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NOTE

반도전성 전극과 가교폴리에틸렌의 전기전도특성

서 광 석 · 이 창 용 · 김 은 주 · 이 미 경*
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Semiconductive Electrodes and Electrical Conduction in Crosslinked Polyethylene

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INTRODUCTION

In measuring voltage-related properties, various types of electrodes such as vacuum evaporated metals and silver pastes are used for applying voltages to the specimen. Two major criteria in selecting the proper electrode are (1) whether it can provide the ohmic or blocking contact and (2) how the contact potential can be reduced.

In some cases, however, these factors may have to be ignored in actual experimentations. A typical example can be found in medium and high voltage power cables, where a so-called conductor strand shield exists between the metal conductor and the insulation layer. This strand shield is the crosslinked polyolefin with a high content of carbon black and acts as a layer to diminish a sudden voltage drop between the metal conductor and the insulation layer and to prevent a direct contact of the insulation layer with the metal conductor strands. In this case, for example, one may encounter the situation where the results obtained with such electrodes as vacuum evaporated metals and silver pastes can not be utilized directly for predicting the dielectric properties of the materials for cable insulations. A modification in electrical conduction characteristics of polyethylene due to different contacts has been already reported in our previous publications.[1,2] It can be said, therefore, that a semiconductive electrode made from the same material as the one for the strand shield has to be selected so as to simulate best the situation encountered in power cables.

This note describes preliminary results on the effect of semiconductive layer on dc conduction characteristics of crosslinked polyethylene, aiming to illucidate the role of semiconductive layer in XLPE-insulated power cables.

EXPERIMENTAL

About 40 μm thick XLPE films were compression molded from a commercially available XLPE, a major insulating material for medium voltage power cables. About 40 μm thick semiconductive electrodes were prepared from the one which is being used in cable manufacturing industries as a conductor strand shield for medium voltage power ca-

Table 1. Conditions of XLPE Specimen and Semiconductive Electrodes

	XLPE 1	XLPE 2	XLPE 3
XLPE	fresh[1]	fresh[1]	fresh[1]
Semicond. electrode	vac. treated[2]	sput. Al[3]	fresh[1]

[1] : Tested within a few hours after the compression molding

[2] : Under vacuum at 80℃ for 100 hours.

[3] : Sputtered Al

bles. Both materials were treated in a vacuum oven, details of which are summarized in Table 1.

J-E(current density-electric field) characteristics of XLPE with semiconductive electrodes having different prior histories were determined at temperatures from 25 to 100℃. Steady state charging currents were recorded at 30 minutes after the dc voltage was applied. Details on both instrumentation and experimentation have been described elsewhere.[1]

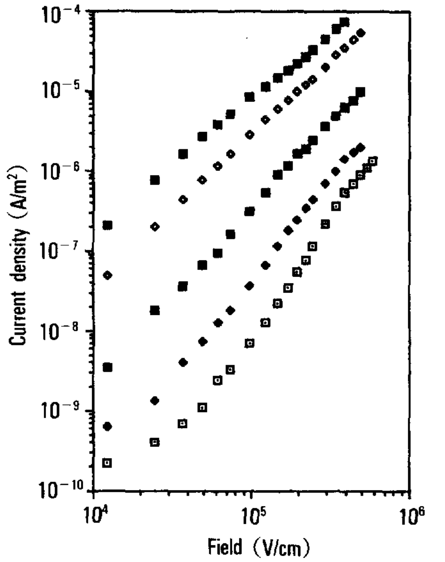

Fig. 1. J-E charactaristics of fresh XLPE with semiconductive electrode treated under vacuum at 80℃ for 100 hours : Temperatures : 25℃(⊡), 50℃(◆), 70℃(◘), 90℃(◇), 100℃(■).

PRELIMINARY RESULTS

J-E curves for XLPEs treated in different conditions can be seen in Fig. 1 to Fig. 3. A classical way to analyse the J-E curves is to investigate the conduction mechanisms from the slopes in a log J vs. log E plot.[3~7] The conduction current, or current density in this case, is proportional to E^n. That is, $J \propto E^n$. If n is equal to 1, then it means that the ohmic conduction mechanism is predominant for that range. If $2 \leq n \leq 6$, then it suggests that the space charge limited conduction(SCLC) mechanism is predominant. When $n=2$, the charges are trapped in single trapping sites. On the other hand, when $2 < n \leq 6$, the charges are trapped in distributed trapping sites.

Figure 1 shows J-E characteristics for XLPE 1 which is the fresh XLPE with the vacuum-treated semiconductive electrode. One can see that at 25℃ the slope, n, is equal to 1 below about 50 kV/cm above which n becomes approximately 2.0. This indicates that the conduction mechanism changes from the ohmic to SCLC at about 50 kV/cm. Also, a 50℃ result shows the change from the ohmic to SCLC at about 30 kV/cm, a little lower than that of a 25℃ result. Above 50℃, however, the SCLC mechanism can be seen over the entire electric fields tested. This observation agrees well with the published ones.[8~10] Similar features were found with the sputtered Al electrodes, as shown in Fig. 2. One can notice that, in both figures, data points at very high fields deviate slightly from the linearity. This may suggest that another type of conduction occur. A further analysis is under way.

However, Fig. 3 shows quite different J-E characteristics from those of both XLPE 1 and XLPE 2. XLPE 3 which is the fresh XLPE with the fresh semiconductive electrode shows a considerable suppression in the rate of change of conduction current density at some electric fields. It seems that the electric field where such suppression starts gets lower at higher temperatures. It was also found that the slope in a log J vs. log E plot changes from about 2.0 to about 1.4 and again to about

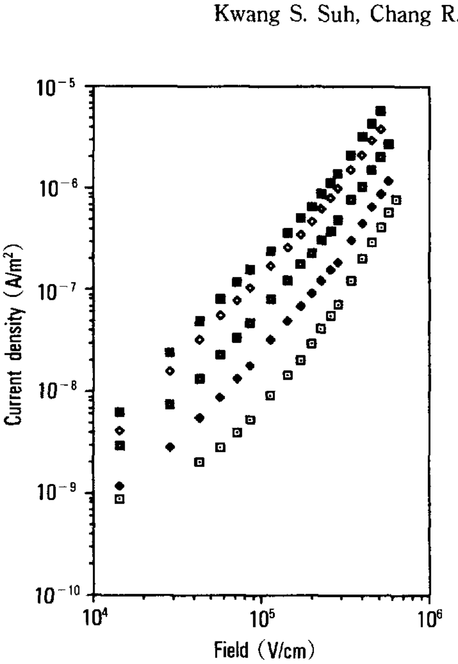

Fig. 2. J-E charactaristics of fresh XLPE with sputtered Al electrode : Temperatures : same as in Fig. 1.

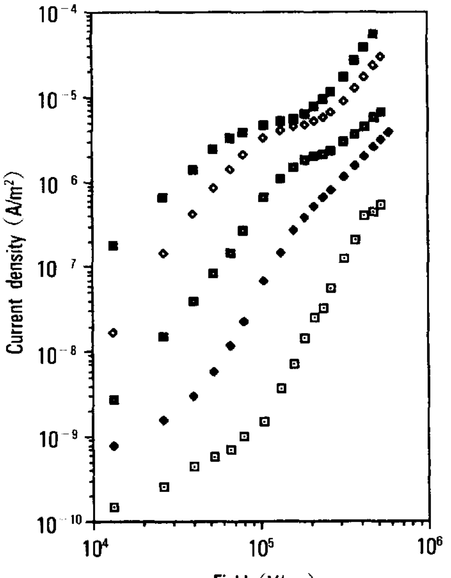

Fig. 3. J-E charactaristics of fresh XLPE with fresh semiconductive electrode : Temperatures : same as in Fig. 1.

2.0. A similar feature was observed in our previous works on the silicone-oil pasted LDPE.[1,2] In case of silicone-oil pasted LDPE, the conduction mechanism was proved, by a thickness dependence of current density, to be the SCLC regardless of different slopes.[1]

A considerable suppression in the rate of change of current density vs. electric field at a certain field range was observed in silicone-oil pasted LDPE[1,2] as well as in other polymers.[7,11~16] Polypropylene is one of the typical polymers having a so-called negative resistance characteristic(NRC). Here, NRC means that the conduction current decreases though the applied voltage increases. PVDF is also known to show a similar phenomenon. In the literature,[11~13] this type of behavior was attributed, without experimental evidences, to (1) the morphological changes caused by high electric fields and (2) the heterocharge formation at the interfacial region.

Regarding the source of current suppression, the present observation is informative. Throughout the present study, two specimens showed no such a marked suppression. These are the sputtered Al electrodes (Fig. 1) and the vacuum-treated semiconductive electrode (Fig. 2). A close comparison suggests that such suppression may come from the impurities or low molecular weight species residing in semiconductive electrodes. Semiconductive compound used as electrodes in the present study is essentially the crosslinked ethenic polymer with a high content of carbon black, so that it may have some residual byproducts such as acetophenone, cumene, moisture, methane, α-methylstyrene, as well as some impurities from the carbon black.[6] These byproducts and impurities may modify the nature of contact between the XLPE and semiconductive electrode possibly by the diffusion of these byproducts and impurities. At this moment, however, their exact roles are not known. Further study is needed to clarify what types of modification occur due to these byproducts and impurities.

An analysis of electrical conduction characteristics based upon the above results is in progress. It includes the conduction mechanism, activation energy and mobility. Also, the possibility of internal charge distribution to affect the conduction behavior is under consideration. These will be reported later.

Nevertheless, the present results suggest that the electrode materials may have to be carefully selected for a correct characterization of electrical behaviors of the system. A wrong choice of electrode material may lead to an observation of different electrical behaviors and consequently to a misunderstanding.

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