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Effect of Gamma Irradiation on the Structural and Properties of High Density Polyethylene (HDPE)

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Abstract

This study presents an experimental analysis of the effect of dose parameter during gamma irradiation of commercial high-density polyethylene (HDPE) samples. The effect of different doses of γ-irradiation on the physical and mechanical properties of HDPE with different thickness (1 mm and 2 mm) was studied. The effect of γ-irradiation on HDPE led to remarkable changes in the physical and mechanical properties of the samples due to chain scission, oxygen effects and crosslinking activities. The experimental results show the mechanical properties reduce as radiation dose increase, also, it was found that HDPE with thickness (1 mm) is more susceptible than HDPE with thickness (2 mm) according to the influence of radiation.

Keywords

HDPE, Gamma Irradiation, Mechanical Properties

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1. Introduction

The TE-NORM waste occurs though the extraction and treatment of liquid and gases hydrocarbons is generally accompanied by the formation and accumulation of radioactive scales, sludges and films. The petroleum waste (scale or sludge) was produced by two mechanisms either in corporate or precipitate into the production equipment such as pipelines, tank storage, pumps etc.

The TE-NORM waste as scale and sludge generated in oil and gas equipments is due to the precipitation of alkaline earth metals as sulphates, carbonates, and/or silicates [1].

Geomembranes are used in solid waste containment systems to create a watertight environment. Geomembranes are often included as part of the engineered barrier system for modern landfills. As defined in ASTM D4439-00, a geomembrane is “an essentially impermeable membrane used with foundation, soil, rock earth or any other geotechnical engineering-related material as an integral part of a man-made project, structure or system”[2]. There are various types of geomembranes including polyvinyl chloride (PVC), chlorinated polyethylene (CPE), chloro sulphonated polyethylene (CSPE), ethylene propylene rubber (EPDM), polypropylene (PP), linear low-density polyethylene (LLDPE), medium-density polyethylene (MDPE) and, more recently, the bituminous geomembrane [2]. Because of their excellent resistance to advective flow and diffusive migration of inorganic contaminants and high resistance to aggressive leachate components. HDPE geomembranes are extensively used as part of a composite liner in landfill applications [3-7].

In this study, we assess the properties of HDPE samples to be used as geomembrane for landfills and the waste of TE-NORM.

2. Methodology

An Egyptian commercial-grade plate of high-density polyethylene (HDPE) with a thickness of 1 and 2 mm was used to produce the samples for the irradiation experiments.

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Firstly, Swelling experiment procedure according to ASTM D471 is carried out by immersing three circular samples cut from the rubber sheets with 5-mm diameter in toluene solvent for 48 h to reach equilibrium at room temperature.

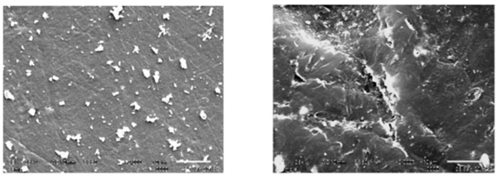
Secondly, for the mechanical tests, five dumbbells tensile specimens according to ASTM standard D 638-91; the mechanical tests were carried out on a ZWICK universal testing machine. Lastly, the hardness was measured using Shore Durometer Zwick 3150 and the Shore D Method. Tests were made before and after an exposure test to determine the relative resistance of a group of compounds to deterioration by γ-irradiation.

The gamma irradiation process was carried out in ^{60}Co source of gamma facility represented at the National Center for Radiation Research and Technology (NCRRT) with rate 6.5 KGy/hr. The HDPE samples were irradiated to the required gamma doses (0, 50, 100, 150, 200, 250 and 500) KGy.

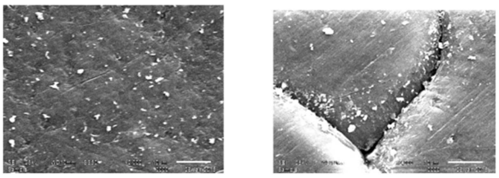
The surface of HDPE at (Zero and 0.6 MGy) was studies with JEOL. JSM-5600 LV Scanning Electron Microscope, (Japan). Samples are cut and are sputter–coated with gold using a microscope sputter coater, viewed through the microscope at National Center for Radiation Research and Technology, Cairo, Egypt.

3. Results and Discussion

3.1. SEM Study



1mm- unirradiated 1mm- 100 KGy



2mm- unirradiated 2mm- 100 KGy

Fig. 1. SEM pictures of HDPE geomembrane.

Fig. 1 represents the surface morphology of the tensile fracture HDPE samples with 1mm and 2 mm thickness at (0, 100) KGy. The surfaces of 1mm – HDPE samples (non-irradiated) appeared rough and irregular but for 2mm- HDPE samples revealed homogenous, smoother surface. After irradiated at 100 KGy, the surface of 1mm seemed more aggregations and small cracks appear on the surface of polymers, but for 2 mm thickness showed more brittle and there are very deep cracks. The cracks, rough and inhomogeneous surface of the polymer is an indicator of the structural integrity of the observed samples, and thus good mechanical properties were obtained.

Many HDPE may crack when exposed to chemical environments and/or under stress due to the release of stored stresses acquired during the extrusion process. The standard polyethylene resins used for the past 10+ years in North America by the membrane manufacturers for waste containment applications are specially formulated to resist stress cracking. Therefore, stress cracking of polyethylene geomembranes is generally not an issue for established formulations that have been tested and certified by manufacturers of HDPE [8].

3.2. Physical Properties

Most thermoplastics polymers undergo degradation on the exposure to gamma irradiation. Deterioration of the physical and mechanical properties of the polymer takes place, due to the competition of increasing in crosslinking and chain scission.

Figures 2, 3 show the results of effect of γ-doses in swelling ratio and crosslinking density, respectively. It was observed that the change in swelling ratio were decreasing initially as dose increases because of increasing in crosslinking density as showed in Figure 2, but at 100 KGy there is an unusual increase in swelling ratio and decreasing in crosslinking density this can be attributed to chain scission in the matrix of the polymers [9].

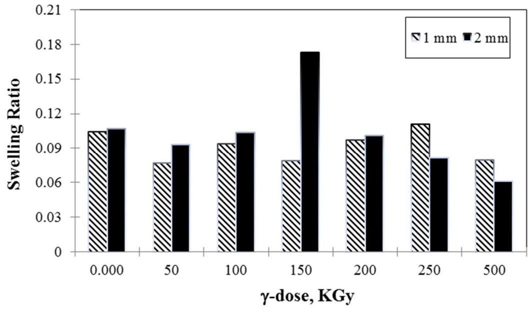


Fig. 2. The effect of g-doses on the swelling ratio of HDPE samples.

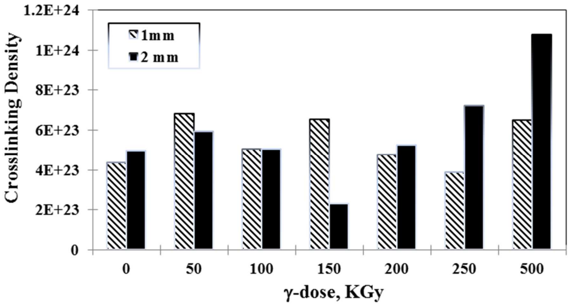


Fig. 3. The effect of g-doses on the Crosslinking Density of HDPE samples.

3.3. Mechanical Properties

Since embrittlement is one of the major consequences of polymer degradation caused by ageing, the strain at break has been considered the appropriate degradation sensitive property, which is generally accepted as a property reflecting the material functionality [10]. The mechanical properties are studied by carrying out tensile test on irradiated samples. Figures (4) and (5) show the effect of different γ- doses on the tensile strength and elongation at break of HDPE samples, respectively. It was observed that as the dose increases the matrix structure of HDPE samples becomes more brittle as indicated by the reduction in elongation up to the fracture occur. The mechanical properties of HDPE samples were also assessed based on its tensile strength as shown in Figure 4. In this case, the tensile strength seems to decrease at lower doses. However, the elongation decrease as dose increases. This contradiction in the two parameters that measure mechanical properties that is, elongation at fracture and tensile strength can be resolved as follows: in general both chain scission and cross linking take place simultaneously and in a nonhomogeneous way across the sample [10, 11].

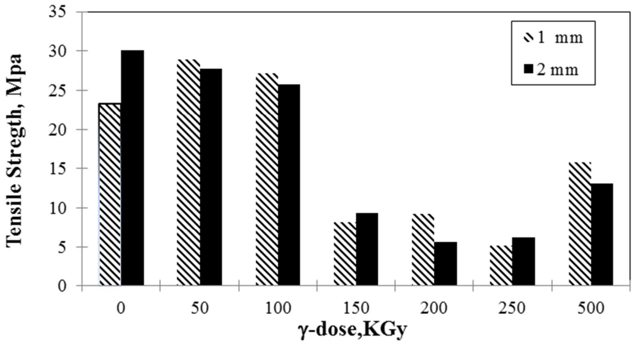


Fig. 4. The effect of g-doses on the Tensile Strength of HDPE samples.

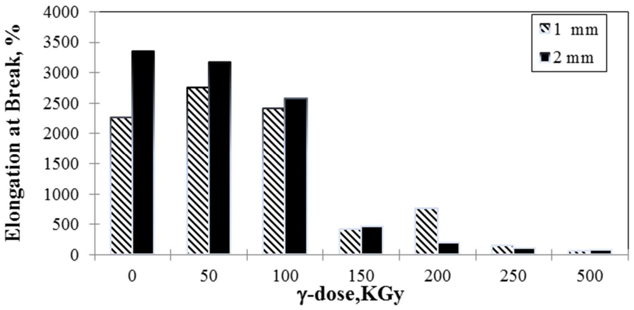


Fig. 5. The effect of g-doses on the Elongation at Break of HDPE samples.

No significant changes of hardness were found after the irradiation on the HDPE samples. For the samples of HDPE with 2mm slightly decreased up to 100 KGy and then increased with increasing of γ-doses. For the samples of HDPE with 1mm the hardness values increased slightly with increasing of γ-dose up to 200 KGy. Higher doses of irradiation had no significant effect on the Shore A Hardness (Fig. 6).

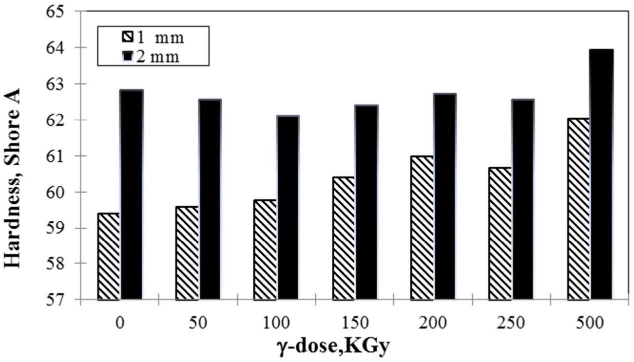


Fig. 6. The effect of g-doses on the Hardness of HDPE samples.

For HDPE with thickness1mm, it is observed that, the tensile strength and elongation at break are increasing as, the γ-dose increases up to 50 KGy and then decreases with the more increasing of γ-doses. This may due to the cross linking density which increasing with γ-doses increased. While for HDPE with thickness 2 mm, it is observed that, the tensile strength and elongation at break are decreasing as, the γ-dose increases, and this may be due to very high densities of crosslinking and chain scission induced by irradiation. It has also been shown that the geomembrane thickness has a significant effect on its oxidative degradation indicated that the rate of oxidation decreases with increasing polymer film thickness and that thick films displayed longer induction time than thin ones [12]. This is because oxidation is a function of the number of oxygen molecules available to attack the polymer chains. Since the availability of oxygen in the geomembrane is essentially diffusion controlled, increasing thickness reduces the potential for oxygen to attack the polymer. Similar effects of geomembranes thickness on their degradation has been reported by Lopes et al. [13] who observed, from laboratory investigations, a greater reduction in the tensile strength for the thin geomembrane (1.0 mm thick) compared to the thick geomembrane (2.0 mm). McKellop [14] mentions a maximum oxidation at a depth of 0.5 to 2 mm. These results are supported by Premnath et al. [15] who suggest a maximum thickness of 1.6 mm as a way of assuring the complete oxygenation of irradiated samples. In addition to the oxidation near the sample surface caused by diffusion processes, some oxidation can also occur due to the dissolved oxygen in the sample core.

4. Conclusion

It is important to observe that the experimental framework used in this work was designed to allow a comparative study of the physical and mechanical properties of non-irradiated and irradiated samples of a specific HDPE material. The results of the measurements of HDPE after irradiation showed significant changes of its mechanical and physical properties. It observed that there is a reduction of tensile strength and elongation with increasing in γ-doses, and the polymer becomes more brittle fracture. Also, it was found that HDPE with thickness (1 mm) is more susceptible than HDPE with thickness (2 mm) according to the influence of radiation. Thus, the validity of the data and conclusions obtained are limited by the assumptions and material used. In order to produce more general data, it is desirable to make use of other complementary tests to better characterize the changes in the microstructure of the material due to the application of gamma radiation**.**

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