Effects of gamma and electron beam irradiation on the properties of calendered cord fabrics

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Abstract

The effects of gamma and e-beam irradiation on mechanical and structural properties of nylon 66 (Ny 66), nylon 6 (Ny 6) and poly(ethylene terephthalate) (PET) fabrics used in tyres were investigated. The untreated (greige), treated cords and calendered fabrics were irradiated at different doses. It is found that the effects of high energy irradiation on greige, treated cords and calendered fabrics are similar. No protective effect of compounds used in calendering was observed against radiation-induced oxidative degradation. The deterioration effect of gamma irradiation on mechanical properties is much higher than that of e-beam irradiation for all types of samples. Limiting viscosity numbers of both gamma and e-beam irradiated nylon 6 and nylon 66 cords were found to decrease with increasing dose. It is concluded that PET calendered fabric has higher resistance to ionizing radiation. Ny 6 and Ny 66 calendered fabrics are more sensitive even at low doses. Therefore, the effects of high energy irradiation on tyre cords have to be taken into consideration during tyre design reinforced with particularly Ny fabrics if pre-vulcanization with high energy radiation is to be applied.

1. Introduction

The curing process is the final step in tyre manufacturing, whereby a green tyre is built from plies made of rubber compounds and reinforcing fabrics. Curing and shaping of tyres are accomplished by internal and external heat treatment. In curing process, green tyre is placed into curing machine while a bladder permanently remains inside of the green tyre and the desired shape of the tyre is formed during curing under press (Han et al., 1999). Curing process has a major effect on tyre uniformity. During bladder expansion the materials should be distributed evenly for more uniform thickness, better balance and uniformity. One of the solutions for tyre uniformity problem is radiation processing of rubber plies for pre-vulcanization.

Radiation processing has been widely accepted for use in many areas of the global industry. Sterilization, polymer cross-linking (tapes, tubes, cables), tyre component curing, the conservation of art objects, the irradiation of selected food items are well-established technologies. One of the successful industrial applications of radiation processing has been the pre-vulcanization of tyres imparting shape stability prior to final vulcanization. It is important to keep the dimensional consistency of each component in due course of tyre building and final vulcanization. The carcass, however, tends to deform and flow during assembly and vulcanization due to an extensive transformation under high pressure, and results in the reduction in thickness and uneven distribution of compounds in the tyre. The conventional tyre technology overcomes this problem by using more thick and expensive compound layers. The results of pre-vulcanization are the improved green strength of the rubber compounds, especially of the inner liner and stabilization of carcass plies and higher quality tyre with more uniform thickness and better balance (Drobny, 2005; Makuuchi, 2007). Dose requirements for pre-vulcanization are in the range of 30–50 kGy (Sarma, 2005; Makuuchi, 2007). Electron beam irradiation in tyre industry for pre-vulcanization is already being applied commercially worldwide, for example, 23 major Japanese tyre companies are using electron accelerators for the production of radial tyres (Makuuchi, 2007; Minbiole, 2008). Since electron beam irradiation can be applied to different components of radial tyre, such as inner liner and carcass which is a composite of reinforcing materials and rubber compounds (Makuuchi, 2007), the influence of high energy irradiation on the reinforcing materials, i.e. on the textile cord needs to be investigated.

In our previous work, the effect of gamma irradiation of untreated and treated high tenacity Ny 66 and PET tyre cords was investigated (Aytac et al., 2007). It has been found that gamma irradiation of tyre textile cords in air has slightly affected some...
mechanical properties of Ny 66 at relatively high doses, but has not affected the mechanical properties of PET cords up to 200 kGy. Some properties such as hot shrinkage, was improved to some extent with dose.

In this study, the investigation of the effects of gamma and e-beam irradiation on mechanical and structural properties of Ny 66, Ny 6 and PET fabrics was aimed. The untreated (greige), treated cords and calendered fabrics (also called as carcass plies) were irradiated at different doses with e-beam and gamma rays. The effects of types of irradiation and cord types on the mechanical properties of the cords are discussed.

2. Experimental

2.1. Material

The Ny 66 and PET greige yarns and treated fabrics were supplied from Kordsa Global (Turkey). The treated Ny 6 cord fabric was supplied from SRF Limited (India). Resorcinol–formaldehyde–latex (RFL) solution was used as dipping solutions where latex was styrene/butadiene/vinyl pyridine terpolymer. All types of fabrics, i.e. Ny 6 (940 dtex), Ny 66 (1400 dtex) and PET (1670 dtex) were calendered by Turk Pirelli Lastikleri A.S. in Izmit, Turkey. Natural rubber based compounds were used for calendering process. Thickness of the calendered fabrics was about 1.0–1.2 mm for all types.

2.2. Method

2.2.1. Irradiation source

Tyre cords and calendered fabrics were irradiated with gamma rays at ambient temperature by using a Gamma cell 220 type γ-irradiator at a fixed dose rate of 0.13 kGy/h. They were also irradiated by high-energy electron beam with an accelerator of 1.5 MeV–25 mA with 25 Gy/pass. All irradiations were carried out in air.

2.2.2. Tensile tests

Tensile tests were performed by using Instron tester 4502, with cross head speed of 300 mm/min and gauge length of 254 mm according to ASTM D885. An average of 5 test results has been reported.

2.2.3. Viscosimetric studies

The viscosities of solutions of unirradiated and irradiated samples were measured by an Ubbelohde type viscometer at 30 °C, formic acid for nylons and o-chlorophenol for polyester cords being the solvents used throughout the experiments.

3. Results and discussion

The breaking strength and the elongation at break values are widely used for the measurement of mechanical properties of tyre cords. In this study, the effects of gamma and e-beam irradiation on these mechanical properties of Ny 6, Ny 66 and PET fabrics were evaluated. The breaking strength–dose curves for the calendered fabrics made of Ny 6, Ny 66 and PET are shown in Fig. 1(a), (b) and (c), respectively. As it can be seen in Fig. 1(a) and (b), the tensile strength decreased with increasing dose for Ny 6 and Ny 66 cords, whereas slightly decreased for PET cords, Fig. 1(c). Both types of Ny fabrics, i.e. Ny 6 and Ny 66 were much affected adversely from ionizing irradiation. In other words, PET fabrics have higher resistance to ionizing radiation than the nylon fabrics. The ultimate effect of irradiation strongly depends on the chemical structure of polymers. It is well known that PET shows good resistance to radiation due to the presence of the aromatic rings on the main chain (Dole, 1973). The deterioration effect of
gamma irradiation on mechanical properties is higher than that of e-beam irradiation for all types of samples for a given dose. This is a well-known fact due to dose rate difference between gamma rays and e-beam. It has been found that the effects of high energy irradiation on untreated, treated cords and calendared fabrics are almost similar conforming to our previous findings for untreated and treated Ny 66 cords. This was also confirmed by FTIR spectra (Aytac et al., 2007). No protective effect of the compounds used in the coating of the cord in calendaring against oxidative degradation was observed. This demonstrates that there has been still remaining oxygen interlayer phase and/or oxygen can easily diffuse into rubber compound during calendaring.

When we compare the effects of irradiations on the calendared fabrics, the breaking strength values were found to decrease down to 90–80% of their original values with increasing dose up to 50 kGy for nylon 66 and nylon 6 fabrics, whereas almost unchanged for PET fabric up to 75 kGy. The elongations at break values for calendared fabrics irradiated at 50 kGy were given in Table 1. Generally, elongation at break values slightly decreased for nylons but unchanged for PET cords. The highest decrease in

![Fig. 2. Limiting viscosity number–dose curves (a) Ny 6 (b) Ny 66, (c) PET tyre cords.](image-url)
elongation at break values was observed for gamma irradiated nylon 6 cords.

In order to see the effects of gamma and e-beam irradiations on the structural properties of fabric materials, the limiting viscosity numbers were determined. Fig. 2(a)–(c), show the effects of gamma and e-beam irradiation on the limiting viscosity numbers of Ny 6, Ny 66 and PET tyre cords. As shown in Fig. 2, limiting viscosity numbers of nylon cords decreased up to 75 kGy irradiation dose, whereas remained almost unchanged for PET cords. The behaviour of PET under irradiation is rather different from that of nylons, because of the presence of aromatic rings that increase the resistance to ionizing radiation. These behaviours can be ascribed to different mechanisms acting in the polymer during irradiation: mainly chain scissions, responsible for the decrease of the molecular weight, and cross-linking working in the opposite way. They both are present at any dose and the overall trend of the molecular weight depends on the prevailing mechanism. Furthermore, oxidative degradation reactions must also be taken into account due to the presence of air during irradiation (Buttafava et al., 2005). The decrease in limiting viscosity number of nylon cords is attributed to the radiation-induced oxidative degradation of the main chain that causes deterioration in the mechanical properties of the nylon cords.

4. Conclusion

The effects of gamma and e-beam irradiation on the mechanical properties of Ny 6, Ny 66 and PET fabrics that are widely used as reinforcing textile materials in radial tyres were investigated. The deterioration effect of gamma irradiation on mechanical properties is higher than that of e-beam irradiation for all types of samples. The effects of high energy irradiation on untreated, treated cords and calendered fabrics are almost similar. No protective effects of both the compound used in the coating of cords in calendering and the treatment process against oxidative degradation are observed. The decrease in limiting viscosity numbers of Ny cords with increasing dose is attributed to oxidative degradation of the main chain that causes deterioration in the mechanical properties. PET calendered fabric has higher resistance to ionizing radiation, and Ny 6 and Ny 66 calendered fabrics are more sensitive even at low doses. Advantages of the use of irradiation in tyre industry, such as improving of tyre uniformity, and the possibility of saving materials and energy have long been acknowledged (Makuuchi, 2007). However, the effect of high energy irradiation on cords in calendered fabrics has to be taken into consideration design of reinforced tyres particularly with Ny fabrics if pre-vulcanization with high energy radiation is to be applied.

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