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The influence of electron-beam irradiation on some mechanical properties of commercial multilayer flexible packaging materials

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ABSTRACT

The influence of electron-beam irradiation on mechanical properties of commercial multilayer flexible packaging materials based on coextruded and laminated polypropylene (PP), low-density polyethylene (LDPE), ethylene vinyl alcohol copolymer (EVOH) and poly(ethylene terephthalate) (PET), irradiated with doses up to 120 kGy, was studied. The tensile strength and elongation at break of the irradiated PET/PP film increase, while the penetration and sealing resistance decreased. In addition, the irradiated PET/LDPE/EVOH/LDPE film presented increase in the tensile strength on some radiation doses and decrease of the penetration and sealing resistance, except for sealing resistance at radiation dose of 15 kGy that resulted in a slight increase of ca 4%.

1. Introduction

The development of methods for controllable modification of the polymeric flexible packaging materials to adjust their physicochemical, mechanical, optical, barrier and other properties is one of the most important areas of modern packaging technology. A promising approach to the modification of properties of the plastic packaging materials is based on treatment with ionizing radiation, particularly, electron-beam irradiation. On the other hand, ionizing radiation can also affect the polymeric materials itself leading to a production of free radicals. These free radicals can in turn lead to degradation and or cross-linking phenomena, with release of gases, discoloration, changes in mechanical, thermal and barrier properties and degradation and leaching of polymer additives into solvents (Buchalla et al., 1993; Riganakos et al., 1999). In recent years electron-beam irradiation have been efficiently applied to modify the properties of the different polymers for versatile applications. In the flexible packaging industry, the manufactures apply specific electron-beam radiation doses to promote cross-linking and scission of the polymeric chains to improve specific material mechanical properties. The relative ease of radiation process, the efficiency for modifying the properties on polymeric materials and the extent of these modifications have motivated several researchers to study the effect of ionizing radiation on plastic food packaging materials (Riganakos et al., 1999; Goulas et al., 2003, 2004; Fintzou et al., 2007 and others). Today, the multilayer coextruded flexible packaging is gaining much attention in packaging industries for food applications, because such materials combine a number of desirable properties (barrier to gases and water vapor, organic compounds, mechanical strength, machinability and relatively low cost) that no single material possesses. Most coextruded multilayer structures of flexible food packaging are based on polyolefins (low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), polypropylene (PP) and biaxially oriented polypropylene (BOPP)). These materials are strongly used because of their low cost, toughness, sealability properties, good chemical resistance and inertness to most foods, good barrier properties to water, are versatile and easy to process (Goulas et al., 2003). Other polymeric layers very common in multilayer structures of the food packaging industry are polyethylene terephthalate (PET), polyamide (PA) and ethylene vinyl alcohol copolymer (EVOH). Recently, the use of EVOH finds increasing applications in high-barrier flexible packaging because of its outstanding gas barrier properties, excellent barrier to food aroma, excellent organoleptic properties, and easy processability on a wide range of conventional coextrusion processing equipment (Kim et al., 2004). The purpose of the present research was to evaluate the influence of electron-beam irradiation on some mechanical properties of commercial multilayer structures of flexible food packaging materials.

2. Experimental

Two commercial multilayer materials, commonly used in food packaging, were chosen for the present study: (i) PET/LDPE/EVOH/

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LDPE film, 132 μm thick, representative of a high-barrier flexible packaging and (ii) PET/PP film, 72 μm thick, a very common multilayer structure used in dry food packaging. The materials were irradiated up to 120 kGy using a 1.5 MeV electrostatic accelerator (Dynamitron II, Radiation Dynamics Inc., 1.5 MeV energy, 25 mA current and 37.5 kW power), at room temperature, in air, dose rate 11.22 kGy/s. Irradiation doses were measured using cellulose triacetate film dosimeters "CTA-FTR-125" from Fuji Photo Film Co. Ltd. The mechanical properties tests were carried out on structures initially eight day after irradiation and six months later to consider post irradiation effects. The tensile tests were carried out according to ASTM D 882-90 (ASTM, 1996), the penetration resistance based on ASTM F 1306-90 (ASTM, 1994) and sealability resistance according to ASTM ASTM F 88–00 (ASTM, 2000). Mechanical properties were determined using an INSTRON Testing Machine model 5564 and a seal packaging machine Mical model SE 450.

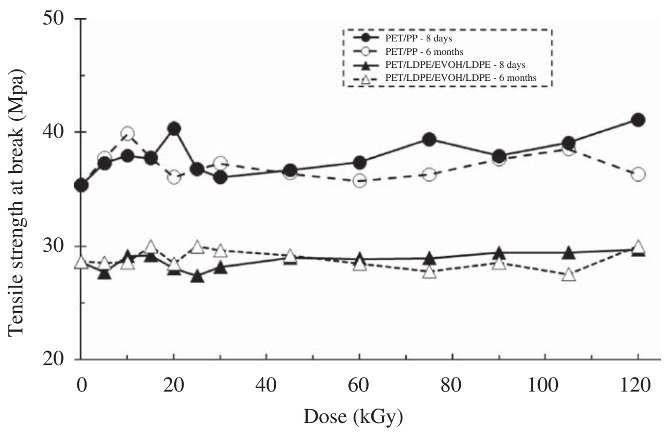

Fig. 1. Tensile strength at break as a function of electron-beam radiation dose for the examined structures.

The difference between results for irradiated and non-irradiated structures was then evaluated statistically by ANOVA using BioEstat software (version 5.0, 2007, Windows 95, Manaus, AM, Brazil). Significance was defined at $p<0.05$.

3. Results and discussion

The tensile strength at break data of non-irradiated (control) and irradiated multilayer structures are given in Fig. 1. Eight days after irradiation took place, there were no significant differences ($p<0.05$) in tensile strength at break of PET/PP irradiated at 25, 30 and 45 kGy, but for the other irradiation doses an increase ($p<0.05$) up to 16% was found. In contrast, six months after irradiation took place, the tensile strength of the PET/PP film increased ($p<0.05$) in the dose range of 5–15 kGy up to 13%, at 90 kGy ca. 7% and 105 kGy ca. 9%. In the case of PET/LDPE/EVOH/LDPE, the results of the tensile tests, eight day and six months after irradiation, showed significant differences ($p<0.05$) to some irradiation dose, but the tensile strength of the film was slightly affected by irradiation, as indicated by changes lower that 5% (Fig. 1). The results of the percent elongation at break tests are summarized in Fig. 2. In terms of elongation at break, the PET/PP (Fig. 2a), eight day after irradiation, showed an increase ($p<0.05$) up to 15% at lower doses (5–30 kGy), at 75 kGy ca. 24% and 105 kGy ca. 32%. Six months after irradiation it was still higher, as indicated by an increase between 22% and 41% (5, 15 kGy ca. 41%), except for the dose range of 75–120 kGy (rise 90 kGy ca. 12%; loss: 75 kGy ca.7, 105 kGy 8%). In contrast, the elongation at break of the PET/LDPE/EVOH/LDPE resulted in a significant decrease ($p<0.05$), eight day after irradiation the values were by 23–34% lower than non-irradiated film, and six months after irradiation were 18–30% lower (Fig. 2b). These results showed that elongation at break of the PET/PP basically improved after irradiation while of the PET/LDPE/EVOH/LDPE fell. Such low elongation at break of the irradiated PET/LDPE/EVOH/LDPE indicated a moderate to severe degradation in this structure. In contrast, the increase in the

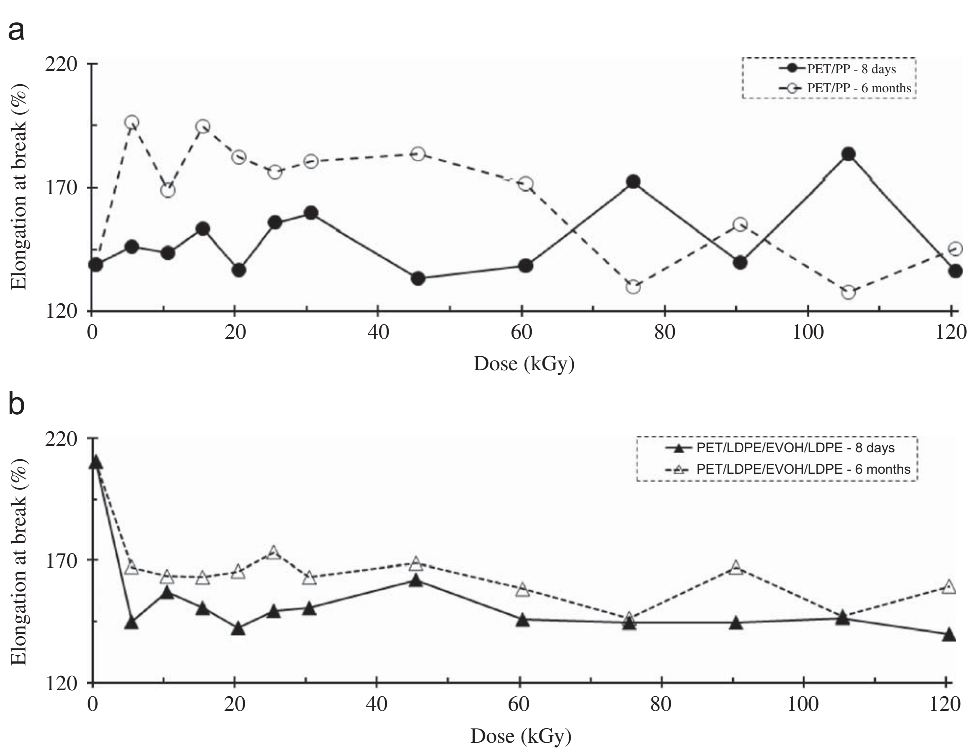

Fig. 2. Elongation at break as a function of electron-beam radiation dose for (a) PET/PP structure and (b) PET/LDPE/EVOH/LDPE structure.

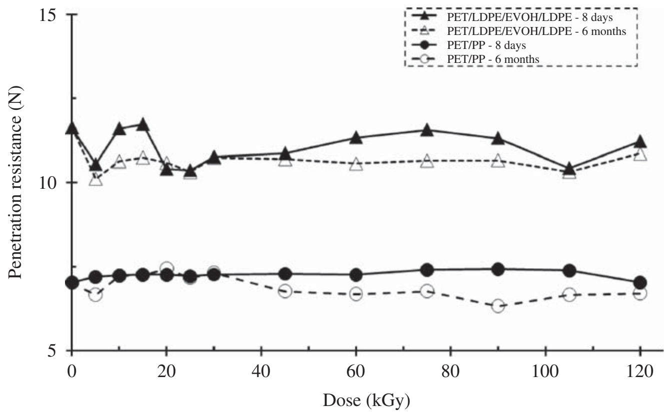

Fig. 3. Penetration resistance as a function of electron-beam radiation dose for the examined structures.

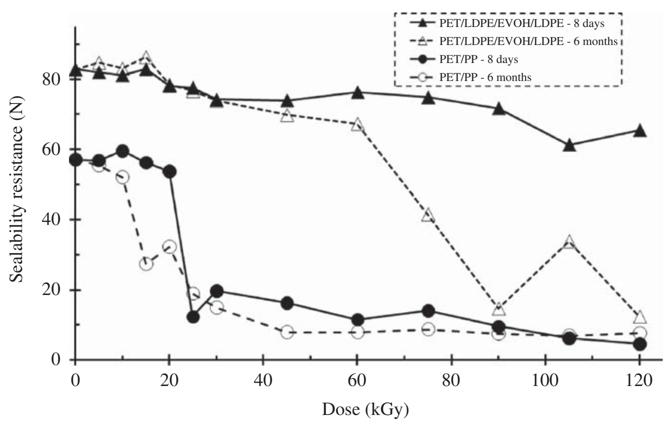

Fig. 4. Sealability resistance as a function of electron-beam radiation dose for the examined structures.

elongation at break of the irradiated PET/PP indicated a possible dominion of the cross-linking on degradation phenomena in this structure. As it can be seen (Figs. 1 and 2), the elongation at break properties of the films were most affected by irradiation that tensile strength. This is in agreement with the observation of Goulas et al. (2004) and Wilski (1987), who reported that the elongation at break is the most radiation-sensitive property that tensile strength of polymers. The penetration resistance test results of the films are given in Fig. 3. Fig. 3 showed statistically significant differences ($p<0.05$) in penetration resistance of the films, eight day and six months after irradiation took place. The penetration resistance of the PET/LDPE/EVOH/LDPE was most affected by irradiation, as indicated by a more than 12% decrease in penetration resistance six months after irradiation, compared with slightly increase of 5% ca. of the PET/PP eight days after irradiation, and decrease lower than 10% six months after irradiation (Fig. 3). In the case of sealing properties (Fig. 4), electron-beam irradiation caused statistically significant differences ($p<0.05$) and a large decrease for both films compared to the other mechanical properties discussed. The sealing properties of the PET/PP was more affected by irradiation than PET/LDPE/EVOH/LDPE, as it can be seen, the loss of sealability of the PET/PE in the dose range of up to 25 kGy was by 65–92% eight days after irradiation, and by 43–88% six months after irradiation in the dose range of up to 15 kGy. When the PET/LDPE/EVOH/LDPE film is considered, the loss of sealability was 6.0–26% eight days after irradiation, and 18–31% six months after irradiation.

4. Conclusions

The objective of the present study was to evaluate the influence of electron-beam irradiation on mechanical properties of two commercial multilayer structures used in dry food packaging. In general, the results showed that mechanical properties of the PET/LDPE/EVOH/LDPE was more deteriorated by irradiation than PET/PP, except in terms of sealing properties that resulted in a greater loss to both irradiated structure, but with a higher degree to the PET/PP. Comparison of both structures leads to the conclusion that electron-beam irradiation with doses up to 45 kGy caused a large improvement in elongation at break property of the PET/PP with minimal effects on tensile strength and penetration resistance, but with a considerable reduction in the sealing property. In contrast, mechanical properties of the irradiated PET/LDPE/EVOH/LDPE presented moderate to severe degradation.

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