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Effect of Gamma Irradiation on the Optical and Structural Properties of Makrofol FR 7-2 polycarbonate

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Abstract: Makrofol FR 7-2 polycarbonate samples exposed to range 20-400 kGy dose of gamma radiation. The modulations created in optical properties and intrinsic viscosity (IV) of the Makrofol samples has been investigated. Further, difference in color and refractive index were performed. In range of 50-250kGy, the obtained crosslinking increases the IV and the average of molecular mass. Accordingly, non-irradiated samples displayed considerable color sensitivity for the irradiation. Color intensity increased by dose to 400kGy and results a raise of red and yellow intensities.

Keywords: Makrofol Polycarbonate; Optical; color; viscosity.

1 Introduction

Radiating polycarbonate is one of the most techniques for expulsion of new polymers that devised with new physical characteristics. Gamma- polycarbonate interactions lead to nominated variations in its properties due to cross-linking and induced chain scissions [1-3]. Polycarbonates have many uses in domains of techniques applications such as nuclear and micro-electronics manufactures. Radiating polycarbonates varying its properties and makes an irreversible amendments in their structures [4]. This leads to scission of polymer chains, covalent bonds breaking, carbon-clusters formation and sometimes new bonds formation [5]. Accordingly, many polymer characteristics like electrical, mechanical and optical are modified [6-14]. It is also worth to mention that such change can used as indicator and/or detector to radiation [15]. In fact some authors used polycarbonates as dosimeter depending on the change in some of their physical properties by radiation [16]. In ref. [17] the modification induced in the structure and optical properties in polycarbonate/polyester blend due to irradiation. On the other hand, color variation is effective in evaluation the physico-chemical changes. Many investigations discussed the use of color variation of irradiated polymers in the nuclear track detectors (NTDs) application in radiation-dosimetry [18-20].
In the present investigation, gamma-irradiation effects on the structural-optical features of Makrofol FR 7-2 have been studied to improve its performance in many applications.

2 Experimental

2.1 Samples

Makrofol FR 7-2 is a transparent film of polycarbonate $C_{16}H_{14}O_3$ (Farbenfabriken Bayer A.G., Leverkusen-(Germany)), its thickness 300 µm and density 1.3g/cm^3.

2.2 Irradiation Processes

A 60Co source (produced by AE of Canada Ltd.) providing dose of rate 2.4 Gy/min was used.

2.3 Samples Analysis

The UV/Vis spectra measured by UV–Vis–NIR spectrophotometer, type Jasco 570, in wavelength of 190–2700 nm. The (CIE units x, y and z) methodology used in color depiction [21].
Measurements of refractive index RI made by Abbe refractometer (Reichert; II, Model-10480, New York). Accuracy of refractive indices, surface prism temperature and wavelength used : ± 0.0001, 19-22 ^{o}C and 5893 ^{o}A. Measurements of viscosity obtained by Oswald viscometer (pinkevitch, 0 No. 2106, made by Poulten, self, and LEE, LTD, England. Its calibration specified in ASTM D 445-IP 71.

3 Some Results and Discussions

3.1 Samples Optical Properties

3.1.1 Optical Analysis of Irradiated and Non-Irradiated Makrofol FR 7-2

Makrofol films were described by spectral absorption and transmission measurements. UV–Vis absorbance-spec of irradiated (non-irradiated) makrofol samples, measured in

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370-780nm range, are shown in Figure 1. The diagrams indicate that gamma dose affects energy band levels.
In disordered, amorphous and defected materials, tail status export in gap part below the essential absorption edge [22] that determined by absorption coefficient (α) which given in ref. [23]:

$$\alpha = \alpha_o \exp\left(\frac{h\nu}{E_u}\right) \qquad (1)$$

A constant α_o characterized the samples and E_U is Urbach energy. Also, band gap energy (E_{gi}) determined using Tauc's equation [24]:

$$\alpha h\nu = B(h\nu - E_g)^n \qquad (2)$$

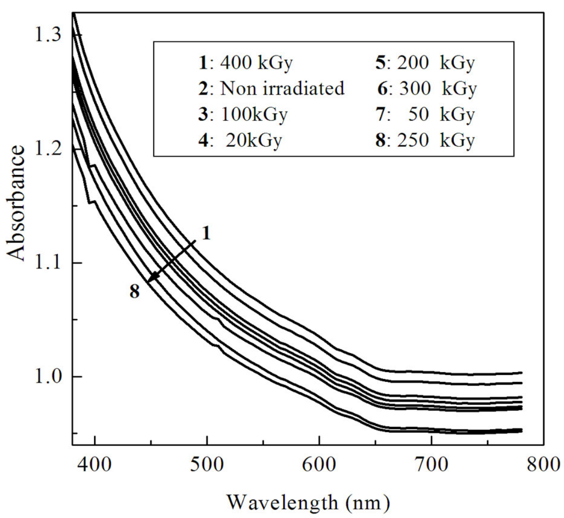

Fig. 1: The UV–Vis absorbance spectra of the non irradiated and irradiated Makrofol films.

hν is approximated by hν=1240/λ, B is constant and n=1/2 and 3/2 for direct allowed and forbidden transitions, n=2 and 3 for indirect, respectively.
The EU represented by (1/ straight line slope) of ln α versus hν plot. The variation E_U with dose is depicted in Figure 2. It is noted that E_U increases to 400kGy and contrast behavior with energy band (Figure 2). This indicates that doses up to 400 kGy affects the Makrofol sample to crosslink caused by new covalent bonds formation between molecules. New different chains are obtained and decrease the optical band gap [25, 26].
Furthermore, the crosslinking reduces crystallinity and increases electronic disorder via defects in lattice which act as scattering centers.

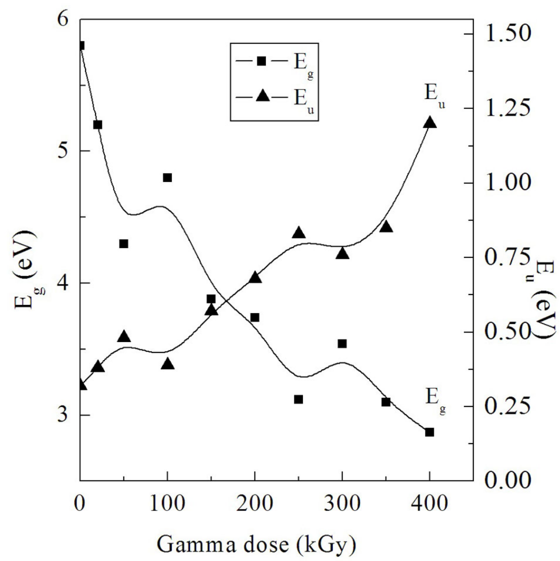

Fig. 2: A plot of the Urbach's energy and optical band gap for the Makrofol films with the gamma dose.

3.1.2 Refractive Index (RI)

Film RI is measured and plotted in Figure 3 versus the dose. Fig. 3. It showed that it decreases up to 50kGy by initial scission, then increases to 300 kGy due to crosslinking. Above 300-400 kGy, it decreases to random breakage of bonds.

The reduction in RI explained by chain scission while the increase in RI with increasing the production of chemical active free radicals that allow the covalent bonds formation and minimizes the character of anisotropic makrofol polymer. These results are in good agreed with ref. [27-28].

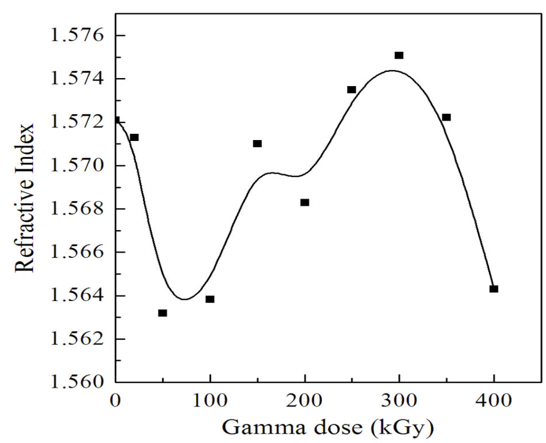

Fig. 3: The variation of the refractive index of the Makrofol films with the gamma dose.

3.1.3 Color Changes

In range 370-780 nm the transmission data are given in figure 4, the values of tristimulus (x, y, z) and of chromaticity (x, y, z) are calculated and given in Table 1. The color change (L^*, a^* and b^*) is depicts in Figure 5. Accuracy of L^* is ±0.05, and is ±0.01 for a^* and b^*. It was noted that a^*, b^* and L^* are changed after irradiation. The green component ($-a^*$) changed to red ($+a^*$) (Figure 5a). Also, blue ($-b^*$) changed to yellow ($+b^*$) after dose

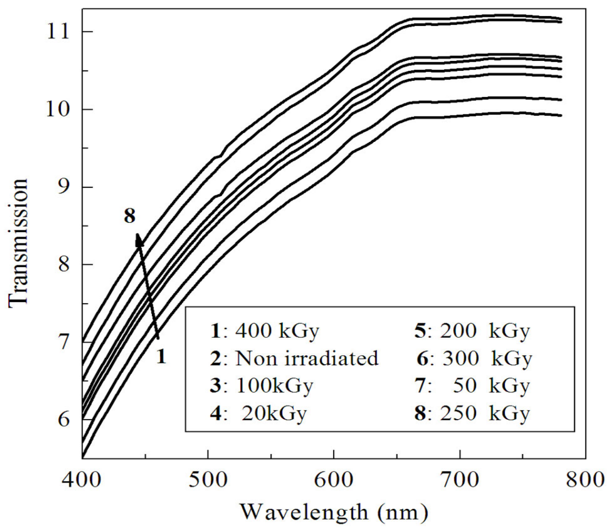

Fig. 4: The UV–Vis transmission spectra of the non-irradiated and irradiated Makrofol films.

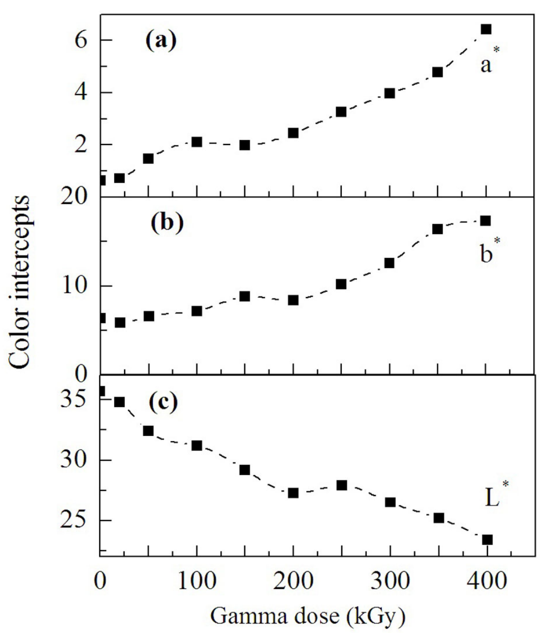

Fig. 5: Variation of color intercepts with the gamma dose.

Exposure to 400kGy (Figure 5b). It was accompanied by a net increasing in samples darkness ($-L^*$) (Figure 5c).

Color intensity ΔE was given in Figure 6. ΔE increases up-to 400kGy. It means that samples of Makrofol responses to colors change by dose. Color changes may be caused by trapping of excited free radicals which resulting from molecule ruptures and give optically coloration [29].

3.2 Intrinsic Viscosity

Different solution concentrations (0.2-0.4-0.-0.8%) are prepared by pure solvent chloroform. It was chosen to avoid secondary interactions.

Kinematic viscosity (η_k) was calculated by ($\eta_k = t \times C$), C (capillary constant). The specific, intrinsic, limiting viscosities are calculated: (($\eta_{spc} = \eta_{rel} - 1$), ($\eta_{red} = \eta_{spc}$ / concentration), ($\eta_{in} = \lim \eta_{red}$). In figure 7, η_{in} plotted vs. dose. η_{in} decreases to minimum value about 50 kGy and increases by dose to 250kGy. Also, above 250-400 kGy, it reduces again.

In range 0-50, η_{in} decreases by the production of a shorter molecules results from degradation that causes random bonds breaking and forming stable lower

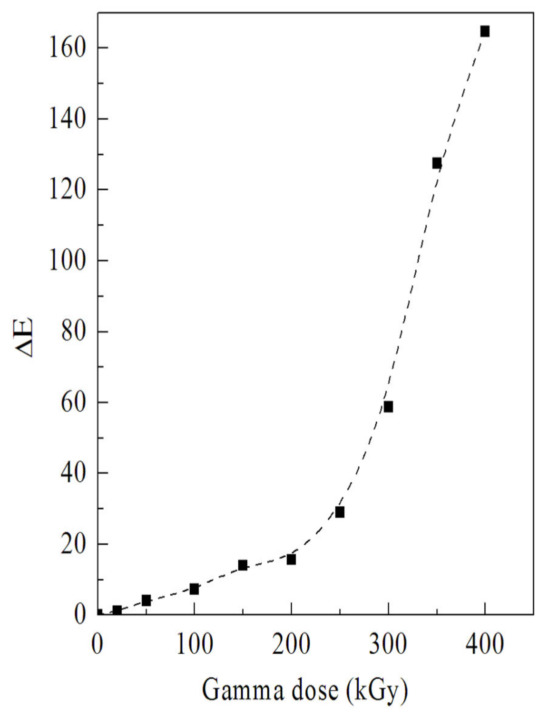

Fig. 6: Variation of the color intensity ΔE with the gamma dose.

Table 1: Tristimulus values and chromaticity coordinates of the non-irradiated and irradiated Makrofol FR 7-2 samples.

Gamma dose (kGy)	Tristimulus values			Chromaticity coordinates		
	X	Y	Z	x	y	z
0	0.09749	0.10083	0.56773	0.12726	0.13162	0.74111
20	0.10158	0.10483	0.59135	0.12733	0.13140	0.74126
50	0.10771	0.11083	0.62676	0.12742	0.13111	0.74147
100	0.10055	0.10383	0.58544	0.12731	0.13146	0.74123
150	0.09953	0.10283	0.57954	0.12729	0.13151	0.74119
200	0.1026	0.10583	0.59725	0.12734	0.13135	0.74129
250	0.10864	0.11144	0.63197	0.12750	0.13079	0.7417
300	0.10354	0.10644	0.60248	0.12744	0.13101	0.74155
350	0.09742	0.10081	0.56736	0.12725	0.13168	0.74107
400	0.09545	0.09883	0.55592	0.12723	0.13174	0.741033

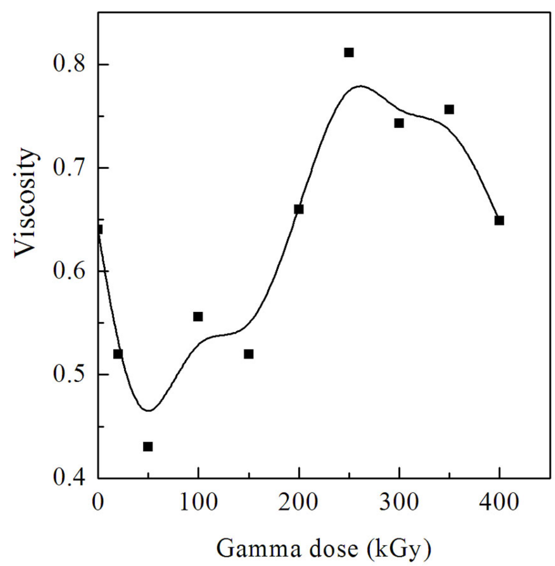

Fig. 7: Variation of the intrinsic viscosity with the gamma dose.

4 Conclusions

The results imply that the irradiation diminish the energy band levels via the increasing in constitutional deficiency of irradiated-samples.
Non-irradiated samples reported significantly color sensibility. The intensity of color ΔE increased by dose to 400 kGy and convoyed with increases in yellow and red. The gamma irradiation up to 400 kGy produce more consolidated structures of Makrofol polymer that increases refractive index and average molecular mass.

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