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Variations of the Electrical Treeing and Breakdown Characteristics on LDPE Due to Gamma-ray Irradiation

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Abstract : The Co^{60} γ-ray irradiation effects on the electrical and thermal characteristics of low density polyethylene crosslinked by Dicumyl peroxide (DCP) were investigated. We experimented on electrical properties as following; electrical tree inception and growing type for applying AC step voltage, AC breakdown strength, volume resistivity with increasing dosage. Also, chemical analyses were performed TGA, gel fraction. These electrical properties changed depending upon its crosslinking degree and byproducts from crosslinking reactions. Crosslinking reactions were considered causing by γ-ray irradiation and DCP had contained in low density polyethylene.

Key words: LDPE, irradiation effects, electrical tree inception, AC breakdown strength

1. Introduction

According to large sized of power system and its apparatus, organic polymeric materials are used as an insulation materials of power cable and apparatus. However, these organic polymeric materials has some disadvantages to radiation, as results of radiation degradation, mis-operation of apparatus or insulating level degradation would be occurred. Especially, even though some materials which used in radiation areas such as nuclear power plant must have radiation resistance, studies on radiation degradation of insulating materials have not been sufficient. For power cable, radiation effects of treeing degradation which causes electrical failure mainly, are much more important [1].

Therefore in this research, we investigated electrical treeing characteristics, conductivity and radiation resistance with low density polyethylene contained dicumyl peroxide, which is used as an insulating materials of power cables.

2. Experiment

2.1 Materials

Low density polyethylene contained 2%wt of dicumyl peroxide (density : 0.92 g/cm^3, Hanhwa chemical corp.) was used as a control specimen. And we made it sheet type of thickness 0.5 mm, 1.0 mm respectively, at 150°C for 3 minutes using hot press. For treeing observation, needle-plane electrodes were inserted, melt and jointed between two plane materials had different thickness as following Fig. 1. For the purpose of observation with clear, three dimensional structure of needle-plane electrodes was converted to two dimension with thin thickness, it was confirmed that no void, contaminant exist between two electrodes.

Each specimen was irradiated with 100, 200, 300, 400, 500 kGy by Co^{60} γ-ray at ambient temperature in air as 12 kGy/hr of dose rate.

2.2 Experimental measurements

2.2.1 Treeing inception voltage and propagation

Fig. 2 shows a schematic diagram of treeing observation. For measuring tree inception voltage and its propagation, we applied AC 1 kV for 1 minute, observed each specimen with optical microscope (Olympus, SZ11), for only specimen doesn't appear treeing initiation, then we applied 1 kV higher voltage than previous applied for 1 minutes, repeatedly until treeing initiation. More than 200 μm of tree length was regarded treeing inception. As soon as treeing initiated, we applied constant AC 10 kV, and observed its propagation. Every mea-

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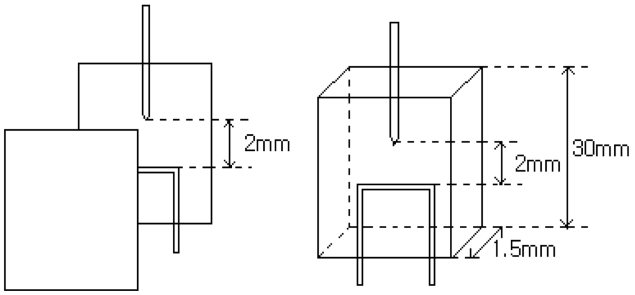


Fig. 1. Shapes of specimens

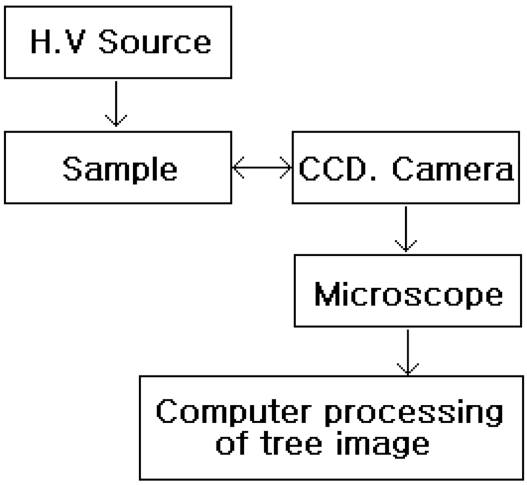


Fig. 2. Schematic diagram of electrical treeing observation

surement was carried out in the silicon oil in order to avoid surface discharge.

2.2.2 AC breakdown strength and volume resistivity

AC breakdown strength was obtained measuring thickness and breakdown voltage of specimens by AC high potential tester (Model YPS-55M), putting the specimens into silicon oil in order to avoid surface discharge.

Volume resistivity was measured by electrometer & high resistance meter (Keithley, Model 6517A) fitting up the specimen between upper and lower electrodes (diameter 70 mm) of the resistivity test fixture (Keithley, Model 8009).

2.2.3 Thermal gravimetric analysis and crosslinking degree

Thermal gravimetric analysis and gel fraction measurement were performed to confirm co-relationship between electrical properties and its probable rule. Thermal gravimetric analysis carried out with 10°C/min of increasing rate, at nitrogen atmosphere using thermo-gravimetry analyzer (TA Instrument, Model 2950). For crosslinking degree, xylene extraction method was applied in accordance with ASTM D2765 [2].

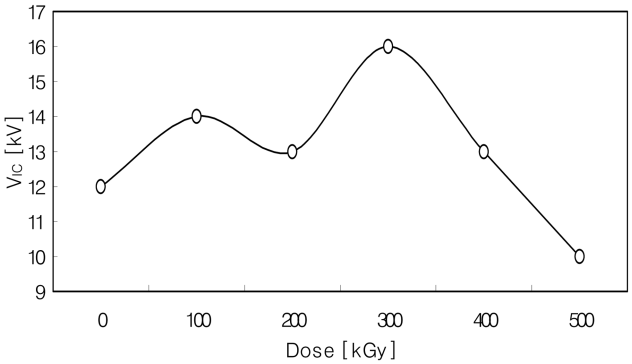


Fig. 3. Treeing inception voltage as a function of dosage

3. Result

3.1 Treeing inception voltage and propagation

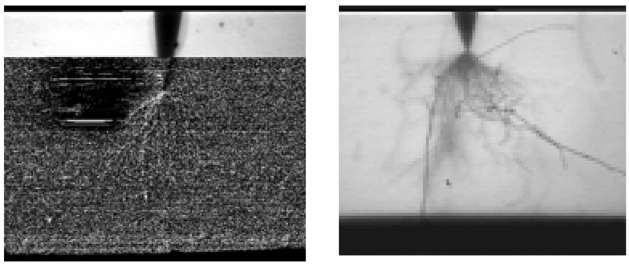
Fig. 3 shows the characteristics of treeing inception voltage as a function of absorbed dose. Beyond 400 kGy, γ-irradiated specimens showed higher treeing inception voltage than non-irradiated specimen, it is due to radiation crosslinking effect by γ-ray[3]. For polyethylene, cross-linking reaction became predominant rather than chain scission, cleavage. In absorbed dose 100 kGy, because of radiation crosslinking effect of polyethylene by itself, its treeing inception voltage wolud be better than non-irradiated. From 100 to 200 kGy, it decreased, this cause could be that radiation crosslinked polyethylene and DCP were degraded slightly. However, acetophenone produced from decomposed DCP and polyethylene at 300 kGy, made its conductivity to increase then field distribution was improved under high electric field, therefore the excellent treeing resistance was shown [4,5,6].

Above 300 kGy, treeing inception voltage became lower for radiation degradation of polyehtylene, decomposed DCP, other byproducts.

On treeing inception, its propagation was observed with applying AC 10 kV. For absorbed dose 100, 300 kGy, treeing propagated similar to bush, Quasi-bush type as shown Fig. 4, the other specimens showed nearly branch type.

3.2 AC breakdown strength and volume resistivity

Fig. 5 and 6 show AC breakdown strength (EBD) and volume resistivity (ρ_v) properties with increasing absorbed dose. These properties showed similar tendency to treeing inception voltage characteristic. It is considered that AC breakdown strength and volume resistivity were increased at 100 kGy for radiation crosslinking and 300 kGy



(a) 100 kGy irradiated AC 10 kV, 18 min.

(b) 500 kGy irradiated AC 10 kV, 18 min.

Fig. 4. Propagation of electrical treeing

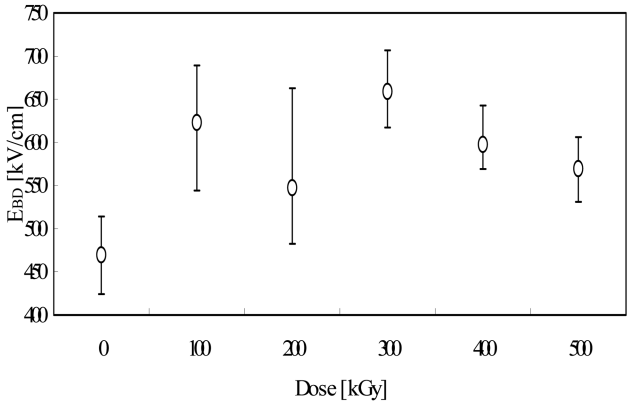


Fig. 5. AC breakdown strength as a function of absorbed dose

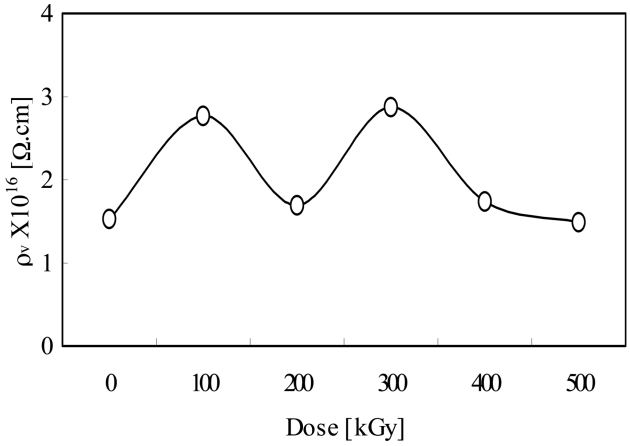


Fig. 6. Volume resistivity as a function of absorbed dose

for byproducts from polyethylene and decomposed DCP.

Also, at absorbed dose 200 kGy and above 300 kGy, it is supposed that a lot of carriers, conductive ions, contaminants produced from chain scission, cleavage by high energy radiation made both parameters be decreased [7].

3.3 Thermal gravimetric analysis and crosslinking degree

Fig. 7 shows the thermal gravimetric curve as a function of the furnace temperature. Beyond 200 kGy, de-

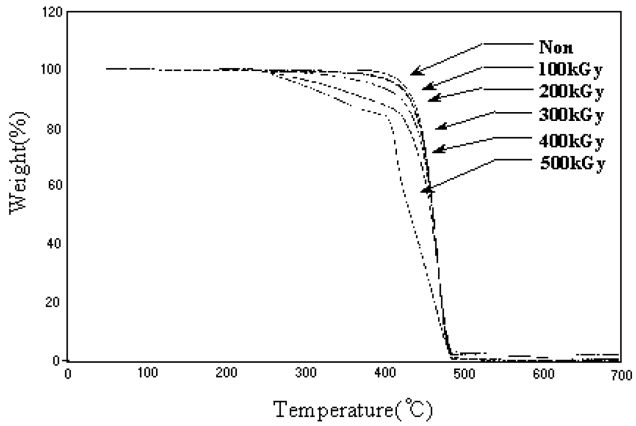


Fig. 7. TG curves plotted as a function of the furnace temperature

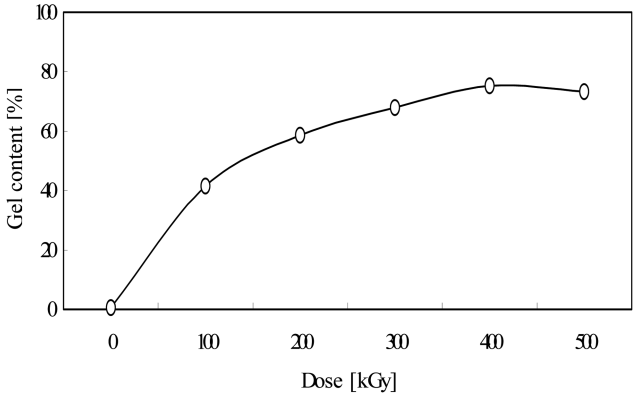


Fig. 8. crosslinking degree as a function of absorbed dose

composition degree did not have any difference, it is considered that DCP could not be activated for not enough energy so it is TGA curves for only polyethylene. At absorbed dose of 300 kGy, it shows decrease of de-composition onset to some extent, it is due to byproducts from crosslinking with activation of DCP.

Above the dosage, radiation degradation of cross-linked polyethylene and byproducts from crosslinking occurred.

Byproducts from DCP crosslinking have a benzene ring structure in general and a benzene ring has radiation resistance, therefore it is considered around 400 to 500 kGy of dosage, these byproducts are decomposed[8].

Fig. 8 shows crosslinking degree with increasing absorbed dose. It is supposed that radiation crosslinking occurred around 100 kGy and both radiation, DCP crosslinking appeared in the range from 100 to 300 kGy.

Above 400 kGy, crosslinked polyethylene and by-products were decomposed.

4. Conclusions

In this research, treeing observation, AC breakdown

strength, volume resistivity, TGA, crosslinking degree of γ-irradiated low density polyethylene contained DCP used for crosslinking agent as a whole, were investigated respectively. From these measurements and results, we concluded as following finally ;

(1) At absorbed dose 100 kGy, free radicals from side chains scission of low density polyethylene recombinated so that radiation crosslinking occurred, on the other hand, DCP which had a benzene ring was not concerned the reaction.

(2) At absorbed dose 200 kGy, radiation degradations were started in some crosslinked parts and non-crosslinked parts.

(3) At absorbed dose 300 kGy, radiation degradation from radiation crosslinked parts and DCP crosslinking happened competitively. Also by-products from DCP crosslinking affected field relaxation so that it showed excellent insulation characteristics.

(4) Above 400 kGy, crosslinked polyethylene and byproducts degraded slightly as a whole.

(5) For specimens which crosslinking became pre-dominant by irradiation, bush or quasi-bush type trees were observed because discharge path couldn't reach out. For specimens which decomposition became predominant, tree has been grew nearly branch type.

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