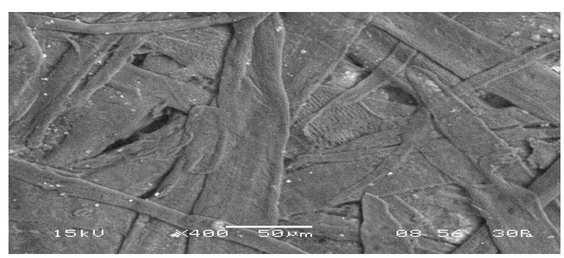


Figure 1. Cylinder-Plane Electrode System used for Breakdown Voltage Measurement

Scanning Electron Microscope (SEM) observations

The samples of Leatherite paper was observed in SEM (JEOL JSM-6480LV). The SEM was operated in low vacuum mode in order to observe the samples, which are difficult to view due to excessive surface charging.

MONITORING OF THE STATE OF LEATHERITE PAPER THROUGH SEM OBSERVATIONS



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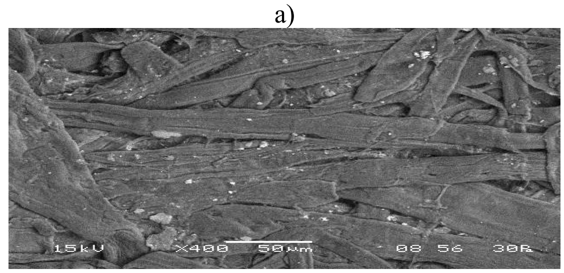

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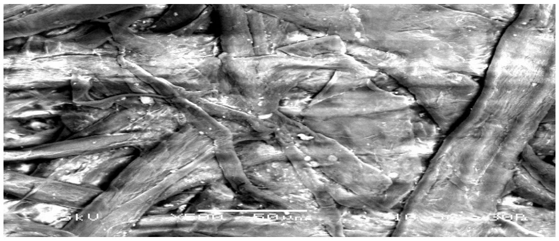

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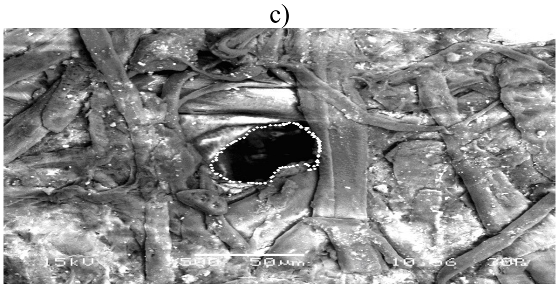
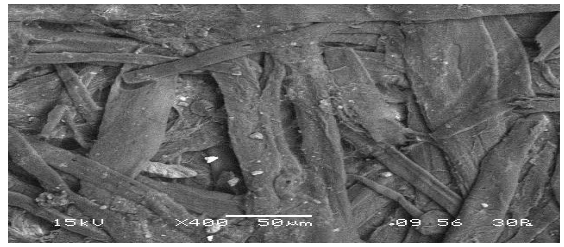


d)

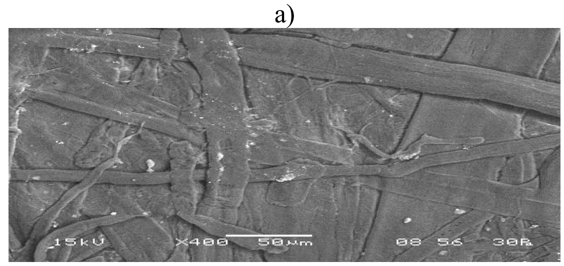
Fig. 2. SEM observations of Leatherite Paper samples a) Virgin; and stressed at b) 1.0 kV c) 1.5 kV d) 2.0 kV(Breakdown) DC Voltages (t=0.13mm, t_l=0.125mm and d=1.5 mm)

Figure 2 shows the SEM observations for the (a) virgin samples of Leatherite Paper (thickness of 0.13 mm) and the samples stressed with a voltage of (b) 1.0 kV, (c) 1.5 kV and (d) 2.0 kV (DC conditions) respectively, while the void depth was 0.025mm and void diameter was 5 mm. The breakdown of the sample took place at a voltage level of 2.0 kV. The center of the samples is healthy in Figure (a) and (b) as expected. But at 75% of the breakdown voltage (i.e. in Figure (c)) the center of the sample appears to be more whitish, indicating excessive charging of the sample. It also means that the sample has started deteriorating. The Figure (d) clearly shows a puncture taking place right at the center along with the whitish colour of the sample. The puncture is having an area of approximately 50 μm by 35 μm (1750 μm^2). The puncture also implies that the center of the sample is highly stressed and the breakdown is due to PD in cavities of the sample.

Similarly , Figure 3 shows the SEM observations for the (a) virgin samples of Leatherite Paper (thickness of 0.13 mm) and the samples stressed with a voltage of (b) 0.7 kV, (c) 1.0 kV and (d) 1.4 kV (AC conditions) respectively, while the void depth was 0.125mm and void diameter was 1.5 mm. The breakdown of the sample took place at a voltage level of 1.4 kV. Figure (a) and b) are healthy samples. The samples starts to become whitish at 75% of the breakdown voltage (i.e. in Figure (c)), indicating the general roughness and deterioration of the sample. From Figure (d) it can be safely inferred that the PD activity is quiet prominent as the puncture area is 180 μm by 100 μm.



a)



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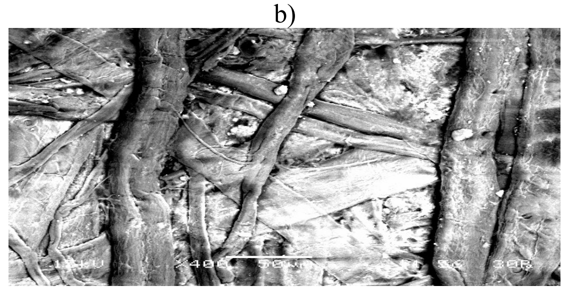

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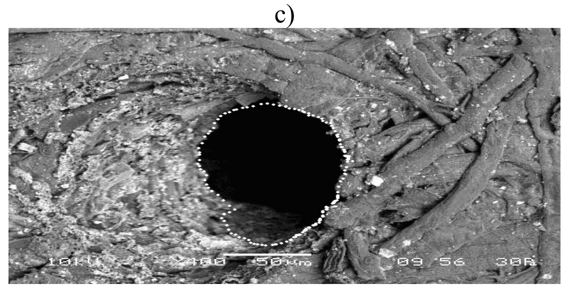

d)

Fig. 3. SEM observations of Leatherite Paper samples a) Virgin; and stressed at b) 0.7 kV c) 1.0 kV d) 1.4 kV(Breakdown) AC Voltages (t=0.13mm, t_l=0.125mm and d=1.5 mm)

CONCLUSION

The SEM images of Leatherite Paper clearly show the degradation of the material with different voltages. At different voltages the center of the sample based on the electrode dimension is stressed, such that either white spots or a conspicuous rupture occur in the samples and the breakdown is primarily due to PD. The artificial voids have been created in between the solid insulating material and the Low Voltage Electrode. In reality, the voids have different geometry and are randomly distributed in the insulating material. But, since the center of the insulating material is stressed by the electrode system considered here, the artificial voids are situated just below the center of the sample with different dimensions.

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