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Leakage Current and Surface Discharge Phenomena: Effect on Tracking and Morphological Properties of LLDPE-Natural Rubber Compounds

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Abstract: Polymeric insulators are widely used for high voltage outdoor insulating application due to their substantial advantages compared to the porcelain and glass insulators. Although polymer materials have been proven good, research on development of new polymer-based materials is still on going since the benefits of using polymeric materials are not yet utilised to their full potential. In this work, a new formulated thermoplastic elastomer materials that are composed of linear low-density polyethylene (LLDPE) and natural rubber (NR) filled with different loadings of alumina trihydrate (ATH) fillers is presented. A surface tracking and erosion test is conducted to investigate the characteristics of leakage current on the material surface under the influence of wet contaminated conditions. A computer-based leakage current monitoring system is developed to monitor the leakage current waveform pattern as well as its frequency spectrum. The scanning electron microscope is used to investigate the morphological properties of the materials before and after the tracking test.

INTRODUCTION

High voltage composite polymeric insulators (PIs) are widely used for replacing the porcelain and glass insulators in the present time. The tremendous growth in the applications of PIs is due to their advantages such as low surface energy, higher mechanical strength to weight ratio, resistance to vandalism and better performance in the present of wet contaminated conditions [1,2]. Survey on the use of PIs all over the world, shows that almost 80% of electrical utilities would actively increase the use of PIs in the future [3].

Today, the silicone rubber, ethylene propylene rubber as well as epoxy are widely used in the manufacture of polymer high voltage insulators. Despite the fact that these materials have been proven to be viable, research on the development of new polymer-based material is still being conducted since the benefits of using polymeric materials have not been utilised to their full potential. With proper use, these materials can offer advantages such as more compact products, reduced maintenance and lower total operating cost [4].

Since most of the PIs are used in outdoors application, the surface discharge phenomenon is known to always occur on the insulator surface especially under the presence of wet and contaminated conditions. This phenomenon, which is normally known as dry-band discharge exists due to the flowing of leakage current (LC). When the insulator is wetted, a resistive surface LC flows which is generally many orders of magnitude higher than the capacitive current in the case of dry insulators. This LC results in non-uniform heating of contamination layer that eventually causes dry-band to be formed at the narrow sections where the LC density is highest. The whole voltage across the insulator appears across the high resistivity dry-band and can result in breakdown of the air above the dry-band and creates carbonised track. The insulation failure eventually occurs when the carbonised tracks bridge the distance between the electrodes.

During surface discharge process, the LC will undergo different stages that result in a deformation of the current waveforms and vary the harmonic contents [5]. This discharge activity will ultimately lead to deterioration of the mechanical and electrical properties of the material due to the chemical reactions. The modes of degradation are the formation of carbon track, cracking as well as progressive material weight loss.

This paper investigates the electrical surface discharge phenomena on the tracking and morphological properties of the newly formulated thermoplastics elastomer (TPE) materials. In order to study the surface discharge characteristics, a surface-tracking test of IEC 587 is conducted. The on-line analysis of the LC waveforms is carried out using LabVIEW software package.

EXPERIMENTAL SET-UP AND PROCEDURES

Sample Preparation

The newly formulated TPE used are the blends of linear low-density polyethylene (LLDPE) and natural rubber (NR) with different loadings of alumina trihydrate (ATH) fillers. The ATH filler is used with the base polymer to improve the surface tracking properties [6]. Table 1 shows the formulation of compounds used throughout this work. The composition of compounds with ratio of 3:2 and 1:4 (NR:LLDPE) are selected because of the good overall properties and also good miscibility blends[7].

Sample	Polymer Ratio NR : LLDPE	ATH (pph of NR/LLDPE)
B1	3 : 2	0
B2	3 : 2	50
B3	3 : 2	100
B4	3 : 2	150
D1	1 : 4	0
D2	1 : 4	50
D3	1 : 4	100
D4	1 : 4	150

Table 1: Material compositions

The NR and LLDPE with ATH are blended in a Brabender Plasti-Corder at 160°C for 13 minutes at a rotor speed of 40 rpm. Then the samples of blends are compression moulded into a 120x50x6 mm dimension in an electrically heated hydraulic press at 160°C. The total moulding time is 15 minutes at a pressure of 100-120 kg/cm^2.

Surface Tracking Test Set-up

The test is conducted based on inclined-plane tracking (IPT) test method of IEC 587 [8], and its schematic diagram is shown in Figure 1.

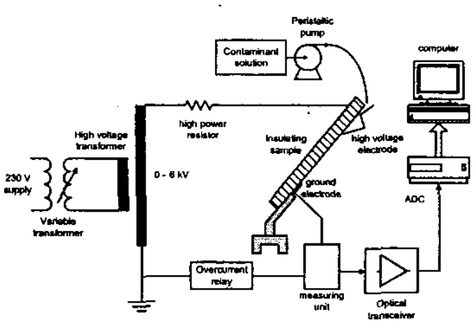

Figure 1: Experimental set-up

The sample is mounted with the flat test surface on the underside, at an angle 45° from the horizontal with the stainless steel electrodes of 50 mm apart. The sample is wetted and contaminated by flowing down continuously with 0.1% by mass of ammonium chloride electrolyte. A high voltage transformer of rating 1.0 kVA, 0-10 kV is used to apply 2.5 kV across the sample. The electrolyte flow-rate of 0.15 ml/min as per standard is used throughout the experiment. In order to get the proper flowing of electrolyte, eight layers of filter paper are clamped between the top electrode and the sample. Basically the test is successfully conducted when the effective scintillation is observed, which means the existence of small yellow to white arcs just above the teeth of the ground electrode. This arc appears within a few minutes of applying the voltage.

The study of surface discharge characteristics is carried out by measurement of surface LC that flows on the material surface. An on-line LC monitoring system is developed to monitor the test as well as to provide information on the performance of the material. A LabVIEW program is written to communicate with an analog-to digital converter (ADC) to sort out the LC signals. In addition, a Fast Fourier Transform (FFT) analysis is performed on-line and its normalised harmonic components are sorted out.

Furthermore, the experiment is extended by conducting a test at increasing electric field across the sample with fixed electrolyte flow-rate. This test is carried-out to study the relative hydrophobicity properties among the materials.

Morphological Studies

The microstructures of the polymer surface are investigated by using a scanning electron microscope (SEM) of model JEOL JSM-5610. A 20 mA sputtering current with 70 seconds coating time is used during the coating process. The electron gun of SEM is energised at 10 kV and 200 times of magnification is used to capture the micrograph of the polymer surface.

RESULTS AND DISCUSSION

The IPT test is conducted continuously for five hours under wet contaminated condition with fixed applied voltage and electrolyte flow-rate. During the test, the different stages of the LC behaviour are identified based on the waveform patterns, as illustrated in Figure 2. For the insulator that preserves the good hydrophobicity properties, the LC waveforms are sinusoidal with very small value (a few μA) is observed. Once the insulator is completely wetted or the conducting film bridged the electrodes, the LC appeared to be sinusoidal and resistive in character as shown in Figure 2(a). The value of LC suddenly increases due to the drastically dropped of surface resistivity.

The cases in which a weak dry-band activity is started or the condition where the partially lost of hydrophobic properties occur, the LC pattern becomes resistive and non-linear as depicted in Figure 2(b). Small spikes are observed at the crests of the waveform due to the corona effect. At this stage, the LC is dropped to a lower value because of the high resistance from the existed dry-band.

The LC waveform in Figure 2(c) is based on the condition when some short discharges are observed at a certain time. These discharges move rapidly from one location to another location without causing any degradation on the insulator surface. Whereas in the presence of intermittent, strong as well as continuous local arcs, the recorded LC waveform is illustrated in Figure 2(d). The electrical discharges stay rooted in a particular spot much longer and the thermal degradation is initiated on the material surface.

The frequency spectrums in the Figure 2 show the harmonic components of the LC waveforms. The symmetrical waveforms contain odd harmonic components while the unsymmetrical waveforms have all harmonic components. The total harmonic distortion (THD) of the waveforms can provide the useful information on describing the state of surface discharge phenomena [10]. In general the higher value of THD indicates that the chances of surface degradation process will initiate is possible if the discharge duration is found to be more than one second [9].

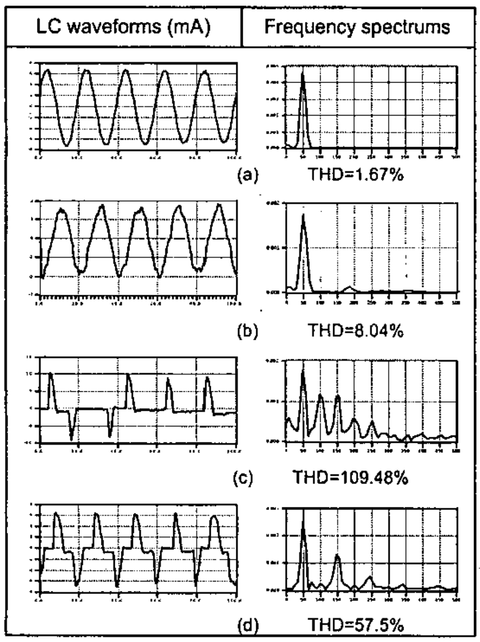

Figure 2: Typical LC waveforms and spectral frequency

Figure 3 shows the effect of ATH fillers on the surface tracking and erosion properties of the compounds. These properties are very related to the level of LC. The compound of 60% NR and 40% LLDPE with 50 pph ATH loadings shows the best in surface tracking properties in their group due to the lowest LC value. However at higher ATH loadings, the LC tends to increase. This can be explained that at higher level of ATH, the filler is difficult to disperse uniformly into polymer matrix and thus resulting in the rougher surface during compound processing. The same trends are also observed on the compound of 20% NR and 80% LLDPE with further incorporation of ATH.

However, for the compound of ratio 1:4 (NR:LLDPE), it is observed that the compound without ATH filler (sample D1) offers the best surface tracking properties. Perhaps the higher contents of LLDPE in the compound could impart high electrical tracking and fire retardance. It is believed that the LLDPE used in this material might contain suitable additive for fire retardance during manufacturing. It is shown that ATH filler is not necessary for certain composition of compounds for improving surface tracking properties. Therefore, the compound formulation is more important than the generic polymer type for outdoor insulation materials.

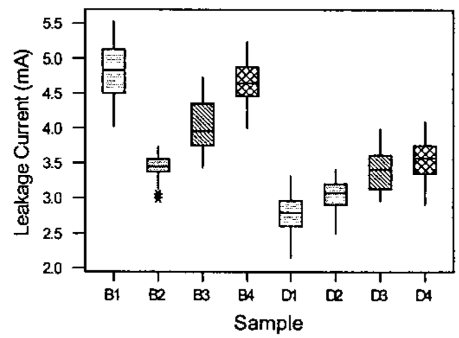

Figure 3: LC magnitude at different composition compounds

The morphological studies on the surface microstructure of the compounds are carried out using scanning electron microscope (SEM) before and after the tracking test. Figure 4 exhibits the SEM micrograph of the best compound (sample D1) and the compound with highest ATH level (sample B4).

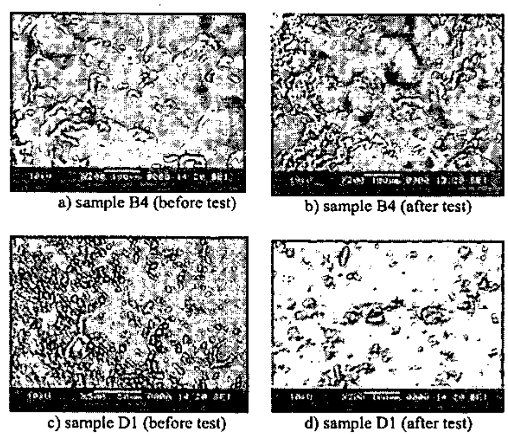

Figure 4: SEM micrograph of material surfaces

The inspection from the micrograph of the compounds without or with less content of ATH (less 50pph) reveals that the compounds are miscible. It is observed that the basic components in the compound are homogeneously dispersed and only small agglomeration of the fillers occurs. This shows that the interaction between fillers and the polymer matrix is strong. However for higher contents of ATH fillers, the material surface become rougher due to the difficulty of dispersing it uniformly in the compound as shown in Figure 4(a) where the particles of ATH fillers appear on the surface.

When the compounds are subjected to high voltage stress under wet contaminated conditions, it is observed that the surface structure is completely damaged due to the dry-band arcing. The surface structure is porous and some cracks appear as shown in Figure 4 (b) and 4(d). The degree of surface damaging depends on the level of LC as well as the characteristics of surface discharge. The sample of D1 (Figure 4(d)) shows the least damaged compared to the rest of the compounds, which is associated with the lowest LC recorded from the experiment It is also observed that the compounds with less concentration of ATH are less damaged compared to the compound with higher level of ATH (100-150 pph).

The values of LC as well as resistance to tracking are strongly related to the hydrophobicity properties. Various methods are possible for determining hydrophobicity of insulators [11]. The contact angles measurement is the most famous method because it gives directly the angle from the water droplet shape on an insulator surface. But in this work, another experiment is conducted by increasing the electric field across the sample at fixed electrolyte flow-rate. This test is carried out to determine the relative hydrophobicity properties among the materials.

Variations of surface total impedances at different electric fields indicate the relative status of hydrophobicity properties. Figure 5 exhibits the total surface impedance of sample D. These impedances are calculated from the LC and the voltage across the sample.

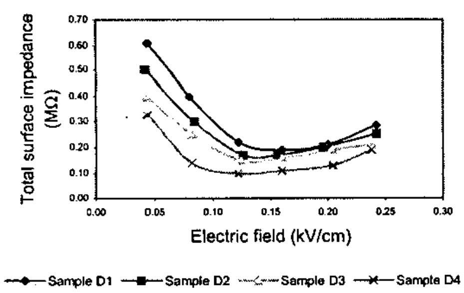

Figure 5: Surface impedance at different applied electric field

From Figure 5, it shows that sample D1 has the best hydrophobicity properties followed with sample D2, D3 and D4. The good surface hydrophobicity gives evidence on the higher surface impedance due to the lower LC that flows on the insulator surface. The same concept is used from other works when studying the surface hydrophobicities on HTV silicone rubber samples [12].

CONCLUSION

The tracking and morphological properties of LLDPE-natural rubber compounds are investigated by analysing the leakage current waveform patterns. Experimental results show that different compositions as well as the condition of material surface clearly affect the characteristics of surface leakage current and discharges. The correlation of the level of leakage current with the surface hydrophobicity properties is also discussed. In comparison to other polymer materials from previous works, it is observed that the used of LLDPE blended with natural rubber is reliable as an alternative high voltage insulating materials in the future.

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