Polymer Blends of PET-PS Compatibilized by SMA and Epoxy Dual Compatibilizers

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ABSTRACT: Poly(ethylene terephthalate) (PET) and polystyrene (PS) are immiscible and incompatible and have been well recognized. In this study, styrene maleic anhydride random copolymer (SMA–8 wt % MA) and tetra-glycidyl ether of diphenyl diamino methane (TGDDM) are employed as reactive dual compatibilizers in the blends of PET–PS. The epoxy functional groups of the TGDDM can react with PET terminal groups (—OH and —COOH) and anhydride groups of SMA at the interface to produce PET-co-TGDDM-co-SMA copolymers. SMA with low MA content is miscible with PS, whereas the PET segments are structurally identical with PET phase. Therefore, these in-situ-formed copolymers tend to anchor at the interface and act as effective compatibilizers of the blends. The compatibilized blends, depending on the amounts of TGDDM and SMA addition, result in smaller phase domain, higher viscosity, and improved mechanical properties. This study demonstrates that SMA and TGDDM dual compatibilizer can be utilized effectively in compatibilizing polymer blends of PET and PS. © 1999 John Wiley & Sons, Inc. J Appl Polym Sci 73: 2029–2040, 1999

Key words: poly(ethylene terephthalate); polystyrene; styrene maleic anhydride; random coploymer; epoxy resin; coupler

INTRODUCTION

Polymer blending has become an important field in finding new commercial plastic materials for achieving cost/performance balances in last two decades. Except for a few polymer pairs that are known to be thermodynamically miscible, most polymer pairs are immiscible. Nevertheless, immiscible systems are actually desirable for better performance because components in a blend may retain their own properties. In a typical immiscible polyblending system, a satisfactory overall physicomechanical behavior depends upon the proper interfacial tension to generate a small phase size and strong interfacial adhesion to transmit applied force effectively between compo-

nent phases.1 Reducing interfacial tension and enhancing phase adhesion between two immiscible phases have been a subject of considerable research; and, nowadays, it is well known that graft or block copolymers can be successfully used as compatibilizers in compatibilizing those immiscible blend systems. 1-3 The choice of a block or graft copolymer is based on the miscibility of its segments with blend components, and such a copolymer tends to concentrate at the interface as an interfacial emulsifier. However, such copolymers usually require a separate preparation step, and some of them are difficult to be synthesized. Besides, these copolymers may not have enough time to migrate and reside at the interface under a typical melt process.

Recently, the *in-situ*-formed compatibilizers in polyblends have attracted great attention as an alternative to replace the conventional block or graft copolymers. Maleic anhydride (MA) and gly-

cidyl methacrylate (GMA) containing copolymers have been the most often used reactive compatibilizers. $^{4-10}$ This approach is especially effective for polymers possessing terminal functional groups, such as polyesters or polyamides. The in situ reaction occurs during melt processing to form block or graft copolymers at interfaces. These in-situ-formed copolymers tend to reside along the interface to reduce the interfacial tension at melt and increase interfacial adhesion at solid state, and, thus, the physicomechanical behavior of resulted polyblend can be improved substantially. $^{11-13}$

Both poly(ethylene terephthalate) (PET) and polystyrene (PS) are low-cost commodity polymers that possess unique properties individually. The blend of PET and PS is expected to be highly desirable due to great commercial potential. However, the research on PET-PS mixtures has been sparse because of incompatibility. Mckay¹⁴ used the polystyrene-b-polycaprolactone diblock copolymer (PS-b-PCL) as a nonreactive compatibilizer for the PET-PS blends but resulted in reduced mechanical and thermal properties. On the other hand, Maa and Chang¹⁵ used the styrene-glycidyl methacrylate copolymer (SG) as an in situ reactive compatibilizer in PET-PS blends and resulted in substantial improvements on mechanical properties and processibility. These results provide an example that a reactive compatibilizer is more effective to compatibilize an immiscible and incompatible blend than a nonreactive one. Styrene maleic anhydride random copolymer (SMA) has been reported as an effective reactive compatibilizer for blends of PS with various polyamides. 10,11,16-18 Kalfoglou et al. 5 reported that the maleic-anhydride-grafted acrylonitrile-butadiene-styrene terpolymer (ABS-g-MA) is able to compatibilize PET-ABS blends through physical interaction, but the property improvements are not very substantial. The PET carboxyl terminal groups do not react with anhydride of SMA, while the reaction between PET hydroxyl groups and the anhydride is insignificant without the presence of a catalyst. A similar problem is expected when SMA is used as a compatibilizer in PET-PS blends and only secondary physical interaction is expected. Epoxy is able to react with polyester terminal carboxyl group to compatibilize effectively many polyester-related blends. 19-23 Epoxy is also well known to react with anhydride readily. The presence of a multifunctional epoxy resin in the PET-PS-SMA blend has the potential to produce PET-co-epoxy-co-SMA copolymer

Table I The List of the Structure and Repeating Units of Each Component

Component	Repeating unit or structure					
PET	HO \leftarrow C \leftarrow					
PS	——————————————————————————————————————					
SMA	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$					
TGDDM	$H_{2}C - CH - CH_{2}$ $N - CH_{2} - CH_{2} - CH_{2}$ $H_{2}C - HC - CH_{2}$ $H_{2}C - HC - CH_{2}$					

at the interface, which is able to function as an effective compatibilizer. In this study, both SMA and epoxy resin are commercially available. We attempt to investigate the effect of epoxy resin on the compatibilized blend of PET-PS-SMA systematically.

EXPERIMENTAL

Materials

PET, Shin PET, I.V. = 1.0, was kindly provided by the Shinkong Synthetic Fibers Inc. of Taiwan. PS, Maxiglac 125, was obtained from the B. C. Chem. Co. of Taiwan. The SMA copolymer containing 8 wt % maleic anhydride, Dylark 232, was purchased from the ARCO Chemical Co. The epoxy resin, tetra-glycidyl ether of diphenyl diamino methane (TGDDM), with the trademark of NPEH-434, was purchased from the Nan Yea Plastics Co. of Taiwan. Table I presents the structures of the epoxy and polymers employed in this study.

Melt Blending and Injection Molding

Prior to the extruder compounding, PET was dried at 120°C, and PS and SMA were dried at 90°C for over 24 h in separate ovens. TGDDM was dried at 60°C for 2 h before using. All blends were prepared by dry mixing first and then melt mixing in a 30-mm corotating intermeshing twin-

Table II Processing Conditions

Extrusion Blending		Inject	Injection Molding		
Stage	Temperature (°C)	Stage	Temperature (°C)		
1 2 3 4 5 6 7	210 260 270 275 280 280 285	1 2 3 Nozzle Mold	275 280 285 290 80		
8 9 Die	285 285 280				

screw extruder (L/D=36 Sino-Alloy Machinery Inc. of Taiwan) with a rotational speed of 250 rpm. The extruded pellets were then dried in a vacuum oven and injection-molded into $\frac{1}{8}$ -in. standard ASTM specimens by using an Arburg 3-oz injection-molding machine. The detailed processing conditions for extrusion and injection molding are listed in Table II.

Torque Versus Time Measurements

To verify potential chemical reactions among PET, SMA, and TGDDM based on the viscosity increase (torque versus time), 30 g of the selected composition was tested at 285°C and 30 rpm without nitrogen purge in a Brabender Plasti-Corder, type PLD 651.

Rheological Properties

Melt flow rates (MFR) of blends were measured at 285°C with a 2.16 Kg loading by using an automatic flow rate timer from Ray-Ran Co. of Britain. The capillary rheological measurements of the blends and matrices were also carried out at 285°C using a capillary rheometer (L/D=40, orifice radius = 0.02 in., and orifice length = 0.8 in.) from Kayeness Co. of USA, Model Galaxy V.

Thermal Properties

Thermal properties of blends and pure components were investigated by differential scanning calorimeter (DSC) with a sample weight of 5–10 mg on a DSC instrument model DSC 910s from TA Co. of USA. The measurements were made between 30 and 300°C at a scanning rate of 10°C

 $\mathrm{min}^{-1}.$ The sample was heated at 300°C for 5 min and then cooled down in determining the crystallization temperature (T_c) and the crystallization temperature range (ΔT_c) of the PET component in the blend. After the cooling treatment, this same sample was heated immediately to measure glass transition temperatures (T_g) of PET and PS, melting temperature (T_m) , melting temperature range (ΔT_m) , and heat of fusion of PET $(\Delta H_{f,\mathrm{PET}}).$

Scanning Electron Microscopies

The morphologies were examined by a SEM, Model S-570, Hitachi Co. of Japan from cryogenically fractured specimens in the plane perpendicular to flow direction of injection molding. Portions of the samples were etched with chloroform to dissolve the PS phase out of the blends. The cryogenically fractures surfaces of specimens were coated with thin film of gold to prevent charging.

Mechanical Properties

Tensile tests were conducted at ambient conditions using an Instron Universal-Testing Machine, Model 4201, according to ASTM D638 method. The crosshead speed was 5 mm min⁻¹. Unnotched Izod impact strengths were measured at ambient conditions according to the ASTM D256 method, by an Impact Tester from TMI Co. of USA, Model 43-1.

RESULTS AND DISCUSSION

Torque Versus Time

A reactive compatibilizer is a compound or a copolymer containing reactive functional groups that are able to react with one or more of the blend components to form a new graft or block copolymer in the blend. This interfacially formed copolymer containing segments of the blend constituents tends to remain at the interface between the two incompatible polymers and acts as a phase emulsifier of the blend. When reactions among functional groups occur, the viscosity of the blend will increase due to molecular weight increase of the blend. Torque measurement has been utilized successfully to obtain qualitative information concerning the chemical reactivity and the extent of reaction in a reactively compatibilized blend. 8,15 Figure 1 presents torque versus

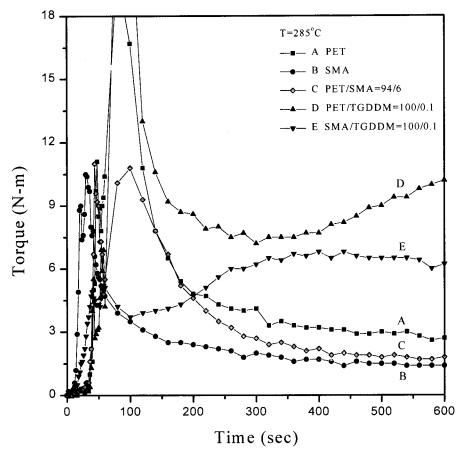


Figure 1 Plots of torque versus time for PET, SMA, PET–SMA = 94/6, PET–TGDDM = 100/0.1, and SMA–TGDDM = 100/0.1 mixture.

time curves for pure PET and SMA, and PET-SMA, PET-TGDDM, and SMA-TGDDM mixtures. The torque value of SMA is low at 285°C, as shown in Figure 1(B). Under the same conditions, the torque value of PET [Fig. 1(A)] is about twice higher than that of SMA and decreases gradually with time. This decrease in torque value can be attributed to the slight hydrolytic degradation because there was residual moisture content in PET and the molten PET contact air moisture during melt mixing. The torque value of the PET-SMA = 94/6 mixture is only slightly higher than the pure SMA [Fig. 1(C)]. This observation indicates that the expected reaction between anhydride groups of SMA and hydroxyl groups of PET does not occur or occurs insignificantly. On the contrary, TGDDM exhibits a much higher reactivity toward PET (hydroxyl and carboxyl groups) and SMA (anhydride groups). The torque of PET containing 0.1 phr TGDDM shows a substantial higher viscosity than the pure PET and continues to rise after 400 s, as shown in Figure 1(D). This

observation is owing to the formation of branched or lightly crosslinked PET-co-TGDDM-co-PET copolymers since the functionality of TGDDM is four, and that of PET is two. The reaction mechanism between epoxy and terminal groups of PET is well established as the following simplified eqs. (1) and (2)²⁴:

The torque values of the SMA-TGDDM = 100/0.1 mixture [Fig. 1(E)] are also higher than that of

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$$\longrightarrow \begin{array}{c} \stackrel{\text{\scriptsize I}}{\underset{\text{\scriptsize HC}}{\text{\scriptsize C-C}}} \stackrel{\text{\scriptsize NR}_3^2}{\underset{\text{\scriptsize HC}}{\text{\scriptsize I}}} & 0 & 0 \\ \stackrel{\text{\scriptsize I}}{\underset{\text{\scriptsize HC}}{\text{\scriptsize I}}} \stackrel{\text{\scriptsize I}}{\underset{\text{\scriptsize C-C}}{\text{\scriptsize I}}} - \stackrel{\text{\scriptsize C-C}}{\underset{\text{\scriptsize I}}{\text{\scriptsize I}}} - \stackrel{\text{\scriptsize I}}{\underset{\text{\scriptsize I}}{\text{\scriptsize I}}} - -\stackrel{\text{\scriptsize I}}{\underset{\scriptsize \scriptsize I}} - -\stackrel{\text{\scriptsize I}}{\underset{\scriptsize \scriptsize I}} - -\stackrel{\text{\scriptsize I}}{\underset{\scriptsize \scriptsize I}} - -\stackrel{\text{\scriptsize I}}{\underset{\scriptsize \scriptsize$$

Scheme 1 The simplified reaction mechanism between epoxy and anhydride catalyzed by tertiary amine.

the pure SMA, as shown in Figure 1(B). Reaction between TGDDM and SMA is somewhat more complicated. An anhydride group can undergo a ring-opening reaction with the tertiary amine as a catalyst and then react with epoxy groups.24 Scheme 1 illustrates the simplified reaction mechanism between epoxy and anhydride groups catalyzed by a tertiary amine. Impurities can transfer quaternary amine salts produced in the reaction and terminate the mechanism. The tertiary amine on the TGDDM epoxy can act as a catalyst, and the self-catalyzed reaction is able to proceed during melting process. Consequentially, the measured torque values of the SMA-TGDDM = 100/0.1 mixture are substantially higher than the pure SMA. This phenomenon is quite different from the result of the PET-SMA mixture shown in Figure 1(C). In real blends of PET-PS-SMA-TGDDM, the reaction between epoxy and anhydride groups can be initiated by a hydroxylcontaining compound to proceed ring-opening reaction, as illustrated in eq. (3):

A hydroxyl-containing compound can be obtained from the reaction between TGDDM and PET or from the terminal group of PET. Then, the ringopened anhydride groups can react with epoxy group as the following simplified equation:

Figure 2 illustrates the effect of TGDDM on the blend of PET-PS-SMA. Curves (A) and (B) in Figure 2 represent the torque versus time plots for the blends of PET-PS = 75/25 and PET-PS-SMA = 75/23/2, respectively; both curves decrease gradually with time. The result of Figure 2(B) indicates that the formation of the desirable copolymer SMA-co-PET through the covalent bond reaction between PET and SMA probably does not occur or occurs insignificantly. That means that SMA alone cannot effectively compatibilize polymer blends of PS and PET. Curve (C) of Figure 2 shows that the presence of only 0.1 phr TGDDM results in substantial torque increase of the blend, about three times higher than curves (A) and (B). This result demonstrates that portion of the TGDDM is able to act as an effective coupler to react with SMA and PET simultaneously to produce the desirable PET-co-TGDDMco-SMA copolymers. As the result of the chemical reaction, these *in-situ*-formed copolymers tend to anchor along the interface. Other portion of the TGDDM may function as a chain extender to react with only one blend component (PET) to increase the molecular weight of PET.

Rheological Properties

Figure 3 presents the effect of TGDDM content on the resultant MFRs of various PET-PS-SMA compatibilized blends. For the blends without containing TGDDM, the presence of SMA in the PET-PS blends results in higher MFR when the quantity of SMA is less than 5 wt %. This result implies that the extent of reaction between PET and SMA is insignificant during extruder com-

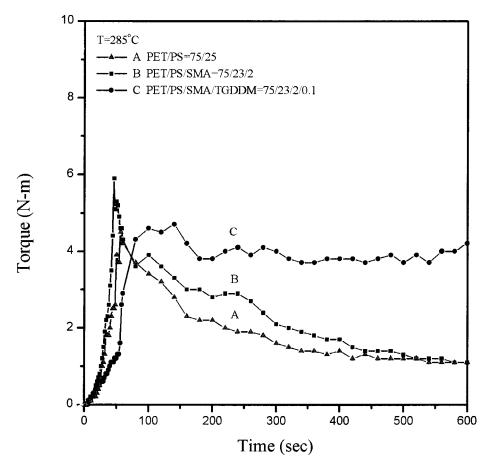


Figure 2 The effect of 0.1 phr TGDDM on the torque change with mixing time of the PET-PS-SMA = 75/23/2 blend.

pounding. When the SMA content is at 10 wt % (TGDDM = 0), the resultant MFR becomes lower probably due to appreciable reaction between PET and SMA. Adding TGDDM into PET-PS-SMA blends results in a substantial reduction in MFR of the blends, as shown in Figure 3. Regardless, the quantities of SMA in the blend, only small quantity of TGDDM (0.1 phr) in the blend is able to reduce the MFR of the blend significantly. This result indicates that the coupling and chain extending reactions indeed occur during the process of melt blending and produces various PETco-TGDDM-co-SMA copolymers and chain-extended PET in the compatibilized blends. The in-situ-formed copolymers tend to anchor along the interface and, therefore, raise the interfacial friction of the compatibilized blends under shear stress. The MFR decreases further with increasing the TGDDM content in the blends and approaches zero for the blend of PET-PS-SMA-TGDDM = 75/15/10/0.5. Too high TGDDM content causes light crosslinking of the blend and

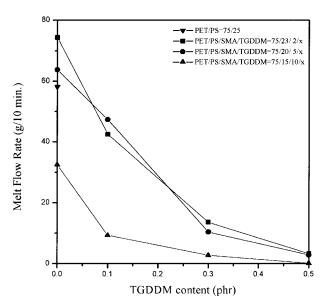


Figure 3 Melt flow rate as function of TGDDM content for PET-PS-SMA blends.

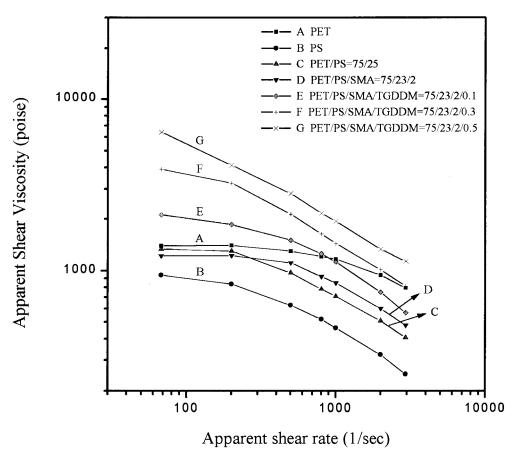


Figure 4 Plots of apparent shear viscosity versus shear rate for base polymers and blends at 285°C.

results in extremely high viscosity, as would be expected.

Plots of apparent shear viscosity versus shear rate of base polymers and blends are displayed in Figure 4. The variation of viscosity for PET and PS with shear rates are shown in Figures 4(A) and 4(B), where PET has higher viscosity and less shear thinning than that of the PS at 285°C. The viscosity of the PET-PS = 75/25 blend [Fig. 4(C)] is between that of PET and PS as expected. The PET-PS-SMA = 75/23/2 blend [Fig. 4(D)] has a comparable viscosity to the PET-PS = 75/25 blend, and this result is consistent with the earlier torque versus time data (Fig. 2). The occurrence of chemical reaction between SMA and PET is unlikely or insignificantly based on the observed low viscosity. On the contrary, the addition of 0.1 phr TGDDM in the PET-PS-SMA = 75/23/2 blend leads to a significant increase in viscosity [Fig. 4(E)] due to the anticipated covalent reaction. With increasing the TGDDM content, the viscosity of blends increases apparently

[Fig. 4(E)–(G)], indicating that a greater quantity of compatibilizer produced is able to give the blend with higher viscosity and improvement of interfacial adhesion.

Thermal Properties

The DSC results of pure components and uncompatibilized and compatibilized PET–PS blends are summarized in Table III. The percentage of PET crystallinity in a blend was calculated based on the heat of fusion of the PET at 100% crystalline state at 121.2 J/g. The amorphous PS exhibits a glass transition temperature (T_{g2}) at 99.3°C. PET is a semicrystalline polymer with a glass transition temperature (T_{g1}) at 71.2°C and a melting temperature at 258.0°C. The corresponding T_{g1} and T_{g2} do not shift inward, even in the compatibilized blends. This distinct glass transition temperature implies that mutual dissolving of PET and PS is negligible, even after compatibilization. Table III shows that the PET

Table III Summary of Thermal Properties of PET-PS-SMA-TGDDM Blends

Blend Composition	$\begin{array}{c} T_{g1} \\ (^{\circ}\mathrm{C}) \end{array}$	$\begin{array}{c} T_{g2} \\ (^{\circ}\mathrm{C}) \end{array}$	$T_c \\ (^{\circ}\mathrm{C})$	$\begin{array}{c} \Delta T_c \\ (^{\circ}\mathrm{C}) \end{array}$	$T_m \\ (^{\circ}\mathrm{C})$	$\begin{array}{c} \Delta T_m \\ (^{\circ}\mathrm{C}) \end{array}$	$\begin{array}{c} \Delta H_{f,\mathrm{PET}} \\ (\mathrm{J/g}) \end{array}$	% PET Crystallinity
PET	71.2		211.8	25.7	258.0	40.0	47.8	39.4
PS		99.3						
PET-PS = 75/25	70.3	96.0	205.4	27.2	257.5	40.9	47.3	39.0
PET-PS-SMA-TGDDM								
75/23/2/0	69.7	97.3	204.4	28.4	256.4	41.5	43.6	36.0
75/23/2/0.1	74.4	97.8	199.6	34.5	256.4	44.4	43.2	35.6
75/23/2/0.3	71.1	97.4	196.2	36.4	255.8	48.0	42.5	35.1
75/23/2/0.5	71.7	97.8	188.9	44.0	254.3	51.8	39.5	32.6
75/20/5/0	70.3	98.4	203.7	30.4	256.9	42.6	47.6	39.3
75/20/5/0.1	69.8	100.7	198.9	33.2	256.8	46.9	47.2	38.9
75/20/5/0.3	69.8	100.3	197.0	37.7	256.0	52.2	46.3	38.2
75/20/5/0.5	71.7	101.4	190.3	45.3	254.8	50.2	43.9	36.2
75/15/10/0	68.6	98.2	203.2	33.7	256.3	44.0	45.6	37.6
75/15/10/0.1	67.8	98.5	200.3	35.5	256.1	45.8	44.9	37.0
75/15/10/0.3	69.2	98.8	194.8	41.5	255.0	47.8	42.7	35.2
75/15/10/0.5	71.6	100.4	193.9	45.5	254.3	50.5	40.9	33.7

in the PET-PS = 75/25 blend crystallizes at a lower temperature than that of the pure PET. The crystallization temperature range of the PET component in the blend (ΔT_c) is indicative of the overall crystallization rate. The pure PET has the smallest ΔT_c , an indication of the highest crystallization rate. For the PET-PS = 75/25 blend, the PET component exhibits a greater ΔT_c than that of the pure PET. Therefore, the molten PS hinders and reduces the crystallization rate of the PET component in PET-PS = 75/25 blends. Increasing the quantity of compatibilizer results in lower T_c and higher ΔT_c , as presented in Table III. This further reduction of the crystallization rate for the PET component in the compatibilized blends can be attributed to the formation of the *in* situ copolymers. The better compatibilized blend possesses greater number of PET-co-TGDDM-co-SMA copolymer molecules that tend to hinder the PET crystallization, especially in the vicinity of interface. The PET component in the uncompatibilized blend exhibits a comparable melting behavior to the pure PET, whereas those in-situformed copolymer molecules exhibit the influence on the melting behavior for the PET component in compatibilized blends. As shown in Table III, the T_m for PET in the compatibilized blends is depressed gradually with the increase of the compatibilizer. The ΔT_m is indicative of crystal perfection and its size distribution. Those copolymers formed at interface prohibit the crystal formation and result in less perfect crystals and wider size

distribution. The presence of copolymers not only causes slower crystallization rate but also reduces PET crystallinity, as shown in Table III.

SEM Morphologies

Mechanical properties of a heterogeneous polymer blend are directly related to its microstructure, especially the size and shape of the dispersed phase. Incompatible polymer blends often have poor mechanical properties relative to their respective components due to their high interfacial tension, leading to poor control of morphology and stress transfer under loading in solid state. An efficient compatibilizer in the blend can reduce the interfacial tension and enhance the interfacial adhesion between two incompatible polymers and thus improves its mechanical properties. Figure 5(A) shows the unetched SEM micrograph of the cryogenic-fractured surface of the PET-PS = 75/25 blend. The large dispersed and spherical PS particles with different dimensions can be easily identified from this uncompatibilized blend due to the incompatibility of these two polymers. The interface between PET and PS is quite sharp, an indication of low interfacial adhesion. Figure 5(B)–(D) present the unetched SEM micrographs of cryogenic-fractured surfaces of the PET-PS = 75/25 series blends containing various amounts of SMA. The general trend indicates that the dispersed PS particle size decreases with the increase of SMA content. Figure 6(A)

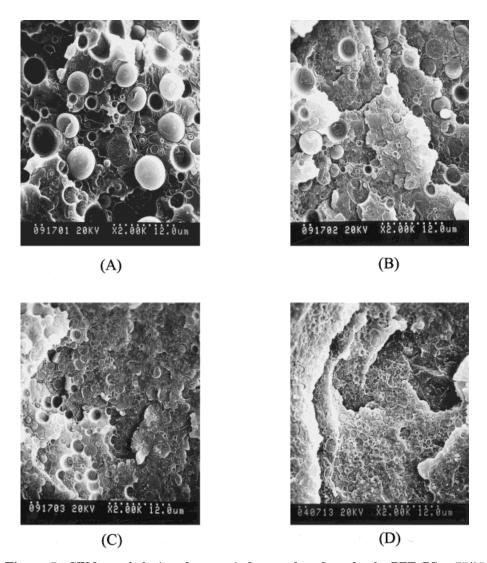


Figure 5 SEM morphologies of cryogenic fractured surfaces for the PET–PS = 75/25 blends with various SMA contents ($\times 2000$): (A) PET–PS = 75/25; (B) PET–PS–SMA = 75/23/2; (C) PET–PS–SMA = 75/20/5; (D) PET–PS–SMA = 75/15/10.

shows the cryogenic-fractured surface of the PET-PS-SMA = 75/20/5 blend after solvent etching. The empty holes are the dispersed PS phase being etched out of the blend by solvent. The sizes of the PS particles decrease obviously with increasing the amounts of TGDDM in the PET-PS-SMA = 75/20/5 series blends, as presented in Figure 6(A)-(D). Reduction of the PS phase domain in the blend can be attributed to the better compatibilization through the formation of PET-co-TGDDM-co-SMA copolymers in these compatibilized blends. Owing to the relatively low molecular weight, TGDDM can diffuse easily between the constituent components and react with PET and SMA simultaneously to produce the desired

copolymers at the interface. The finer phase domains are the indication of better compatibilization of the blends. Sundararaj Macosko²⁶ reported that the main advantage of using compatibilizer in polymer blends is the suppression of coalescence achieved through stabilizing the interface, not a reduction in the interfacial tension. Figure 6 illustrates that the *in-situ-*formed compatibilizers reduce the interfacial tension during melt blending and result in a smaller domain size of the dispersed phase particles.

Mechanical Properties

In developing high-performance polymer blends based on two immiscible polymers, the objective is

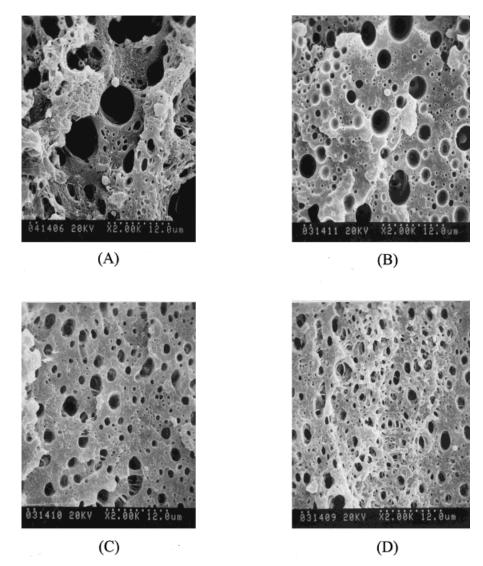


Figure 6 SEM morphologies of cryogenic fractured surfaces for the PET-PS-SMA = 75/20/5 blends with various TGDDM contents (etched by chloroform) ($\times 2000$): (A) PET-PS-SMA = 75/20/5; (B) PET-PS-SMA-TGDDM = 75/20/5/0.1; (C) PET-PS-SMA-TGDDM = 75/20/5/0.3; (D) PET-PS-SMA-TGDDM = 75/20/5/0.5.

to raise the compatibility of these two components. Compatibilized polyblends have finer phase domain size and greater interfacial contact area and interfacial adhesion than the corresponding uncompatibilized blends, as shown in the SEM morphologies, so a given stress can be transferred efficiently between phase domains. Figures 7 and 8 present the effects of SMA and TGDDM contents on the tensile properties of the PET-PS = 75/25 blends. Because of the poor compatibility between PET and PS, the mechanical properties of the uncompatibilized PET-PS = 75/25 blend is less than desirable. On the other hand, tensile properties of this incompatible

blend have been improved significantly through compatibilization. The tensile strength of the PET-PS = 75/25 blend increases about 5–8 MPa due to the presence of different amount of SMA, as presented in Figure 7. Figure 7 shows that the tensile strength of the compatibilized blends can be enhanced progressively with increasing the TGDDM content. For the blend containing the smallest quantity of SMA, a further increase on TGDDM does not result in additional improvement in tensile strength, as shown in Figure 7. Small amount of SMA in the blend (2 wt %) limits the quantity of the desirable copolymers to be produced, even though the TGDDM content is

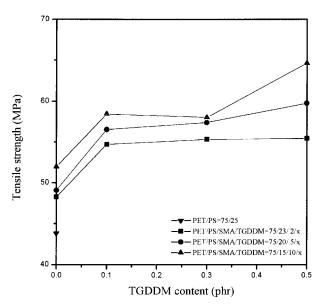


Figure 7 Tensile strength of PET-PS-SMA blends with various amounts of TGDDM.

further increased in these blends. Figure 8 demonstrates a substantial improvement in the tensile elongation of the compatibilized blends. Again, only limited additional enhancement on tensile elongation for the PET-PS-SMA = 75/23/2 blends containing various amounts of TGDDM is observed. The improvement is particularly drastic for the blends of PET-PS-SMA = 75/20/5 and

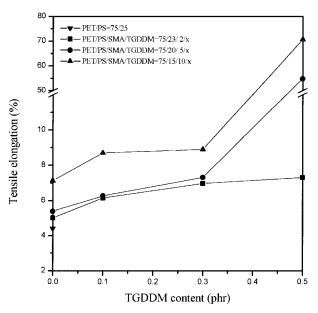


Figure 8 Tensile elongation of PET-PS-SMA blends with various amounts of TGDDM.

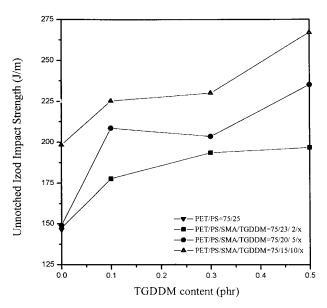


Figure 9 Unnotched Izod impact strength of PET-PS-SMA blends with various amounts of TGDDM.

PET-PS-SMA = 75/15/10 containing 0.5 phr of TGDDM.

Unnotched impact strength is commonly used to differentiate toughness change resulting from compatibilization for notch sensitive blends. Figure 9 presents the effect of compatibilizer content on the unnotched impact strength. The trend of unnotched impact strength for PET-PS-SMA blends with various amounts of TGDDM is consistent with corresponding tensile properties. TGDDM exhibits a significant effect on the enhancement of mechanical properties for PET-PS-SMA blends, which can be attributed to the insitu-formed PET-co-TGDDM-co-SMA copolymer molecules anchoring along the interface. A greater number of in situ copolymer molecules tend to be produced with increasing the quantity of SMA and TGDDM and anchor along the interface as the result of chemical reaction. Combination of SMA and TGDDM has been demonstrated to be an excellent dual reactive compatibilizer for PET-PS blends based on drastic improvement in their mechanical properties.

CONCLUSIONS

The reactivity and the extent of reaction between the terminal groups of PET, maleic anhydride of SMA, and epoxy groups of TGDDM are studied qualitatively by the measurements of torque change in melt mixing. Due to the low reactivity between SMA and PET without the presence of catalyst, the quantity of the PET-co-SMA copolymer is insignificant, and property improvement of the compatibilized blend is not substantial. Addition of a small amount of epoxy (TGDDM) can act as a coupling agent to produce PET-co-TGDDMco-SMA copolymers at the interface. These interfacially formed copolymers tend to anchor along the interfaces and act as effective emulsifiers. Consequently, the compatibilized blend gives finer phase domain size of the dispersed phase and greater interfacial adhesion. Tensile and impact properties of the PET-PS blends have been substantially improved by employing the dual compatibilizers, SMA and TGDDM.

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