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ScienceDirect
Nuclear Instruments and Methods in Physics Research B 265 (2007) 271–275
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Effect of gamma irradiation on the properties of tyre cords

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Available online 14 September 2007

Abstract

Gamma irradiation of high tenacity Nylon 6.6 (Ny 66) and polyester (PET) tyre cords was investigated. The untreated and treated tyre cords with different twist levels were irradiated at different dose rates in air. The effects of irradiation on both Ny 66 and PET cords were not found to be depending on the twist levels of the cords. The changes in the mechanical and thermal properties with absorbed dose at two different dose rates were measured. The mechanical properties were observed to deteriorate with increasing dose for Ny 66 cords, whereas remained almost unchanged for PET cords both in greige and dipped forms. Hot shrinkage value for the greige Ny 66 cords was found to be improved, i.e. decreased. This decrease was much lower for greige PET than Ny 66 cords. It is concluded that PET cord has higher radiation resistance than Ny 66 cord and the effects of high energy irradiation on tyre cords have to be taken into consideration during tyre design if pre-vulcanization with high energy radiation is to be applied.

PACS: 81.05.Lg; 61.80.Ed

Keywords: Nylon 6.6; Polyester; Gamma irradiation; Tyre cord; Pre-vulcanization; Mechanical properties

1. Introduction

Tyre is a composite material consisting of reinforcing materials and rubber compounds. The reinforcing materials used are mainly textile cords, steel cords and steel bead wire [1]. Reinforcing elements carry the major share of the structural load of the automobile tyres. For the better service life of a tyre, the reinforcing material should exhibit excellent strength properties, fatigue resistance, modulus, cord-tyre adhesion level and dimensional stability [2,3]. The tyre cord fabrics can be produced with different type of materials. Yarns offered at the market are typically, Nylon 6 and 66, PET, Rayon and Aramid. Production of tyre cord fabric consists of mainly three process steps: twisting, weaving and treating (dipping-heat setting).

The changes in the physical properties of polymers induced by ionising radiation are attributed mainly to crosslinking and main chain scission (degradation) reactions. The efficiency of these two types of reactions depends mainly on polymer structure and irradiation atmosphere. However, dose rate, types of radiation source and temperature during irradiation can influence the reaction rates [4].

In recent years, radiation processing of polymeric materials has increased significantly. Radiation processing of rubber formulations in tyre industry offers many advantages, such as high processing rates, energy saving, etc. On the other hand, since the required dose for rubber cure is very high and the mechanical properties may suffer from main chain scission, radiation vulcanization has not yet been widely adopted in the rubber industry except in pre-vulcanization of some types of tyres [5].

One of the successful industrial applications of radiation processing has been the pre-vulcanization of tyres imparting shape stability prior to final vulcanization. The results of pre-vulcanization are higher quality tyre with more uniform thickness and better balance. Dose requirements for pre-vulcanization are in the range of 30–50 kGy [6]. Electron beam pre-vulcanized body neither decreases in

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doi:10.1016/j.nimb.2007.08.085

thickness nor can be displaced subsequent construction and vulcanization of the tyre. Electron beam irradiation of green tyres for pre-vulcanization is already being applied commercially in Japan. Six companies produced about 170 million tyres in Japan according to estimates of 1997. Five major companies have installed electron accelerators for pre-vulcanization of carcass ply to increase green strength [7]. Since tyre is a composite of reinforcing materials and rubber compounds, the influence of high energy irradiation on the reinforcing materials, i.e. on the textile cord needs to be investigated.

This paper investigates the changes in the properties of high tenacity Ny 66 and PET tyre cords induced by gamma irradiation. The untreated tyre cords with different twist levels were irradiated at two different dose rates in air. The changes in the mechanical and thermal properties with absorbed dose were measured. Treated (dipped) tyre cords were irradiated and mechanical properties were measured and then were compared with the values of the untreated cords.

2. Experimental

2.1. Material

The commercial Ny 66 (940 dtex) and PET (1100 dtex) greige yarns supplied from KORDSA (Turkey) were used in this study. Tyre cords were prepared by twisting the yarns into two ply construction with 200, 350 and 470 turns/m by using ring twister equipment and same twist level was applied to the single yarns to keep filaments together. 350 turns/m Ny 66 and PET greige cords were treated in the mixture of resorcinol, formaldehyde and latex (RFL) and were then heat set in a series of ovens to get proper rubber adhesion and tensile properties.

2.2. Method

2.2.1. Irradiation source

Tyre cords were irradiated with gamma rays at ambient temperature up to 150 kGy by using a Gammacell 220 type γ-irradiator at a fixed dose rate of 0.13 kGy/h and another ^{60}Co gamma source at a fixed dose rate of 11.5 kGy/h.

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. The average of 5 test results has been reported.

2.2.3. Shrinkage

Hot shrinkage of the greige cords were measured using Testrite shrinkage tester at 177 °C for 2 min according to ASTM D4974. In the case of the thermal and free shrinkages pretension used were 0.05 g/denier. An average of 3 test results of each cord has been reported.

2.2.4. Infrared spectroscopy

The IR spectra of the tyre cords were recorded by a FTIR (Thermo Nicolet Instruments) in the wave number range 500–4000 cm^{-1}.

3. Results and discussion

Mechanical properties of Ny 66 and PET cords are generally characterized by two parameters, namely the tensile strength and the elongation at break. The tensile strength-dose curves for the greige Ny 66 and PET cords with 3 different twist levels are shown in Fig. 1(a) and (b), respectively. As it can be seen in Fig. 1(a), the tensile strength was decreased with increasing dose for Ny 66 cords with different twist levels, whereas tensile strength values of the PET cords were decreased slightly with dose, Fig. 1(b). In industrial textile production, twist is applied to yarns in order to increase the strength until reaching the optimum twist level where the strength starts to decrease. The mechanical properties of a cord depend strongly on the amount of twist applied. Therefore, the effects of

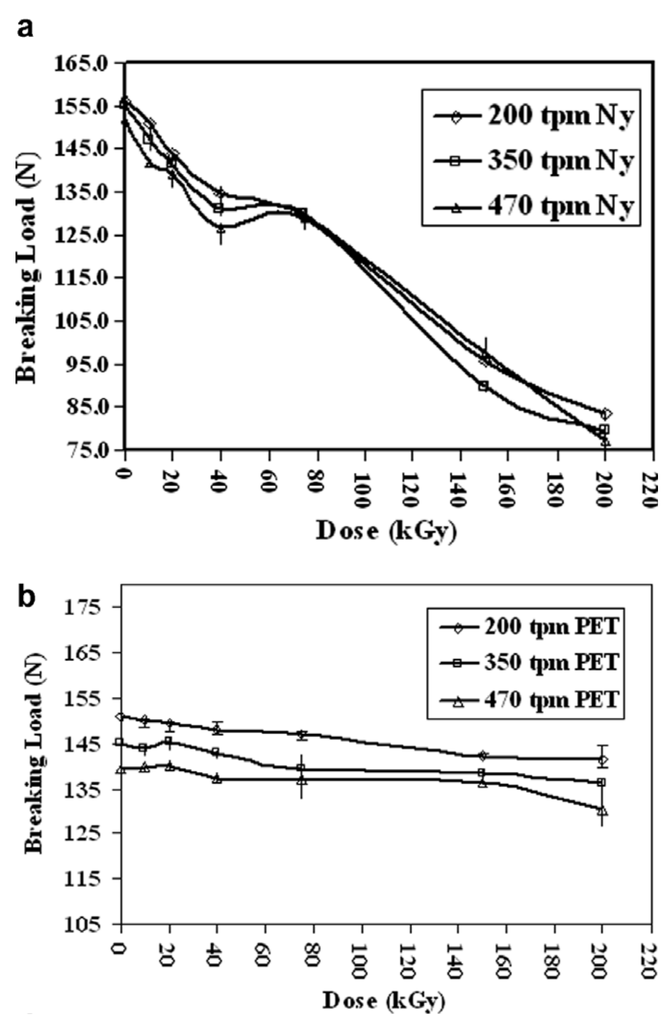

Fig. 1. Tensile strength-dose curves with different twist levels: (a) Greige Ny 6.6 (b) Greige PET tyre cords.

gamma irradiation on the cords with different twist level were investigated. It has been observed that the effect of irradiation on both Ny 66 and PET cords was not depend on the twist levels of the cords.

With the aim of evaluating the effect of dose rate on the mechanical properties, the cords were irradiated with different gamma sources at low dose rate of 0.13 kGy/h and high dose rate 11.5 kGy/h. Tensile strength measured versus absorbed dose for both Ny 66 and PET cords irradiated in air at these dose rates are given in Fig. 2. It has been determined that almost 100-fold increase in dose rate does not affect the mechanical properties of PET cord, but slightly affects the mechanical properties of Ny 66 cord at relatively high absorbed doses, Fig. 2.

The elongation at breaks values are given in Fig. 3(a) and (b). The elongation values at break slightly decreased with increased dose depending on the cord twist level for Ny 66, whereas almost unchanged for PET.

Changes in tensile strength values of treated cords with gamma irradiation are given in Fig. 4. The tensile strengths at breaks decrease with increasing dose in all cases. It has been observed that Ny 66 cords were more sensitive to gamma irradiation than PET cords. In other words, the decrease in tensile strengths with increasing dose for Ny 66 cords was higher than PET cords. The ultimate effect of gamma irradiation strongly depends on the chemical structure of polymers. It is known that PET shows good resistance to radiation due to the presence of the aromatic rings on the main chain. It can be seen from Fig. 4 that the PET cords keeps 98% of their original strength up to 50 kGy (maximum dose used for pre-vulcanization), whereas Ny 66 cords can keep only 85% of the initial properties. No significant differences between untreated and treated cords are observed for both Ny 66 and PET cords.

Hot shrinkage is a critical property for textile tyre cord for controlling of dimensional stability during curing processes. Hot shrinkage values of irradiated greige cords are given in Table 1. It has been found that hot shrinkage was improved, i.e. decreased for irradiated nylon cords. A slight decrease was observed in the hot shrinkage of

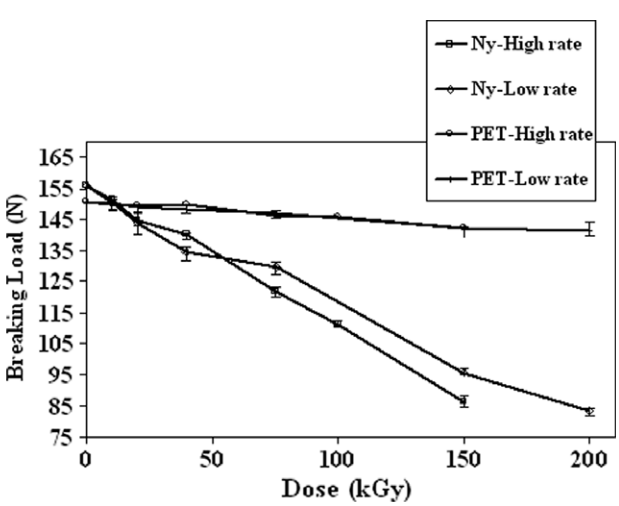

Fig. 2. Effect of radiation dose rate on the tensile strength of irradiated greige cords.

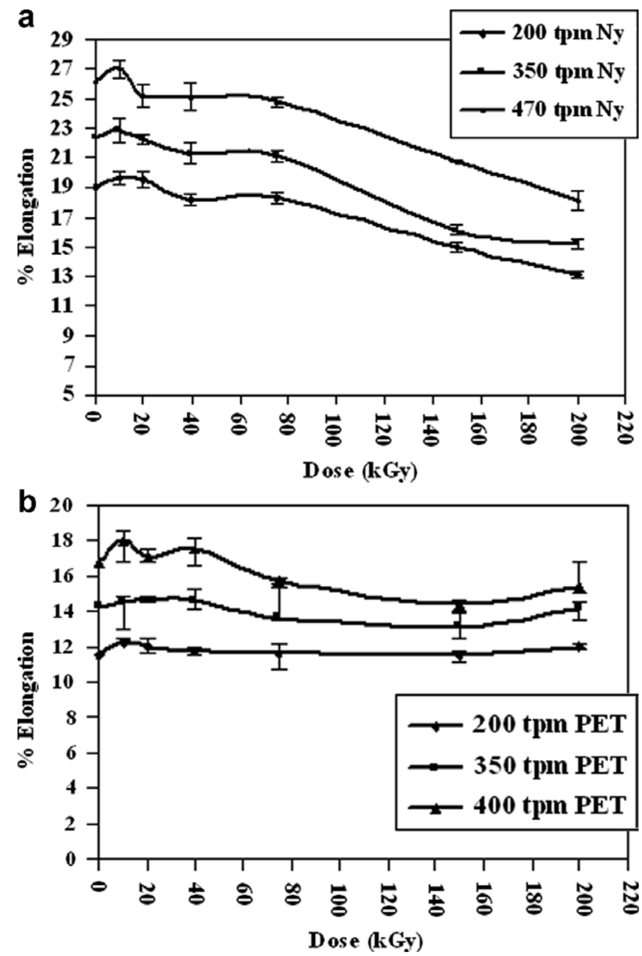

Fig. 3. %Elongation-dose curves for low dose rate irradiation: (a) Greige Ny 66 (b) Greige PET tyre cords.

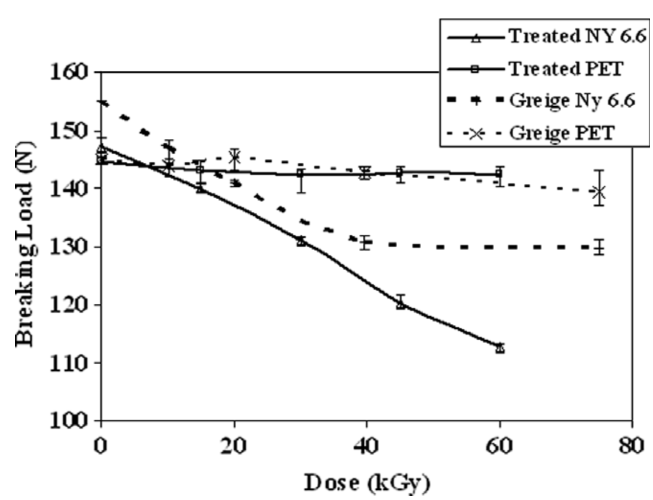

Fig. 4. Changes in tensile strength values with irradiation for Ny 66 and PET cords (350 tpm).

Table 1
Effects of irradiation on the hot shrinkage for gerige cords

DOSE (kGy)	Ny 6.6 (200 tpm)	Ny 6.6 (350 tpm)	Ny 6.6 (470 tpm)	PET (200 tpm)	PET (350 tpm)	PET (470 tpm)
0	6.7	7.6	8.6	4.83	5.3	5.7
10	5.6	5.8	6.6	4.8	4.9	5.0
20	5.0	5.4	6.3	4.7	5.0	5.3
40	4.1	4.1	4.8	4.6	4.8	4.8
75	3.5	4.0	4.8	4.5	4.8	4.8
150	1.7	1.7	2.3	4.1	4.3	4.3
200	1.7	1.7	2.1	4.1	4.2	4.2

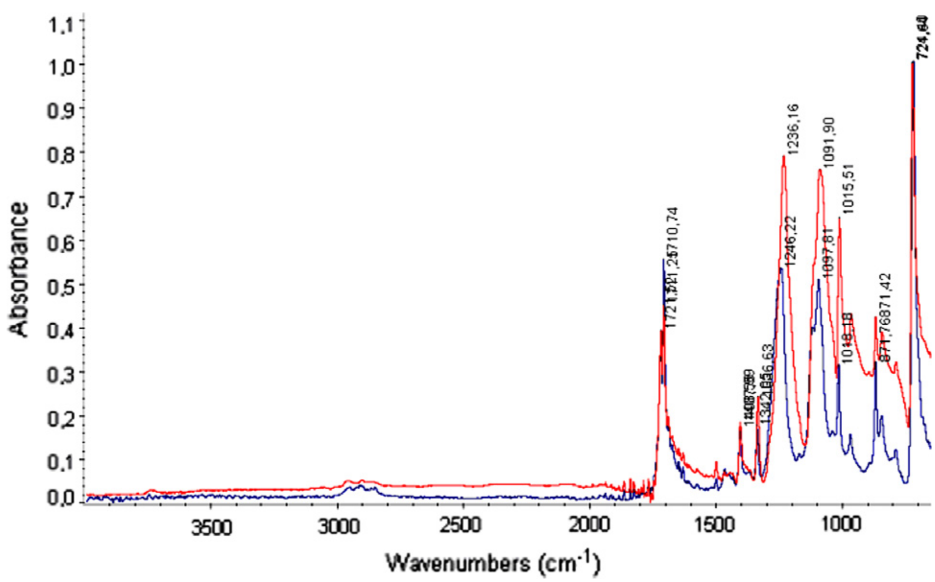

Fig. 5. FTIR spectra of: (a) un-irradiated PET cord (dark blue) (b) irradiated PET cord (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

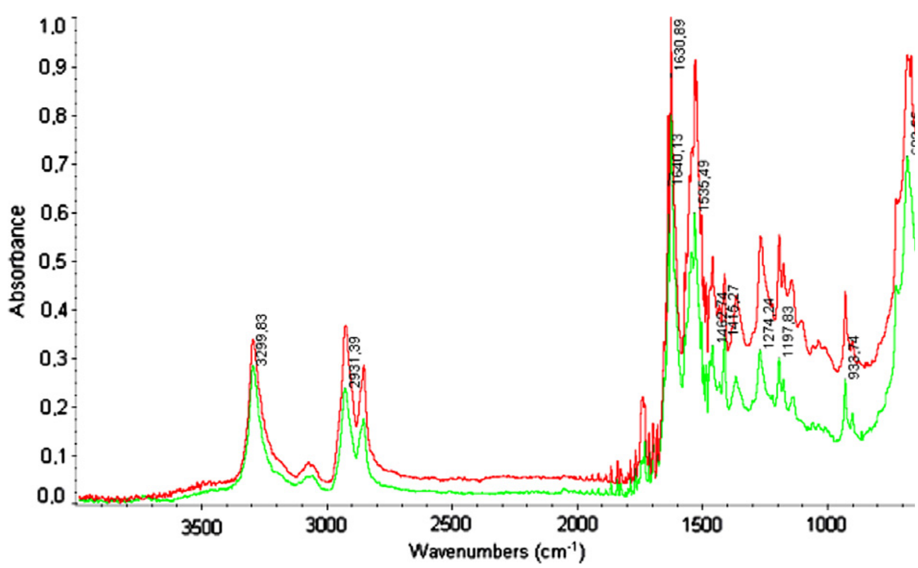

Fig. 6. FTIR spectra of: (a) un-irradiated nylon cord (red) (b) irradiated nylon cord (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

irradiated PET cords. Hot shrinkage values do not only depend on polymer structure but also spinning process. In general, different draw ratio and rates are applied during spinning of PET and Ny 66 yarns. Furthermore, PET has good dimensional stability due to presence of aromatic rings; Ny 66 has relatively linear and simple structure.

With the purpose of evaluating structural changes in the cords, irradiated cords were characterized by Fourier transform infrared (FTIR) technique. The FTIR spectra of PET and nylon cords are given in Figs. 5 and 6. The FTIR spectrum of PET cords has characteristic absorption bands at 1710, 1236, 1091, 1015 and 724 cm^{-1} whereas the FTIR spectrum of nylon cords show characteristic absorption bands at 3300, 2931, 1630, 1535 1274, 1197 and 933 cm^{-1}. No change in the FTIR spectra of irradiated cords was observed, but only the intensities of some absorption bands of the PET cords slightly changed upon irradiation. This is attributed to oxidative degradation in the backbone chain which causes slight deterioration in the mechanical properties.

4. Conclusion

The results obtained showed that gamma irradiation of tyre textile cords in air has slightly affected some mechanical properties of Ny 66 at particularly high doses, but has not affected the mechanical properties of PET cords. On the other hand, some properties such as hot shrinkage, is improved to some extent with dose.

It is concluded that PET cord has higher radiation resistance than Ny 66 cord and the effects of high energy irradiation on tyre cords have to be taken into consideration during tyre design if pre-vulcanization with high energy radiation is to be applied.

Acknowledgements

The authors are grateful to KORDSA Global Industrial Yarn and Tire Cord Fabric Manufacturing and Trading Inc. in Izmit (Turkey) for their support and the permission to use of their laboratories.

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