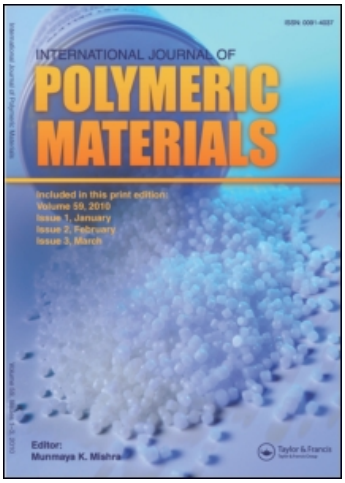

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Electrical Properties of 10 MeV Electron Beam Irradiated and Aged Low Density Polyethylene

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Polymers play a very important role in electrical systems as insulation materials. The microscopic failures occurring in the polymer under working conditions will be important in its required characteristics. In this work we focused on the effects of accelerated aging on the electrical properties of low density polyethylene (LDPE) and crosslinked polyethylene (XLDPE). The samples of LDPE were prepared in sheet form with the thickness of 0.6 ± 0.1 mm and were irradiated under the 10 MeV electron beam of a Rhodotron accelerator at the dose range of 70 to 370 kGy. Then, the samples were stored in an oven at temperature 75°C for 3, 6, 10 and 13 days. Electrical properties such as the breakdown voltage and resistance of the aged samples were measured and compared. Increasing the aging time for unirradiated samples has a serious and moderate influence on their surface resistivity and breakdown voltage, respectively. The results indicated a maximum value for the surface resistance at the optimum radiation absorbed dose, which is approximately 220 kGy for all the samples.

Keywords accelerated aging, breakdown voltage, electrical properties, electron beam, low density polyethylene

INTRODUCTION

Polymers have found extensive applications in cables and capacitors as dielectric materials [1–3]. Meanwhile, polyethylene (PE) and its derivatives

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are widely used as insulating materials for medium and high voltage wire and cable because of their excellent electrical properties. PE-insulated wire and cables are almost maintenance-free and they have a lower weight, price and thermal resistance for a given voltage and conductor cross-section. Due to these advantages, much work has recently been done to develop PE-insulated high voltage cables [4–5]. In a previous work, the influence of electron beam irradiation and the crystallinity percentage on the resistance and breakdown voltage of polyethylene has been studied [6]. It has been shown that the resistance and breakdown voltage in polyethylene are not much affected by variation in the absorbed dose of electron beam radiation. Throughout the years electrical aging of the polymeric insulation has been studied in order to increase the lifetime of high and medium voltage power cables [7]. The ultimate cause of cable failure is the localized effect of dielectric breakdown. However the dielectric properties of the insulation (bulk properties) start to change at earlier stages of aging. Therefore studying the electrical relaxation properties might help to characterize the aging status and may predict the remaining cable lifetime. In laboratory-accelerated aging experiments a good characterization of sample properties prior and after aging is important. Some previous works have investigated the changes with electrical aging in the dielectric relaxation spectra for LDPE and crosslinked polyethylene (XLDPE), showing the importance of space charge accumulation [8,9]. The purpose of this work was to study the effects of accelerated aging on the resistance and breakdown voltage and electron beam irradiated LDPE. The reason for using the elevated temperature was the possibility to perform accelerated aging nearer the service temperature.

EXPERIMENTAL

Material

Low density polyethylene (LDPE 0075) with density of $0.92\,g/cm^3$, was used in this investigation and supplied by Bandar Imam Petrochemical Company, Iran.

Sample Preparation

The samples were prepared in a sheet form with 0.6 ± 0.1 mm thickness using the warm press system. The samples were prepared in five sets and eight sheets in each set. Four sets out of five sets were stored in an oven at 75°C temperature for different times of 3, 6, 10 and 13 days. Another set was used as the non-aged samples.

Irradiation

The samples were irradiated with doses varied from 70 to 370 kGy with a constant dose rate. The irradiation was performed using the Rhodotron type electron accelerator machine, TT200 model, using a 10 MeV electron beam with a maximum of 8 mA beam current.

Characterization

Resistance

A Tera-Ohm-Meter system, P/N 6148.000 CEAST Company (Italy) was used for determining the resistance of the samples [10].

Electric Breakdown

Failure of a material, due to the application of a voltage stress, is called voltage breakdown (kV), and the voltage gradient at failure is called the dielectric strength or electric strength (usually expressed as kV/mm). A dielectric rigidity system, P/N 6135.053, CEAST Company (Italy), is used for determining the breakdown voltage of the samples [11].

RESULTS AND DISCUSSION

Two main effects result when polyethylene is subjected to ionizing radiation in the presence of air: crosslinking and oxidation. The dominance of one or the other of these processes, in the same irradiation conditions, is controlled by structural peculiarities of the polymers [12–13]. It was shown previously that the resistance and breakdown voltage in polyethylene is not affected very much by variation in the absorbed dose of electron beam radiation [6].

The non-aged samples in Figure 1 and also in Figure 2 show the same result as before. It is evident that the increase in the carbonyl content is caused by the electron beam irradiation, and the accelerated aging caused decrement in the resistance and the breakdown voltage in the samples (Figures 3 and 4, respectively). Suljovrujic et al. [12] found out that there are two different carbonyl groups because of significant growth in the absorption at about 1700 cm^{-1} and breadth of the carbonyl region, using IR analysis. The carbonyl groups are mainly ketone groups at 1718 cm^{-1} and aldehyde groups at 1728 cm^{-1} and both are formed in the amorphous region of the polymer [14]. Aldehyde-end groups are formed by decomposition of peroxides and hydroperoxides in the polymer, or by a rearrangement of the peroxy radical intermediate, caused by chain scission [12]. The relative contribution of aldehydes and ketones depends on the competition between the chain scission

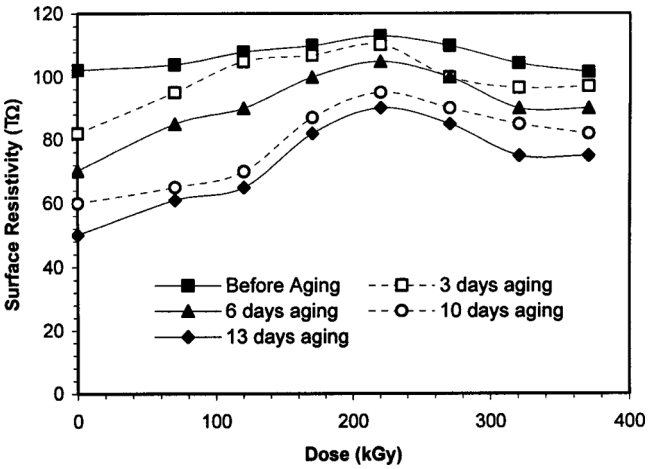

Figure 1: Surface resistance variation of the aged polyethylene samples vs. the radiation absorbed dose.

reactions and decomposition of hydroperoxides in which water is produced. On the other hand, the lower evolution of oxidized products in the samples indicates greater resistance of that polymer to radiation-induced oxidation and accelerated thermo-oxidative aging.

Furthermore, the amount of polar groups increases with increasing the absorbed dose, causing modification of the dielectric properties of LDPE. It has been established that the concentration of polar groups increases with aging as a result of post-irradiation weathering [12]. Another important aging

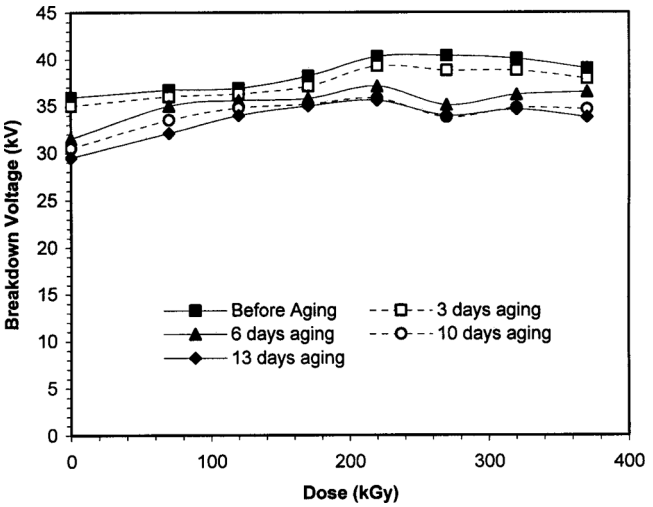

Figure 2: Breakdown voltage variation of the aged polyethylene samples vs. the radiation absorbed dose.

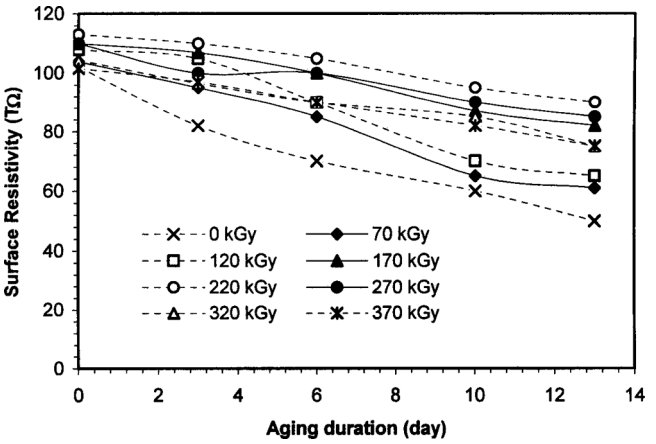

Figure 3: Surface resistance variation of the 10 MeV electron beam irradiated polyethylene samples vs. aging time.

process involved (main) chain scission. As a result of this, the average molecular weight of the polymer decreases and the molecular weight distribution changes as the reaction proceeds [15]. The change in the molecular weight distribution of polyethylene during degradation should affect the dielectric and reduce the resistance accordingly. Table 1 shows the effect of aging time on unirradiated samples, which has a serious and moderate influence on the surface resistivity and breakdown voltage, respectively. In our assumption, for the aged and irradiated samples, there is a competition between the crosslinking, oxidation and chain scission processes that makes a maximum value for

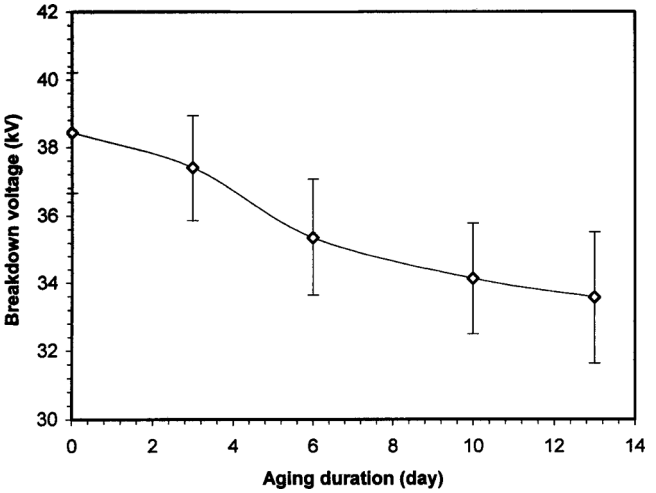

Figure 4: Breakdown voltage variation of the 10 MeV electron beam irradiated polyethylene samples vs. aging time.

Table 1: Aging effect on unirradiated LDPE samples

Aging duration (days)	Surface resistivity (TΩ)	Breakdown voltage (kV)
0	102.2	35.9
3	82.0	35.0
6	70.2	31.5
10	60.0	30.5
13	50.1	29.5

Table 2: Effect of radiation on the difference between maximum and initial surface resistivity (ΔS)

Aging duration (days)	Initial surface resistivity (TΩ)	Maximum surface resistivity (TΩ)	(ΔS) (TΩ)
0	102.2	113.0	10.8
3	82.0	110.3	28.3
6	70.2	105.0	34.8
10	60.0	95.0	35.0
13	50.1	90.1	40.0

the resistance at the optimum radiation absorbed dose, which here is obtained approximately at 220 kGy (aged samples in Figure 1).

The maximum and initial surface resistivity values at the various aging time along with their difference (ΔS) are depicted in Table 2. It can be clearly seen that ΔS seriously increases due to increasing the aging time. It means that at the lower doses the crosslinking is the dominant process, whereas, at the higher doses the chain scission will be dominated. On the other hand while the aging time is lower, the crosslinking process doesn't show its effect considerably. But, when the aging time increases, the effect of crosslinking in optimum dose can clearly be seen, to have the lower oxidation effect in this dose region. Thus, the radiation doesn't change the resistance considerably, but time will show its benefits if the samples have been treated at the optimum radiation dose.

CONCLUSION

An increase in the aging time causes a decrease in the resistance and the breakdown voltage in the polyethylene samples. The radiation dose doesn't change the breakdown voltage of the aged polyethylene samples considerably. For the aged and irradiated PE samples, there is maximum value for the resistance at the optimum radiation-absorbed dose, which here is obtained approximately at 220 kGy. Therefore, the increasing of the radiation dose

doesn't change the resistance immediately after irradiation considerably, but time will show its benefits if the samples have been treated at the optimum radiation dose.

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