

## Improvement of Compatibility of Poly(ethylene terephthalate) and Poly(ethylene octene) Blends by $\gamma$ -Irradiation

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**ABSTRACT:** Blends of poly(ethylene terephthalate) (PET) and poly(ethylene octene) (POE) were prepared by melt blending with various amounts of trimethylolpropane triacrylate (TMPTA). The mechanical properties, phase morphologies, and gel fractions at various absorbed doses of  $\gamma$ -irradiation have been investigated. It was found that the toughness of blends was enhanced effectively after irradiation as well as the tensile properties. The elongation at break for all studied PET/POE blends (POE being up to 15 wt %) with 2 wt % TMPTA reached 250–400% at most absorbed doses of  $\gamma$ -irradiation, approximately 50–80 times of those of untreated PET/POE blends. The impact strength of PET/POE (85/15 wt/wt) blends with 2 wt % TMPTA irradiated with as little as 30 kGy absorbed dose exceeded 17 kJ/m<sup>2</sup>, being approximately 3.4 times of those of untreated blends. The improvement of the mechanical properties was supported by the morphology changes. Scanning electron microscope images of fracture surfaces showed a smaller dispersed phase and more indistinct inter-phase boundaries in the irradiated blends. This indicates increased compatibility of PET and POE in the PET/POE blends. The changes of the morphologies and the enhancement of the mechanical properties were ascribed to the enhanced inter-phase boundaries by the formation of complex graft structures confirmed by the results of the gelation extraction and Fourier Transform Infrared analyses. © 2012 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* 000: 000–000, 2012

**KEYWORDS:** poly(ethylene terephthalate); toughening; irradiation; compatibilization; blends; poly(ethylene octene)

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### INTRODUCTION

Research into polymer blends is rapidly increasing since single polymer materials can not meet the actual needs of more demanding requirements of polymeric materials. Recently, polypropylene blends, nylon blends, and polystyrene blends have been manufactured in commercial quantities. As an engineering plastic, poly(ethylene terephthalate) (PET) has many advantages over other polymers, for instance, good degradability, superior chemical resistance, outstanding strength, etc. Yet perhaps its most favorable attribute is its significantly lower production costs when compared with other engineering plastics such as polycarbonate (PC), polyoxymethylene (POM), or polyamide (PA). However, PET has not been widely used as an engineering material mainly due to its brittleness. Therefore, many studies have focused on improving its toughness to expand its application scopes.

A common and effective approach to improve the impact toughness of PET is to blend it with other polymers. PET/PC/

E-GMA-MA ternary blends were found to undergo the brittle ductile transition in a certain blending order and the impact toughness reached 17.12 kJ/m<sup>2</sup> at a special composition.<sup>1</sup> PET was blended with high density polyethylene (HDPE) at a ratio of 75/25 (wt/wt) and compatibilized with an ionomer of PEMA-Li so that the impact strength exceeded 600 J/m, when 30 wt % PEMA-Li was added to the HDPE phase.<sup>2</sup> The toughening effects of ethylene-propylene rubber (EPR), maleic anhydride grafted styrene-butadiene rubber, or natural rubber on PET were investigated and found that the impact strength was increased rapidly when PET/EPR blends were compatibilized with an extremely small amount of ethylene-glycidyl methacrylate copolymer (E-GMA).<sup>3</sup> The fracture characteristics of maleic anhydride grafted styrene/ethylene-butadiene/styrene copolymer modified PET were investigated and the impact strength reached the maximum of 17 kJ/m<sup>2</sup> when the modifier content was 20 wt %.<sup>4</sup> A series of PET blends toughened with various thermoplastic elastomers were studied and a toughness of 1000 J/m was obtained when PET blended with 18 wt % ethylene/

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methacrylate/glycidyl methacrylate copolymer.<sup>5</sup> Among many other related works,<sup>6–14</sup> modifications of PET were focused, in recent years, to improve the compatibility of PET and suitable modifier, which was the key to enhance the toughness, since PET was thermodynamically immiscible with another polymer in many cases. The most commonly used method to improve compatibility is to add certain compatibilizers with grafting or blocking structures to strengthen the poor inter-phase adhesions. However, it is very complicated and costly to synthesize appropriate compatibilizers for different blends.

High energy irradiation may eliminate both disadvantages and has been widely used in polymer material processing, especially as a novel modification approach for single polymers. Mechanical properties of ethylene-vinyl alcohol and styrene-butadiene-styrene block copolymer were improved by irradiation reported by Deng et al.<sup>15</sup> and Datta et al.,<sup>16</sup> respectively. In addition some monomers were successfully grafted to polymers by irradiation and specialized functional materials were prepared.<sup>17–19</sup>

When polymer blends are exposed to irradiation, a large number of macromolecular radicals are formed and combined, leading to grafting or blocking structures, and compatibilization on the interfaces confirmed by Elmaghor et al.<sup>20</sup>: when the quinary systems of HDPE/PS/PVC blended with small amounts of ethylene-vinyl acetate copolymer and styrene/ethylene-butadiene/styrene copolymer were irradiated by gamma-rays, the impact strength was apparently enhanced.

However, in general, PET is irradiation resistant due to its aromatic groups<sup>21</sup> and the radical chains of PET do not react easily with other macromolecular radicals in the polymer blends, so little compatibilization substance can be generated when these PET blends being irradiated. Earlier our group pioneered research into irradiating PET blends with crosslinking agents and were the first to report on its effects.<sup>22</sup> In that study, a minute amount of crosslinking agent, trimethylolpropane trimethacrylate (TMPTA) was added and effectively promoted the compatibility of PET and HDPE in the PET/HDPE blends with  $\gamma$ -irradiation, therefore improved mechanical properties were obtained.<sup>22</sup> It was not confirmed whether the approach of  $\gamma$ -irradiation with a crosslinking agent presence was universally applicable to other PET blends. In the present study, the same approach is applied to the blends of PET and POE with the same crosslinking agent, TMPTA. The effects of  $\gamma$ -irradiation on the phase morphology and mechanical properties are presented. The authors demonstrate that the compatibility of PET and POE in PET/POE blends as well as blends toughness can be significantly improved.

## EXPERIMENTAL

### Raw Materials and PET/POE Blend Preparations

PET (CB651) with the intrinsic viscosity of 0.75 dL/g and POE (5061) with the MFI of 0.5 g/10 min were purchased from Far Eastern Industry (Shanghai) and ExxonMobil Chemical, respectively. The viscosity ratio of PET and POE is 1:7.5 at the temperature of 260°C. TMPTA was supplied by Laiyu Chemical (Shandong, China). 1,1,1,3,3,3-Hexafluoroisopropanol (HFIP)

and toluene were purchased from Zeus Fluors Technology Shanghai and Beijing Chemical Works, respectively.

After drying PET in a circulating air oven at 120°C for 4 h, the raw materials, namely PET, POE, and TMPTA were premixed in a high-speed mixer, then simultaneously added to a feeding device and transported to a co-rotating twin-screw extruder (TSE-30A, China) with the screw diameter of 30 mm and L/D ratio of 32. To prevent obvious decrease of strength and rigidity of original material as well as significant increase of materials cost with addition of the toughener, the amount of POE was confined to 15% by weight. Blends of PET/POE (95/5, 90/10, 85/15 wt/wt) mixed with various fraction of TMPTA (0, 1, 2, 3, 5 wt %) were prepared in the extruder. The temperature of the first to seventh regions were 220, 240, 250, 250, 260, 265, 260°C, and the temperature in the die was 250°C. The feeding rate and screw speed were ca.160 and ca.200 r/min, respectively. After pelletizing, the extrudates were dried at 110°C to remove the water. Dumb-bell tension and single-edge notched specimens used in mechanical tests were made by an injection machine (CJ80M3V, China) with the screw diameter of 31 mm and L/D ratio of 23. The clamping force of the injection machine is 800 kN. The specimens were molded at the injection pressure of 100 MPa and the screw rate of 30 r/min. The temperatures of the three regions were 250, 260, 260°C, respectively and the cooling time was 35 s.

### Gamma-Ray Irradiation

Injection-molded samples were sealed in bilayer polyethylene bags filled with nitrogen. These bags were irradiated in Co-60 source with absorbed doses of 10, 30, 50, 100, and 150 kGy at room temperature (RT).

### Gelation Extraction

Irradiated samples covered with nickel mesh were extracted in a Soxhlet extractor with HFIP at 85°C, then toluene at 100°C, and HFIP at 85°C again. PET and POE were extracted by HFIP and toluene, respectively. The weight of measured samples were between 0.1 and 0.5 g. The extraction time for each stage was 30 h. Extracted samples were dried to constant weight in vacuum at 120°C. The gel fraction,  $C$  (wt %), was calculated by the following formula:

$$C = \frac{W_1}{W_0} \times 100\%$$

where  $W_0$  and  $W_1$  are mass of the samples before and after extraction, respectively.

### Mechanical Tests

Tensile tests of dumb-bell specimens were conducted with a static-mechanical material testing machine (INSTRON 1121, USA) at the drawing rate of 50 mm/min according to GB/1040.2-2006 (China norm). IZOD tests of samples with single edge notch were operated with a radial-boom impact tester (UJ-40, China) according to GB/1843-2008 (China norm). Ten specimens for each sample were tested and average values are reported.

### Scanning Electron Microscopy

The fracture surfaces of various samples after impact tests were gold-coated under vacuum and then the scanning electron microscopy (SEM) photos of the fracture surfaces were taken using a SEM (XL30 ESEM FEG, USA) at 20 kV.

### Fourier Transform Infrared Spectroscopy

To observe the chemical structure of gel, FTIR measurement was carried out at RT using a BRUKER Vertex 70 FTIR. The FTIR spectra of gel were recorded in the range of 400–4000  $\text{cm}^{-1}$ , with the resolution of 2  $\text{cm}^{-1}$ , and the number of sample scans was 32. The membranaceous sample was prepared by hot pressing of the gel.

## RESULTS AND DISCUSSION

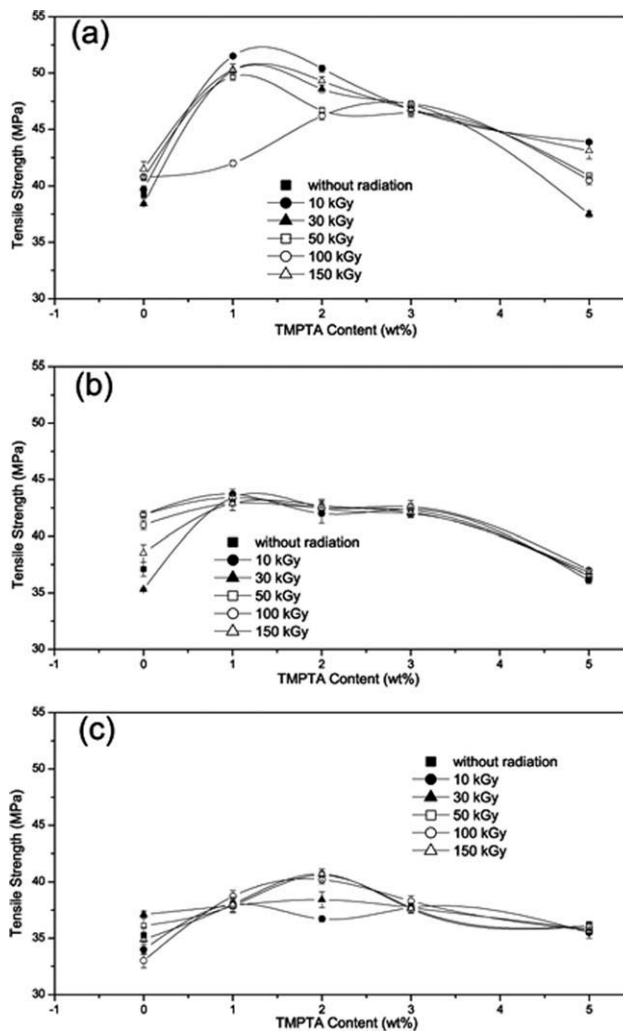
### Mechanical Properties

Nonirradiated PET/POE blends without TMPTA were also tested in the same manners for comparison purposes and the black-solid squares in the following figures represent the results for nonirradiated samples.

The plots of the tensile strengths of blends versus the TMPTA contents at various  $\gamma$ -irradiation absorbed doses are shown in Figure 1. First of all, without  $\gamma$ -irradiation, the increase of POE contents led to a decrease in the tensile strength of blends due to lower strength of POE when compared with PET. The tested-tensile strength for PET/POE blends at PET to POE ratio of 95/5, 90/10, and 85/15 was 39.2, 37.1, and 35.2 MPa, respectively. However, with the addition of small amounts of TMPTA and the introduction of  $\gamma$ -irradiation, tensile strengths of blends were enhanced. For a given blend composition, tensile strength increased with the TMPTA contents first then decreased slightly. The tendency had to be attributed to change of compatibility between PET and POE. As the addition of TMPTA, the interface adhesion was gradually improved after irradiation. When TMPTA could just cover all the two-phase interface zones in monoatomic layer, the critical amount was the optimum. Accordingly, the mechanical properties achieved the best. As the content was higher than the critical value, further addition of TMPTA aroused stress concentration at interfaces due to the crosslinking reactions among the small molecular additives themselves and the substance generated on the interface areas. Consequently, the tensile properties of the blends were deteriorated.

The optimum content of TMPTA for 95/5 and 90/10 PET/POE blends was 1 wt % as shown in Figure 1(A, B). In contrast, the optimum value for 85/15 PET/POE blends increased to 2 wt % seen in Figure 1(C). The increase of the optimum TMPTA content was attributed to the enlargement of total interface areas as the increase of POE content. As a result, the blending systems needed more TMPTA to completely cover the interfaces in monoatomic layer.

Because of the relatively high-reaction activity, TMPTA reacted completely at low  $\gamma$ -irradiation doses, so the further increase of absorbed doses did not improve the tensile strength remarkably anymore. Among the three-studied ratios of PET to POE, the blends with lowest POE amount (PET/POE 95/5) showed the greatest improvement in tensile strength by  $\gamma$ -irradiation,

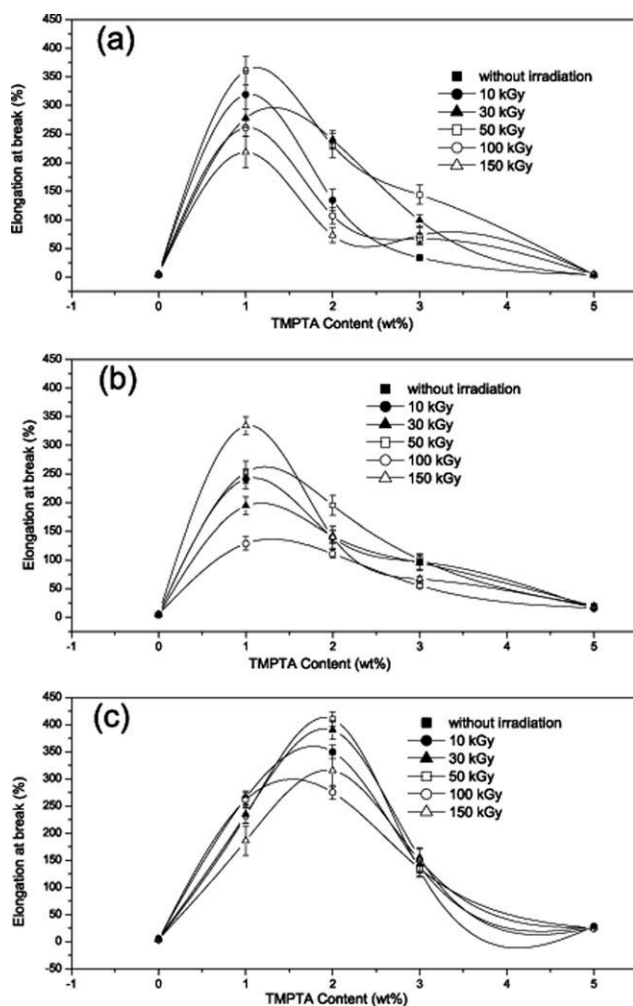


**Figure 1.** Tensile strengths of PET/POE/TMPTA blends versus TMPTA content at various  $\gamma$ -irradiation absorbed doses: (A) PET/POE 95/5 wt/wt; (B) 90/10 wt/wt; (C) 85/15 wt/wt.

increasing from 35 MPa to about 50 MPa with 1 wt % TMPTA presence. The effect of  $\gamma$ -irradiation on tensile strength decreased as POE amount in the blends increased for a given TMPTA content [see Figure 1(B, C)].

The elongation at break of blends increased initially with the amount of TMPTA, and then decreased to the original level as shown in Figure 2. The tendency similar to the changes of tensile strength verified above speculation up on the interfaces.

It is clear that the PET/POE blends were toughened according to the dramatic increase of elongation at break with the introduction of TMPTA and  $\gamma$ -irradiation. The optimum contents of TMPTA for the increase of elongation at break are also around 1–2 wt %, as the same with that for tensile strength. A total of 1 wt % addition of TMPTA was optimum for 95/5 and 90/10 blends as seen in Figure 2(A, B), while the amount of 2 wt % was the best for 85/15 blends as shown in Figure 2(C). The change of the optimum amount of TMPTA as the increase of POE was still resulted from the enlargement of the overall interface areas as mentioned above.



**Figure 2.** Elongation of PET/POE/TMPTA blends versus TMPTA content at various absorbed dose: (A) PET/POE 95/5 wt/wt; (B) 90/10 wt/wt; (C) 85/15 wt/wt.

With 1 wt % TMPTA, the maximum elongation at break value for the PET/POE (95/5) blends was over 350% occurring at 50 kGy, being approximately 35 times of that of nonirradiated blends. As 2 wt % TMPTA was added to 85/15 PET/POE blends, the elongation at break exceeded 400% after irradiation at 50 kGy when compared with ca. 10% for the same samples without irradiation processing.

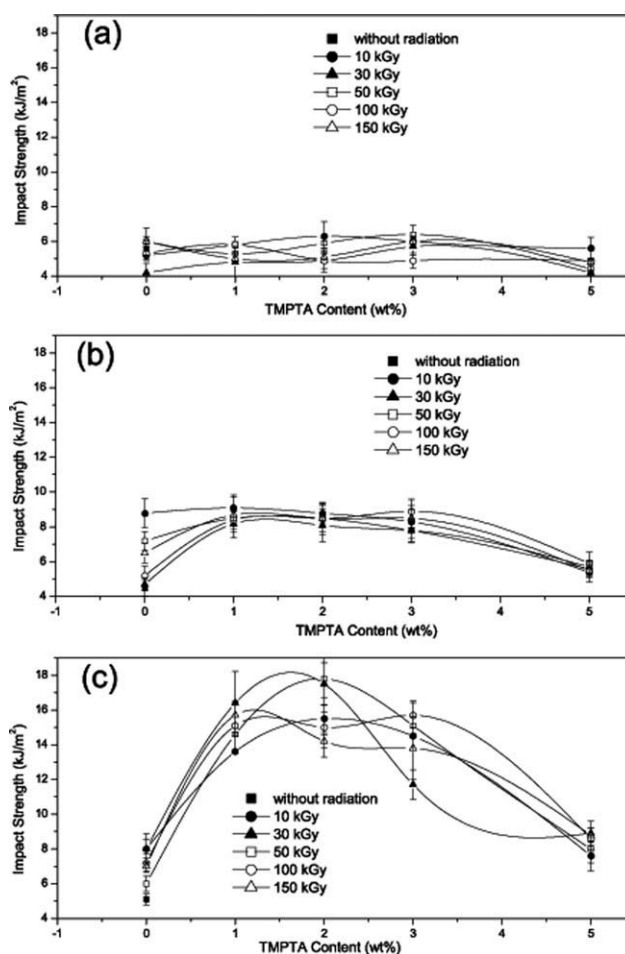
There is no simple correlation between the elongation at break and the irradiation absorbed doses. However, in the most-studied cases, 10–50 kGy seems effective enough for most improvement of elongation at break. When compared with the tensile strengths, improving effect of enhanced  $\gamma$ -irradiation is much more obvious on the elongation at break.

The impact strength variations shown in Figure 3 revealed a similar trend to that of the tensile properties discussed earlier. The impact strength first increased and then decreased with the addition of TMPTA after irradiation, which is shown most distinctly in Figure 3(C). This trend is still attributed to the reactions at interfaces and the concomitant improvement of compatibility between PET and POE phases. However, by

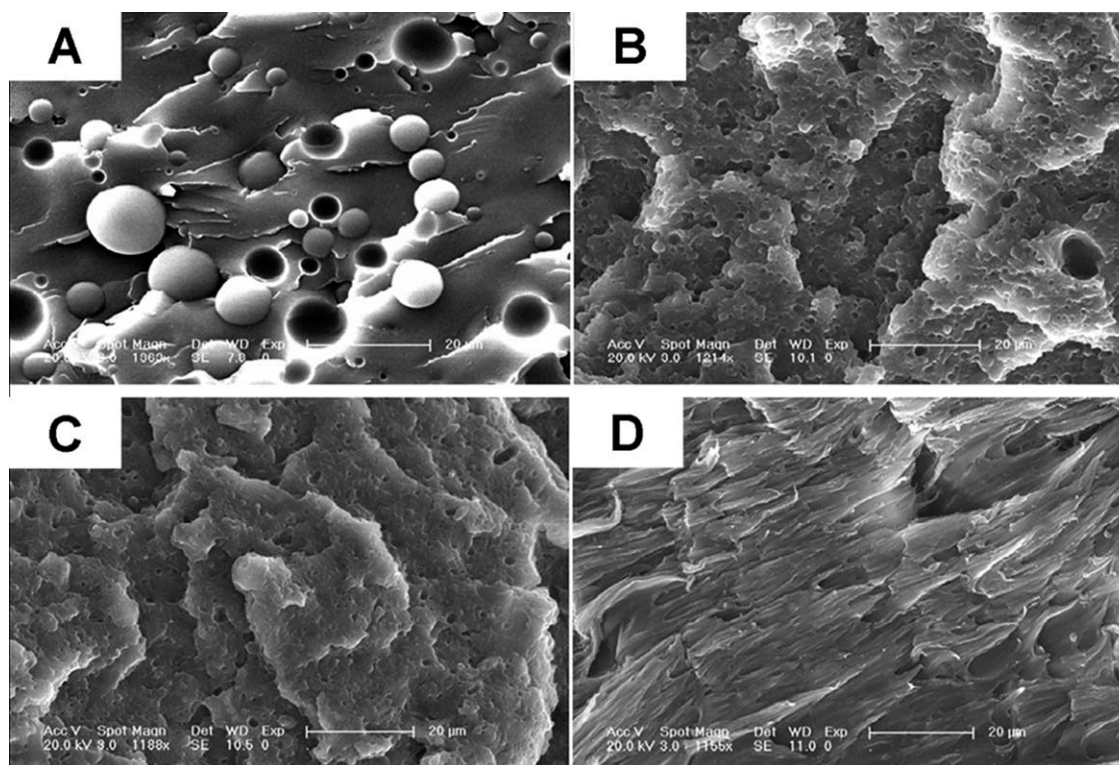
comparison of Figure 3(A–C), it was found that the improving effect of enhanced irradiation was more and more obvious as the increase of the POE content. It is because that the content of POE as well as the compatibility has an important impact on the toughening of PET. Wu<sup>23</sup> indicated there was a critical content of rubber when using for toughening of other plastics. Only if the rubber volume fraction exceeds a certain value, the rubber particles in blends can be near enough with each other. Short distance of dispersed particles causes superposition of stress fields and a sudden improvement of the toughness.

For 90/10 PET/POE blends, 1 wt % TMPTA was enough to toughen PET during irradiation processing, while 2 wt % TMPTA showed the best toughening effect for 85/15 blends. The increase of the optimum content of TMPTA again confirmed the theories about total interface area from tensile properties.

For the blend composition PET/POE 85/15, the addition of 2 wt % TMPTA improved significantly the impact strength from a value of 5 kJ/m<sup>2</sup> (without TMPTA or irradiation) to 17 kJ/m<sup>2</sup> after irradiation. The impact strength of the PET/POE blends prepared by  $\gamma$ -irradiation is greater than those (maybe



**Figure 3.** Notched impact strengths of PET/POE/TMPTA blends versus TMPTA content at various absorbed dose: (A) PET/POE 95/5 wt/wt; (B) 90/10 wt/wt; (C) 85/15 wt/wt.



**Figure 4.** SEM photos of fractured surfaces of blends: (A) PET/POE/TMPTA 85/15/0 wt/wt/wt, without irradiation; (B) 85/15/1 wt/wt/wt, 10 kGy; (C) 85/15/1 wt/wt/wt, 30 kGy; (D) 85/15/1 wt/wt/wt, 100 kGy.

noncompatibilized) reported by Chupleau et al.<sup>5</sup> and Chiu and Hsiao,<sup>24</sup> being about  $10 \text{ kJ/m}^2$  at a similar blending ratio as 85/15.

The mechanical results above demonstrate unequivocally that  $\gamma$ -irradiation is an effective approach to improve the toughness of PET/POE blends with a small amount of TMPTA. Not only for the PET/HDPE blends reported earlier,<sup>22</sup> the approach using  $\gamma$ -irradiation in the presence of a suitable crosslinking agent may be an universal method to enhance the toughness of the PET blends. However, different blends may need to have different irradiation levels with different optimized amounts of different crosslinking agent when PET/POE blends when compared with PET/HDPE blends as reported earlier.<sup>22</sup> A further improvement of the toughness would be expected when compatibilized PET/elastomers blends are irradiated in the presence of a suitable crosslinking agent.

### Morphology

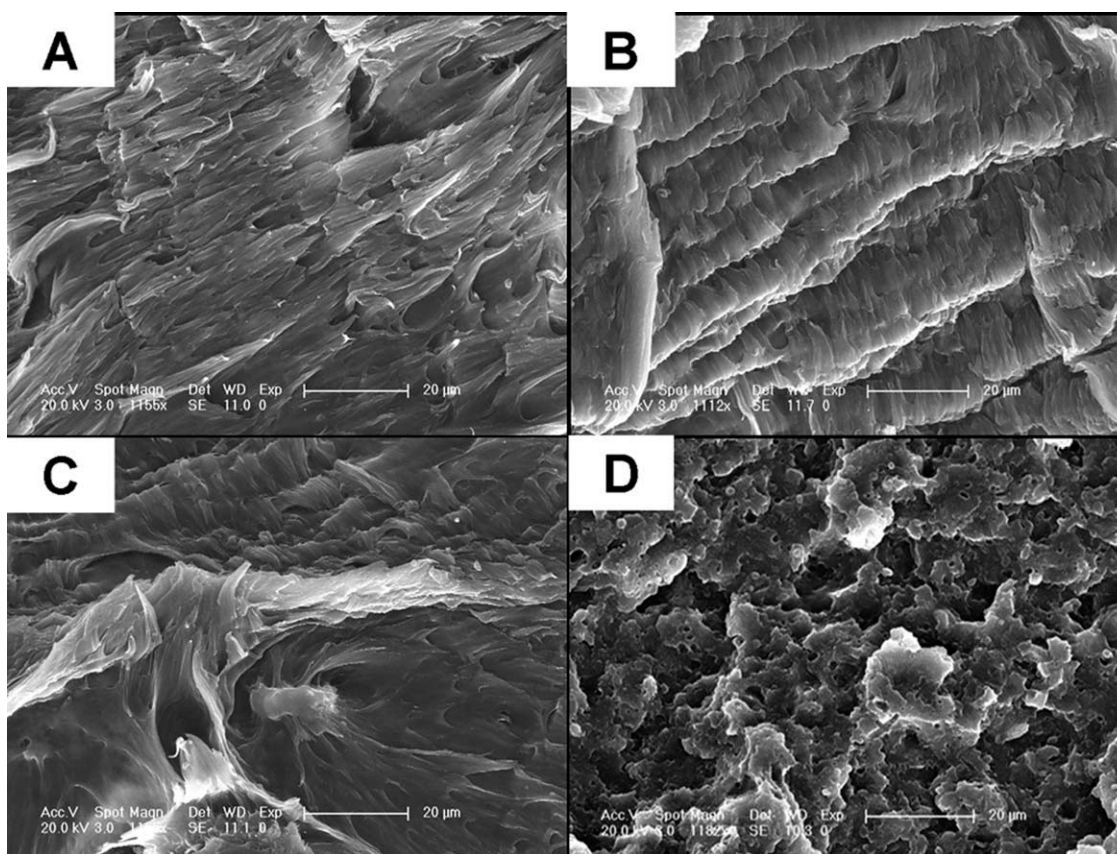
SEM was used to study the morphological structures of blends before and after  $\gamma$ -irradiation. SEM photos of impact fracture surfaces are shown in Figures 4 and 5. PET/POE (85/15) blend without irradiation has a typical two-phase structure as shown in Figure 4(A). Poor inter-phase adhesion is indicated by the smooth surfaces of the holes where POE particles were pulled out. The diameter of POE particles ranged from 1.9 to  $15.6 \mu\text{m}$  and the mean value was  $6.2 \mu\text{m}$  as measured from Figure 4(A). The use of  $\gamma$ -irradiation and a small amount (1 wt %) of TMPTA changed the fracture-surface morphology. The mean particle size of the dispersed phase (POE) was decreased to  $1.5 \mu\text{m}$  and indistinct interfaces showed up as seen in Figure 4(B, C),

which reveals the improvement of compatibility between PET and POE phases. When PET/POE/TMPTA (85/15/1) blend was irradiated at 100 kGy, the fracture appears to be a ductile model causing evident plastic deformation shown clearly in Figure 4(D). The elongation at break of such a PET/POE/TMPTA (85/15/1) blend irradiated at 100 kGy was as high as 250% and the impact strength was as high as  $15 \text{ kJ/m}^2$ . However, the greater improvement of compatibility by higher  $\gamma$ -irradiation may not lead to further improvement of toughness even though the morphology shows more ductile deformation, for example, in Figure 4(D). The best impact strength for the PET/POE/TMPTA (85/15/1) blend occurred at 30 kGy [corresponding to the morphology in Figure 4(C)] with 1 wt % TMPTA, being approximately  $17 \text{ kJ/m}^2$ . Interestingly, it was found that increasing irradiation level is not the most significant parameter for improving toughness of the PET blends, which is consistent with the effects of separate irradiation on mechanical properties.

The effect of TMPTA amounts on the morphology of the fracture surfaces of the blends is shown in Figure 5. The plastic deformation (ductile model) is clearly presented in Figure 5(A–C), but decreases with TMPTA contents larger than 5 wt % [shown in Figure 5(D)], thus reflecting the decreases of mechanical properties (shown in Figures 1–3) when TMPTA exceeds 3 wt %. A total of 1–3 wt % is the optimized amount of TMPTA for the most improved toughness of the blends.

### Gel Fraction

Gel fractions of POE separately blended with various amounts of TMPTA after irradiation are listed in Table I. As TMPTA



**Figure 5.** SEM photos of fractured surfaces of PET/POE (85/15) blends mixed with various amount of TMPTA after irradiated at 100 kGy: (A) 1 wt % TMPTA; (B) 2 wt %; (C) 3 wt %; (D) 5 wt %.

content is fixed, the gel fractions first increase, then decrease, and increase finally with the increase of absorbed dose. This phenomena is typical for crosslinking polymers blended with polyfunctional monomers (PFMs). At the preliminary irradiation stage, free radicals gradually generated on macromolecular chains were quickly captured by PFMs with high activity, so networks were achieved and gel fractions increased. When PFMs were used up, networks were hardly formed within a short-time due to the low reaction activity and concentration of macromolecular radicals. However, during this short time, the breaks of chains, which was an important method to produce radicals led the decreases of molecular weight and gel fractions. After undergoing this short time, the concentration of radicals accumulated to a relatively high level, and crosslinking became the dominant reactions again. As a result, the gel fraction gradually increased to the maximum value, which depended on the structural characteristic of POE.

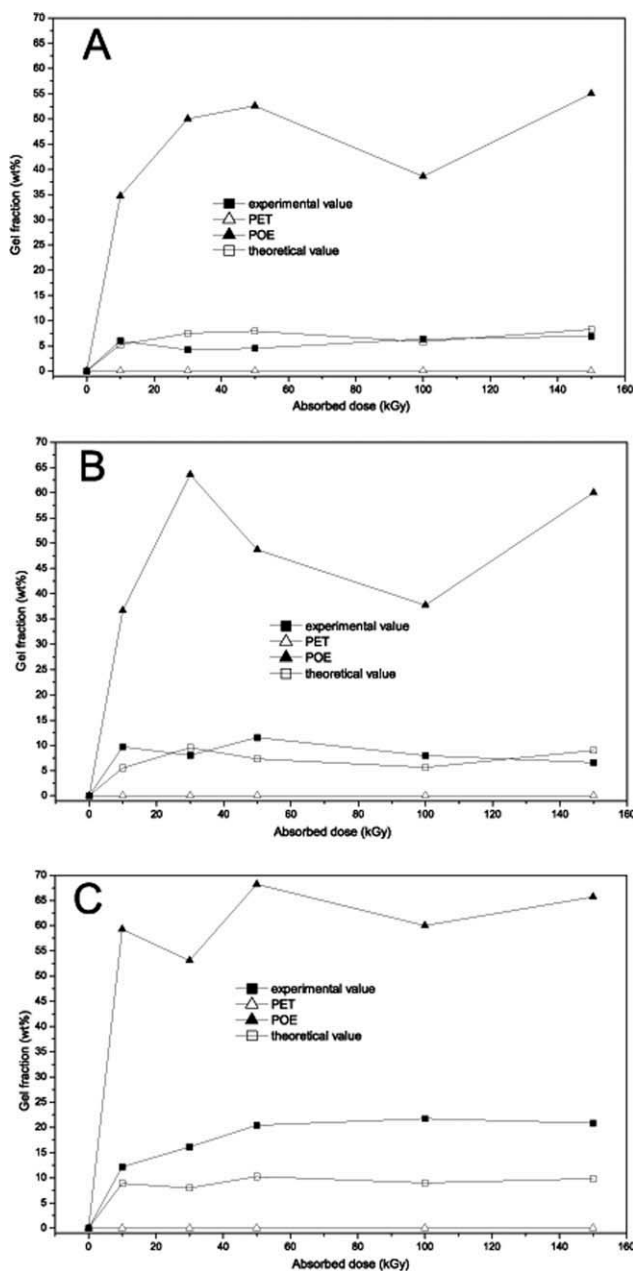
Typical comparison of theoretical and experimental gel fraction of PET/POE blends mixed with TMPTA are shown in Figure 6. On the assumption that there was no influence between POE and PET, these two phases would react with TMPTA separately during the irradiation, so the gel fractions of blends had to be calculated by summation of their respective gel generated during irradiation in the presence of TMPTA. For a typically immiscible-binary polyblend, theoretical value  $C_T$  can be achieved by a certain formula.<sup>22</sup> For the present study, provided that the dispersion of TMPTA in the blend is homogeneous, the theoretical value  $C_T$  can be achieved by the following formula:

$$C_T = C_{T-POE} \times P + C_{T-PET} \times (1 - P)$$

where  $P$  is the mass fraction of POE in blends.  $C_{T-POE}$  and  $C_{T-PET}$  were measured as the gel fractions of PET and POE, respectively, after they were blended with the same amount of TMPTA separately and exposed to the gamma rays.

**Table I.** Gel Fraction of POE Blended with Various Amounts of TMPTA after Irradiation

TMPTA content (wt %)	Gel fraction of POE after enhanced irradiation (wt %)					
	Without irradiation	10 kGy	30 kGy	50 kGy	100 kGy	150 kGy
1	0	34.7	50	52.6	38.6	55
3	0	36.6	63.6	48.7	37.7	60
5	0	59.3	53.1	68.2	60	65.7



**Figure 6.** Typical comparison plots of the experimental and theoretical gel fraction of PET/POE (85/15/) after irradiation: (A) blended with 1 wt % TMPTA; (B) 3 wt %; (C) 5 wt %.

The experimental value can also be expressed by a similar formula as follows:

$$C_E = C_{E-POE} \times P + C_{E-PET} \times (1 - P)$$

where  $C_{E-POE}$  and  $C_{E-PET}$  are the actual gel fraction of POE and PET in the blends of PET/POE/TMPTA, respectively, after irradiation.  $C_E$  stands for the experimental gel fraction of the blends.

The actual gel fraction of POE ( $C_{E-POE}$ ) in the blends will not be higher than the corresponding theoretical value ( $C_{T-POE}$ ) since the crosslinking of POE during irradiation is inhibited, when it is blended with the irradiation resistant/degradable polymer, PET,

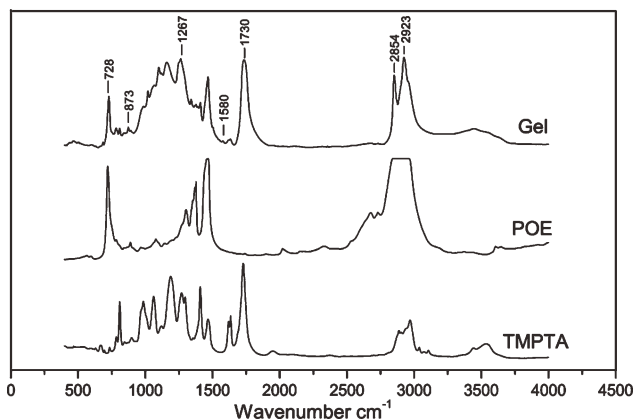
according to the theory reported by Zhang et al.<sup>25</sup> If the experimental gel fraction of blends ( $C_E$ ) is not lower than the theoretical one ( $C_T$ ), the actual gelation amount of PET ( $C_{E-PET}$ ) will be greater than  $C_{T-PET}$  (equal to zero, as seen in Figure 6), indicating that PET chains enter the networks of POE and co-crosslinking occurred. Oppositely, if  $C_E$  is lower than  $C_T$ , it can not be determined whether PET chains enter the networks by the formulas mentioned above.

As seen in Figure 6, no gel formed during irradiation, if neat PET is separately blended with TMPTA, since aromatic groups made PET hard to crosslink. When 1 wt % TMPTA was added to PET/POE (85/15) blend as seen in Figure 6(A), the experimental and theoretical gel fractions were very close. The experimental value was higher than the theoretical one within some ranges, and lower within the left ranges. When compared with Figure 6(A), the absorbed dose ranges in which experimental value was higher than the theoretical one were larger in Figure 6(B). According to these, two conclusions could be speculated. First, the possibility of that the PET chains entered the POE networks in the presence of TMPTA can not be excluded. Second, the gel of the PET/POE blends was mainly formed by POE phase as TMPTA content was lower than 3 wt %. When TMPTA content reached 5 wt %, the experimental value totally exceeds the theoretical value as shown in Figure 6(C), which confirmed that the PET chains entered the POE networks in all doses selected.

Taken together, when TMPTA was added to PET/POE blends, the PET chains could be linked to the networks mainly consisted of POE phase by chemical bounds after irradiation. And the content of POE phase in the gel was increased with TMPTA content.

#### Fourier Transform Infrared Spectrum Analyses of the Gel

The previous speculation on the formation of the “graft” structure by gelation analysis has been supported by the infrared analyses. The FTIR spectrum of the gel is shown in Figure 7. The peaks at 2850, 2920, and 1463  $\text{cm}^{-1}$  are attributed to the vibrations of  $\text{CH}_2$ . The peak at 1733 due to the stretching vibration of  $\text{C}=\text{O}$ , combining with the peaks of 1100 and 1263  $\text{cm}^{-1}$  attributed to  $\text{C}-\text{O}-\text{C}$  stretching vibrations confirms the existence of the ester groups.<sup>26</sup> The peak at 1377  $\text{cm}^{-1}$  is assigned to the symmetrical deformation vibration of  $\text{CH}_3$ .



**Figure 7.** Comparison of FTIR spectrums of gel samples after irradiation at 100 kGy: (A) PET/POE/TMPTA (85/15/1); (B) neat POE blended with 1 wt % TMPTA.

Almost all of the above absorption peaks due to alkyl and ester groups can be found in the spectrum of the gel formed with TMPTA and neat POE after irradiation, as seen in Figure 7(B).

By comparison, the absorption peaks of benzene rings in the PET chains can be found in the spectrum of the gel of PET/POE/TMPTA blends after irradiation, as seen in Figure 7(A). The peaks at 728 and 873  $\text{cm}^{-1}$  are assigned to the aromatic ring C—H out-of-plane bending vibrations<sup>27</sup> and deformation vibrations,<sup>26</sup> respectively. The weak peaks at 1577 and 1629  $\text{cm}^{-1}$  are due to in-plane aromatic ring vibrations.<sup>22</sup> Otherwise, the peak at 1733  $\text{cm}^{-1}$  in Figure 7(A) is more intense than the one in Figure 7(B), which can be attributed to the absorption of ester groups in PET chains. It is confirmed that the gel of PET/POE blends definitely contains PET chains, when only 1 wt % TMPTA was added and the gel fraction of the blends was lower than 10 wt %.

These four peaks have confirmed the existence of PET chains.

The gelation analysis and FTIR characterization confirmed the existence of both POE and PET chains in the network formed after irradiation. Since the incompatibility between PET and POE phases, the chemical structure changed was definitely resulted from the formation of analogous to “PET-g-TMPTA-g-POE” at the interface area. Because of the good mobility, TMPTA monomers could play the role of a bridge, connecting PET, and POE chains. Since the chemical reactions of polymer blends during gamma-irradiation are very complicated, the detailed structure of the new substance is not explained in the present study. The chemical structure changes of PET/POE/TMPTA polymers will be studied in the future study instead. This new grafting material acting as a compatibilizer enhanced the interface adhesion *in situ* through entanglements of polymer chains with similar segments, and optimized the morphology structure. As a result, the mechanical properties were obviously improved.

## CONCLUSION

$\gamma$ -Irradiation has been proved to be an effective approach to significantly improve the compatibility of PET and POE in the PET/POE blends in the presence of the crosslinking agent, TMPTA. Gelation analysis and FTIR spectra of the gel confirm the formation of a new grafting structure containing both PET and POE segments, namely PET-g-TMPTA-g-POE at the interphase boundaries. The morphologies of the fracture surfaces of the PET/POE blends, obtained by SEM, changed toward a ductile-model plastic deformation with  $\gamma$ -irradiation. As a result, the mechanical properties, particularly the elongations at break and the impact strengths have been greatly improved by  $\gamma$ -irradiation with little effect of various absorbed doses. The optimum contents of the crosslinking agent, TMPTA, was found to be between 1 and 3 wt %, and the impact strength reached 17  $\text{kJ/m}^2$ , approximately 3.4 times of that of the counterpart neither without TMPTA nor irradiation, and the elongation at break reached 400%, about 80 times of that of the same PET/POE blend neither without TMPTA nor irradiation.

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