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Observation of Space Charge Formation in XLPE/MgO Nanocomposite

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ABSTRACT

The presence of space charges that tend to distort the local electric field distribution in insulation materials have become a major concern. Preceding research works have proven that electric properties of polymer insulation can be improved by the addition of nano-sized inorganic filler. This work investigates the space charge distribution of Cross Linked Polyethylene (XLPE) nanocomposites mixed with nano-sized MgO filler. The distribution is measured using the Pulsed Electro-Acoustic (PEA) system. The results indicate that the introduction of MgO nanoparticles improves the space charge suppression substantially compared to unfilled XLPE.

1. Introduction

In recent years, polymeric nanocomposites have been regarded as the next generation insulation material with the intention to enhance insulation performance by increasing its electrical properties, especially improving the suppression of space charge injection and controlling of dissipation [7]. Nano-sized particles have been proven as an effective method to suppress the space charge accumulation in dielectric composites [8]. Currently, the mechanism of inorganic particles on the electrical and mechanical properties of polymers is of great interest. Several reports revealed that the interfaces between additives and the polymer bulk account for the space charge suppression [5].

In polymer nanocomposites, chemically dissimilar components are combined at the nanometer scale, and stronger interactions between the polymer and nanoparticles produce markedly improved materials with better electrical, mechanical and thermal performances than the conventional filled polymer composites [3]. In recent years, polymer nanocomposites have been extensively studied in optical, thermal and mechanical properties, but there has been relatively little research into dielectric

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properties. Considering polymers and polymer composites as traditional electrical insulating materials, but with some exceptions, few polymer nanocomposites are used in electrical insulation industry. Therefore, it is very important to investigate the dielectric properties of polymer nanocomposites.

The formation of space charge may distort the electrical field and distribution throughout the cable insulation thickness which may lead to the premature failure of the cable insulation at stresses below the anticipated value [4]. This condition becomes more severe during dc application.

2. Experiment

2.1 Materials

The base polymer used was an additive free cross linked polyethylene (XLPE) with a grade of 4201R and a density of 0.9–1.0 g/cm^3 provided by Borealis AG, Austria. The nanoparticles used was Magnesium Oxide (MgO) with a density of 5.61 g/cm^3 and particle size in the range of 10 to 30 nm were used, supplied by US Research Nanomaterial, USA. The weight percentage of nanoparticles in MgO is varies at 1%, 2% and 3%.

Figure 1 below shows the example of cylindrical thin film samples with an average thickness of 200 µm and a diameter of 70 mm.

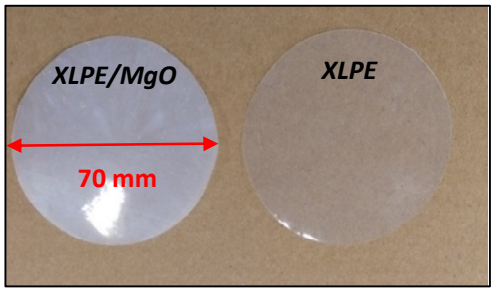

Fig. 1. The dimension of sample

2.2 Sample Preparation

Unfilled XLPE and nanoparticles were melt-blended in a twin-screw extruder at 130°C after dried in an oven for 16 hours at 55°C. After that, the nanocomposites were press moulded at 185°C and at a pressure of 10 MPa to produce thin films. Then, the samples were removed from the press and cooled down for 180 seconds to room temperature. Before the test for space charge measurement, the samples were put in a vacuum oven for 24 hours at 60°C due to uniform initial conditions. For the FTIR analysis, the samples can be used directly.

2.3 Space Charge Measurements

In this experiment, space charge measurement was performed for two different times which are at 30 minutes and at 60 minutes using a pulsed electro-acoustic (PEA) system Maeno [6] supplied by Techimp. All measurements were carried out at room temperature, the pulsed length of 10 ns, pulse amplitude is 400 V and a DC electric field of 25 kVmm^{-1}. A semi-conductive layer was sandwiched between the upper brass electrode and samples to reduce mismatch acoustic impedance. The high voltage pulse module supplied a pulsed length of 10 ns, 400 V, at 150 Hz. Calibration was conducted

at a DC field of 10 kV mm^{-1} with a short period as to minimize its influence on space charge accumulation.

2.4 FTIR Measurements

Fourier transform infrared (FTIR) spectroscopy was used to identify the unfilled XLPE and inorganic materials in nanocomposite by producing an infrared absorption spectrum. Infrared spectra were collected using a Bruker Tensor 27 equipped with a KBr beamsplitter (Pike Miracle single-bounce) with using a DTGS (deuterated tri-glycine sulphate) detector. For this testing, spectra were collected over the range of 400 to 4000 cm^{-1} with the co-addition of 32 scans at a spectral resolution of 4 cm^{-1}.

3. Results

3.1 Structure and Morphology

Figure 2 shows FTIR absorbance spectrum of the XLPE/MgO with 1 wt% to 3 wt% in comparison to unfilled XLPE spectrum. The absorption band at 1263 cm^{-1} exhibits characteristics of the bending mode of vibration in water (HOH) and the sharp and shallow band observed in the band at 2848 cm^{-1} shows the stretching mode of vibration in hydroxyl group (O-H). The peak wavenumber of 2916 cm^{-1} represents the existence of the brucite phase of $Mg(OH)_2$ [2]. Also, the wavenumber of 1463 cm^{-1} indicates to the Mg-O stretching vibration.

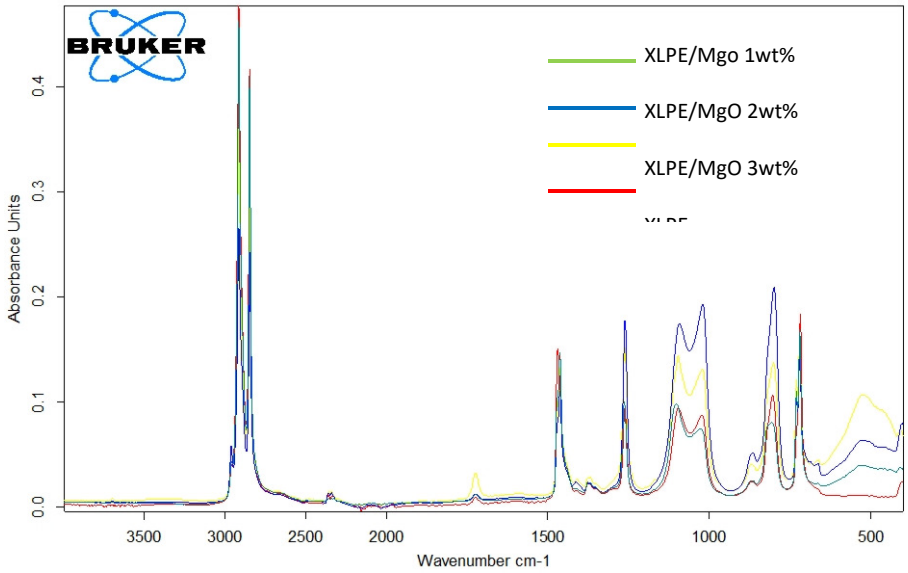

Fig. 2. FTIR spectra of XLPE/MgO nanocomposites with different weight percentage

Figure 3 shows the space charge distributions of XLPE/MgO containing 1 wt%, 2 wt% and 3 wt% nanofiller at an applied DC voltage of 25 $kVmm^{-1}$. Space charge distribution of an unfilled XLPE sample used for reference shows a minimal amount of homocharge development existing near the cathode. Also, as revealed by the graph, the injected space charge starts to form in the sample and then accumulates obvious homocharge at both electrodes. Besides that, the charge density in nanocomposites were reduced at both electrodes when compared with unfilled XLPE. The similar profiles of space charge distribution as a function of time shows that almost all types of samples had similar properties which is homocharge accumulation near both cathode and anode. The amount of

charge formed is quite similar for both electrodes.

Refering to the result in Table 1, it can be expected that the adding of the larger content of Magnesium Oxide nano filler to XLPE is more effective in suppressing the charge injection. With the addition of 3 wt% MgO, the charge injected in cathode are reduced to 75.53% while 68.9% reduction is obtained at the anode because the metal oxide nano-sized filler acts as a trap side under high DC voltage as mentioned in Arakane *et al.*, [1]. Therefore, these experiments show that the sample with the higher contents of the filler is expected to show better performance of the suppression effect.

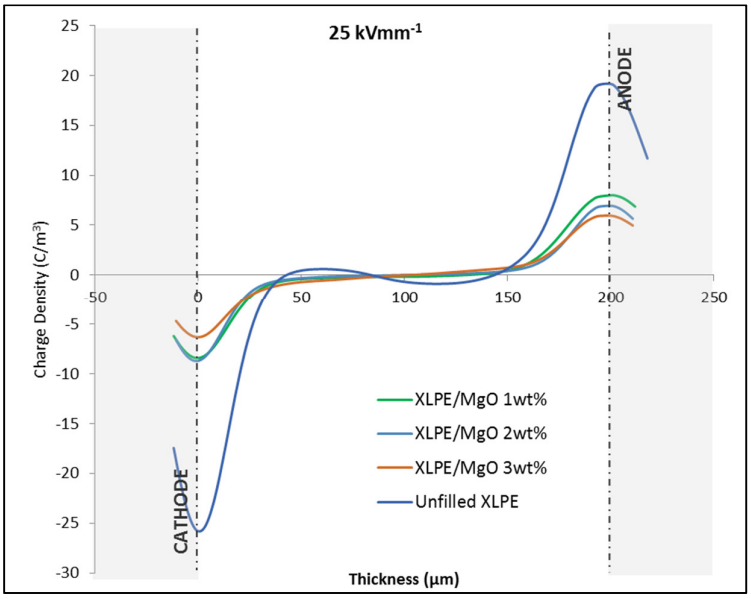

Fig. 3. Space charge measurements in XLPE and MgO nanocomposite

Table 1
Percentage reduction of charge density by Mgo nanofillers

Material	At cathode (C/m^3) %	At anode (C/m^3) %
XLPE/MgO 1 wt%	67.4	62.54
XLPE/MgO 2 wt%	66.33	65.14
XLPE/MgO 3 wt%	75.53	68.9

For this case, it can be seen that homocharge development when applied with 25 $kVmm^1$ is obviously in all the nanocomposites sample the charge magnitude decreasing with increasing of MgO contents.

Figure 4 shows the space charge distribution after 30 minutes and 60 minutes polarization. This shows the suppression of injected charge at both electrodes after voltage application. The space charge distribution is consistent with the results shown in Figure 3. For sample XLPE/MgO with 1 wt% charges injected at the cathode reduced about 38.4% and at anode is 39.92%. The sample with 2 wt% has slightly lower reduction at the cathode and anode around 6.93% and 5.24% respectively. The sample with 3 wt% also has a substantial drop at the cathode and anode with values around 31.67% and 34.01% respectively.

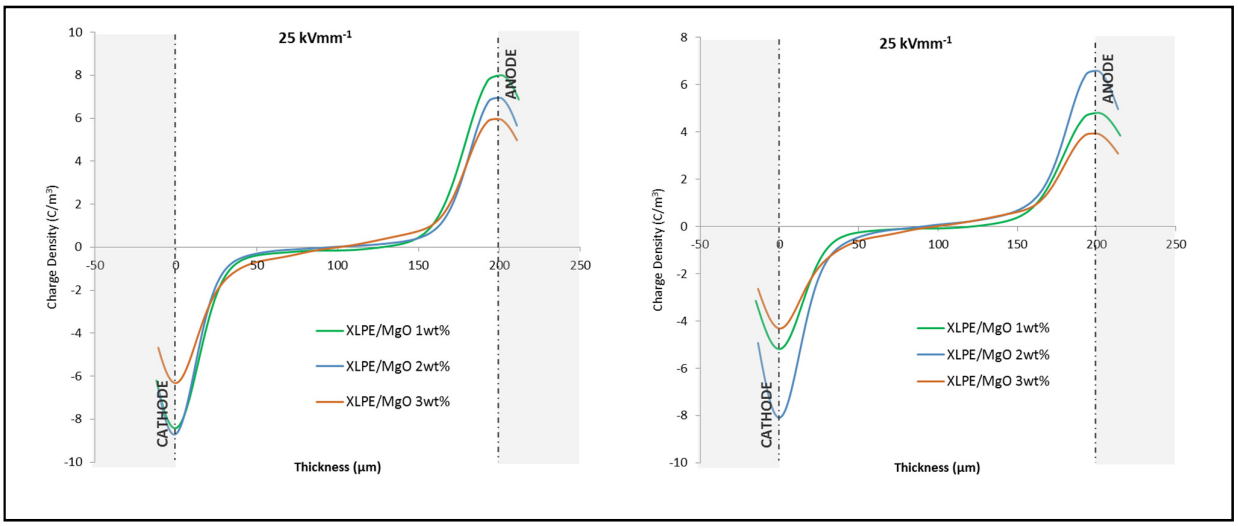

Fig. 4. Space charge measurements in XLPE and its MgO nanocomposite at (a) after 30 minutes voltage application and (b) after 60 minutes voltage application

4. Conclusion

In this study, the effect of nanofiller on space charge distribution of XLPE loaded with different weight contents of nano-sized MgO has been investigated under high 25 kVmm^{-1} DC voltage using the PEA technique. The introduction of nanocomposites will reduce carrier injection that contributes to the suppression of space charge accumulation. The amount of injection charge in the samples and its duration of time were observed. The experimental result revealed that the homocharge is formed and this injection charge is suppressed when nanofillers are added. The space charge distribution on the sample with 3 wt% suppresses 75.53% more compared to the others. Also it can be seen that the amount of charge in the sample decreases with the duration of the applied voltage.

Acknowledgements

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