에폭시의 분극 및 전하 이동

안종현[1], 최충석[2]
[1]동신대학교, [2]전주대학교

Polarization and Charge Transport in Epoxy

Jong-Hyun Ahn[1], Chung-Seog Choi[2]
[1]Dongshin University, [2]JeongJu University

Abstract – The investigations included the measurements of volume currents and also internal space charges on epoxy samples of mm thicknesses. The current versus time relations were shown to correspond well with classical forms of dielectric response such as the Curie-von Schweidler model. After the time transient, near steady currents were extremely small and exhibited a significant temperature dependence, similar in relation to the Poole-Frenkel hoping transport model. Equivalent resistances were on the order of 10^{19} ohms and represent very weak charge transport. Electrically stimulated acoustic waves were used to quantify the small internal charges that would accumulate within the epoxy. There was a notable homocharge near both anode and cathode. The dielectric response and the internal charge were related to show a consistent model for charge transport within unfilled epoxy.

1. Introduction

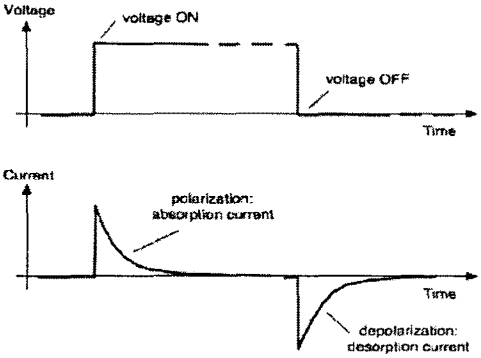
Due to the complex nature of polymer materials, conduction can rarely be explained by space-chargelimited theories, [1]. Electron conduction is usually considered to be either electrode or bulk controlled. At moderate fields, conduction is often explained as a Poole-Frenkel electron hoping effect or as a result of Schottky injection. [1] In LDPE Pool-Frenkel was reported to be the main mechanism for space charge trapping and de-trapping. [2] Others report the possibility of chemical reactions or by-products which may cause ionic charges and charge carriers, hole injection from the anode as a cause for space charges, [3] and a decrease in conduction current was linked to a decrease in heterocharge. [4]

Besides charge transport, there is polarization phenomena from the deformation and alignment of molecules. Polarization may not be fully uniform throughout the polymer and may also exhibit very localized phenomena, especially near electrodes where there is a sharp transition in material and electrical properties.

In the present studies an un-filled epoxy material is measured for polarization/conduction and additionally for internal space charge. The goal is to understand both the electrical performance of the epoxy and to establish useful means to quantify the state and condition of the material.

2. Experiment

To quantify polarization effects a fixed DC voltage was applied as a step to the sample under test while it was maintained at constant temperature (measured via an RTD) within a grounded shield enclosure. Currents as small as 10^{-14} ampere were measured by an electrometer in series with the sample. To attain fields to 10 kV/mm involved stabilized voltages as high as 50 kV. Samples were thermally stabilized at least 12 hours before voltage application and measurement began. Absorption current were measured during a polarization period of 24 hours with voltage ON, the sample was then grounded and desorption currents were measured for 48 hours. Figure 1 depicts the typical sequence for these current measurements.



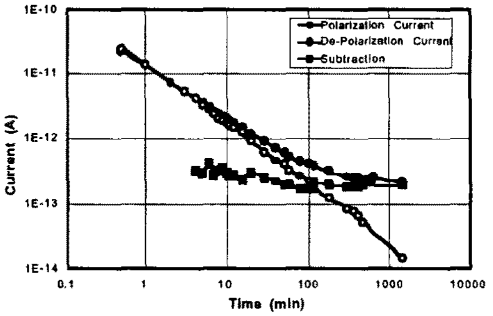
<Fig. 1> Polarization and depolarization, absorption and desorption currents.

Space charge was measured using the electrically stimulate acoustic wave (ESAW) method in a separate but parallel setup from the polarization. This is like the pulsed electro-acoustic method (PEA) and is well documented in the literature. [5] The ESAW achieved a positional resolution of about 20μm for samples up to 5 mm thick and was highly sensitive and could resolve a planar charge density of 1 nC/cm2-mm, an equivalent density of 0.01 C/m3. For these tests the sample was at room temperature, 293° K (20℃).

The epoxy samples were vacuum cast in two different forms. One was a simple small square sheet, 7.5 cm by 7.5 cm, and the other a larger disk of 20 cm diameter and tapered being thickest in the center. Sample thickness ranged from 2 to 11mm. The base epoxy was a Bisphenol-A resin hardened with phthalic acid anhydride. The samples were baked to 150° C as a final cure step. Finally, vacuum evaporated gold electrodes of 30 mm diameter were applied centrally on both sides.

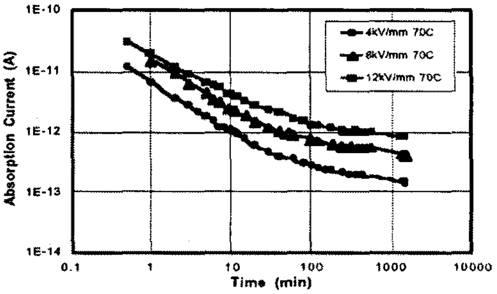
3. Result and Discussion

The measured absorption (polarization, solid dots) and desorption (de-polarization, open dots) currents, Figure 2 are very closely related during short time intervals of about 10 minutes or so. But at longer times a more constant component dominates during absorption. Here the difference of absorption minus desorption (solid squares) is nearly constant and represents a net current that is related to charge transport through the bulk of the material. The polarization component follows the Curie-von Schweidler, t-n model [6] and is a current that is not part of the bulk transport but rather concerns charges that are local near the electrodes.



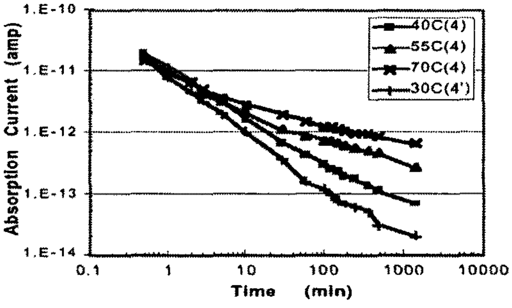
<Fig. 2> Example absorption, desorption and net currents, 8kV/mm 55℃.

Absorption and desorption currents change according to the applied electric field. This is depicted in Figure 3 for field values of 4, 8 and 12 kV/mm as measured with the large samples. A very similar set of field dependence data was obtained with the small samples.



<Fig. 3> Absorpt ion current at constant 70℃ (4 to 16 kV/mm Field),

In contrast to the current variations with field, when temperature is varied at the same applied field, the absorption currents do not change significantly at short times, and show nearly the same values. However, at longer times the currents increase significantly with increased temperature. Figure 4 depicts this for the case of 4 kV/mm and the small samples.



<Fig. 4> Currents at constant applied field 4kV/mm (30℃ - 70℃),

4. Conclusion

The resistivity values for this epoxy at fields of 1 to 16 kV/mm were very high and ranged from about 10^{+18} to almost 10^{+20} ohm-cm. The conduction exhibited a weak field dependence but strong inverse exponential (Arrenhius like) temperature dependence.

[Acknowledgement]

This work was finally supported by MOCIE program (I-2006-0-092-01).

[References]

[1] B. Sanden, E. Ildstad, R. Hegerberg, "Space charge accumulation and conduction current in XLPE insulation", 7th DMMA, pp368-373, Sept 1996.
[2] H. Seung et al, "The effect of space charges on conduction current in polymer by modified PEA method", IEEE-EI vol2, pp6678-681, 1996.
[3] N. Yoshifuji and C.M. Cooke, "Charge-Response of XLPE Power Cables to Low DC Test Stress", 8th ISH, Yokohama, Japan, pp167-170, August 1993.
[4] S. H. Lee et al, "The effect of low-molecular-weight species on space charge and conduction in LDPE", IEEE Trans. DEI-4, No.4, pp425-432, 1997.
[5] C. Cooke, "Charge Accumulation and Dynamics by Pulsed Acoustic Wave Methods", 3rd Intn'l. Conf. Electric Charge in Solid Insulators, July 1998.
[6] A. K. Jonscher, Dielectric Relaxation in Solids. Chelsea Dielectrics Press, London, 1983.