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ORIGINAL ARTICLE

Influence of gamma irradiation on mechanical and thermal properties of waste polyethylene/nitrile butadiene rubber blend

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Abstract Gamma irradiation radical–radical interaction crosslinking of elastomers and thermoplastic is a special type of crosslinking technique that has gained importance over conventional chemical crosslinking method as process is fast, pollution free, and simple. In this work a blend polymer, based on waste polyethylene and nitrile butadiene rubber, has been irradiated with gamma-rays, mechanically and thermally investigated at varying NBR content. FTIR and SEM techniques were used in addition to the swelling behavior to emphasize the blend formation. Mechanical properties like tensile strength, elongation at break and modulus at different elongations were studied and compared with those of unirradiated ones. A relatively low-radiation dose was found effective in improving the level of mechanical properties. Differential scanning calorimeter and thermogravimetric analysis were used to study the thermal characteristics of the irradiated polymer. Enhancement in thermal stability has been observed for higher NBR containing blends and via radiation-induced crosslinking up to ≈50 kGy.

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1. Introduction

Acrylonitrile–butadiene rubber (NBR) seals are commercially available for more than 50 years because of its low cost, excellent resistance to oil, fuels and greases, and easy processability (Yasin et al., 2002). NBR belongs to the crosslinking type rubber when exposed to high energy radiation. It is well known that the exposure of crosslinking type polymers to radiation provides improved stability and mechanical properties. However to crosslink NBR, high radiation doses are required to reach the desired crosslink density. But at high radiation doses the mechanical properties are adversely affected due to the degradation induced by radiation (Shafy et al., 2011; Clavreul and Pellegrin, 2001). NBR is widely used in oil seals, automotive

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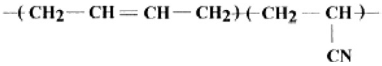
hoses and other applications. The acrylonitrile content in commercial nitrile rubber can vary from 25% to 50%. The property of the nitrile rubber is dependent on the acrylonitrile content (Chakraborty et al., 2007). The amount of acrylonitrile content determines the oil resistance of the rubber (Balachandran et al., 2010, 2012). Its use in automotive applications is interesting but the ageing resistance is limited because of the unsaturated backbone of the butadiene (Chakraborty et al., 2007). The chemical structure of NBR is shown below:



$$-(CH_2-CH=CH-CH_2)(CH_2-\underset{\underset{CN}{|}}{CH})-$$

Several studies on NBR based nanocomposites have shown that the addition of nanoclay gives a marked improvement in mechanical and barrier properties (Hwang et al., 2004; Kim et al., 2003; Balachandran et al., 2010).

The plastics waste alone is about 10 million tons per year. This is only one fifth of the actual plastics production in Europe. The difference is explained partly by long-term application (automobile industry: 15 years use; building applications: 50 years use), and partly by exports. In order to target specific polymers for recycling research, it is instructive to compare the relative quantities of the main polymer types in the municipal waste stream. In the US, five main types of polymers dominate the stream. The highest polymer waste results from low density polyethylene (LDPE), at 5 million tons per year. High density polyethylene (HDPE) is second, at 4.1 million tons.

The technology of polymer blending has emerged as a useful tool in tailoring polymers to the needs of the end users. According, blending with waste plastics is important both from the point of view of disposal of waste and the reduction in the product cost (Siddique et al., 2008). This work aimed at extending the knowledge of the impact of gamma irradiation on the thermal and mechanical properties of waste polyethylene/NBR blend.

2. Experimental

2.1. Materials

Nitrile-butadiene rubber, under the commercial name of KRYNAC 4050, was supplied by Bayer, Leverkusen, Germany, with an average acrylonitrile content of 40 wt.%, Mooney viscosity ML_{1+4} (100 °C) 50 + 5 and density 0.98 g/cm^3.

2.2. Molding

Sheets of 1 mm thickness were obtained by compressing molding between Holland cloth in clear and polished molds, adjusted beforehand to the melting point temperature of polypropylene at 170–175 °C for about 10 min. Pressure of 10 MPa was experienced by the press on the mold surfaces for 5 min. Moldings were then cooled under compression.

2.3. Gamma radiation treatment

Irradiation was carried out at the National Center for Radiation Research and Technology, Atomic Energy Authority, Cairo, Egypt. The samples were subjected to gamma radiation (gamma cell type 4000 A, India), in air, at ambient humidity and temperature. The absorbed doses were 50, 75,100 and 150 kGy at a radiation dose rate of ≈4 kGy/h.

2.4. Mechanical measurements

Tensile properties of the blends were determined by using Houns Fild computer aided testing machine, UK. The ISO 37-1977 (E) and ISO 34-1975 (E) standards were followed in measuring tensile strength, elastic modulus and elongation at break, respectively. Mechanical properties measurements were carried out on dumbbell shaped specimens of 4 mm width and 50 mm length. Experiments were progressed in triplets and the mean value was determined out of the gained results.

2.5. Differential scanning calorimetry (DSC)

The thermal properties of all composites were investigated by means of the DSC employing a Perkin–Elmer Pyris 1 calorimeter system under constant operating conditions 20 ml/min within the temperature range from ambient to 200 °C at a heating rate of 10 °C/min.

2.6. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) was performed with a Shimadzu TGA-50 system, Japan, and heated within the temperature range 20–600 °C at a rate of 20 °C/min, under a controlled dry nitrogen flow of 20 ml/min.

2.7. Infrared spectroscopic analysis

The infrared spectra were performed by using FTIR spectrophotometer, Mattson 100, Unicam, UK, over the range 500–4000 cm^{-1}. The samples were dried in a vacuum oven at 80 °C for 2 h. A dry constant weight from each blend was ground with 3 mg KBr and then pressed to form transparent discs.

2.8. Swelling measurements

The swelling degree was determined on the basis of equilibrium solvent-swelling measurements in toluene. The samples were submerged in the solvent and after the swelling equilibrium was reached, that means, no change in the weight of the swollen sample was observed, the mass of solvent was determined according to the ASTM D 471. The results were expressed as the mass of solvent absorbed per gram of blend and composite.

2.9. Morphological characterization

An ISM-5400 scanning electron microscope, JEOL, Japan, was used for morphological observation of fracture cross-section samples in liquid nitrogen and coated with gold before testing.

3. Results and discussion

3.1. Elucidation of compounding

Fig. 1. displays the FTIR spectra of unirradiated and irradiated recycled PE and its blends with NBR at various compositions. The hydrocarbon compound is represented by a strong

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