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Investigations of surface characterization of silicone rubber due to tracking phenomena under a.c. and d.c. voltages

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Abstract. In the present work, tracking phenomena has been studied with silicone rubber material under the a.c. and d.c. voltages following IEC-587 standards. The surface condition of the tracked zone was analysed using wide angle X-ray diffraction (WAXD) and thermogravimetric differential thermal analysis (TG–DTA) studies. The tracking time was different for a.c. and d.c. voltages.

Keywords. Silicone rubber; surface degradation; tracking; WAXD; TG–DTA.

1. Introduction

Power transmission at high voltages has acquired considerable prominence in recent times and the insulation engineers are in search of reliable insulation structures for efficient operation of the network. Silicone rubber insulators are the best alternative to glass and porcelain insulators because of their better dielectric properties, light weight and cost effectiveness. The single largest problem yet to be overcome in the overhead power transmission line insulation structures is the tracking (Yoshimura *et al* 1997). In order to improve reliability phenomena and performance of insulation material, the tracking phenomena is being investigated worldwide.

Most of the tracking studies carried out in polymer insulation are under a.c. voltage (Yoshimura *et al* 1997; Kumagai *et al* 1998; Kumagai and Yoshimura 2001). Now with the advancement of d.c. power transmission, it has become necessary to understand the tracking phenomena in polymer insulators under d.c. voltages. Hence the tracking phenomena under d.c. voltages has to be thoroughly understood especially in silicone rubber, as it is used as a best construction material for a.c. applications. A separate experimental methodology has been adapted, to understand the influence of acids on the surface condition of the polymeric material and on tracking phenomena. In addition residues formed due to tracking and the surface condition of the tracking formed zone were analysed using WAXD and TG–DTA studies.

2. Experimental

The schematic diagram of the experimental setup and the electrode configuration used in the present work are shown in figure 1. The present work has been carried out for the a.c. and d.c. voltages, following the IEC-587 (1984) test method. The specimen used in the present work was silicone rubber insulation with ATH material as filler. The a.c. and d.c. voltages were fixed at 4·5 and 4 kV, respectively. The contaminant used in the present study was 0·1 N NH_4Cl solution. The flow rate used here was 0·6 ml/min and other flow rates could be achieved using the peristallitic pump. The times to failure due to tracking arrived at once the arc inception took place near the bottom electrode and crossed two third of the gap or once the bulk volume of the material was totally eroded otherwise the process lasted for 6 h and the experiment was properly terminated.

To understand the chemical and thermal stability of the silicone rubber material, ageing studies were also carried out. The WAXD measurement was done with Philips X-ray diffractometer. The TG–DTA study was carried out with Netzch STA 409C equipment.

3. Results and discussion

The variation in tracking time of the virgin silicone rubber specimen under a.c. and d.c. voltages with NH_4Cl as the contaminant, at different conductivity levels, is shown in figure 2. It is observed that no failure of specimen occurred due to tracking under the a.c. voltages. Under the positive d.c. voltage, it is observed that the tracking is high compared to negative d.c. voltage. Table 1 shows the variation in tracking time of the silicone rubber insulation (aged under different conditions) under a.c. and d.c. voltages with NH_4Cl as the contaminant (of 2500 μs). It observed no tracking under a.c. voltage and the samples failed due to tracking under d.c. voltages.

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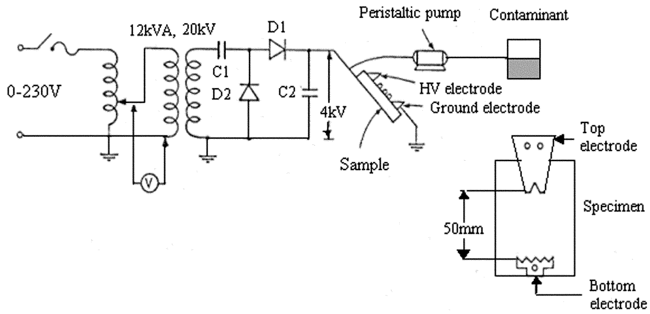

Figure 1. Experimental setup for tracking test (IEC 587).

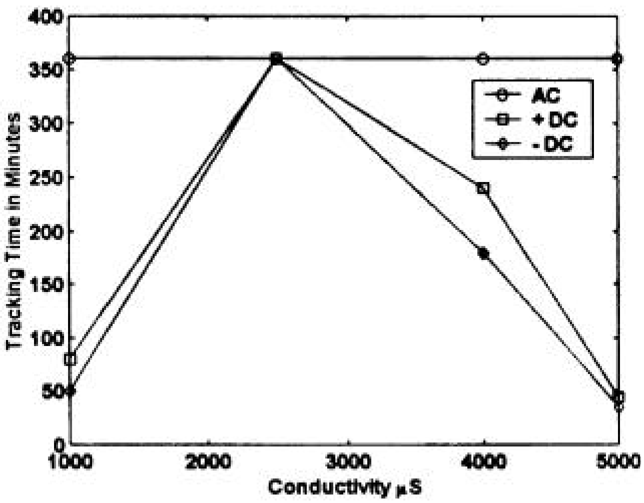

Figure 2. Variation in tracking time of silicone rubber material with different conductivity of the contaminant under different voltages.

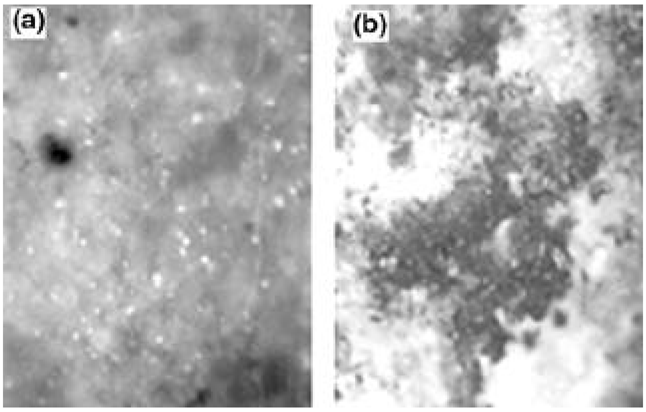

Figure 3. Optical photographs of (**a**) virgin and (**b**) tracked zone.

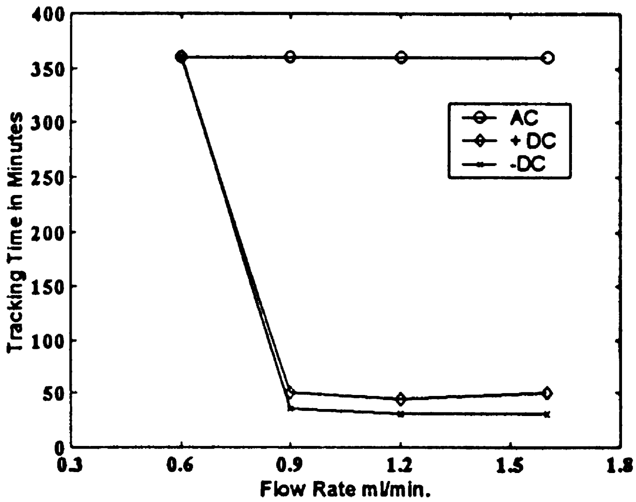

Figure 4. Variation in tracking time of silicone rubber material with different flow rates of the contaminant under different voltages.

Table 1. Variation in tracking time of aged specimen.

	Tracking time (min)		
Ageing condition	a.c.	+ d.c.	– d.c.
Virgin specimen	NF	NF	NF
Liquid nitrogen quenched	NF	105	45
Thermal aged at 150°C for 250 h	NF	NF	NF
Hexane ageing	NF	NF	NF
Nitric acid ageing	NF	NF	90

NF, No failure

Figure 3 shows the optical picture of the surface of the virgin and the tracked zone of the specimen. It is clear from the figure that tracking is a localized carbonization process. The variation in the tracking time of silicone rubber specimen under a.c. and d.c. voltages with NH_4Cl as contaminant, at different flow rates, is as shown in figure 4. It is observed that under a.c. voltages, no specimen failed in the specified time duration. Under d.c. voltages, a drastic reduction in tracking time is observed.

Figure 5 shows WAXD spectra of silicone rubber insulation material (aged under different conditions) used in the present work. The broad peak in the range 10–15° indicating that the material is silicone polymer and the peak near 20° is due to the ATH filler in the material. The peaks above 20° match with the peaks of the crystalline ATH filler material. WAXD spectra were also obtained for the residues obtained during tracking process. At the tip of tracked zone only white carbon is observed and in the body of the tracked zone black carbon is noticed. The presence of white carbon indicates that the temperature near the tip of tracked zone has raised to 1000°C, which leads to the tracking process (Kumagai *et al* 1998).

Figure 6 shows TG and DTA spectra of silicone rubber insulation aged under different conditions. The TG curve shows gradual weight loss between 200 and 550°C for

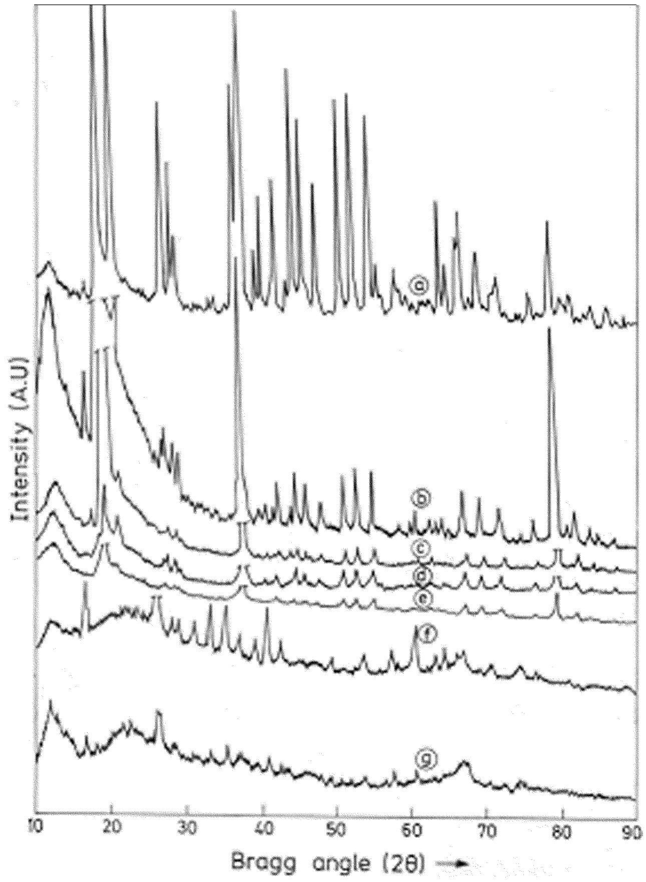

Figure 5. WAXD spectra: (a) ATH material, (b) virgin silicone rubber, (c) aged in nitric acid, (d) water aged, (e) thermal aged, (f) black carbon residue and (g) white carbon residue.

the virgin sample and for the aged samples. The DTA curve indicates a large endothermic dent at the temperature around 660°C indicating that the thermal decomposition of the silicone rubber becomes more active above 660°C. Comparing the DTA spectra of virgin and the tracked surface zone, the characteristic exothermic peaks observed at 235°, 310° and at 507°C are altered in the tracked zone indicating variation in the surface condition of the tracked zone material.

4. Conclusions

It is observed that the silicone rubber material is an ideal insulation material for a.c. voltage application. The tracking time is less under negative d.c. voltage compared to positive d.c. voltage. Increase in flow rate of the contaminant shows reduction in tracking time especially under the d.c. voltages. The WAXD and TG–DTA results indicate that the tracking process is a surface degradation process.

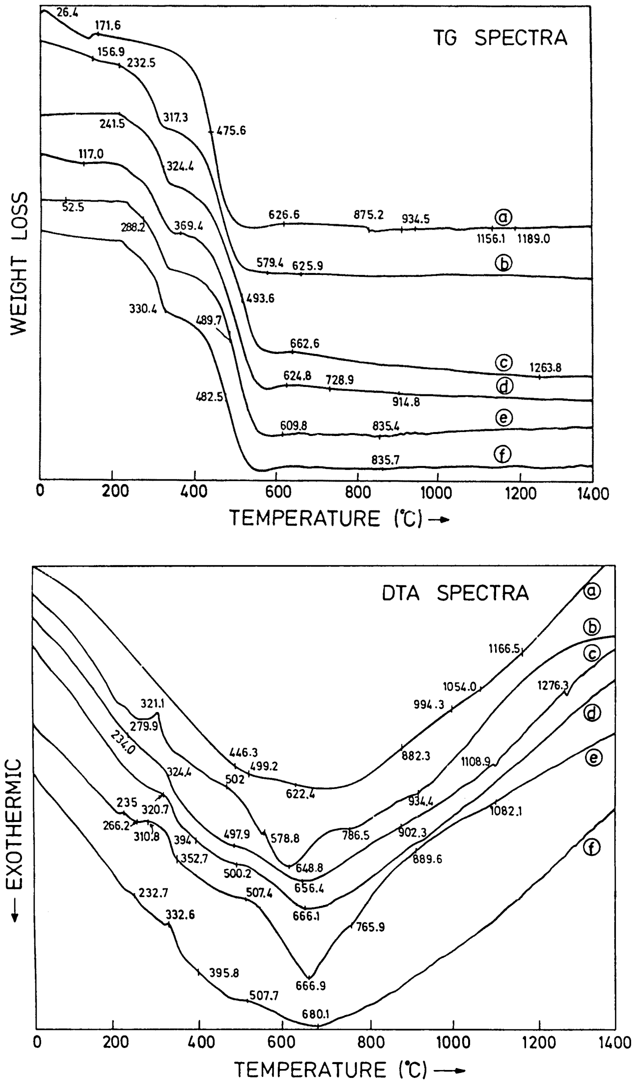

Figure 6. TG–DTA spectra of silicone rubber: (a) tracked surface, (b) samples aged in nitric acid, (c) sample dipped in hexane, (d) thermal aged sample, (e) virgin sample and (f) water aged sample.

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