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Charateristics of electroluminescene phenomenon in virgin and thermally aged LDPE

Nurul Aini Bani, Zulkurnain Abdul-Malek and Hussein Ahmad

Abstract

High voltage cable requires a good insulating material such as low density polyethylene (LDPE) to be able to operate efficiently in high voltage stresses and high temperature environment. However, any polymeric material will experience degradation after prolonged application of high electrical stresses or in other extreme conditions. The continuous degradation will shorten the life of a cable therefore requires further understanding on the behaviour of the aged high voltage cable which can be observed through electroluminescence (EL) measurement. EL occurs when a solid-state material is subjected to a high electrical field stress and associated with the generation of charge carriers within the polymeric material and that these charges can be produced by injection, de-trapping and field-dissociation at the metal-polymer interface. The behaviour of EL emission can be affected by applied field, applied frequency, ageing time, ageing temperature and types of materials, among others. This paper focuses on the measurement of EL emission of additive-free LDPE thermally aged at different temperature subjected to varying electric stresses at 50Hz. It can be observed that EL emission increases as voltage applied is increased. However, EL emission decreases as ageing temparature is increased for varying applied voltage.

Keywords

Electroluminescence, insulating material, thermal ageing

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Introduction

Insulators for high voltage cables require certain criteria to be met such as low dielectric loss, reasonable flexibility and thermomechanically stable. These criteria also determine the service life of a cable as prolonged application of stresses on the cable will cause the cable to be degraded. Defects such as poor adhesion, voids and inclusion are some of the possible factors of initiating degradation and ageing processes in polymeric insulating material. Electrical degradation in high voltage cable is usually initiated in the bulk or at the interfaces of the insulation material [1-3] and this can be detected using EL method. This method monitors the occurrence of light emission in dielectric material when subjected to high electric field. EL occurs when the atoms of the material are being excited to new excitation state due to the application of an external electrical field. In this paper, the EL measurement is employed to determine the effect of applied voltage on virgin and thermally aged LDPE at fixed applied frequency of 50Hz. A comparison of characteristics and behavior of EL emission of virgin and thermally aged LDPE is made under identical experimental conditions. It can be observed that EL emission increases as voltage applied is increased for both virgin and aged LDPE. However, EL emission is lower for higher ageing temperature for varying applied voltage. This is supported by the changes in the chemical bonds of the aged LDPE as observed in FTIR spectroscopy. The emission of light can be observed through Peltier-cooled electron multiplying charge coupled device (EMCCD) camera.

Materials and method

Sample preparation

Measurements were taken on additive-free LDPE films of 100μm ± 5μm. For aged LDPE, a large film is placed in a fan oven for 3 days at an elevated temperature of 310K (A310), 330K (A330) and 350K (A350). Samples are cut into 60mm x 60mm squares. Both sides of the samples are metalized with about 20nm thick of semi-transparent gold layer with sputter time of 2.5 minutes on each side and produces a gold electrode of 35mm diameter. Silicone rubber was applied around the edge of the gold electrodes to reduce the presence of other forms of discharges that can initiate breakdown. Fourier transform infrared (FTIR) spectroscopy was used to identify changes in the chemical bonds and to analyze the degree of oxidation for aged LDPE. A Perkin Elmer, FTIR Spectrum GX system with MIRTGS sensor at a resolution of $1cm^{-1}$ was used over the range 500 - $4000cm^{-1}$.

Electroluminescence Measurements

Figure 1 shows the uniform field configuration of EL experimental setup at room temperature. A plane electrode is connected to high voltage supply and a ring electrode is connected to ground. Sample is sandwiched between both electrodes and placed inside the glass chamber. Chamber is evacuated using a vacuum pump and backfilled with 1 bar of dry nitrogen to reduce any discharges that may affect the experimental results. The chamber was re-pressurized manually to ensure a constant pressure reading. This EL arrangement consists of a Peltier cooled EMCCD camera with operating temperature of 200K, a zero crossing point trigger to synchronize both EL and alternating applied field, a high voltage amplifier and a function generator. Sample is subjected to a 3kV peak to 7kV peak voltage at 50Hz, sine wave AC voltage. Voltage is increased at 0.5kV peak steps and is kept constant for 4 minutes at every steps. Phase-resolved or point-on-wave (POW) of EL measurements are taken at each step for virgin and aged samples. POW involve 100 sets of 1000 measurements with 2.168ms exposures each to improve the signal-to-noise ratio.

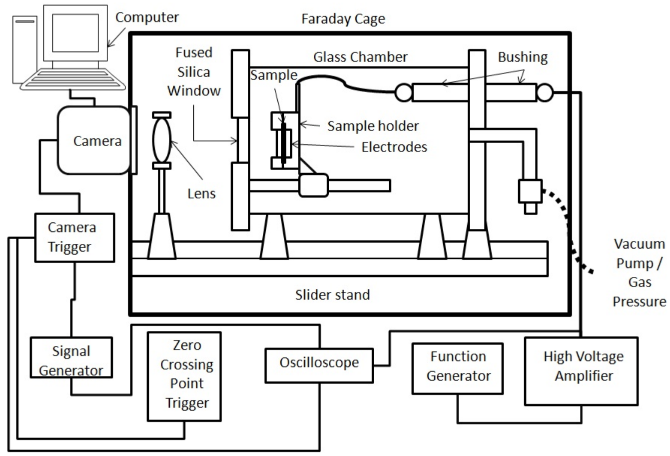

Figure 1 Experimental setup for EL measurement on LDPE samples.

Results and discussion

Electroluminescence Measurement

Figure 2 shows the POW of EL measurement of virgin sample under a 50Hz sinusoidal waveform from 3kV to 7kV peak in 0.5kV steps. It can be observed that EL emission intensity for virgin sample increases as applied voltage increases. By increasing the voltage applied, the charge injection increases and thus increases the chances of charge recombination processes [4]. It can also be seen that EL intensity is much larger at positive half cycle than that of negative half cycle for all applied voltage. This is because it is much easier for charge injection and recombination to take place at positive half cycle than at negative half cycle. The peak of the EL emission occurs prior to the peak of the applied field. This is true for both positive and negative half cycle of the applied field and supported by work of other literature [4-7]. Shifting of peak emission away from peak of applied field should occurs as applied field is increased due to increasing charge build up near the injecting electrode thus reducing the local field as obtained by other work of literature [7]. However, a closer observation shows that it happened for applied field below 4.5kV. Above 4.5kV peak, the phase angle of the EL peak tends to move towards the applied field peak.

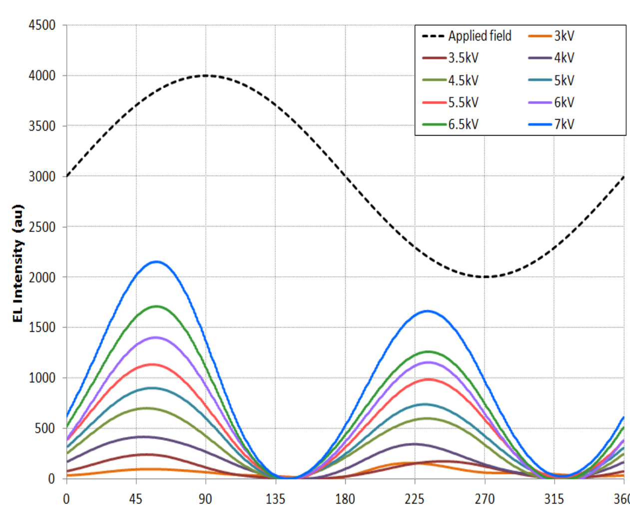

Figure 2 EL measurement of virgin sample at 50Hz, AC varying electrical stresses.

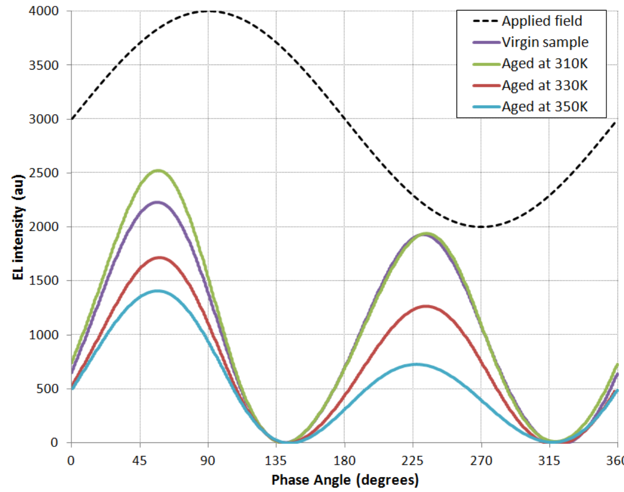

Figure 3 EL measurement of virgin and aged LDPE at 7kV peak.

Figure 3 compares the POW of EL intensity for virgin and aged LDPE. The EL intensity of A310 is higher than that of virgin LDPE at positive cycle but produce negligible variation in negative cycle. This is also true for A330 and A350 where EL intensity in positive half cycle is higher than negative half cycle. However, the EL intensity decreases as ageing temperature increases for A330 and A350. All EL peaks occur prior to the peak of the applied field but the peak of EL emission in aged samples moves towards the applied field peak for lower ageing temperature in both positive and negative half cycle. This phenomenon in the aged samples could be caused by the increased in the mobility of the charges and hence charges are able to travel deeper into the material reducing the charge build up in the electrode-polymer interface [7].

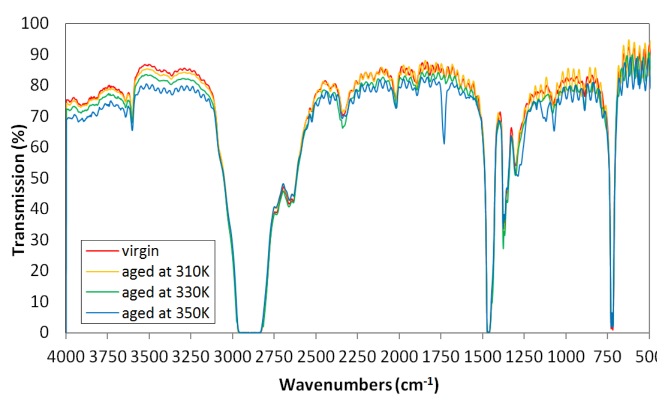

Figure 4 FTIR optical transmission for virgin and aged LDPE

The changes in the chemical bonds of the aged samples can be observed by using FTIR spectroscopy. Figure 4 shows the FTIR optical transmission of virgin and aged LDPE before being used in EL measurements. Similar changes in the FTIR spectra were observed in all the samples but with some new peaks generated for aged sample. There are two phases involve during the oxidation process of polymeric material; hydroxyl groups and carbonyl groups. The former is related to the accumulation of hydroperoxides in the areas between 3000 - 3500cm^{-1} [5]. The latter is related to the autoxidation of hydroperoxides in the area between 1500 - 1800cm^{-1} [5]. A significant change of IR spectra absorption of the LDPE samples in Figure 4 occurred at 1710cm^{-1}.

This area corresponds to the stretching vibration of carbonyl group. The virgin LDPE samples showed very low concentration of carbonyl groups which is anticipated as a result of oxidation caused by the ambience during storing and preparation under atmospheric level. A progressive increase in the absorbance of these bands can be seen in aged sample but is more evident for samples aged 350K. Another significant change in the IR spectra of thermal aged samples occurs at the 3000-3250cm^{-1} region which corresponds to hydroxyl groups. The virgin LDPE samples showed very low absorbance of hydroxyl groups but the absorbance increases as sample is aged at higher temperature. More evident changes can be seen in sample aged at 350K.

Conclusions

The characteristics of EL phenomenon in virgin and thermally aged LDPE have been discussed. The ageing temperature has changed the morphological characteristics of the material and this is evident through investigation of the optical properties of the material. The EL measurement undertaken further proves that aged LDPE greatly affects the electrical properties of the material and this measurement can be used to predict the life of a high voltage cable. As applied voltage increase, a greater amount of charges are being injected into the material. Some are trapped near the electrodes while some recombines with trapped holes resulting in the increased of EL intensity. The increased of charge build up near the electrodes also shifted the peak of the EL emission away from the peak of applied field.

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