

# Polymer Blends of Poly(Ethylene-2,6-naphthalate) with Polystyrene Compatibilized by Styrene-Glycidyl Methacrylate Copolymers. I. Rheology, Morphology, and Mechanical Properties

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**ABSTRACT:** The compatibilization of blends of poly(ethylene-2,6-naphthalate) (PEN) with polystyrene (PS), through the styrene-glycidyl methacrylate copolymers (SG) containing various glycidyl methacrylate (GMA) contents, was investigated in this study. SG copolymers are able to react with PEN terminal groups during melt blending, resulting in the formation of desirable SG-g-PEN copolymers in the blend. These *in situ* formed copolymers tend to reside along the interface preferentially as the result of interfacial reaction and thus function as effective compatibilizers in PEN/PS blends. The compatibilized blends exhibit higher viscosity, finer phase domain, and improved mechanical properties. It is found that the degree of grafting of the *in situ* formed SG-g-PEN copolymer has to be considered as well. In blends

compatibilized with the SG copolymer containing higher GMA content, heavily grafted copolymers would be produced. The length of the styrene segment in these heavily grafted copolymers would be too short to penetrate deep enough into the PS phase to form effective entanglements, resulting in the lower compatibilization efficiency in PEN/PS blends. Consequently, the *in situ* formation of SG-g-PEN copolymers with an optimal degree of grafting is the key to achieving the best performance for the eventually produced PEN/PS blends through SG copolymers. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 87: 967–975, 2003

**Key words:** PEN; PS; styrene-glycidyl methacrylate copolymer; reactive compatibilization; graft copolymer

## INTRODUCTION

Poly(ethylene-2,6-naphthalate) (PEN) has become an important and widely used engineering thermoplastic, replacing poly(ethylene terephthalate) (PET) for some applications in fibers, films, and bottles in the last decade. Because of the naphthalene ring in the chemical structure, PEN possesses superior thermal, chemical, and mechanical properties relative to PET. In addition, PEN is especially useful for food packaging due to its low permeability toward oxygen and carbon dioxide.<sup>1,2</sup> Although PEN seems to be a promising material for numerous commercial applications, the high manufacturing cost limits its comprehensive use.

Obviously, the most economical and fast way to achieve the cost/performance balance is to blend PEN with other polymers. In practice, blends of PEN with other polyesters have attracted great interest lately, in both industry and academia. Transesterification reaction always occurs in blends of PEN with other polyesters or polycarbonate during the melt processing

and ultimately leads to the formation of random copolymers consisting of blend constituents, and therefore, the compatibility problem in these blends usually can be neglected. The most familiar subject is the PEN/PET blending system, in which the reactive processing,<sup>3</sup> miscibility,<sup>4–6</sup> phase behavior,<sup>7</sup> and dynamic mechanical properties<sup>8</sup> were studied in detail. On the other hand, blends of PEN with polyester-type liquid crystalline polymer (LCP),<sup>9,10</sup> polycarbonate,<sup>11</sup> poly(butylene terephthalate) (PBT),<sup>12</sup> and poly(butylene-2,6-naphthalate) (PBN)<sup>13</sup> were also reported. Except for polyesters, studies on PEN blends with other commodity polymers are relatively few. Kim et al.<sup>14</sup> studied mechanical properties of biaxially drawn films prepared from PEN/poly(ether imide) (PEI) blends. The compatibilization of PEN/polyamide-6 (PA6) blends using poly(allylether-co-maleic anhydride) [P(Al-MAn)] as a compatibilizer was investigated by Akiba et al.<sup>15</sup>

Polystyrene (PS) is a low-cost commodity polymer with unique properties, and one can expect that it is immiscible and incompatible with PEN. For blends of polymers containing functional groups, reactive compatibilization is a better approach to improve compatibility.<sup>16–20</sup> The reactive compatibilization technique usually employs a functionalized polymer as a non-

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**TABLE I**  
**Properties of PEN, PS, and SG Copolymers**

Material	$M_n^a$ (g/mol)	$M_w^a$ (g/mol)	MFR <sup>b</sup> (g/10 min)
PEN	—	—	41
PS	102,500	307,000	45
SG2	96,000	259,000	—
SG5	104,000	240,000	—
SG10	109,700	273,000	—

<sup>a</sup> Determined by g.p.c. (Hitachi Co. of Japan, model L-7100).

<sup>b</sup> Determined at 280°C with 2.16 Kg loading.

specific type *in situ* compatibilizer, the main structure of which is identical or miscible with one of the blend constituents and also contains suitable functional groups that can react with the other component. During the process of melt blending, a portion of the added reactive compatibilizer has the chance to reside along the vicinity of the interface and then make contact and react with the other component to form graft or block copolymers. Consequently, these *in situ* formed copolymers tend to anchor and concentrate at the interface to serve as effective compatibilizers between two immiscible polymers. Thus, the performance of a compatibilized blend can be improved due to the enhanced interphase adhesion in the solid state.

In our previous article, styrene-glycidyl methacrylate copolymer (SG) was demonstrated as an efficient reactive compatibilizer for PET/PS blends.<sup>17</sup> In this study, SG copolymers with various glycidyl methacrylate (GMA) contents were employed to compatibilize PEN/PS blends in a similar manner. We intend to report their specific compatibility and correlation with their rheology, morphology, and mechanical properties.

## EXPERIMENTAL

### Materials and sample preparation

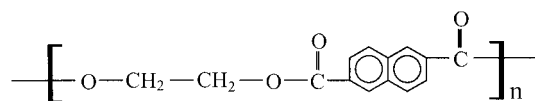
Additive-free PEN, intrinsic viscosity (I.V.) = 0.52, was kindly provided by the Shinkong Synthetic Fibers Inc. of Taiwan. PS, Maxiglac 125, was obtained from B. C. Chemical Co. of Taiwan. SG copolymers with various weight fractions of GMA were prepared in our laboratory by suspension polymerization, which has been described in detail in the previous article.<sup>17</sup> Herein, the reactive compatibilizers SG2, SG5, and SG10 represent 2, 5, and 10 wt % of GMA contents in the SG copolymers. Molar masses of PS and SG copolymers, along with the melt flow rates of base polymers, are summarized in Table I. The catalyst, ethyl triphenylphosphonium bromide (ETPB), was purchased from Merck. The chemical structures of materials are given in Scheme 1.

PEN was dried at 100°C, while PS and SG copolymers were dried at 80°C, for over 8 h in separate ovens prior to extruder compounding. All blends were prepared in a 30-mm corotating twin-screw extruder (L/D = 36, Sino-Alloy Machinery Inc., Taiwan) by maintaining the barrel temperature between 260 and 290°C and a constant screw speed of 250 rpm. The extruded pellets were dried at 100°C for over 8 h and then molded into standard ASTM specimens using an Arburg 3-oz injection-molding machine.

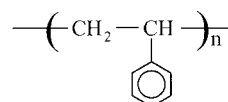
### Characterizations

Torque versus time behavior was obtained by a Brabender Plasti-Corder (type PLD 651) at 280°C and 30 rpm. The capillary rheological measurements of base polymers and blends were carried out at 280°C using a capillary rheometer (L/D = 40, orifice radius = 0.02 in.) from Kayeness Co., USA, Model Galaxy V. Melt flow rates (MFRs) were measured at 280°C with a 2.16 kg loading by an automatic flow rate timer from Ray-Ran Co., U.K.

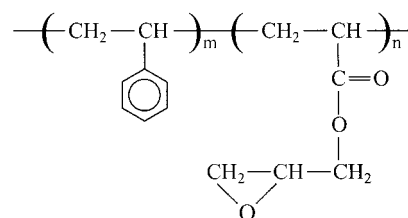
Morphologies of cryogenically fractured surfaces of injection-molded specimens were inspected in the plane perpendicular to the flow direction by a scan-



Poly(ethylene-2,6-naphthalate) (PEN)

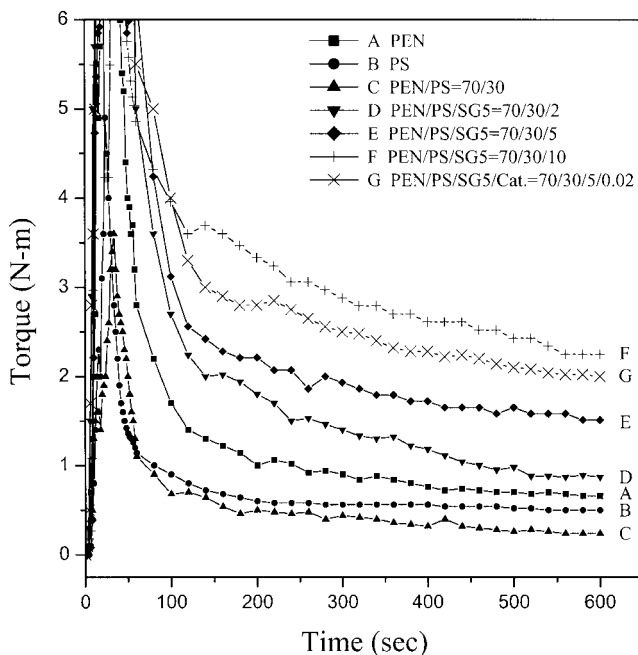


Polystyrene (PS)



Styrene-glycidyl methacrylate copolymer (GMA)

**Scheme 1** The chemical structures of materials.



**Figure 1** Plots of torque versus mixing time for PEN, PS, and PEN/PS = 70/30 mixtures containing various amounts of SG5 at 280°C and 30 rpm.

ning electron microscope (SEM) from Hitachi Co. of Japan (Model S-570). Portions of the specimens were etched with chloroform to dissolve the PS phase out of the blends.

Standard tensile tests were performed on an Instron Universal Testing Machine (Model 4201) according to the ASTM D638 method with a crosshead speed at 5 mm/min under ambient conditions. Unnotched Izod impact strengths were measured at ambient conditions by an impact tester from TMI Co. of USA (Model 43-1) by following the ASTM D256 method. All the data of mechanical properties were analyzed via standard statistical methods and an error magnitude of 5% was determined.

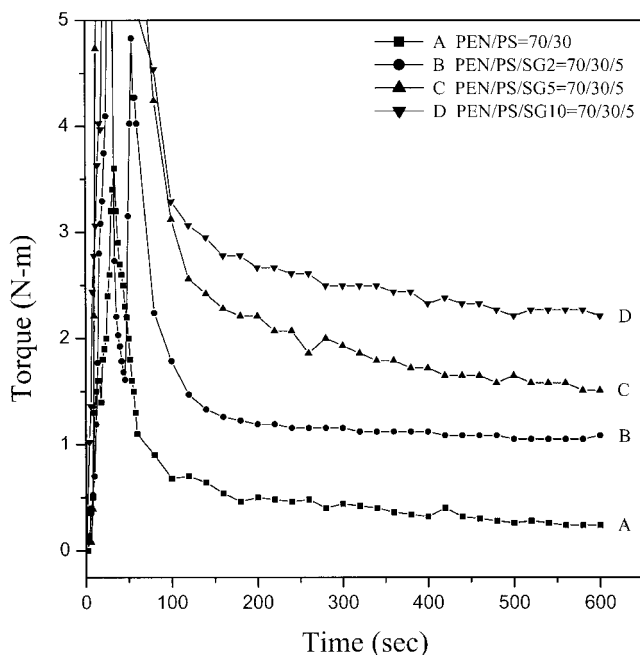
## RESULTS AND DISCUSSION

### Torque versus time

Torque measurement is a convenient method to obtain qualitative information concerning the chemical reactivity and the extent of reaction in compatibilized blends. When reactions among functional groups occur, the viscosity of the desired blend will increase because of the increase of overall molecular weight. Figure 1 presents the torque curves as a function of mixing time at 280°C for the pure PEN, PS, and PEN/PS = 70/30 mixtures with various amounts of SG5 added. The torque of PS is low and steady at 280°C, as displayed in Figure 1(B), whereas that of PEN [Fig. 1(A)] is also low and only slightly higher than PS because of the low intrinsic viscosity of PEN

(0.52) used in this study. Under the same conditions, the torque of the PEN/PS = 70/30 mixture is even lower than that of pure PS or PEN, as shown in Figure 1(C). Evidently, this result can be attributed to the low interfacial friction between phases arising from the high incompatibility of PEN and PS. When 2 phr SG5 is added into the PEN/PS mixture, as depicted in Figure 1(D), the torque exhibits substantial increase relative to the uncompatibilized one [Fig. 1(C)], even higher than that of the pure PEN [Fig. 1(A)]. This torque increase in the compatibilized PEN/PS blend suggests the occurrence of the anticipated reaction between PEN and SG5 during the melt processing. The reaction mechanisms of the epoxy group toward terminal groups of polyesters (carboxyl and hydroxyl groups) have been well recognized.<sup>21</sup> Thus, it is expected that the epoxy group of SG copolymers is able to react with terminal groups of PEN *in situ* during melt blending to form SG-g-PEN copolymers and results in higher overall molecular weight in the compatibilized blend. In addition to the increased molecular weight, the enhanced interfacial friction under shear caused by these copolymers anchoring along the interface also partially contributes to the observed torque increase. Most of the SG copolymers are expected to dissolve in the PS phase, preferentially in the melt because SG copolymers with low GMA content are miscible with PS. During the process of melt blending, SG copolymers have the opportunity to migrate to the interface and to contact with the PEN phase. Consequently, the reaction between PEN and SG copolymers takes place at the interface, leading to the formation of desirable SG-g-PEN copolymers. These *in situ* formed graft copolymers tend to anchor along the interface as the result of interfacial reaction, allowing them to function as effective compatibilizers to reduce the interfacial tension and to enhance the interfacial adhesion. Hence, the compatibilized PEN/PS blend exhibits higher viscosity in comparison with the uncompatibilized one. By increasing the SG5 content in the PEN/PS blend, as depicted in Figure 1(D–F), it can be seen that the torque increases gradually. This viscosity increment indicates that both molecular weight and interfacial friction increase progressively as the amount of SG5 is increased.

The influence of catalyst on the torque behavior of the PEN/PS/SG5 = 70/30/5 mixture is displayed in Figure 1(G). It can be seen that the presence of 200 ppm catalyst results in a significant increase in viscosity of the PEN/PS/SG5 = 70/30/5 mixture as compared with the noncatalyzed one [Fig. 1(E)]. If all the epoxy groups in SG5 are consumed in the reaction with PEN in the PEN/PS/SG5 = 70/30/5 mixture, one would expect to obtain a similar or close torque value between Figure 1(E) and 1(G). Thus, the lower viscosity observed in Figure 1(E) indicates that only a portion of SG5 reacts with PEN during melt process-



**Figure 2** Plots of torque versus mixing time for PEN/PS = 70/30 mixtures containing 5 phr SG copolymers with various GMA contents at 280°C and 30 rpm.

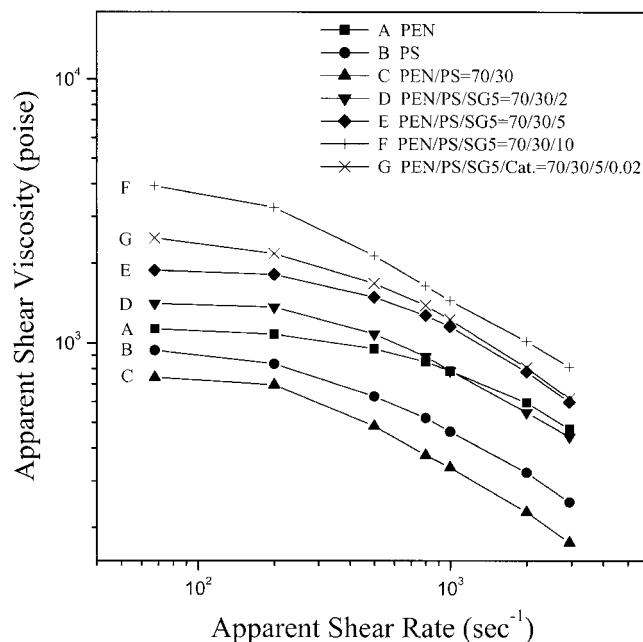
ing to produce lightly grafted copolymers. By adding catalyst into the PEN/PS/SG5 mixture, the extent of reaction between PEN and SG5 can be raised, and a greater fraction of SG5 is involved in the interfacial reaction, as evidenced by a further viscosity increment, as shown in Figure 1(G). It is noteworthy that the raised extent of reaction can also lead to the formation of SG-g-PEN copolymers with a high degree of grafting or even a crosslinked network. Apparently, these heavily grafted copolymers cannot function as effective compatibilizers in PEN/PS blends. This effect will be discussed later.

Plots of torque versus mixing time at 280°C for PEN/PS = 70/30 mixtures with the addition of 5 phr SG copolymers containing various GMA contents are given in Figure 2. It can be seen that the viscosity of the compatibilized mixture increases progressively with the increase of the GMA content. This result originated from the greater extent of the grafting reaction due to the higher amount of epoxy in the blend that was compatibilized with the SG copolymer containing higher GMA content. The higher viscosity indicates increased molecular weight and interfacial friction under shear, as discussed previously.

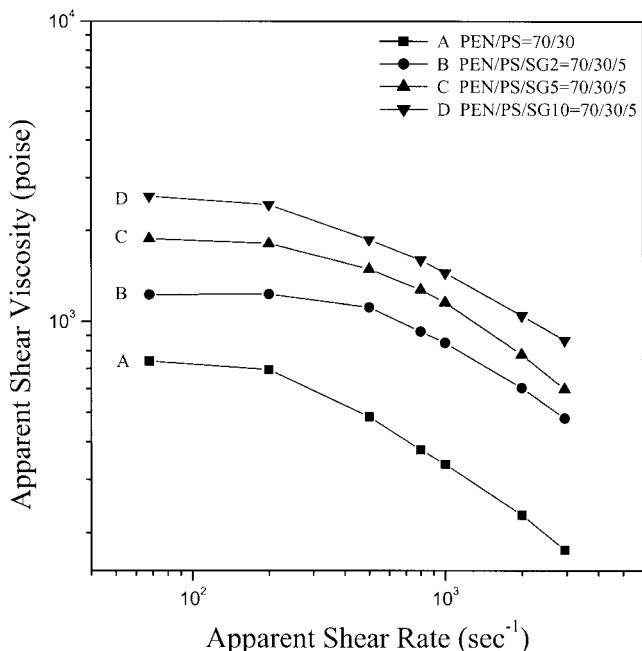
### Capillary rheometry and MFRs

Figure 3 presents the shear viscosity versus shear rate behaviors of base polymers and various PEN/PS = 70/30 blends containing different amounts of SG5 at 280°C. PEN exhibits higher viscosity and less shear

thinning than that of PS at 280°C, as shown in Figure 3(A,B). Again, the uncompatibilized PEN/PS = 70/30 blend has lower viscosity than PS or PEN, as presented in Figure 3(C). These results are consistent with the torque measurements obtained previously [Fig. 1(A–C)]. For the compatibilized PEN/PS = 70/30 blends, the presence of 2 phr SG5 results in a substantial increase in viscosity, as shown in Figure 3(D), and the viscosity increases progressively with increasing SG5 content [Fig. 3(D–F)]. This viscosity increment relates to the increase of molecular weight and interfacial friction under shear, which can be attributed to the presence of *in situ* formed SG-g-PEN copolymers anchoring along the interface. Also, the PEN/PS/SG5 = 70/30/5 blend, with 200 ppm catalyst added, possesses a higher viscosity relative to the noncatalyzed one, as shown in Figure 3(G,E), respectively. The variations of shear viscosity with shear rates for PEN/PS = 70/30 blends compatibilized with 5 phr SG copolymers containing various GMA contents at 280°C are given in Figure 4. It can be discerned clearly that the viscosity of the compatibilized blends increases with increasing GMA content, illustrating that the extent of grafting reaction between PEN and SG copolymer is increased because of the higher epoxy content in the blends. Plots of MFR versus SG content for PEN/PS/SG blends with entire compositions prepared are shown in Figure 5. As would be expected, the MFR decreases gradually with an increasing amount of SG copolymer, as depicted in Figure 5. The resultant MFRs as a whole are in accordance with the capillary rheometry data.



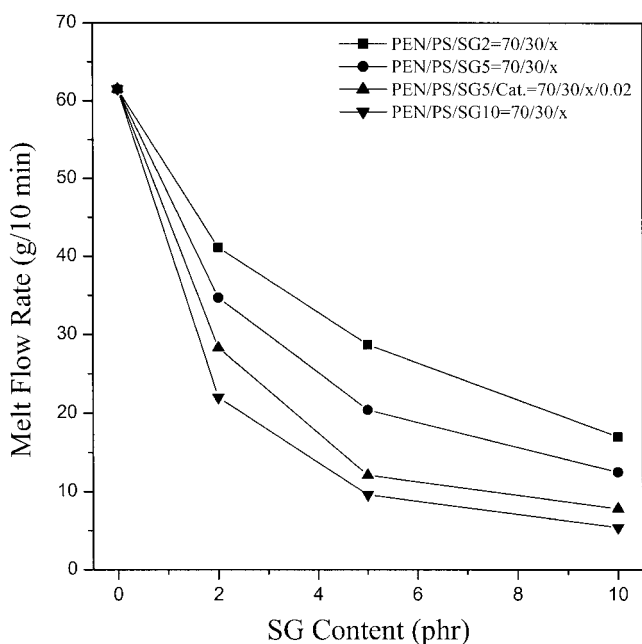
**Figure 3** Variations of apparent shear viscosity with apparent shear rates for PEN, PS, and PEN/PS = 70/30 blends containing various amounts of SG5 at 280°C.



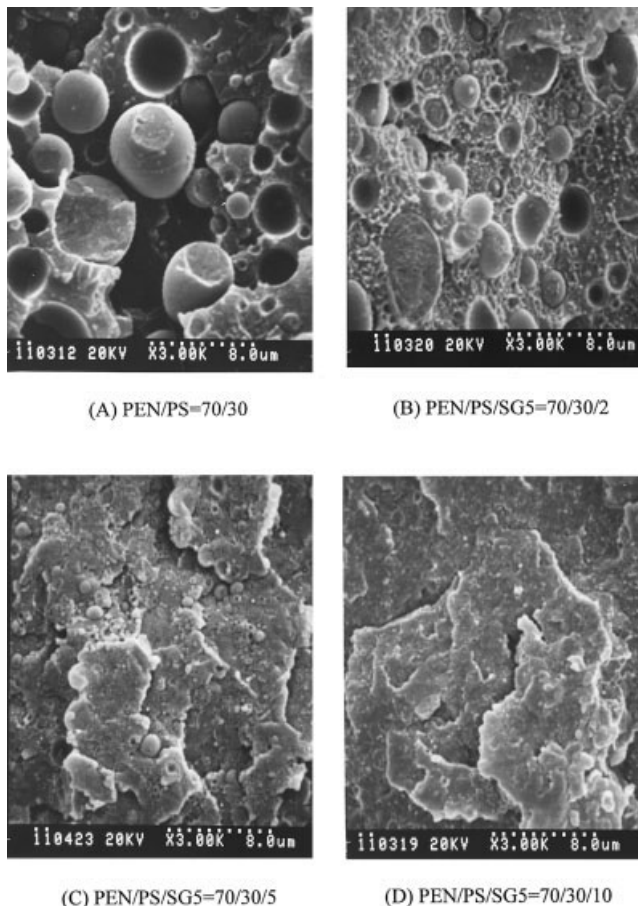
**Figure 4** Variations of apparent shear viscosity with apparent shear rates for PEN/PS = 70/30 blends containing 5 phr SG copolymers with various GMA contents at 280°C.

**SEM morphologies**

In compatibilizing two incompatible polymers, the ultimate goal is to improve the mechanical performance of the eventually produced blend. The improved mechanical properties of a compatibilized blend usually can be related to its phase morphology, such as the size and shape of the dispersed phase. Thus, when



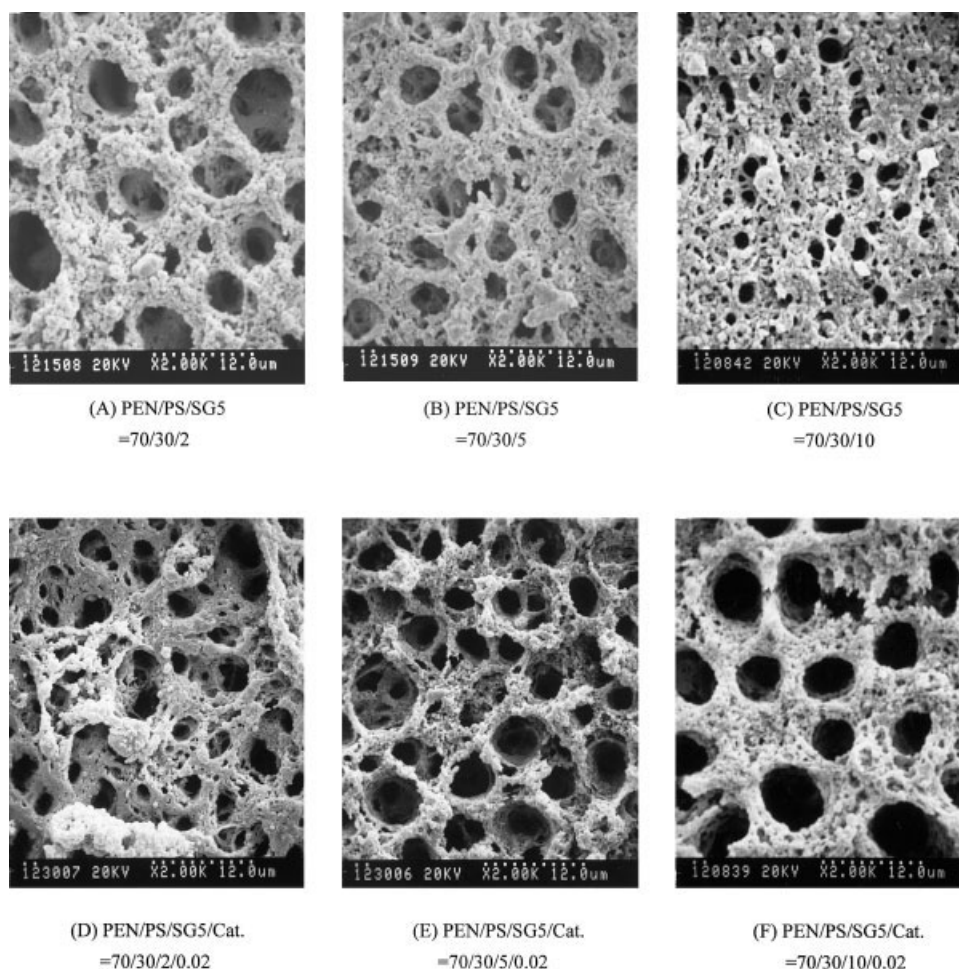
**Figure 5** Melt flow rates as function of SG copolymers content for PEN/PS = 70/30 blends.



**Figure 6** SEM micrographs of the cryogenically fractured surfaces of PEN/PS = 70/30 blends containing various amounts of SG5.

observing the morphology evolution, which is greatly dominated by interfacial properties, it is important to know the compatibilization efficiency and to understand resultant mechanical properties of blends. An incompatible blend usually can be characterized by large dispersed phase domains and coarse morphology due to high interfacial tension. This high interfacial tension is also responsible for the poor interfacial adhesion in the solid state, resulting in lower mechanical performance relative to that predicted by the Rule of Mixture. In general, the interfacial properties can be improved through the addition of a suitable compatibilizer. An effective compatibilizer tends to reside at the interface and consequently serves as phase emulsifier to reduce the interfacial tension, leading to smaller dispersed phase domains in the blend. As a result, the fine phase domains are stabilized against coalescence and the interfacial adhesion between two immiscible polymers is enhanced to improve the mechanical properties of blends.

The compatibilization effect of the SG copolymer on the morphology of PEN/PS blends is represented in Figure 6, where SEM micrographs of cryogenically

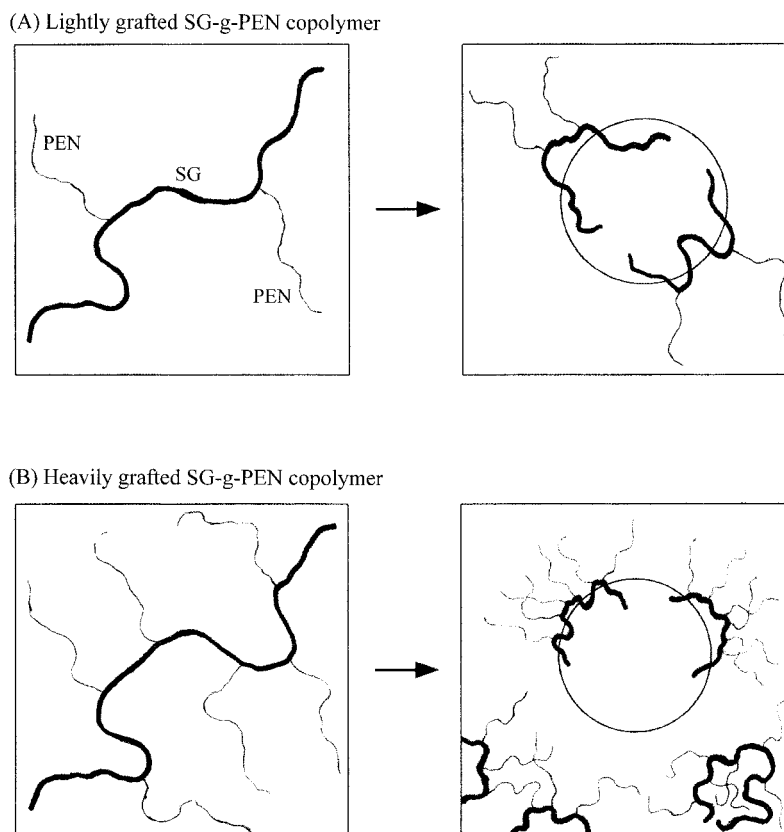


**Figure 7** SEM micrographs of solvent etched surfaces of PEN/PS = 70/30 blends containing various amounts of SG5 with and without catalyst.

fractured surfaces of PEN/PS = 70/30 blends containing various amounts of SG5 are presented. The dispersed large and spherical PS phase domains can be discerned easily in the uncompatibilized blend, as shown in Figure 6(A), a typical morphology of blends comprising two immiscible polymers. After the addition of 2 phr SG5 in the PEN/PS blend, the domain size of the PS phase is reduced substantially, as displayed in Figure 6(B), indicating the reduction of interfacial tension in this compatibilized blend. Eventually, the dispersed phase domains can hardly be identified in the blend containing 10 phr SG5, as shown in Figure 6(D). Figure 6 illustrates the improvement of compatibility of PEN/PS blends through the increase of SG5 content. The *in situ* formed SG-*g*-PEN copolymers that reside along the interface cause the reduction of interfacial tension and stabilize the minor phase against drop coalescence. Consequently, these copolymers are able to contribute to the enhancement of interfacial friction in the melt and interfacial adhesion in the solid state.

The SEM micrographs of etched surfaces of PEN/PS = 70/30 blends containing various amounts of SG5, noncatalyzed and catalyzed, are given in Figure 7. In

noncatalyzed PEN/PS/SG5 blends, the domain size of the dispersed PS phase reduces substantially and evenly with increasing the SG5 content, as shown in Figure 7(A–C). The finer phase domain in the compatibilized blend with higher SG5 content is evidence of better compatibilization. By contrast, the dimensional change of the dispersed phase domain in catalyzed PEN/PS/SG5 blends exhibits a different trend from that in noncatalyzed counterparts. For the blend containing 2 phr SG5, the compatibility is further improved through the addition of catalyst, due to the greater extent of the grafting reaction, which is evidenced by the significant reduction in domain size of the dispersed phase, as compared in Figure 7(A,D). When the amount of SG5 increases, quite unexpectedly, the domain size of the dispersed phase in catalyzed PEN/PS/SG5 blends tends to increase slightly and becomes obviously larger than that in the corresponding noncatalyzed counterparts, as presented in Figure 7(E,F). It has been shown in torque measurements that the extent of reaction between PEN and SG copolymers can be increased by the addition of catalyst and/or the increase of the epoxy content in SG



**Figure 8** The schematic representations of (A) lightly grafted and (B) heavily grafted SG-g-PEN copolymers and the imagination of the position of copolymers in blends.

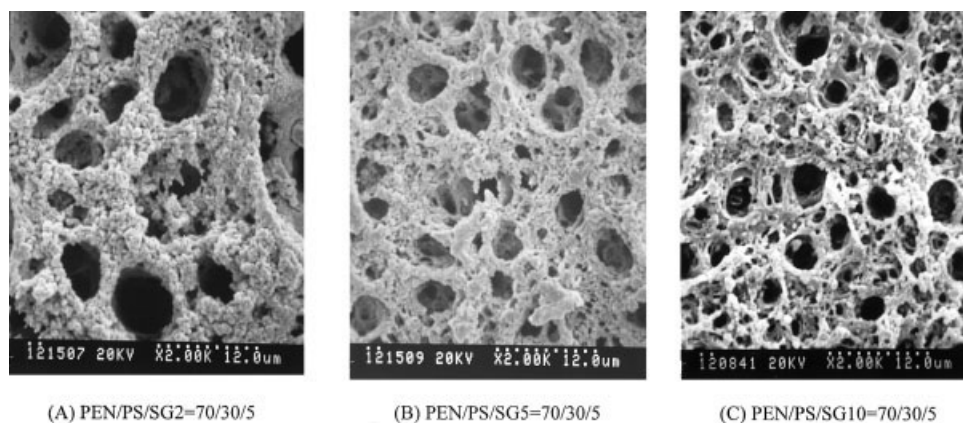
copolymer in the blend. Nevertheless, the high extent of reaction may result in the production of SG-g-PEN copolymers with a high degree of grafting or even a slightly crosslinked network. Figure 8 gives the schematic representations of lightly and heavily grafted SG-g-PEN copolymers and their likely locations in the blend. For lightly grafted copolymers, the length of styrene segment between junction points or between junction point and chain end is still sufficiently long to penetrate into the PS phase to make effective entanglements, as represented in Figure 8(A). Such copolymers are, undoubtedly, able to function as effective compatibilizers in the blend. As for heavily grafted copolymers [Fig. 8(B)], on the contrary, the styrene segment is too short to penetrate deep enough into the PS phase, and the extent of entanglement between PS and graft copolymers would be low. Consequently, the heavily grafted copolymer would lose its role as a phase compatibilizer. In the extreme case, heavily grafted copolymers may be pulled out of the PS phase during melt processing and reside in the PEN phase or even form a lightly crosslinked SG-co-PEN-co-SG copolymer due to the high functionality of SG, as represented in Figure 8(B). That is why the domain size of the dispersed phase in those catalyzed PEN/PS/SG5 blends does not exhibit the expected trend of reduction with increasing the SG5 content. Furthermore,

when a SG copolymer with higher GMA content, such as SG10, is employed as a reactive compatibilizer, one also can expect to obtain highly grafted SG-g-PEN copolymers in blends. Similar results have been observed in our previous studies<sup>17,22</sup> as well.

SEM micrographs of etched surfaces of PEN/PS = 70/30 blends compatibilized with 5 phr SG copolymers containing various GMA contents are displayed in Figure 9. It can be seen that the domain size of the dispersed phase in the PEN/PS/SG5 blend is smaller than that in the PEN/PS/SG2 blend, as shown in Figure 9(A,B). On the other hand, the PEN/PS/SG10 blend demonstrates a comparable dimension of the dispersed phase domain to that in the PEN/PS/SG5 blend, as displayed in Figure 9(B,C). Apparently, this result can be attributed to the formation of highly grafted SG-g-PEN copolymers in the PEN/PS/SG10 blend, as discussed previously. According to these SEM observations, it is inferred that the formation of SG-g-PEN copolymers, with a proper degree of grafting, is the key for the compatibilization of PEN/PS blends through SG copolymers.

#### Mechanical properties

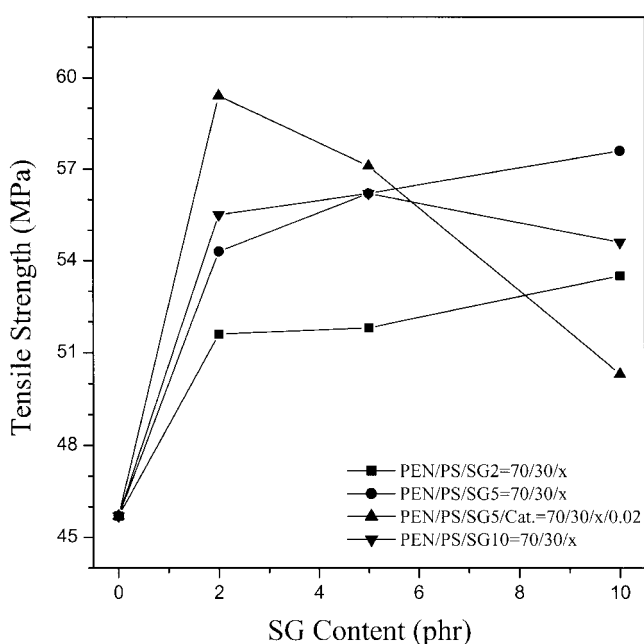
Tensile properties of PEN/PS = 70/30 blends compatibilized with SG copolymers containing various



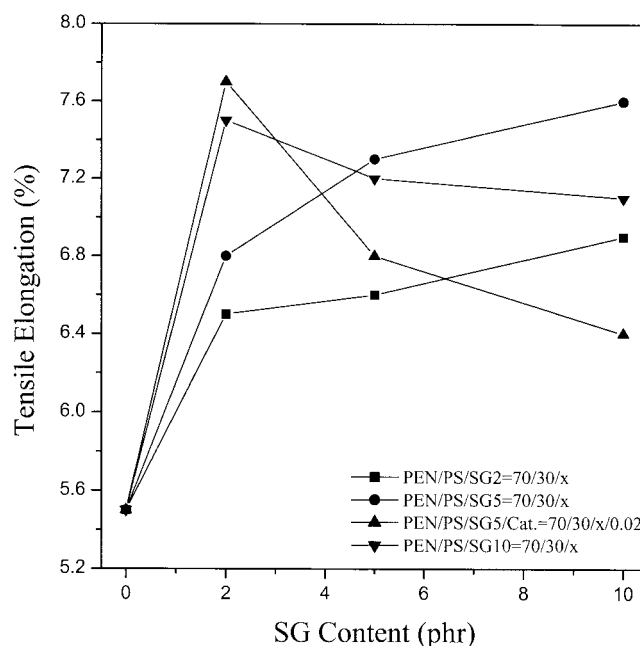
**Figure 9** SEM micrographs of solvent etched surfaces of PEN/PS = 70/30 blends containing 5 phr SG copolymers with various GMA content.

GMA contents are presented in Figures 10 and 11. After compatibilization, the tensile properties of this originally incompatible blending system are improved as a whole. When the amount of GMA in the employed SG copolymer is less than 5%, both the tensile strength and the tensile elongation of the PEN/PS blends increase gradually with increasing amounts of SG copolymers, as depicted in Figures 10 and 11. On the other hand, the tensile strength of the PEN/PS/SG10 blend appears to decrease when the SG10 content is greater than 5 phr, as shown in Figure 10. A similar result is observed in Figure 11 where the tensile elongation of the PEN/PS/SG10 blend decreases with increasing the amounts of SG10 when the SG10 content is greater than 5 phr. In addition, it can be discerned that the catalyzed PEN/PS/SG5 = 70/30/2

blend exhibits the best performance in tensile properties among all the blend compositions, as shown in Figures 10 and 11. When the quantity of SG5 is 5 phr and higher, the tensile properties of the catalyzed PEN/PS/SG5 blends clearly decrease with increasing SG5 content. Apparently, the observed reduction in tensile properties, for those PEN/PS/SG10 and catalyzed PEN/PS/SG5 blends containing higher quantity of SG copolymers, can be correlated to the formation of heavily grafted SG-g-PEN copolymers, as shown by the SEM morphologies. It is well known that better compatibilized blends possess finer and more stable morphology, greater interfacial contact area, and enhanced interfacial adhesion in the solid state. Therefore, a given stress can be transferred efficiently between phases, resulting in the improvement of me-

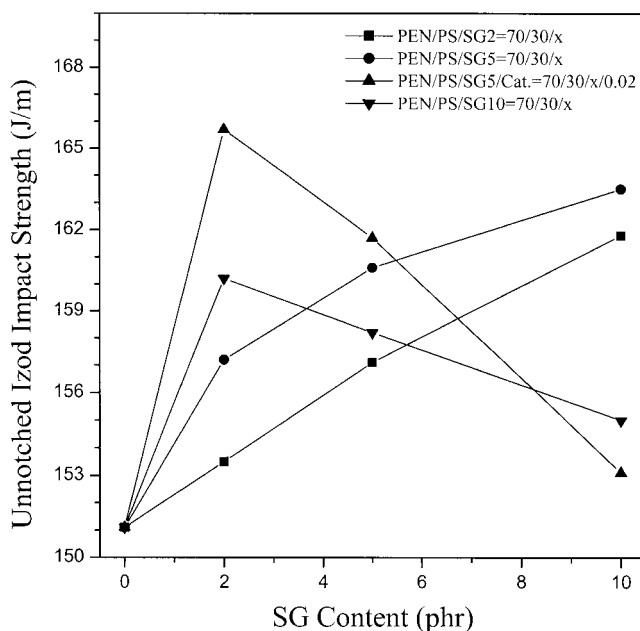


**Figure 10** Tensile strength as function of SG copolymers content for PEN/PS = 70/30 blends.



**Figure 11** Tensile elongation as function of SG copolymers content for PEN/PS = 70/30 blends.





**Figure 12** Unnotched Izod impact strength as function of SG copolymers content for PEN/PS = 70/30 blends.

chanical performances. Since it is shown in SEM morphologies that heavily grafted copolymers cannot serve as effective compatibilizers, the reduction in tensile properties is expected for blends compatibilized with the SG copolymer containing high GMA content. Figure 12 presents the unnotched impact strength of PEN/PS = 70/30 blends containing various amounts of SG copolymers. The general trend is consistent with the corresponding tensile properties. Accordingly, to achieve the greatest performance of the eventually produced PEN/PS blends through SG copolymers, the key is to form the SG-g-PEN copolymers *in situ* with an optimal degree of grafting, which is controlled by proper adjustment of the GMA content in the SG copolymer, the presence of suitable catalyst, and proper blending conditions.

### CONCLUSION

The compatibilization of PEN/PS blends through SG copolymers containing various GMA contents has been investigated. The reactivity and extent of reaction between PEN and SG copolymers in the blend, catalyzed and noncatalyzed, were examined qualitatively by torque measurements. SG copolymers are able to react with PEN during melt processing, resulting in the formation of desired SG-g-PEN copolymers in the blend. These *in situ* formed copolymers tend to reside along the interface preferentially as the result of interfacial reaction and thus function as effective compatibilizers in PEN/PS blends. The reduced interfacial tension in compatibilized blends is evidenced by the smaller dispersed-phase domain size, as demon-

strated in SEM morphologies, which is an indication of the improvement of compatibility. Consequently, the improvement of mechanical performances in compatibilized blends is achieved because of the enhanced interfacial adhesion in the solid state. Nevertheless, the degree of grafting of the *in situ* formed SG-g-PEN copolymer also has to be considered. In blends compatibilized with the SG copolymer containing higher GMA content, heavily grafted copolymers would be produced. The length of the styrene segment in heavily grafted copolymers would be too short to penetrate deep enough into the PS phase to form effective entanglements, resulting in the lower compatibilization efficiency, as shown in SEM morphologies and mechanical performances. Thus, to achieve the greatest performance for the eventually produced PEN/PS blends through SG copolymers, the key is to form SG-g-PEN copolymers *in situ* with an optimal degree of grafting, which is controlled by proper adjustment of the GMA content in the SG copolymer, the presence of suitable catalyst, and proper blending conditions.

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