Mechanical Properties of
HDPE/(PEC/PS)/SEBS Blends

M. C. SCHWARZ, J. W. BARLOW, and D. R. PAUL, *Department of Chemical Engineering and Center for Polymer Research, University of Texas, Austin, Texas 78712*

Synopsis

Various amounts of a styrene-butadiene-based triblock copolymer (SEBS) was used to compatibilize immiscible blends of high density polyethylene (HDPE) and an amorphous glassy phase consisting of either pure polystyrene (PS) or a miscible blend of PS and a polyether copolymer (PEC). PEC is structurally similar to poly(2,6-dimethyl-1,4-phenylene oxide) (PPO). Mechanical properties were determined for blends fabricated by injection and compression molding. The inherently brittle two-phase HDPE/(PEC/PS) blends show significant increases in ductility and impact strength resulting from addition of SEBS. These improvements coincide with a slight loss in modulus and yield strength. If the amount of HDPE and SEBS is held constant, impact strength and ductility increase with the amount of PEC in the glassy phase. These trends evidently result from the added ductility of glassy phases containing PEC and perhaps from better interfacial adhesion in blends after adding SEBS. The latter stems from the thermodynamic miscibility between PEC and PS endblocks of SEBS which provide an enthalpic driving force for compatibilization. Differences between the properties of compression and injection-molded blends can be attributed to the degree of crystallinity and orientation induced during molding.

INTRODUCTION

Several recent studies[1-7] have demonstrated that the mechanical properties of blends of polystyrene with both high and low density polyethylene can be significantly improved by adding styrene–olefin-based block and graft copolymers. These copolymers evidently form interfacial layers that improve adhesion between the dissimilar phases and act to stabilize the mixtures against gross phase segregation. This is the second paper in a series dealing with the use of related block copolymers as compatibilizers for blends of high density polyethylene (HDPE) with polystyrene (PS) containing varying amounts of a polyether copolymer (PEC) to improve the thermal and mechanical performance of the glassy phase. PEC is similar in structure to poly(2,6-dimethyl-1,4-phenylene oxide) or PPO (except for the random incorporation of approximately 5% of trimethyl phenol as a comonomer), and it forms miscible blends with PS just like PPO[8]. Therefore, in HDPE/(PEC/PS) blends, HDPE forms one phase and the PEC/PS mixture forms another. The addition of PEC should result in blends with HDPE having somewhat improved mechanical properties and heat resistance relative to blends based on pure PS.

The first paper in this series[9] described the processing methods used to prepare blends of the type mentioned and illustrated how phase morphology was influenced by composition, compatibilizer type, and processing. It was

CCC 0021-8995/88/082053-15$04.00

found that addition of a styrene–butadiene-based block copolymer produced a larger reduction in phase size and more evidence of interfacial adhesion when the glassy phase contained some PEC in addition to PS. This apparently stems from a greater thermodynamic driving force for the PS endblocks to mix with a phase containing PEC rather than pure PS, as argued earlier.[9] The previous paper also presented a preliminary screening of various potential compatibilizers for this blend system. A particular styrene–butadiene–styrene triblock copolymer (SEBS), with a hydrogenated midblock comparable to an ethylene-butene copolymer, was found to improve the blend toughness more than other candidates considered. The purpose of this paper is to give a more complete report on the mechanical properties for this system containing the selected triblock copolymer.

Samples for testing were fabricated by both injection and compression molding, and the mechanical properties differed for identical compositions prepared by the two methods. The properties of multiphase blends are influenced by supramolecular features like phase or molecular orientation, crystallinity, and phase sizes established during the fabrication process. Molecular orientation induced parallel to the flow axis in injection molding substantially increases strength in this direction at the expense of properties perpendicular to the axis of flow.[10, 11] For multiphase blends, there may also be phase elongation and orientation which ultimately influence the properties. Ideally, compression-molded materials are isotropic with equivalent properties in all directions. However, immiscible blends molded this way often have larger phase sizes than ones made by injection molding owing to coalescence without concurrent breakup of these phases due to the lower level of stresses involved in compression molding. Addition of SEBS was found to retard coalescence in HDPE/(PEC/PS) blends.[9] Dissimilar stresses and cooling rates during compression and injection molding introduce possible differences in crystallinity and crystalline texture of the polyethylene phase. Generally, greater crystallinity leads to stiffer and stronger materials.[11, 12] The relative degree of crystallinity, orientation, and the dispersed phase size are, thus, factors to be considered when comparing properties of compression- and injection-molded blends.

EXPERIMENTAL

Materials

Characteristics of the materials used in this study are described in detail in the earlier paper.[9] Injection-molding grades of high density polyethylene (melt index in the range of 2–7 g/10 min) were supplied by Union Carbide Corporation. An extrusion grade of polystyrene, Cosden 550 PS, was supplied by Cosden Oil and Chemical Company.

The polyether copolymer (PEC) was supplied specifically for this study by Borg-Warner Chemicals, Inc. in the form of preblends with Cosden 550 PS containing 80% PEC/20% PS (PEC80), and 60% PEC/40% PS(PEC60). To fill in the composition range, 20% PEC/80% PS (PEC20) and 40% PEC/60% PS (PEC40) blends were made by mixing PEC60 or PEC80 with additional PS in a single-screw extruder as described later. Table I gives the glass transition

TABLE I
Glass Transition Temperature of PEC/PS Blends

Blend composition (%)	Abbreviation	$T_g{}^a$ (°C)
PS	PS	105
20 PEC/80 PS[b]	PEC20	111
40 PEC/60 PS[c]	PEC40	128
60 PEC/40 PS	PEC60	158
80 PEC/20 PS	PEC80	178

[a] T_gs were determined by DSC at 20°C/min.
[b] Made by diluting PEC60 with additional PS by extrusion compounding.
[c] Made by diluting PEC80 with additional PS by extrusion compounding.

temperatures for the various PEC/PS blends determined using a Perkin Elmer DSC-2 at 20°C/min. The T_gs for the PEC/PS blends are comparable to those for PPO/PS blends of the same composition.[13]

The compatibilizer used here is the one designated as SEBS-L in the previous paper;[9] for convenience the L has been omitted here. SEBS is a triblock copolymer based on styrene and butadiene supplied by Shell Chemical Co. as Kraton G 1652. Its polybutadiene midblock (MW = 37,500) contains both 1,4- and 1,2-diene structures that have been hydrogenated to give a structure similar to an ethylene-(butene-1) random copolymer. The molecular weight of the PS endblocks is about 7,000.

Blend Fabrication

Processing temperatures were selected based on torque–temperature data of the individual components recorded in a Brabender Torque Rheometer and varied with blend composition as described earlier.[9] All materials were dried at 60°C in an air oven for at least 6 h before extruding and again before molding. Extrusion was carried out in two passes through a Killion extruder using a shear-mixing screw. Degradation at high processing temperatures was minimized by adding 0.1% of an antioxidant mixture of Irganox B 225 and Irganox 1035 supplied by Ciba-Geigy Corporation. High temperatures were not required to process HDPE/PS blends; therefore, the antioxidant was not added to these blends.

Tensile and impact specimens were prepared in an Arburg injection molder. Compression-molded sheets were fabricated in a compression press from extruded pellets of each blend and cooled under pressure with air circulation through the mold platens. Slow air cooling was found to reduce warping of blends with a HDPE matrix (50–100% HDPE) which occurred during more rapid cooling with water. These sheets were cut into tensile and impact specimens using a Tensilkut router. All injection-molded samples and compression-molded sheets were held for at least 24 h before cutting or testing.

Specific problems were encountered while compression molding PEC60- and PEC80-rich blends containing SEBS. Removal of thick disposable aluminum sheets used as a mold release was especially difficult without peeling away small sections on the surface of the specimen. Phase separation resulted in poor surface quality and samples that were visibly heterogeneous, both of

which contributed to inferior properties. For these reasons, the data obtained for these blends are not discussed in detail here.

Testing Procedures

Mechanical properties were determined by ASTM D638 on an Instron Testing Machine using a crosshead speed of 0.2 in./min. The modulus and yield stress were obtained using a strain gauge extensometer and automatically calculated by a dedicated computer using the original cross-sectional area. Notched Izod impact strength was determined according to ASTM D256 using Testing Machines, Inc. equipment. In some blends the force of the heaviest hammer did not completely fracture the impact specimen. Instead the sample deflected from the path of the hammer by bending, which precluded complete fracture. Such behavior may be expected for tough materials with low stiffness. The energy absorbed by this process was recorded and is indicated as a point of reference in subsequent discussions.

Statistical averages of all mechanical property data were calculated from a minimum of 5 test specimens, unless otherwise indicated.

In order to compare crystallinity levels resulting from different molding processes, areas under the HDPE melting peak were determined from a first-heat differential scanning colorimetry (DSC) thermogram at a rate of 20°C/min.

RESULTS

The results presented here for HDPE/(PEC/PS) blends consist of various parameters determined from stress–strain diagrams (modulus, yield strength, strain at break) and Izod impact values. Samples for testing were fabricated by both injection and compression molding. As indicated previously, HDPE forms a single phase in this heterogeneous mixture while the second phase contains either pure PS or PEC/PS blends of different compositions. SEBS is presumed to form an interphase between the polyolefin and glassy phases, which provides interfacial adhesion in the solid state and phase stability for the blend during melt processing. Analysis of this complex blend system may be simplified by viewing the same results in several ways while varying the composition of one component at a time.

Results are given for injection-molded materials as a function of the weight percent HDPE in blends with PS, PEC60, or PEC80. Specific data for the same injection-molded materials were replotted against the composition of the glassy phase (wt% PEC) while maintaining a constant HDPE content (0, 25, 50, 75% HDPE). In both cases the effects of adding SEBS to the blends are considered. For systems with a HDPE matrix, the mechanical properties of compression-molded materials are compared to blends of the same composition made by injection molding.

Properties of Injection-Molded Blends

Incompatibility in polymer blends is frequently reflected by very poor ductility and toughness compared to the pure components, which often precludes practical use of these materials. Figure 1 illustrates the inferiority of

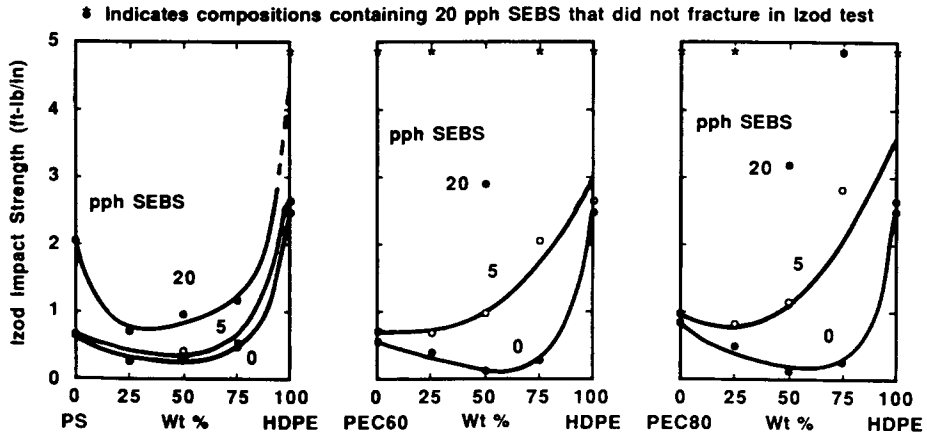* Indicates compositions containing 20 pph SEBS that did not fracture in Izod test

Fig. 1. Notched Izod impact strength for HDPE/PS (left), HDPE/PEC60 (center), HDPE/PEC80 (right) blends containing the indicated amount of SEBS.

the notched Izod impact strength for blends of HDPE with either PS, PEC60, or PEC80. Although pure PS, PEC60, and PEC80 show relatively poor impact strength, the unmodified blends containing one of these glassy materials with HDPE exhibit even lower impact strengths, as might be expected. In all three cases, adding 5 pph SEBS increases toughness of the blends and additivity between the properties of the endpoint materials is approached. Several compositions containing 20 pph SEBS did not fracture in the Izod test as described earlier. These blends are indicated by an asterisk along the top axis of the plots and the values recorded for the energy absorbed by the hammer during impact are given in Table II. The only PEC60- or PEC80-based blends containing 20 pph SEBS that fractured were those with 50% HDPE and are shown as single values on the graph.

In order to obtain a better perspective of the influence of PEC on the properties of these blends, the same results are replotted in Figure 2 as a function of the weight percent PEC in the glassy phase. The impact strengths for the miscible PEC/PS blends without HDPE are similar to results Cizek[13] found for PPO/PS blends. Addition of SEBS increases the impact strength

TABLE II
Energy Absorbed by HDPE/(PEC/PS) Samples that
Deflected rather than Fractured during Impact Testing

Blend composition (%)	SEBS content (pph)[b]	Energy absorbed[a] (ft-lb/in)
PEC60	20	6.7
PEC80	20	21
25 HDPE/75 PEC60	20	9.3
25 HDPE/75 PEC80	20	6.3
75 HDPE/25 PEC60	20	12
75 HDPE/25 PEC80	20	11
HDPE	20	13

[a] Samples did not fracture in an Izod impact test.
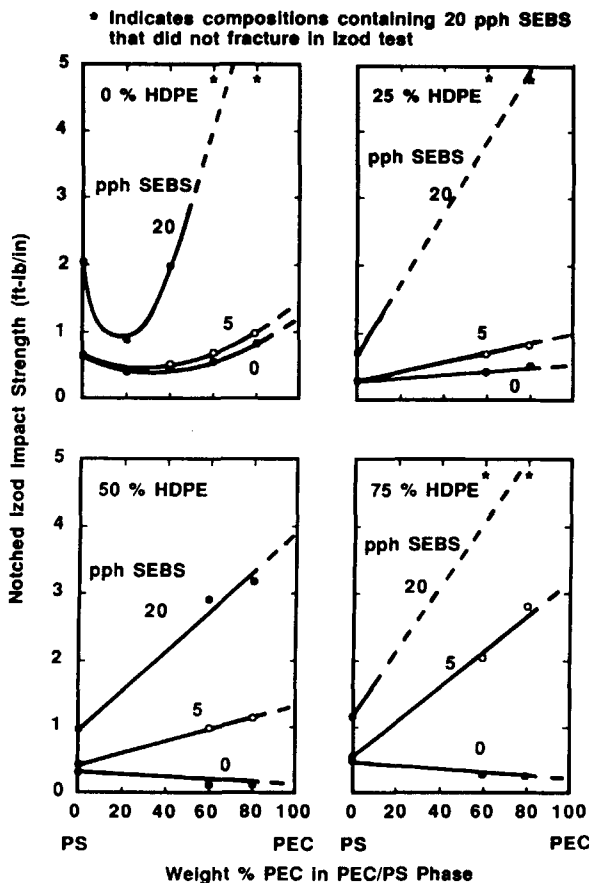[b] Parts per 100 of base blend.

Fig. 2.   Notched Izod impact strength for HDPE/(PEC/PS) blends containing SEBS versus the quantity of PEC in the glassy phase for the HDPE contents shown.

and toughness of the miscible PEC/PS blends. When HDPE is present (25, 50, 75%), blends without SEBS are very brittle and the relative amount of PEC in the glassy phase has little effect on the strength. Addition of SEBS increases toughness for all blends, but these improvements are greater for blends containing PEC-rich phases instead of pure PS regardless of the quantity of HDPE. In fact, in blend systems with the same amount of HDPE, the Izod impact strength of PEC60 and PEC80 blends containing 5 pph SEBS is approximately the same as or greater than PS blends containing 20 pph SEBS. Significant evidence for the beneficial effect of PEC on toughness is the fact that several samples containing PEC-rich phases and 20 pph SEBS did not fracture under these test conditions. Such compositions are marked with an asterisk as previously described.

As seen in Figure 3, the strain at break for HDPE/(PEC/PS) blends follow virtually identical trends as the Izod impact strength. The values of the elongation at break reported for injection-molded PEC60 and PEC80 excluded results from many samples in each set where premature failure was obviously caused by foreign particles in the specimen.

Some HDPE/PS blends have lower strains at break than pure PS. Addition of SEBS increases ductility for both PS and its blends with HDPE. The strain
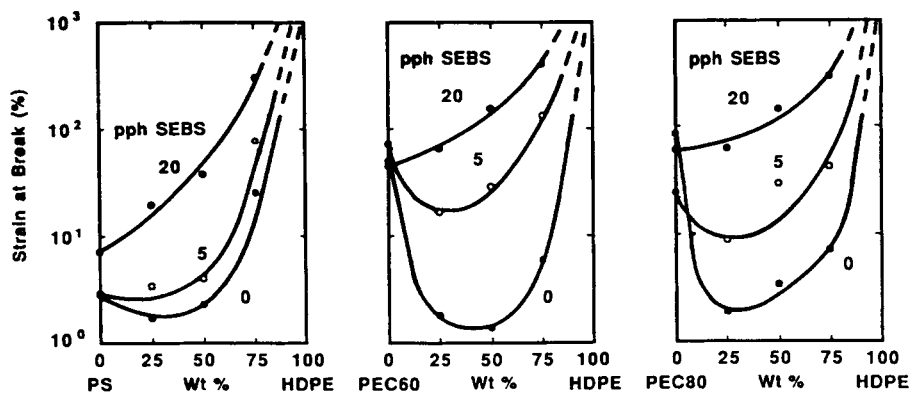
Fig. 3. Strain at break for HDPE/PS (left), HDPE/PEC60 (center), HDPE/PEC80 (right) blends containing SEBS.

at break exhibited by blends containing 20 pph SEBS is approximately an additive function of composition based on the measured endpoint values as shown. Similar results were obtained by Lindsey et al.[1] for blends of the same components. PEC is significantly more ductile than PS so the minimum in the strain at break for blends containing either PEC60 or PEC80 with HDPE is more dramatic. These results clearly illustrate the inferior properties obtained by combining these two ductile but incompatible polymers. Adding 5 pph SEBS has little effect on the strain at break for either PEC60 or PEC80, but greatly improves the values for their blends containing HDPE. After adding 20 pph SEBS, the minimum in the strain at break is virtually eliminated and the values more nearly approach additivity.

Figure 4 shows the strain at break replotted against the quantity of PEC in the glassy phase. PEC/PS blends containing no HDPE undergo a brittle to ductile transition between 40 and 60 wt% PS. Blends with less than 60% PEC visibly craze and fracture in a brittle mode while PEC60 and PEC80 yield and neck throughout the gauge section of the sample prior to fracturing. Yee[14,15] found that PPO/PS blends also exhibited a similar brittle to ductile transition within the same composition range (40–60% PPO depending on strain rate). Ductility is enhanced in brittle PEC/PS blends (PS, PEC20, and PEC40) by adding SEBS.

HDPE/(PEC/PS) blends exhibit low strains at break regardless of the amount of PEC in the glassy phase. The strain at break for these blends increases as a result of adding SEBS. As seen previously for the impact strength, the improvement is substantially greater for blends containing PEC-rich glassy phases instead of pure PS. For 75% HDPE blends containing 5 pph SEBS, the strain at break increased from about 80% to 140% on changing the glassy phase from pure PS to PEC60.

Improvements in ductility and impact resistance are often accompanied by sacrifices in strength and stiffness.[1] Figure 5 shows that the moduli of blends containing either pure PS, PEC60, or PEC80 and HDPE fall just below the weighted averages of the pure component values. A decrease in modulus is expected when the SEBS elastomer is added to the blends as the data clearly show for all compositions. The modulus lines for HDPE/PS blends containing
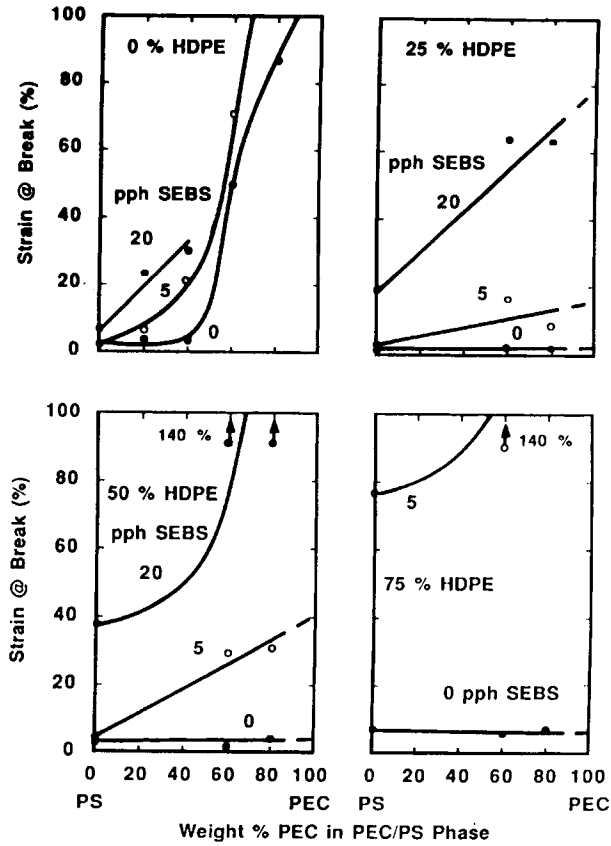
Fig. 4.   Strain at break for HDPE/(PEC/PS) blends containing SEBS versus the quantity of PEC in the glassy phase for the HDPE contents shown.
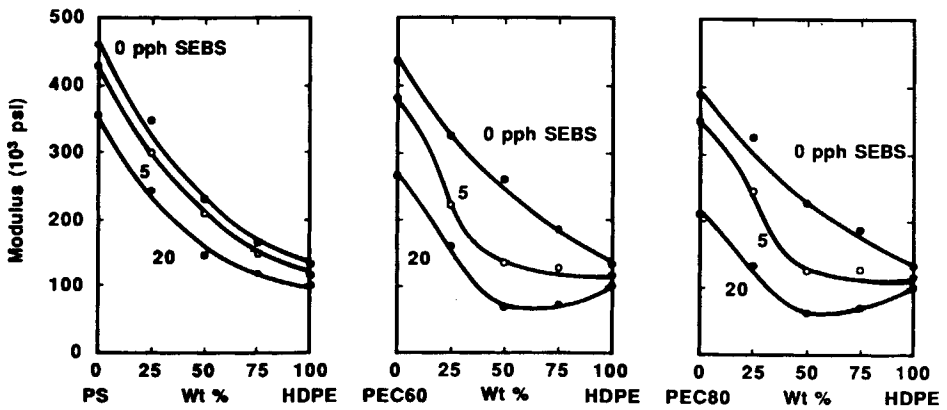
Fig. 5.   Modulus for HDPE/PS (left), HDPE/PEC60 (center), HDPE/PEC80 (right) blends containing SEBS.
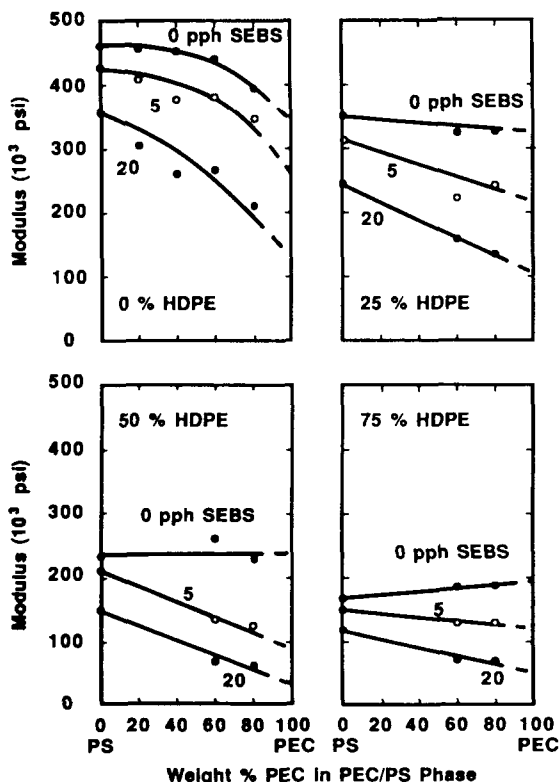
Fig. 6. Modulus of HDPE/(PEC/PS) blends containing SEBS versus the quantity of PEC in the glassy phase for the HDPE contents shown.

5 and 20 pph SEBS remain essentially parallel to that for 0% SEBS as reported previously.[1] However, for blends containing PEC60 and PEC80 phases, addition of SEBS causes the modulus to drop further than observed for blends with PS. These curves show considerable departure from additivity and exhibit minima in some cases.

Plots of these data as a function of the PEC concentration in the glassy phase, shown in Figure 6, provide additional insight. PEC/PS blends without HDPE show a synergistic modulus response comparable to that reported for miscible PPO/PS blends.[16] Addition of SEBS decreases the modulus and suppresses this synergism in modulus until at 20 pph SEBS the values lie close to a tie line between the endpoints. For the blends containing 25, 50, and 75% HDPE without SEBS, the modulus remains relatively constant as the weight percent of PEC in the amorphous phase is changed. However, for those blends also containing SEBS, the modulus decreases as the amount of PEC in the glassy phase increases. For instance, the modulus for 50% HDPE blended with 50% PEC60 or 50% PEC80 containing 5 pph SEBS (about 130,000 psi) is considerably lower than the 200,000 psi for 50 HDPE/50 PS with 5 pph SEBS. Since the quantity of the low modulus components, either HDPE or SEBS, remains constant in this comparison, the lower moduli observed must result from some changes caused by the presence of PEC.
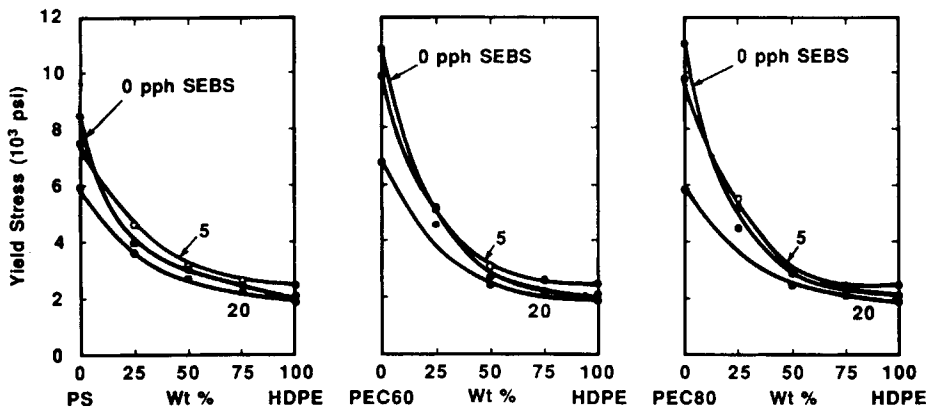
Fig. 7. Yield stress for HDPE/PS (left), HDPE/PEC60 (center), HDPE/PEC80 (right) blends containing SEBS.

These results would be most easily understood in terms of changes in the morphology caused by the presence of PEC instead of pure PS; however our previous examination of morphology for these blends gave no direct clues. The response is as if the effective volume fraction of the SEBS component increased because of the presence of PEC. Since the modulus of SEBS is almost two orders of magnitude lower than all other blend components,[17] small increases in the volume fraction of this phase could significantly reduce the modulus of the multiphase system. Alternately, such a response would result if the SEBS elastomer assumed a semicontinuous character in the blends. Previously,[9] we noted an apparently stronger adhesion between phases in blends containing some PEC and attributed this to a greater thermodynamic driving force for the PS endblocks of SEBS to penetrate into a glassy phase containing PEC. However, it is not very clear how to unambiguously connect this propensity with the types of morphology changes mentioned.

The yield stress curves shown in Figure 7 fall well below additivity but no minimum is seen. Addition of 5 pph SEBS to blends of HDPE with either PS, PEC60, or PEC80 (25–75% HDPE) results in yield stress values which are greater than the peak stress values for the two-phase blends without SEBS. The SEBS increases ductility so that these materials display greater strength by yielding rather than failing by brittle fracture. Addition of larger amounts of SEBS (20 pph) decreases the yield stress further, as expected. Blends containing HDPE exhibited little significant change in yield stress as the composition of the glassy phase changed; hence these data are not replotted here. The yield or peak stresses measured for PEC/PS blends are virtually identical to those reported for PPO/PS blends.[13]

To summarize, Figure 8 shows the type of stress-strain diagrams that were observed over the full composition range of HDPE/PS and HDPE/PEC80 blends containing 0 and 5 pph SEBS. The brittleness of HDPE/PS blends is reflected by the low elongation of most of these materials. The 75 HDPE/25 PS binary is not entirely brittle, and it fails by a tearing mode at 20% strain. Improvements from adding 5 pph SEBS are somewhat limited by the brittle nature of pure PS, but all blends show improved ductility with a small
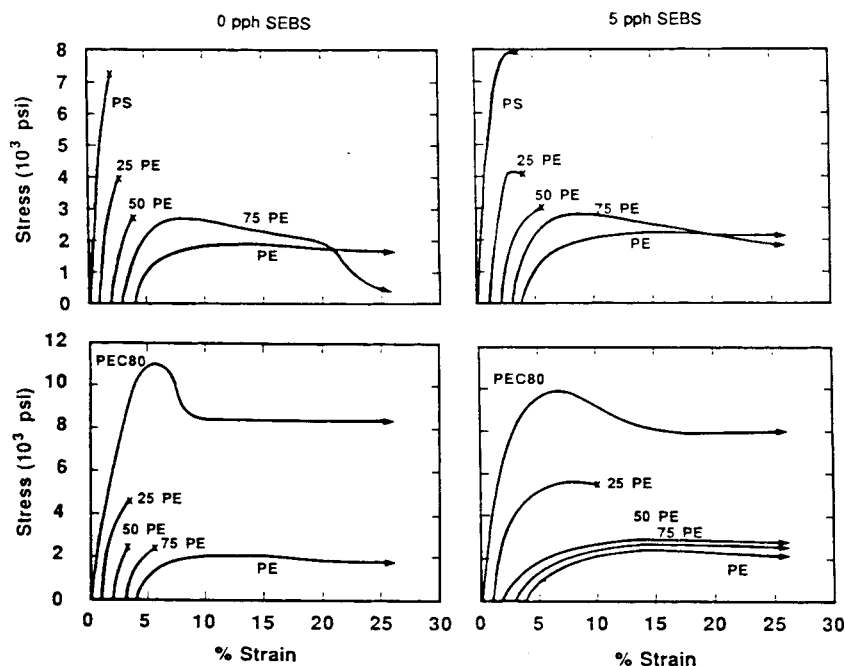
Fig. 8. Stress-strain curves for HDPE/PS (upper) and HDPE/PEC80 (lower) blends with 0 (left) and 5 (right) pph SEBS. Curves have been shifted along strain axis for clarity.

reduction in modulus. On the other hand, both HDPE and PEC80 are relatively ductile, but blends of the two are distinctly brittle as indicated by the low elongation at break of these samples. Adding 5 pph SEBS lowers and broadens the yield point of PEC80 and significantly improves ductility of all blends with HDPE while reducing the modulus. From this figure, it is obvious that there is a more pronounced effect of SEBS on the stress–strain response for blends containing PEC rather than pure PS. As an example, blends containing 50% HDPE and either 50% PS or 50% PEC80 fracture at quite low strains. After adding 5 pph SEBS to both blends, the blend with PEC80 reaches an elongation greater than 25% without fracturing, while the blend with PS fractures before 5% strain. However, the latter is still tougher than the unmodified blend. Likewise, impact strength is also greater in blends with PEC-rich phases but, on the other hand, modulus is reduced to a greater extent.

Effect of Molding Technique

Trends in the mechanical properties for blends fabricated by compression molding are identical to those presented for injection-molded materials but, as expected, the absolute values are not always the same. To illustrate the differences in the properties which can be attributed to the method used to mold the test specimens, this discussion will focus on blends with a HDPE matrix (50–100% HDPE). Problems encountered while compression-molding blends rich in PEC60 or PEC80 containing SEBS resulted in specimens

TABLE III
Properties of Compression-Molded and Injection-Molded Blends

Blend composition (%) SEBS pph[a]	Peak (yield) stress (10³ psi)		Modulus of elasticity (10³ psi)		Notched Izod impact (ft-lb/in)		Area under HDPE melting peak[b] (cal/gm)	
	Compression molded	Injection molded	Compression molded	Injection molded	Compression molded	Injection molded	Compression molded	Injection molded
50 HDPE/50 PS								
0	2.4	3.0	275	232	0.72	0.32	17.6	12.3
5	2.7	3.1	183	207	0.66	0.43	17.2	14.8
20	2.0	2.7	76	150	1.5	0.97	15.2	12.5
50 HDPE/50 PEC60								
0	2.4	2.4	192	261	0.46	0.12		
5	2.2	3.1	158	135	0.65	0.99		
20	2.3	2.7	47	92	1.95	2.9		
50 HDPE/50 PEC80								
0	2.6	2.5	234	229	0.42	0.12	22.1	20.7
5	2.3	3.0	184	126	0.69	1.1		
20	2.7	2.9	63	63	2.0	3.2	18.8	17.7
75 HDPE/25 PS								
0	2.7	2.5	196	167	0.33	0.48		
5	2.5	2.6	151	150	0.39	0.54		
20	2.3	2.3	107	119	1.2	1.2		
75 HDPE/25 PEC60								
0	2.9	2.6	248	186	0.35	0.29		
5	3.1	2.5	163	129	1.1	2.0		
20	2.4	2.2	110	71	3.8	12[c]		
75 HDPE/25 PEC80								
0	3.2	2.5	254	187	0.13	0.27		
5	3.1	2.5	163	129	1.2	2.8		
20	2.4	2.1	90	69	5.1	11[c]		
HDPE								
0	3.4	1.9	196	133	0.73	2.5	44.4	41.0
5	3.4	2.5	181	116	1.1	2.6		
20	2.6	2.1	134	103	15.4	13[c]	39.0	35.5

[a] Parts per 100 of base blend.
[b] Based on total mass of blend.
[c] Specimens did not fracture (see text and Table II).

decidedly inferior to injection-molded ones of the same composition. These results will not be discussed further.

Table III gives the modulus, yield stress, and notched Izod impact strength for compression- and injection-molded blends of the compositions mentioned. In general, the modulus and yield stress are greater for compression-molded materials while the impact strength is greater for their injection-molded counterparts. The graphical comparison in Figure 9 shows the differences in these properties for 75 HDPE/25 PS and 75 HDPE/25 PEC60 blends molded by both techniques. Table III also presents values obtained for the area under the HDPE melting peak in selected blends, which is a measure of the crystallinity. From these results, it is clear that all compression-molded materials are somewhat more crystalline than injection-molded blends of the same composition. The slower air cooling used in compression molding (approximately 10°C/min) compared to the much faster water cooling used in injection molding (may be as rapid as 150–200°C/min) allows more time at elevated temperatures for crystallization. Higher modulus and yield stress of compression-molded materials apparently reflect this greater crystallinity.

Table III suggests that the differences in properties and crystallinity between compression- and injection-molded materials are greater in blends containing PEC60 and PEC80 than for blends with PS. As an example, the heat of fusion for 50 HDPE/50 PEC80 (22.1 cal/g) is greater than that
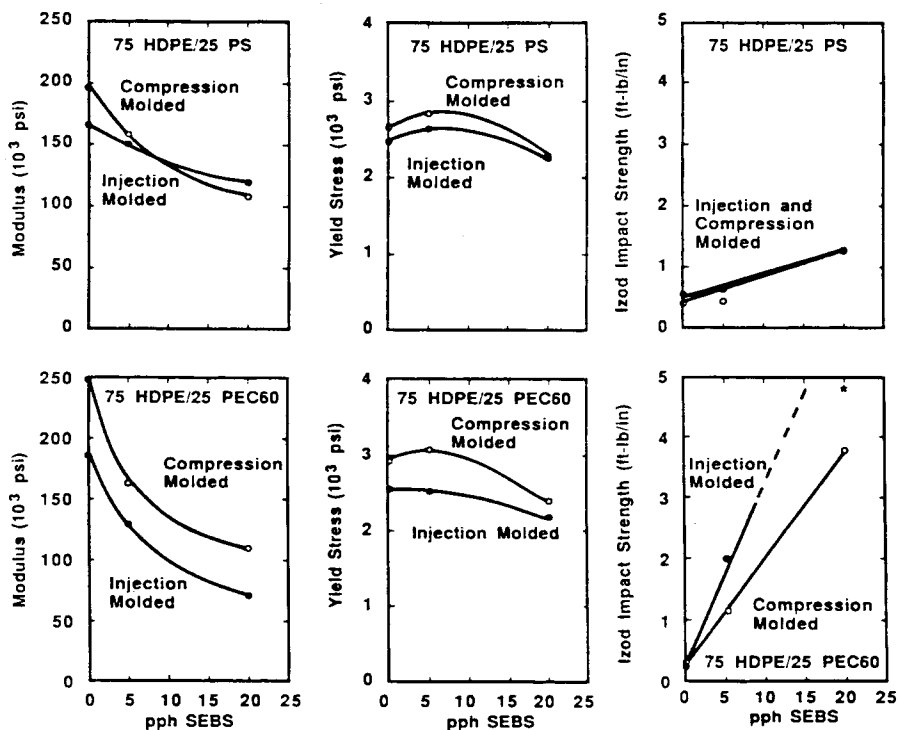

Fig. 9. Modulus, yield stress, and notched Izod impact strength for compression and injection molded 75 HDPE/25 PS (top) and 75 HDPE/25 PEC80 (bottom) blends plotted versus SEBS content.

obtained for 50 HDPE/50 PS (17.6 cal/g). Figure 9 clearly shows that the differences in modulus and yield stress of compression- and injection-molded 75 HDPE/25 PEC60 are significantly greater than for 75 HDPE/25 PS. The higher temperatures required to fabricate blends containing PEC correspond to longer time at elevated temperatures leading to greater crystallization of the HDPE phases and the larger differences in the mechanical properties.

Superior impact strength and elongation of the injection-molded blends is probably related to orientation induced by the molding process.

SUMMARY

The results presented here demonstrate that an SEBS triblock copolymer significantly increases the Izod impact strength and strain at break of brittle HDPE/(PEC/PS) blends; however, there is a sacrifice in stiffness and ultimate strength. This compatibilizing effect by SEBS is more dramatic when the glassy phase contains PEC rather than pure PS. At least two factors may be at issue. Miscible blends of PEC and PS are considerably more ductile than pure PS. Therefore, the immiscible blends of HDPE with the former involves two relatively ductile phases, but the composite is quite brittle owing to the lack of interfacial adhesion between these phases. Improvement of this adhesion by addition of SEBS allows the composite to realize the ductility of both its phases. Thus, the relative change in toughness of these blends is greater than for blends based on PS, which forms a brittle phase even after mechanical coupling to HDPE. As described previously,[9] the thermodynamic affinity of PEC for the PS endblocks of SEBS may lead to a more effective coupling of HDPE to a PEC/PS phase than a PS phase by the SEBS compatibilizer. The presence of PEC apparently is responsible for a greater reduction in modulus for the composite when SEBS is added. This may be a consequence of a greater effective volume fraction or more continuous nature of the low modulus SEBS phase.

Higher molding temperatures and slower cooling rates increase the length of time the blend is at elevated temperatures and subsequently allows greater HDPE crystallinity to develop. This is the most likely cause of the higher modulus and yield stress values in HDPE-rich compression-molded blends compared to injection-molded ones. This increase is greater for blends containing PEC60 and PEC80 phases as a consequence of the higher processing temperatures required for these materials. However, orientation induced in the flow direction of injection-molded samples increases the strain at break and notched Izod impact strength of the same blends.

The third paper in this series will deal more fully with the mechanisms of deformation of these materials during uniaxial straining. Both compression- and injection-molded blends will be considered.

References

1. C. R. Lindsey, D. R. Paul, and J. W. Barlow, *J. Appl. Polym. Sci.*, **26**, 1 (1981).

2. R. Fayt, R. Jerome, and Ph. Teyssie, *J. Polym. Sci. Polym. Lett. Ed.*, **19**, 79 (1981).

3. R. Fayt, R. Jerome, and Ph. Teyssie, *J. Polym. Sci. Polym. Phys. Ed.*, **19**, 1269 (1981).

4. R. Fayt, R. Jerome, and Ph. Teyssie, *J. Polym. Sci. Polym. Phys. Ed.*, **20**, 2209 (1982).

5. R. Fayt, P. Hadjiandreou, and Ph. Teyssie, *J. Polym. Sci. Polym. Chem. Ed.*, **23**, 337 (1985).

6. S. D. Sjoerdsma, A. C. A. M. Bleijenberg, and D. Heikens, in *Polymer Blend Processing, Morphology, and Properties*, E. Martuscelli, R. Palumbo, and M. Kryszewski, Eds., Plenum, New York, 1980, pp. 201–237.

7. D. Heikens, N. Hoen, W. Barensten, P. Piet, and H. Laden, *J. Polym. Sci. Polym. Symp.*, **62**, 309 (1978).

8. R. I. Warren, *Polym. Eng. Sci.*, **25**(8), 477 (1985).

9. M. C. Schwarz, J. W. Barlow, and D. R. Paul, *J. Appl. Polym. Sci.*, submitted for publication.

10. C. B. Bucknall, *Toughened Plastics*, Applied Science Publishers, Ltd, London, 1977, Chap. 11.

11. T. Alfrey, in *Science and Technology of Polymer Processing*, N. P. Suh and H. H. Sung, Eds., MIT Press, Cambridge, MA, 1979, pp. 185–199.

12. C. A. Sperati, W. A. Franta, and H. W. Starkweather, *J. Am. Chem. Soc.*, **75**, 6127 (1953).

13. E. P. Cizek, U.S. No. Patent 3,383,435, May 14, 1968, assigned to General Electric Co.

14. A. F. Yee, *Polym. Eng. Sci.*, **17**(3), 213 (1977).

15. A. F. Yee, *Polym. Prepr. Amer. Chem. Soc. Div. Polym. Chem.*, **17**, 145 (1976).

16. L. W. Kleiner, F. E. Karasz, and W. J. MacKnight, *Polym. Eng. Sci.*, **19**(7), 519 (1979).

17. G. Holden, E. T. Bishop, and N. R. Legge, *J. Polym. Sci. Polym. Symp.*, **26**, 37 (1969).