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The Effects of Gamma Radiation on the Microstructure and Mechanical Properties of Polypropylene

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A B S T R A C T

In this study, polypropylene (PP) samples were manufactured using the hot-pressing technique. The influence of gamma ray irradiation exposure time (0, 2, 4, and 6 hours) on the microstructure and mechanical properties of commercial polypropylene (PP) has been investigated using an optical microscope and tensile test. All the samples were subjected to gamma irradiation in the presence of air. The microstructure and tensile tests were performed for non-irradiated and irradiated samples. The results show that the microstructure of polypropylene changes from a rough surface to fracture-like defects at 2, 4, and 6 hours. The stress and strain of polypropylene (PP) are increased markedly at an exposure time of 4 hours. It is identified that the tensile stress and strain have increased to 21.5 MPa and 7.2%, respectively, which amounts to an improvement of 30.3% and 24.1%, respectively. On the other hand, the irradiation exposure time of 6 hours can deteriorate the mechanical properties; it is identified that the stress and strain are decreased to 19.42 MPa and 6.6%, respectively.

1 Introduction

Polypropylene (PP) is an attractive thermoplastic with low density, a cheap production cost, excellent mechanical properties, and wide industrial and commodity applications such as food packaging, medical devices (operation gowns and covers and drug packaging), textile fibres, hygiene (diapers, disposals), absorbents, wipes, filters, or battery separators, several of which require high energy radiation. PP are mainly synthesised in three tactic forms: isotactic, syndiotactic, and atactic. But the most commercial polypropylene is isotactic and has an intermediate level of crystallinity between that of low-density polyethylene and high-density polyethylene. Isotactic polypropylene is a polymorph that crystallises in three crystalline forms, namely: monoclinic, hexagonal, and triclinic. The most common crystal modification, formed under normal processing conditions for commercial grades of PP, is the monoclinic α form. The use of gamma radiation in the processing of polymers is gaining more and more interest because it can be suggested as an alternative to the traditional chemical methods to modify the molecular structure of polymers. The possibility of radiation processing the polymeric material in the solid state opens up new opportunities to obtain materials with excellent properties. (1, 2, 3)

The major chemical changes occurring in polymers as a result of gamma irradiation are: (a) scission and/or crosslinking of the polymeric chains, their net effect determining the changes in polymer properties; (b) formation of gases and low molecular weight

radiolysis products; and (c) formation of unsaturated bonds. (2,5)

Gamma-ray radiation is a particularly useful technique for altering polymeric materials. causes highly reactive intermediates, free radicals, ions, and excited states to develop in polymeric materials. These mediators can go through a number of different reactions that result in disproportionate hydrogen extraction, configurations, and/or the production of new bonds. The extent of these changes is determined by the polymer's structure and the processing conditions before, during, and after irradiation. It is simpler to change polymers via radiation therapy when all of these parameters are under control. Radioactive crosslinking, radiation-induced graft polymerization, radiotherapy, and polymer degradation are all examples of polymer alteration at the moment. (6-8)

The aim of this work is to study the effects of gamma radiation exposure time on the mechanical properties and microstructure of commercial polypropylene.

2 Materials and Methods

2.1. Materials

Polypropylene (PP) granules shown in Figure (1.a) used in preparing the test samples were manufactured by SABIC Company, and the country of origin is the Kingdom of Saudi Arabia. We used PP with the molecular formula C_3H_6, as shown in Figure. (1.b), which is a thermoplastic additive made from a mixture of propylene monomers. It has a density of 0.91 g/cm3 and a melting point between 165 and 170 degrees Celsius (7,8). In addition, PP is resistant to abrasion and tolerates the effects of temperature well.

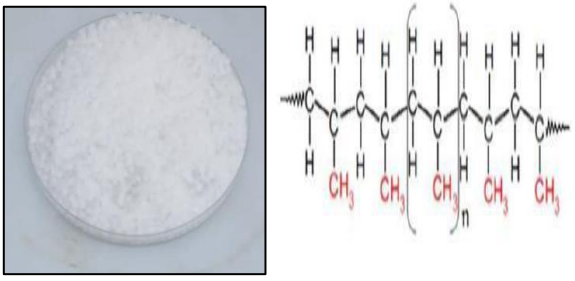

Fig. 1**:** Granules of PP used in this study (a), and PP structure (b).

2.2 Sample Preparation

2.2.1 Sample for Microstructure

These samples were manufactured using the hot-pressing technique in the laboratories of mechanical engineering at Omar Mukhtar University, Al-Bayda. The raw material was put into an iron mould, which was made according to certain standards with a diameter of 10 cm and a thickness of 2 cm, as shown in Figure (3.9). The raw material was melted in separate tube furnaces (3 zones) of HZS and TVS types shown in Figure 3.10 at 270 °C for half an hour. Then the mould was placed under the pressure device, as shown in Figure 3.11, when it was taken out of the oven directly and subjected to a pressure force of 4 bar to obtain the final shape of the samples.

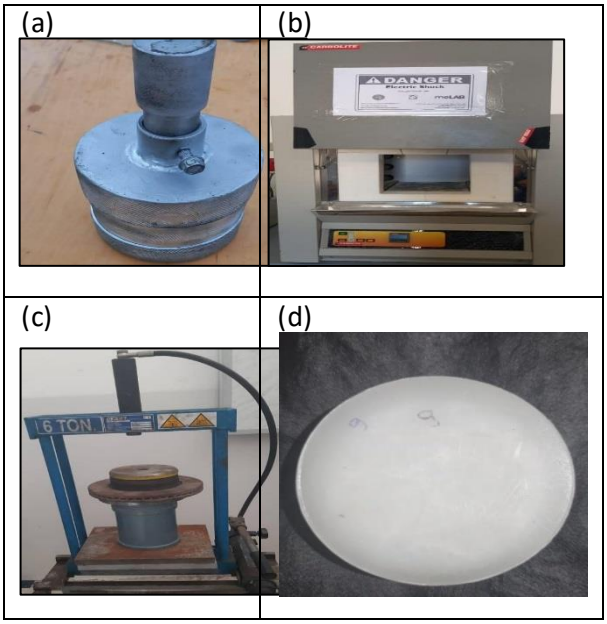

Fig. 2 iron mould (a), tube furnaces (b), pressure device (c), samples (d).

2.2.2 Sample for the tensile test

The granules were formed into samples by hot pressing. The same furnace and pressure apparatus used for the manufacture of the microstructure property samples were used. Figures (3.a) and (3.b) show the mould and shape of the obtained samples. The injection pressure was 4 bars, and the temperature used was about 230 °C. The dimensions of the samples were 4 mm in thickness, 6 mm in width, and 42 mm in length, according to ASTM (9).

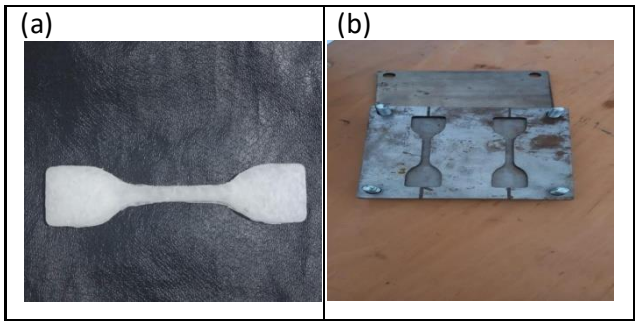

Fig. 3 sample (a), mould (b).

2.3 Gamma Ray Sources

The sources of gamma rays used in this study are cesium, which has a half-life of 30.04 years and an emitted energy of 662 KeV. Figure 4 shows the gamma-ray spectrometer that was utilised in this study.

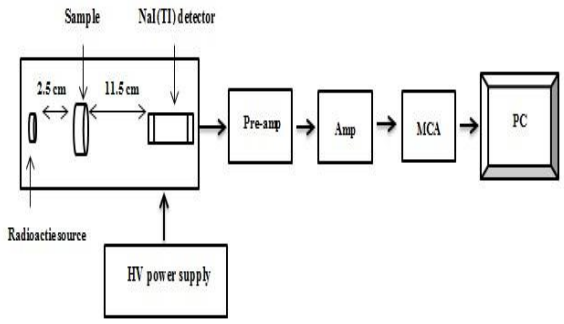

Fig .4: Schematic view of the experimental setup.

2.4 Irradiation of the Specimens

After forming the samples for tensile testing by hot pressing techniques, the next experimental step was the irradiation process. Twenty-four groups of samples (six samples without irradiation, six samples irradiated for 2 hours, six samples irradiated for 4 hours, and six samples irradiated for 6 hours) were irradiated with CS137 in the presence of oxygen with a constant 662 kV power source. The irradiation processes were carried out in the laboratories of the Department of Physics, Faculty of Science, Omar Al-Mukhtar University. The distance between the irradiated source and the samples was fixed at 3 cm. In the final experimental step, both radioactive and non-radioactive samples were tested in order to verify the effects of irradiation in the laboratories of the Faculty of Mechanical Engineering Technology, University of Benghazi.

The microstructure samples had a diameter of 10 cm and a thickness of 2 cm and consisted of four samples, one without irradiation and the others irradiated for a total of 2, 4, and 6 hours.

2.5 Mechanical Properties and the Microstructure

2.5.1 Tensile tester machines Z3, Z5

Tensile properties were measured using the universal testing machine 20+2500 N single column with tension. Testing equipment made by MPK-LUDWIG can test a wide range of materials, including metal, plastic, wood, and ceramic, and it can accurately test crucial tensile stress limits. A crosshead speed of 7 mm/min at a span distance of 25 mm was maintained during the tests. A minimum of six specimens were tested in each case to obtain the average value.

2.5.2 Microstructure Testing

The optical microscope images of the films were obtained by the OLYMPUS BX-61 system microscope under bright light. A lens with a magnification of 50 m was used to take the microscopic images. The microstructure samples were 2 cm thick and consisted of four samples, one without irradiation and the other irradiated for 2, 4, and 6 hours with a CS137 gamma ray source at an energy of 662 keV. After irradiation, the microstructure test was conducted in the mechanical engineering laboratories at Omar Al-Mukhtar University.

3 Results and Discussions

3.1 Mechanical Properties

Figure 5 shows tensile strength values for non-irradiated and irradiated samples at different times for PP using C137 with an energy of 662 KeV. The tensile strength of the samples increased with the increase in irradiation time, and the maximum value of the irradiation time was 4 hours, reaching 21.53021 MPa. However, at the end of 6 hours of irradiation, there was a slight decrease in the tensile strength, and it decreased to 19.41771 MPa.

Figure 6 shows a comparison of strain between non-irradiated tensile samples and those irradiated at different times (2, 4, and 6 hours) by C137 with an energy of 662 KeV. As shown in the figure, the irradiated samples had the maximum elongation after 4 hours, while the unirradiated samples had the lowest elongation rate. The graphic also shows that the

elongation rate value was lower at 6 hours of irradiation than at 2 and 4 hours. That is, when the irradiation time increased, there was an improvement in the amount of elongation of the material, and then it decreased by a slight amount when the irradiation time reached six hours.

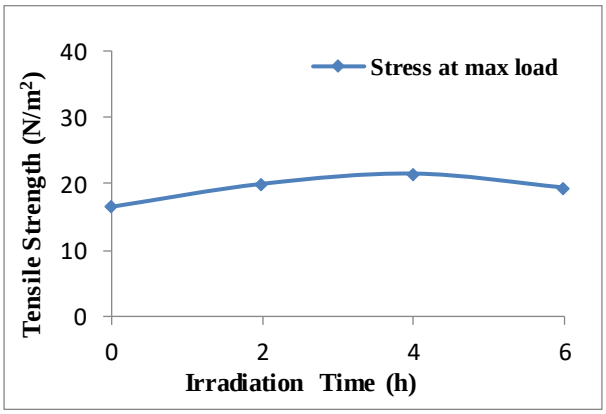

Fig. 5: Gamma radiation effects on the tensile strength (TS) of the PP

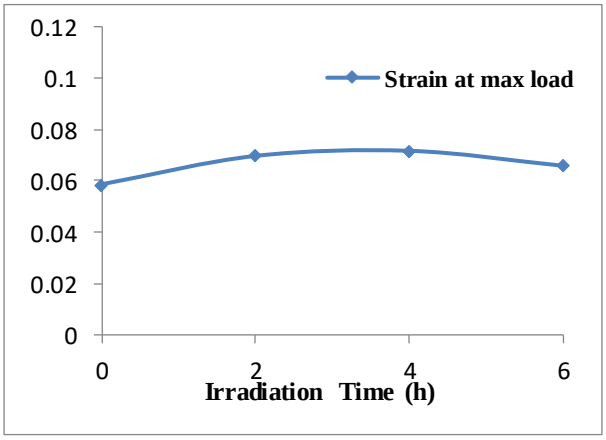

Fig. 6: Gamma radiation effects on the strain of the PP

Such a trend may be attributed to the different actual doses absorbed in each case. This can be explained by the fact that, in the presence of air, there is additional oxidative chain scission and oxidation of the polymer. More specifically, polypropylene suffers a very notable oxidative degradation, even at fairly low doses, when irradiation takes place in the presence of air. The high sensitivity of this polymer to oxidative degradation undoubtedly results from the large number of tertiary carbon atoms in its molecule. This indicates that oxygen and gamma irradiation accelerate polypropylene degradation. It is the radiation-induced oxidative degradation of polymers in the presence of air that causes the deterioration in mechanical properties such as maximum stress and strain at high doses (6 h), as shown in fig 5&6. That agreement with many researchers (10–13)

3.2 Microstructure

Figure 7 show a comparison of unirradiated and irradiated PP at different times (0, 2, 4, and 6 hours) for the microstructures, which were obtained by optical microscopic. The surface is rough for unirradiated shown in figure (a) until after irradiation dose (2,4 hours), when the roughness decreases to disappear at irradiation dose 6 hour. Exposure of the polypropylene to radiation can lead to numerous changes in the polymer structure, which in turn change the physical and chemical properties of the polymer. The changes in the polymer structure depend on the type of radiation, the polymer composition, the dose amount, and the irradiance conditions. The defects due to gamma radiation can be seen when a comparison is made between non-irradiated and irradiated surfaces; there are fracture-like defects in radiating surfaces, as seen in figs. (b–d). In general, these defects increasingly appear with increased irradiation time.

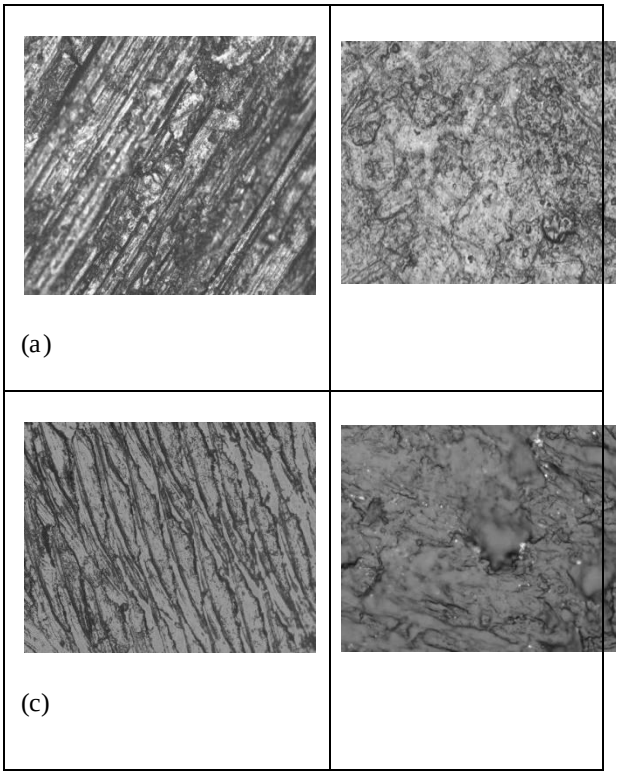

Fig. 7 (a) unirradiated pp. (b) irradiated PP 2 hours. (c) irradiated PP 4 hours. (d) irradiated PP 6 hours

That is, as the radiation increased, the discontinuity increased, and there was crosslinking of polypropylene. During the irradiation process, there is a 4 hour increase in the movement energy of the molecules in the polypropylene chain with an increase in the irradiation doses to 6 hours, which leads to a weakening of the bonding forces between the partial chains of the polymer, that causes the deterioration in mechanical properties as seen in Fig. 5. The general behaviour of the samples in this work tended to scission because of the gamma ray-induced oxidative degradation due to chain scission of the polymer backbone, where the free radicals that result from the radiation process interact with oxygen because the radiation process is done in the presence of air. Also, gamma rays lead to degradation in polymer chains with an increase in irradiation dose, as shown in Fig. (d). The present results are in good agreement with those of many researchers (13, 14).

4 Conclusion

The objective of the present study was to compare the effect of exposure irradiation time on the microstructure and mechanical properties of commercial polypropylene. In general, the results showed that:

1. The absorbed irradiation doses change the microstructure of polypropylene from a rough surface to fracture-like defects at 2, 4, and 6 hours. We observed that it is possible to improve the mechanical properties of the polypropylene by increasing the cross-linking in the chains by radiating it with gamma rays. Exposure of the polymer to radiation for 6 hours can lead to the degradation of polypropylene chains in the presence of air due to chain scission, which causes deterioration in mechanical properties.

2. The tensile strength and strain of polypropylene (PP) are increased markedly at an exposure time of 4 hours. It is identified that the tensile strength and strain have increased to 21.5 MPa and 7.2%, respectively, which amounts to an improvement of 30.3% and 24.1%, respectively. On the other hand, the irradiation exposure time of 6 hours can deteriorate the mechanical properties; it is identified that the tensile strength and strain are decreased to 19.42 MPa and 6.6%, respectively.

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