Material Effects of Low-Energy EB Treatment of Polypropylene and Low-Density Polyethylene

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Low-energy electron beam (EB) technology is increasingly being deployed for packaging applications—including sterilization of medical device, pharmaceutical, food and beverage packaging materials; curing of inks, coatings and adhesives for packaging and industrial applications; and strengthening of polymeric materials. Although EB has been employed for more than a decade, applications have been limited to EB systems with high and medium energies (300keV to 10MeV). Technology in this voltage range requires specialized equipment that can be expensive and requires expertise in vacuum technology. Low-energy electron beams (typically in the 80-150kV range) can be deployed more simply. Compact, low-energy equipment can actually be incorporated into existing manufacturing lines. With the availability of viable low-energy systems, the range of electron beam applications is growing dramatically.

Advanced Electron Beams and the Plastic Engineering Department of University of Massachusetts, Lowell, performed collaborative research to understand the effect of low-energy electron beams on polymeric materials commonly used for packaging applications. The changes of material properties after EB treatment can be used as a guideline for the material selection and operational optimization of EB applications. The first phase of the project focused on

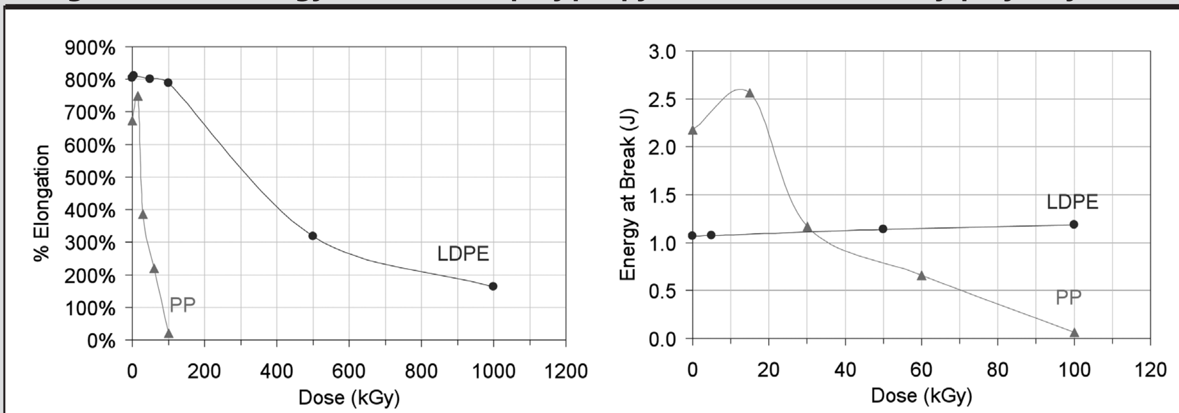
Table 1

Melt flow index of polypropylene and low-density polyethylene

Irradiation Dose (kGy)	Melt Flow Index of LDPE (g/10min)	Melt Flow Index of PP (g/10min)
0	2.9	3.9
5	1.6	
15		28.0
30		43.7
50	No discharge (very viscous)	
60		243.0

Figure 1

Elongation and energy at break for polypropylene and low-density polyethylene



(a) Elongation at break (b) Energy at break

low-density polyethylene (LDPE) and polypropylene (PP). These materials are widely used as packaging materials due to its low manufacturing costs, light weight, good moisture barrier, good chemical resistance and bulk mechanical flexibility. There has been substantial research done on the impact of high-energy electron beams on these two polymers in the past.[1-9] However, there has been virtually no formal research conducted at low-energy regimes (≤150 keV). This study focuses on mechanical and morphological changes upon the electron beam exposure at 150 keV.

Experimental Procedure

PP and LDPE sheets with thickness ranging from 200 to 250 microns were formed at the peaked temperature of 240°C using a sheet extruder from Welex Inc. (Model No. 1.5-24D with 3-roll stack), equipped with a Davis Standard AG438 puller. PP resin was purchased from Huntsman (solid density of 0.900g/cm,^{3} melt flow index (MFI) of 4g/10min), while LDPE was blown film resins LD 100BR manufactured by Exxon Mobil (solid density of 0.9225g/cm^3, MFI of 2 g/10min).

The EB treatment was performed on both sides of the thin films using AEB's e250H electron beam emitter. The materials were treated at an energy level of 150 keV under ambient air with various surface doses with a dose rate of 2,400 kGy m/min. After treatment, the irradiated and control samples were evaluated using the ASTM D1238 procedure for MFI; ASTM D638 for tensile properties; and ASTM D1709 for impact strength. The MFI was measured in an AD987 extrusion plastometer from Tinius Olsen in which the melted samples were flowed through a 2.0 mm diameter orifice for 10 minutes under a loading of 2.16 kg at a temperature of 230°C for PP and 190°C for LDPE.

For tensile measurement, the samples were cut into the dumbbell shape and tested using an Instron 4400R tester at room temperature with a pulling rate of 508 mm/min and using 91 kg load cell. Impact strength was measured on the films using a Dynisco Polymer Test model DDI-120 free-falling dart impact tester.

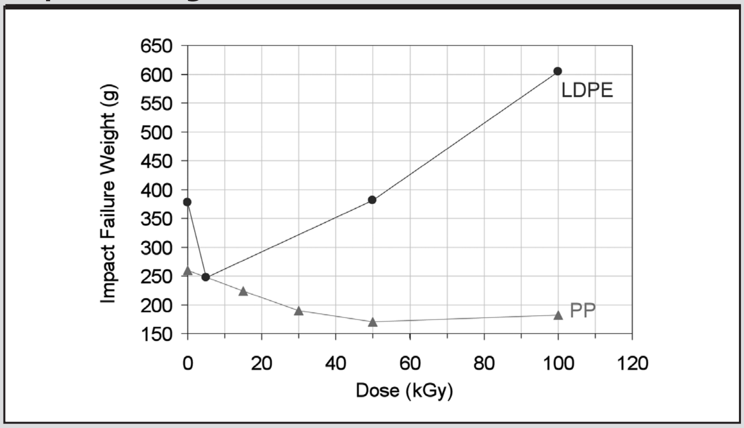
Results and Discussion

It was found that after EB treatment at 150keV, crosslinking was the dominant transformation for LDPE, whereas chain scission (i.e., degradation) was shown in PP. Table 1 shows the MFI results of PP and LDPE as a function of irradiation dose. As can be seen, the MFI of PP is increased with the irradiation dose, showing the sudden reduction of viscosity as an evidence of chain scission effect in PP. On the contrary, the irradiated LDPE showed an opposite phenomenon in which the crosslinking dominated, increasing the molecular weight after exposed to the EB.

Figure 1 depicts % elongation and energy at break of both PP and LDPE. It was found that the elongation of LDPE was gradually reduced and its energy at break slightly increased with the EB dose. Because of the crosslinking effect in LDPE, the three-dimensional, gel-like structure was formed and, thus, caused a decrease in chain mobility and elongation. Because of additional carbon-carbon linkage and chain length, it was also more difficult to break the material,

FIGURE 2

Impact strength of PP and LDPE



as evident by the increase in energy required to break the irradiated LDPE. On the other hand, the drastic decrease of both elongation and energy at break was observed with PP. This is because the reduction in the chain length due to chain scission in PP caused the sharp reduction in energy at break and elongation. Additional tensile and morphological properties of LDPE can be found in a paper that will be presented at the Society of Plastic Engineers Annual Technical Conference.[10]

Figure 2 shows the comparison of impact strength between PP and LDPE. The impact resistance of LDPE was significantly improved with increasing the EB dose as expected when the crosslinking effect increases the network density and, thus, the stiffness of polymer structure. The reduction in impact strength resulted in PP, mainly because of the degradation effect of electron beam. The same effect was observed in gamma irradiated PP.[11]

Summary

The results obtained from our research are in good agreement with other studies of material effects of high-energy electron beam for both LDPE and PP.[3, 11–14] These results show the promise of developing new materials for engineering applications that leverage the higher dose rate, low-energy EB technologies for in-line processing of polymer materials. ◗

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