Rheology and Morphology of High Impact Polystyrene Polyethylene Blends and the Effect of Compatibilization on Their Properties

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Rheology and Morphology of High Impact Polystyrene/ Polyethylene Blends and the Effect of Compatibilization on Their Properties

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ABSTRACT: Attempts were made to study rheology and morphology of high impact polystyrene/polyethylene (HIPS/PE) blends. The Effect of compatibilization using styrene-butadiene-styrene copolymer (SBS) and styrene-ethylene-butylene-styrene copolymer (SEBS) on their properties was also studied. The results of linear viscoelastic properties showed negative deviation of viscosity and elasticity from the mixing rules in low HIPS content blends, while positive deviation was observed for high HIPS content blends. The former was related to weak interface and the latter was attributed to the hydrodynamic interaction of PE and PB particles. A wide range of co-continuity was observed for HIPS/PE blends which decreased using compatibilization. It was found that SEBS had better efficiency of compatibilization than SBS due to lower molecular weight and the presence of ethylene block in SEBS structure. The fracture behavior of low and high HIPS content blends showed different mechanism because of higher volume contraction of PE than HIPS in solidification process and also different mechanical properties of HIPS and PE. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 114: 2235–2245, 2009

Key words: HIPS/PE blends; rheology; morphology; compatibilization

INTRODUCTION

Blending of two or more polymers to form a new polymer with desirable properties is now an established route to developing new materials.[1–4] Because of the negligible entropy and positive enthalpy of mixing, most of polymer blends are immiscible and therefore they display multiphase morphology.[5,6] Mechanical properties of such blends can strongly be affected by phase morphology and interface properties. Moreover, morphology of a blend is influenced by the rheological parameters and also process conditions.[7] Therefore mechanical behavior of immiscible polymer blends becomes more complicated.

High impact polystyrene/polyethylene (HIPS/PE) blends can be used in many applications, in particular where the higher environmental stress cracking resistance (ESCR) to fatty oil materials is required. Since the recyclable plastic mixtures contain these components (HIPS and PE) in a large scale, study on the morphological and mechanical properties of these blends can attract great interest. It is well known that HIPS and PE are incompatible and therefore their simple blends display very poor mechanical properties. To enhance their mechanical properties, an effective compatibilization using appropriate compatibilizers should be applied. Compatibilization of polystyrene/polyolefin blends such as PS/PE,[8–10] PS/PP,[11] HIPS/PP,[12] and HIPS/PE[13–15] blends have been done using many different compatibilizers. The most frequently used compatibilizers are diblock styrene-butadiene copolymer (SB), styrene-butadiene-styrene triblock copolymer (SBS) and styrene-ethylene-butylene-styrene copolymer (SEBS). In compare to PS/PE blends, there are a few works on the HIPS/PE blends. Fayt et al.[15] studied the effect of a tapered hydrogenated poly (butadiene-block-styrene) on the morphology and mechanical properties of HIPS/LDPE blends. Brahimi et al.[16] studied rheology and morphology of HDPE/HIPS blends and reported co-continuous morphology in a wide range of composition. The most interesting research work on the HIPS/PE blends has recently been carried out by Fortelny et al.[14] They focused on the partitioning of SB copolymer in these blends and showed that the localization of copolymer is dependent on the blend composition and the used PE grade (HDPE or LDPE).

It has clearly been understood that the rheological parameters such as viscosity and elasticity ratio of the blend components have a remarkable influence

on the phase structure of the blends. The rheological behavior of the blends is also dependent on the type of morphology as well as interfacial interaction between phases.[17–19] So that, the information obtained from the rheological studies in particular at low frequency ranges (low shear rates) can be used in the prediction of morphology and therefore mechanical properties of the blends. Chirawithaya-boon and Kiakamjornwong[13] studied the rheology of HIPS/HDPE blends. The studied range of shear rate did not include sufficiently low shear rates to give reliable information about the phase structure and interfacial interaction.

The main objective of the present work was to study the melt linear viscoelastic properties of HIPS/HDPE blends in particular at low frequencies in order to evaluate the interfacial interaction between phases. The morphology of the blends and the effect of different compatibilizers (SBS and SEBS) on their properties were also studied.

EXPERIMENTAL

Materials

The blends constituents used in this study were of industrial origin; HIPS-7240 (MFI=5.5 g/10 min; 200°C, 5 kg) and HDPE-3840 (MFI = 4.2 g/10 min; 190°C, 2.160 kg) were supplied by Tabriz petrochemical company, Iran. SEBS three block copolymer (Kraton G1652: styrene content = 32 wt %; M_w values of EB and PS blocks are 35,000 and 7500, respectively) from Shell development company and SBS (Calprene 501: butadiene/styrene = 69/31 thermoplastic copolymer with linear structure and M_w values of PB and PS blocks 41,400 and 9300, respectively) from Dynasole company, Spain, were used as received.

Blend preparation

The melt compounding of all the uncompatibilized and compatibilized blends were carried out in a laboratory batch internal mixer (Brabender W50 EHT, Duisburg, Germany) at set temperature of 180°C and with rotor speed of 60 rpm. The chamber was filled with a dry blended mixture of HIPS and PE and the melt compounding was continued until the mixing torque reached to its steady state values (about 8 min). In the case of compatibilized samples, the compatibilizer was fed to the chamber after 2–3 min of the process beginning and the process was continued up to the same time as uncompatibilized samples. In all the compatibilized samples 5 wt % of SBS or SEBS were used. A small amount of the prepared blend samples were rapidly quenched in liquid nitrogen for morphological studies.

Rheological studies

The flow behavior and melt linear viscoelastic properties of neat HIPS, neat PE, and HIPS/PE blends were investigated by using a rheometric mechanical spectrometer (RMS; UDS 200, Anton Paar) equipped with parallel plate geometry (diameter = 25 mm, gap = 1 mm). The frequency sweep tests were performed in the range of 0.1–625 s^{-1} at temperature of 190°C and with an amplitude of 1% to maintain the response of materials in the linear viscoelastic regime.

Morphological studies

An LEO 440I scanning electron microscopy (SEM) instrument was used for morphological studies according to ASTM-F1372. Cryofractured surfaces in liquid nitrogen were gold sputtered for good conductivity of the electron beam and microphotographs were taken within different magnifications. For PE-matrix blends, tetra-hydro furan (THF) solvent was used to remove the HIPS phase.

The continuity index of the HIPS phase was determined using selective extraction method.[20,21] Samples of specified weight of each blend were stirred in THF for 72 h at a constant temperature of 40°C to selectively extract the HIPS phase. The continuity index of the HIPS phase (CI_{HIPS}) was quantified using following equation:

$$CI_{HIPS} = \frac{m_{ini} - m_{ext}}{m_{ini}} \times 100\%$$

where m_{ini} is the weight of the HIPS phase initially present in the blend and m_{ext} the weight of the HIPS phase in the blend after extraction. In the case where the sample is not disintegrated, the PE phase is considered as continuous phase and the continuity of HIPS is quantified from the equation. If the sample disintegrates completely, then PE is considered as fully dispersed in the HIPS matrix and HIPS is considered as continuous phase.

RESULTS AND DISCUSSION

Figure 1 shows the complex viscosity (η^*) and storage modulus (G') for neat HIPS and PE as functions of angular frequency (ω). Both polymers display pseudo-plastic behavior and HIPS shows more shear thinning than PE. Although HIPS has higher viscosity and elasticity than PE at low frequency ranges, but at higher frequencies PE has higher viscosity and elasticity than HIPS.

The results of complex viscosity and storage modulus versus angular frequency for different blend samples are shown in Figures 2 and 3, respectively. All the blends exhibit shear thinning behavior
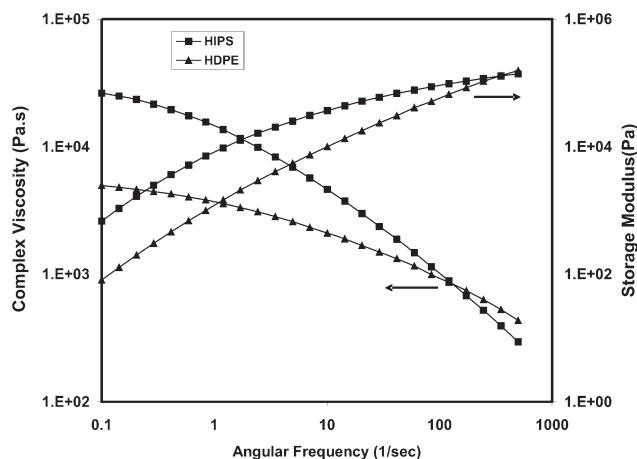
Figure 1 Complex viscosity (η^*) and storage modulus (G') versus angular frequency (ω) for neat HDPE and neat HIPS.
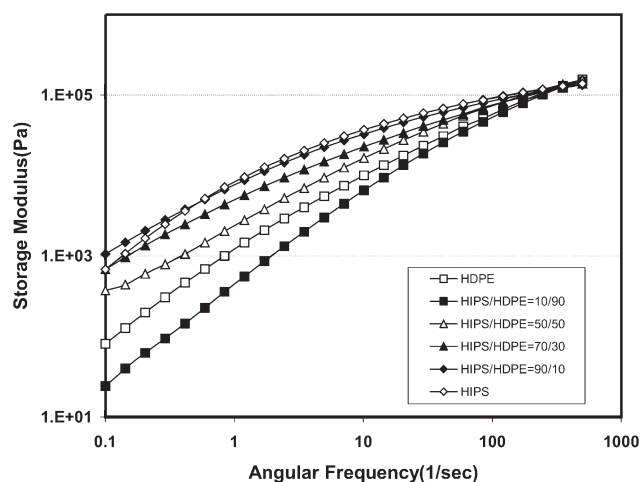
Figure 3 Storage modulus (G') versus angular frequency (ω) for different blend compositions.

similar to the pure components. By considering these results, one can clearly see that addition of 10 wt % of high viscose HIPS into PE decreases its viscosity and elasticity in particular at low frequency ranges. It is interesting to note that the addition of 10 wt % of low viscose PE onto HIPS increases viscosity and elasticity at low frequencies (~ 0.1 s^{-1}).

It has been clearly understood that the rheological behavior of immiscible polymer blends is widely affected by blend microstructure as well as interfacial interaction between phases.[22] So, the results of linear viscoelastic studies, applied in small amplitudes, can provide reliable information on microstructure of the blends. The viscoelastic response of the blends in low frequencies (low shear rates), where the effect of flow induced molecular orientation on the viscosity and elasticity become more less, can be used in evaluating of the interfacial interaction between phases.
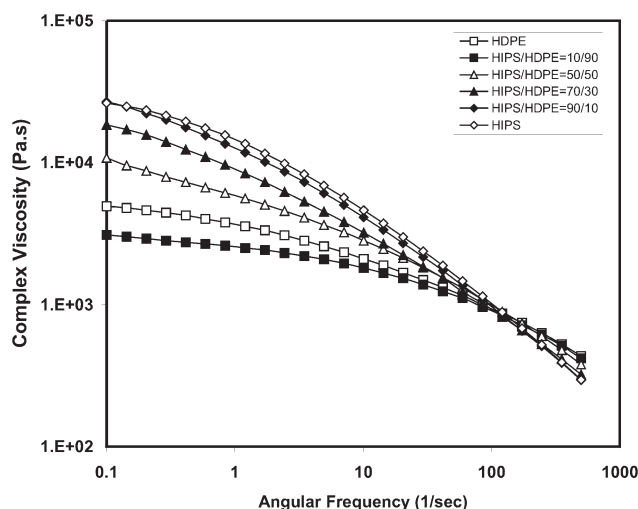
The complex viscosity and storage modulus versus blend composition together with the same results, calculated using mixing rule (additivity rule), at angular frequency of 0.1 s^{-1} are presented in Figures 4 and 5, respectively. The results show that the complex viscosity and storage modulus display negative deviation from mixing rule at low HIPS content blends, while at higher HIPS contents the positive deviation can be observed. This type of behavior, negative positive deviation behavior (NPDB), is usually observed where the interfacial interaction between phases is affected by the blend composition.[2] At first glance it may be thought that this type of behavior is representative of high interfacial interaction between phases in high HIPS content blends and low interfacial interaction in high PE content blends. On the other hand, it has been
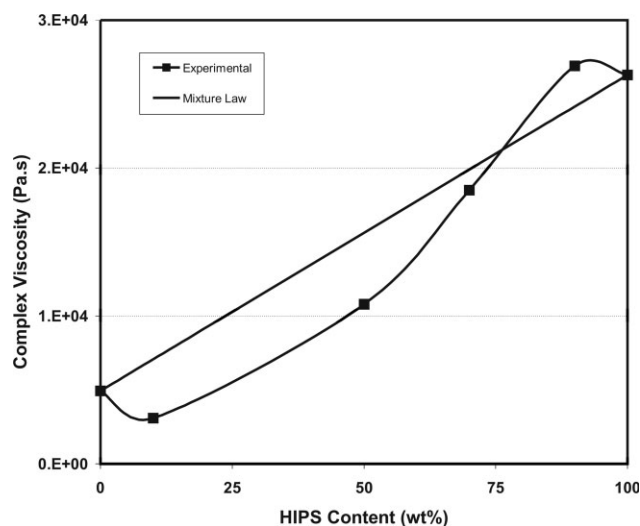

Figure 2 Complex viscosity (η^*) versus angular frequency (ω) for different blend compositions.

Figure 4 Complex viscosity (η^*) versus blend composition obtained from experimental and calculated using mixing rule at angular frequency of 0.1 s^{-1}.
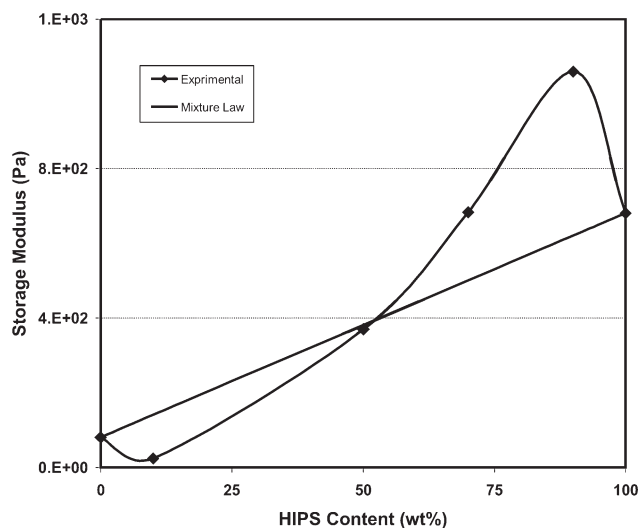
Figure 5 Storage modulus (G′) versus blend composition obtained from experimental and calculated using mixing rule at angular frequency of 0.1 s^{-1}.

shown that the viscosity and elasticity of most incompatible blends such as PS/PE blends, show negative deviation from mixing rules (NDB) in all the blend compositions due to the low interfacial interaction between phases and slippage at the interface.[2,13,23–26]

Since different structure of HIPS and PS relates to the presence of PB particles in HIPS, it may be the main reason of the principal discrepancy in rheological behavior of HIPS/PE and PS/PE blends. Therefore, it will be useful to have an attention to schematic morphology of HIPS/PE blends and its probable effect on the rheology, before than the morphology is studied experimentally. Figures 6 and 7 show the schematic morphology of high PE content and low PE content HIPS/PE blends, respectively.

In HIPS/PE blends with PE as a matrix phase, there are two kinds of dispersed phase, PB rubber
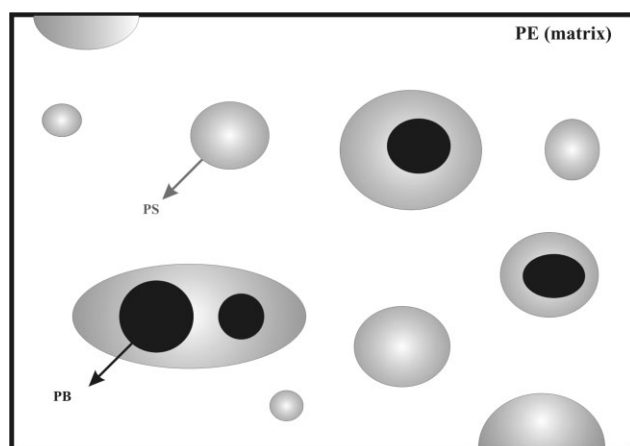

Figure 6 Schematic morphology of the HIPS/PE blends with low HIPS content.
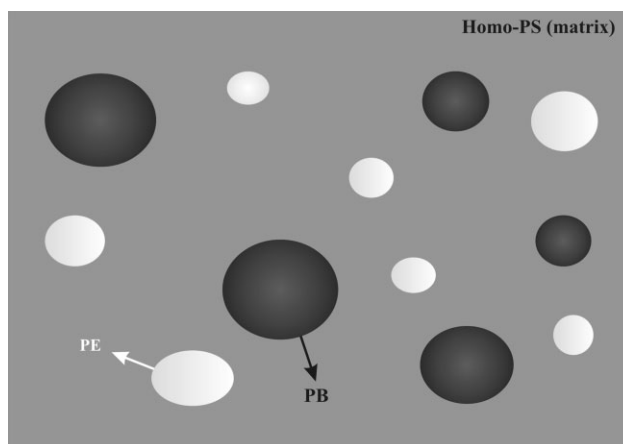
Figure 7 Schematic morphology of the HIPS/PE blends with low PE content.

particles surrounded by a thin layer of PS, and individual homo-PS particles (Fig. 6). The latter is in the result of separation of PS around of PB rubber particles during melt compounding process. Although a part of homo-PS is separated but because of the presence of grafted PS chains on PB particles, there is always a layer of homo-PS around the PB particles. Therefore, it can be concluded that the interfaces presented in PE-matrix HIPS/PE blends, are similar to PS/PE interface, with low interfacial interaction. By the results, the poor interfacial interaction between PE matrix and different dispersed particles is the main reason of negative deviation in low HIPS content blends.

In low PE content (high HIPS content) blends, homo-PS plays the matrix role where PB and PE particles are dispersed (Fig. 7). In such a case, there is a low interfacial interaction between PE particles and matrix. So, the observed positive deviation for high HIPS content blends would be in the results of interaction between PB and PE particles. Although the PE phase can not encapsulate the PB particles to form a core-shell type of morphology due to the presence of grafted PS chains on PB particles, but because of more affinity of PE to PB compared to homo-PS, PE particles may preferentially be localized near the PB particles rather than they disperse in PS matrix. So, the previously discussed positive deviation can be due to the hydrodynamic interaction of PE and PB particles. Hydrodynamic interaction between the particles from one side and their elastic response from the other side can increase the viscosity and in particular elasticity. It should also be noted that with adding PE to HIPS, the effective volume of the matrix phase decreases more than those of simple binary blends. If it is supposed that PB phase (PB inclusions containing occluded fine PS particles) is 20 wt % of HIPS, when 10 wt % of PE is added to the HIPS, the matrix (homo-PS) will be
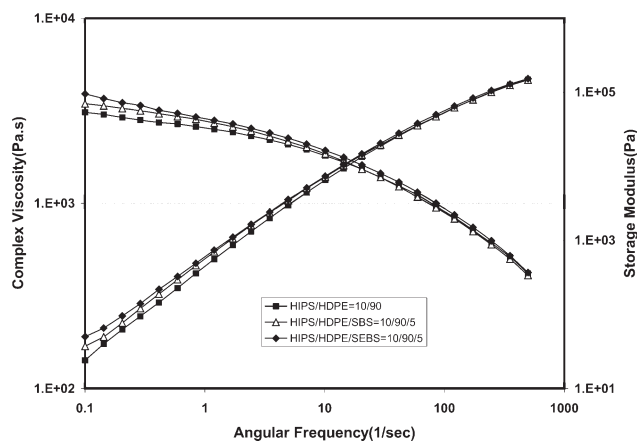
Figure 8 Effect of compatibilization on the rheological properties of HIPS/PE (10/90) blend.

72 wt % of the blend and dispersed phases will be 28 wt % of the blend (18 wt % PB and 10 wt % PE). This also can increase the viscosity and elasticity at low frequencies.

The effect of compatibilization on the rheological properties of two different blends (PE-matrix and HIPS-matrix blends) can be seen in Figures 8 and 9. These results show that compatibilization increases the viscosity and elasticity of the blends in particular at low frequency ranges representative of increasing interfacial interaction in the presence of compatibilizer. The results also show that the efficiency of compatibilization of SEBS is more than SBS. This can be due to the presence of ethylene block in SEBS which makes it more affine to PE compared with SBS. Also the lower molecular weight of SEBS than SBS cause the better localization of SEBS in the blend interface than SBS. The reliability of these claims will be confirmed via direct morphological observations.

Figure 10 shows the SEM micrographs of the etched and not-etched surfaces of uncompatibilized and compatibilized HIPS/PE (10/90) blends. A matrix-disperse morphology with a broad particle size distribution (bimodal distribution) can be observed in this blend [Figs. 10(a,b)]. Although the broad particle size distribution is not abnormally in incompatible polymer blends[8,9,13,14] but in this blend, the main reason of the broad size distribution is the presence of two kinds of dispersed particles, as discussed earlier. PB rubber particles are semi-crosslinked during polymerization process. Therefore, their morphology is less affected during melt compounding.[14] Whereas homo-PS particles can be breakup during this processes. So, it can be concluded that the observed particles in not-etched sample and dark holes in etched sample correspond to the PB rubber particles encapsulated by homo-PS (big particles) and individual homo-PS particles (small particles).

Incorporation of both compatibilizers decreased the particles size while bimodality of size distribution remained unchanged yet. The former is due to the reduction of interfacial tension between PS and PE by adding compatibilizer and the latter is because of less deformable nature of PB particles. By addition of compatibilizer, only the thickness of homo-PS layer around the PB particles is reduced.

Comparison made between the SEM micrographs of SBS and SEBS compatibilized samples implies that SEBS has more efficiency of compatibilization than SBS by means of reducing the particles size. This is due to the presence of ethylene block in SEBS, which makes PE more affine to SEBS than SBS and lower molecular weight of SEBS than SBS as discussed earlier.

Figure 11 shows the SEM micrographs of uncompatibilized and compatibilized HIPS/PE (30/70) blends. The results indicate that this blend display near matrix-disperse morphology involving larger domains of dispersed particles, due to the higher HIPS content compared to 10/90 blend. In this blend composition, SEBS had also better compatibilization efficiency than SBS.

For HIPS/PE (50/50) blend, PE is the main continuous phase, but the blend seems to be near the co-continuous morphology (Fig. 12). As the results of rheological studies showed, PE had lower viscosity and elasticity than HIPS. Moreover, the presence of semirigid PB rubber particles leads PE to form matrix phase in this blend composition. The compatibilizer type had the same effect on the morphology as 30/70 blend. This means that the efficiency of SEBS, in reducing the homo-PS layer thickness from the around of PB particles and also in decreasing the individual homo-PS particle size, is higher than SBS.

Figure 13 shows the SEM micrographs of compatibilized and uncompatibilized HIPS/PE (70/30) blends. Although the HIPS content is more than two times of PE content, but PE is not a clear dispersed
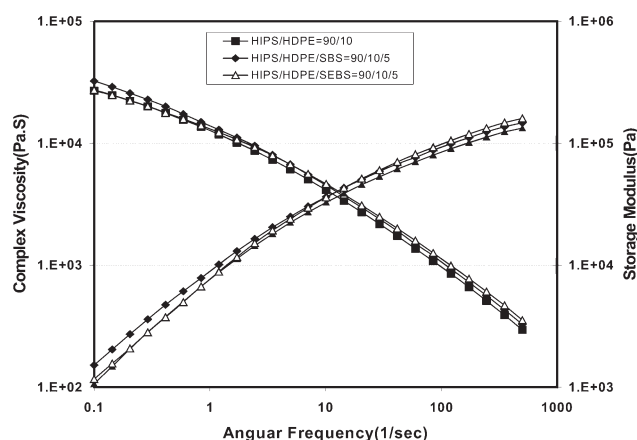

Figure 9 Effect of compatibilization on the rheological properties of HIPS/PE (90/10) blend.
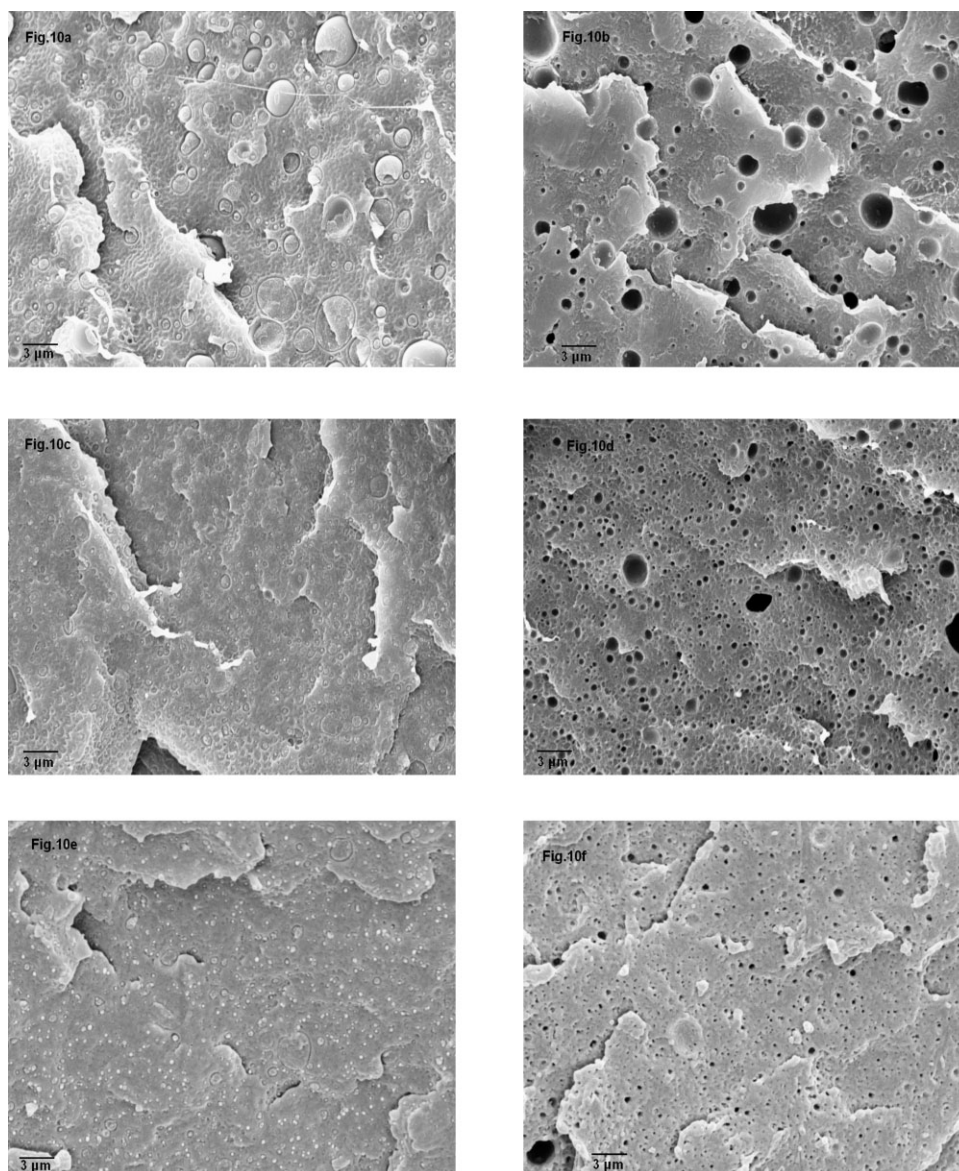
Figure 10 SEM micrographs of the HIPS/PE (10/90) blends: (a,b) uncompatibilized, (c,d) SBS compatibilized, and (e,f) SEBS compatibilized.

phase yet and it seems PE and HIPS phases form semi co-continuous morphology in this blend composition. As mentioned in previous sections, PB rubber particles are less deformable and they appear as a dispersed phase in all the blend compositions. Based on this concept, in 70/30 blend both PE and homo-PS act as continuous phases running through each other where the PB rubber particles are dispersed in continuous homo-PS phase. In the etching process, PB rubber particles are extracted together with the continuous homo-PS phase.

The composition of phase inversion region for this blend (HIPS/PE blend), was predicted using Paul,[27] Blekht,[28] and Utracki[29] models. The maximum content in phase inversion region, predicted from these models, was 60 wt % of HIPS, while the experimen-

tal results indicate that phase inversion will take place higher than 70 wt % of HIPS. Although the composition of phase inversion region not always matches to theoretical predictions even for binary blends, but in this case the discrepancy can also be related to the fact that HIPS phase includes less deformable PB particles and homo-PS phase, and the blend can be assumed as a ternary blend. Therefore, the models developed for binary blends shows higher deviation compared to experimental results.

When HIPS/PE (70/30) blend is compatibilized using SBS and SEBS, two different types of morphology are created. Using SBS leads PE phase to forms fibrillar morphology and HIPS phase to form the main continuous phase, while SEBS disturbs the co-continuity and converts the morphology to matrix-
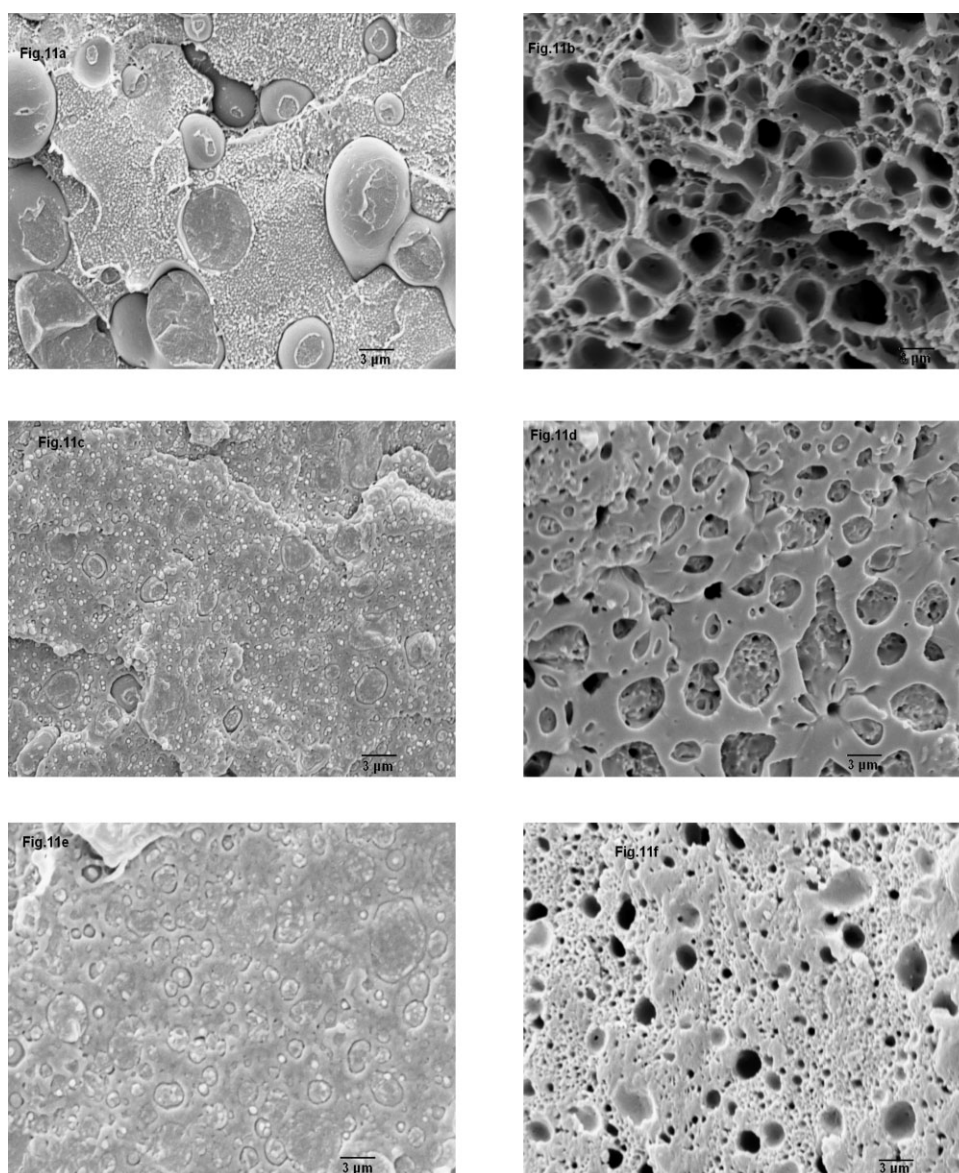
Figure 11 SEM micrographs of the HIPS/PE (30/70) blends: (a,b) uncompatibilized, (c,d) SBS compatibilized, and (e,f) SEBS compatibilized.

disperse, where PE forms continuous phase and PB rubber particles together with homo-PS particles form dispersed phases. This difference between the compatibilization effects of SBS and SEBS can be related to their different structures and therefore relative affinity of these compatibilizers to PE and PS phases. SEBS has more affinity to PE phase when it is compared to SBS. In other words, SEBS is preferentially localized at the interface of PS and PE and reduces the interfacial tension leading to formation of PE continuous phase. Although SBS can also be localized at the interface, but it has more affinity to PS phase than PE phase in compare to SEBS. Also SBS has higher molecular weight than SEBS. So, some part of SBS may remain in PS phase and form another dispersed phase leading to decrease in PE

phase content, and therefore inverts continuous PE phase to fibrillar morphology. Using TEM images Fortelny et al.[14] reported that when HDPE/HIPS blend, with HDPE as a matrix phase, is compatibilized using SB copolymer, a small amount of SB is localized at the interface of HDPE and homo-PS phases and most part of SB forms aggregate of very small particles in HDPE phase and the remained form fibers in the homo-PS phase linked to PB inclusions. In compare to SB, SBS has more affinity to PS phase rather than PE phase. Therefore, in our experiments SBS may diffuse to homo-PS phase and form aggregates. This decreases the effective volume of PE phase.

Figure 14 shows the SEM micrographs of compatibilized and uncompatibilized HIPS/PE (90/10)
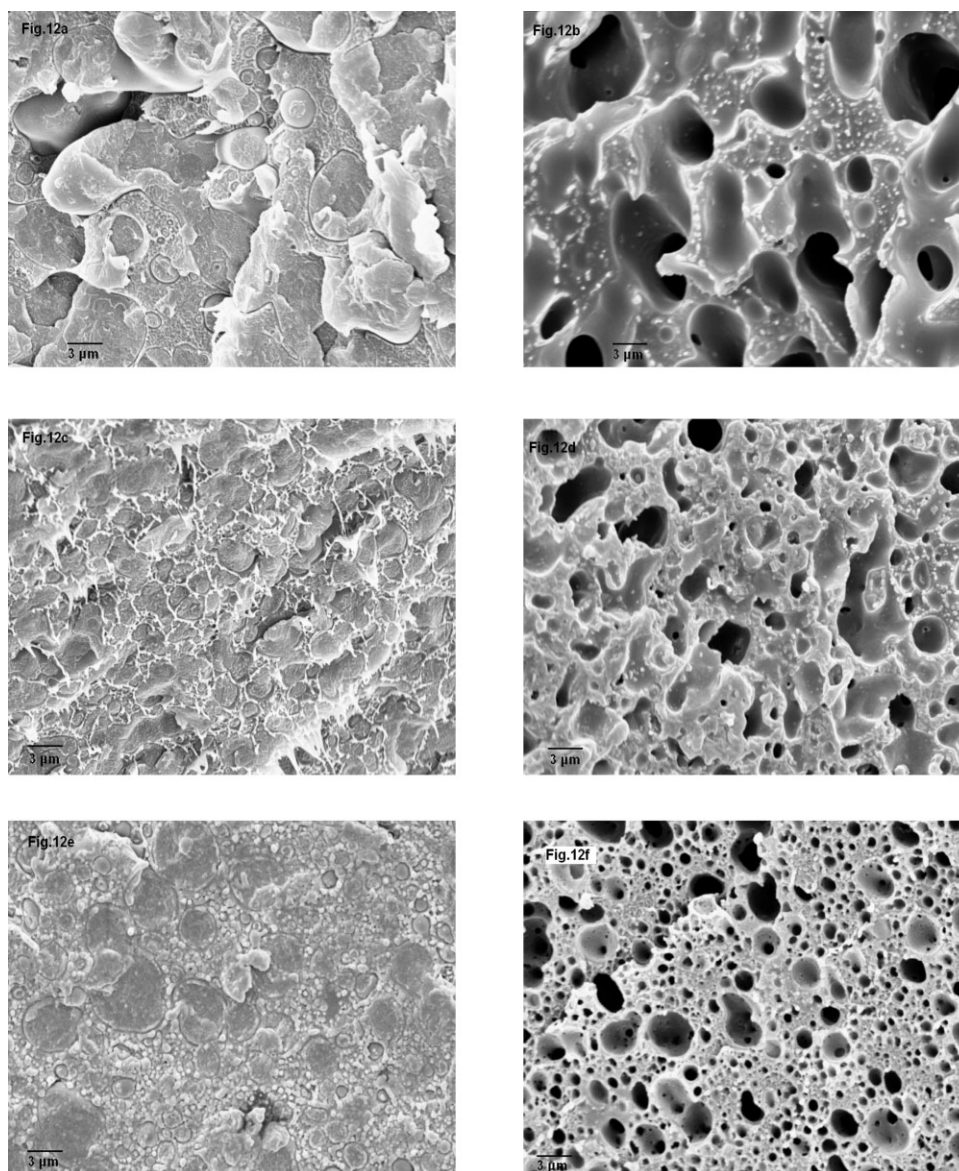
Figure 12 SEM micrographs of the HIPS/PE (50/50) blends: (a,b) uncompatibilized, (c,d) SBS compatibilized, and (e,f) SEBS compatibilized.

blends. It is clear that although dispersed PE particles has a broad size distribution, but it has not a clear bimodality as 10/90 blend [compare Fig. 10(a) and Fig. 14(a)]. In HIPS/PE (90/10) blend the observed particles are only PE particles and PB particles are not clear in this image. However, the broad particle size distribution is in the result of weak interface between PS and PE phases. The smooth surface of spherical PE particles indicates that the adhesion between these particles and PS matrix is very low. It is interesting to note that in this blend composition, during cryo-fracturing process, when crack tip meets with dispersed particles, crack follows the interface instead of growth through the PE particles in contrary to 10/90 blend, where the breakage of some dispersed particles (PS or PB par-

ticles) has been occurred [see Fig. 10(a)]. Since in both blends (90/10 and 10/90), there is a very weak interface between homo-PS and PE phases at the melt state, this difference in fracture behavior can be attributed to the semicrystalline nature of PE and amorphous nature of HIPS and their volume contraction in solidification process. PE undergoes more volume contraction (shrinkage) than HIPS during solidification process. Therefore, when PE acted as a dispersed phase, because of its higher volume contraction during cooling and weakening of particles-matrix interface, cracks tend to follow the interfaces. It is obviously seen that particles have not remarkably deformed and some of the particles come-out from their places and many cavities have been created. When PE acted as a matrix phase, its higher
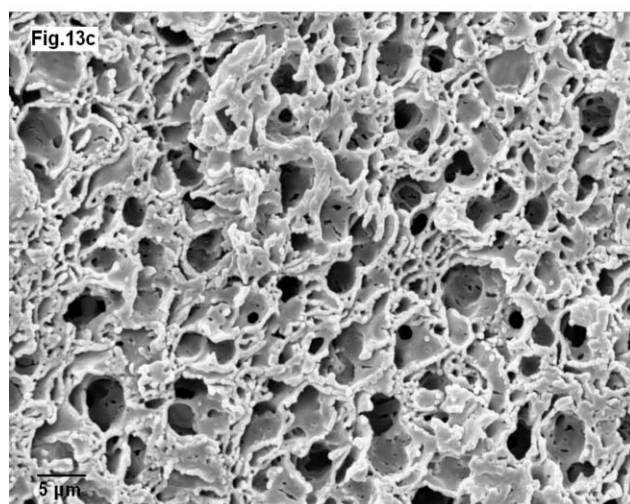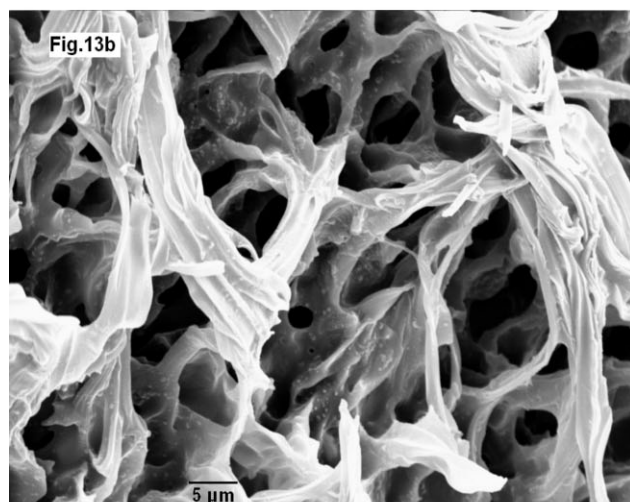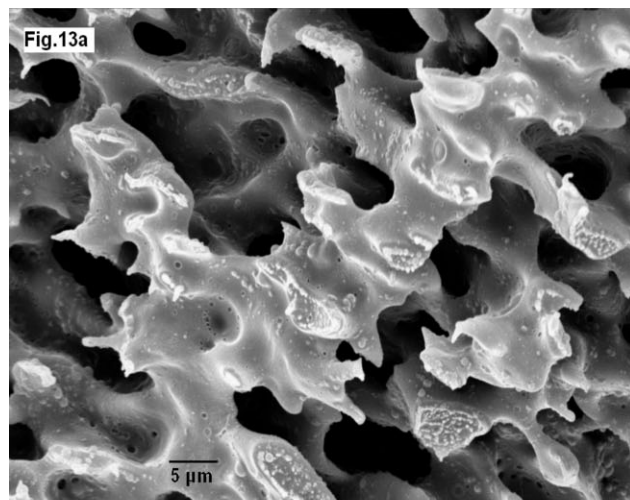
Figure 13 SEM micrographs of the HIPS/PE (70/30) blends: (a) uncompatibilized, (b) SBS compatibilized, and (c) SEBS compatibilized.
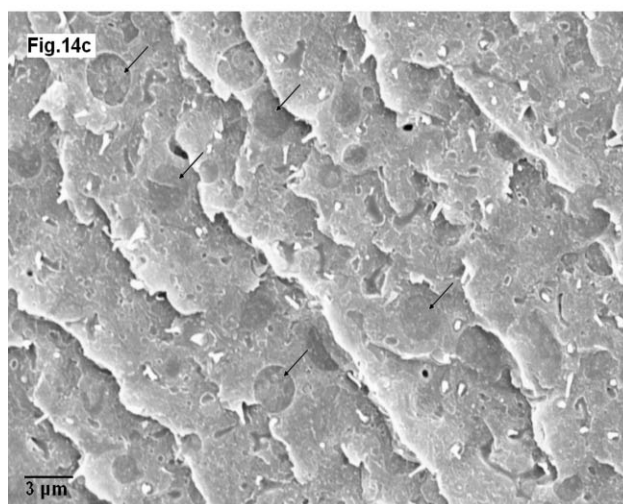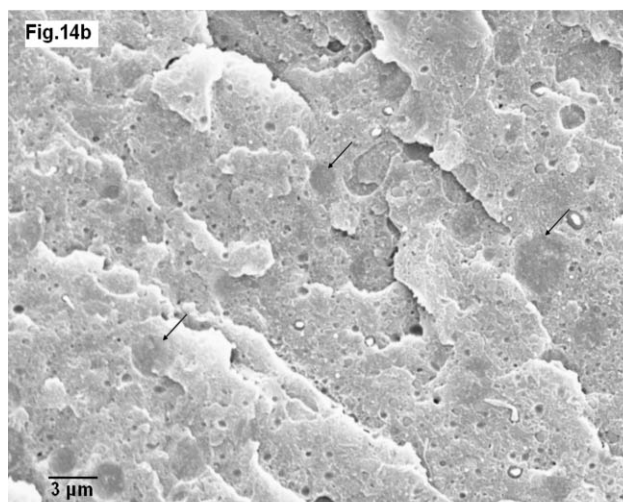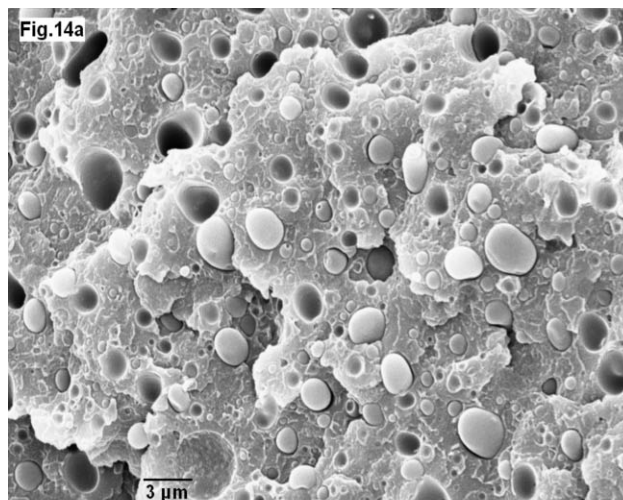

Figure 14 SEM micrographs of the HIPS/PE (90/10) blends: (a) uncompatibilized, (b) SBS compatibilized, and (c) SEBS compatibilized.

volume contraction during solidification process compresses dispersed phase leading to increase in interdiffusion of polymer chains at the interface and therefore increase in interfacial adhesion. In discussion of the crack propagation the differences between mechanical properties of the HIPS and PE should also be considered. HIPS is much brittle than PE particularly at cryo-fracturing condition. Therefore, HIPS particles have more tendencies to fracture than PE particles. Based on aforementioned discussions, it can be predicted that the mechanical properties of these blends are influenced by their different behavior in solidification process.

Comparing the SEM micrographs of compatibilized and uncompatibilized blends clearly shows that the compatibilization dramatically decreases the PE particle size. In the case of SEBS compatibilized sample due to the strong interfacial adhesion between dispersed PE particles and matrix, breakage of PE particles has occurred after their plastic deformation and debonding of spherical particles can not be observed. This confirms the higher efficiency of SEBS in compatibilization process of HIPS/PE than SBS. In the SEM micrograph of compatibilized 90/10 blends, semi dark region (shown by arrows) are the PB particles. These particles are not seen in uncompatibilized 90/10 blend. In the case of uncompatibilized samples, due to the very low strength interface of HIPS/PE, the crack preferentially tends to follow the interface instead of propagate through the PE or PB particles. But in compatibilized samples, in particular SEBS compatibilized samples, the interface of PE and HIPS is more strength and therefore cracks have more tendencies to growth through PE and PB particles. Fortelny[14] reported that the compatibilization using SB copolymer has only a negligible effect on the HDPE particle size in HIPS/HDPE (90/10) blend. These differences may be due to the different grades of the used HDPE and HIPS and different used compatibilizers in different experiments. They used blow molding grade of HDPE with a high molecular weight (high viscose) and HIPS with a lower molecular weight (lower viscosity), while in our experiments HDPE had lower viscosity than HIPS. So, the lower viscosity of our used HDPE from one side and more affinity of SEBS to HDPE compared with SB cause more efficiency of HDPE emulsification by SEBS than SB.

The continuity index of HIPS phase versus HIPS content, determined using solvent extraction method, is presented in Figure 15 for uncompatibilized and compatibilized blends. The results clearly show that uncompatibilized HIPS/PE blends exhibit near the co-continuous morphology in a wide range of composition (30 to 80 wt % of HIPS phase). This is due to the presence of less deformable PB rubber particles which decrease the effective volume ratio
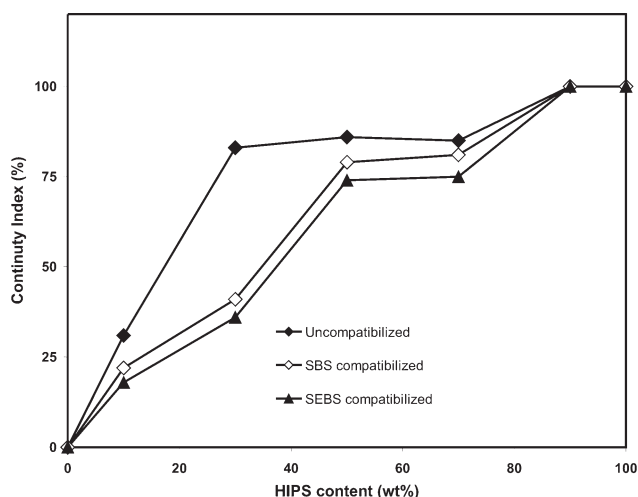

Figure 15 Continuity index of HIPS phase versus HIPS content for uncompatibilized and compatibilized blends.

of homo-PS to PE. As it can be seen the continuity index is substantially lower than 100% also for blends where HIPS formed a matrix. This discrepancy can be related to the morphology of HIPS. HIPS contains semi-crosslinked PB rubber particles which can not completely be dissolved in the solvent (Xylene) but they can be swelled. Therefore, in extraction process the PB rubber particles at the surface of the samples can effectively be extracted while the extraction of the swelled PB particles in the bulk may be restricted. This leads to not completely extraction of the HIPS phase but completely extraction of homo-PS phase and therefore to lower than 100% of HIPS extraction. Compatibilized and uncompatibilized HIPS/PE 90/10 blends and pure HIPS were completely disintegrated during the extraction process representative of 100% continuity of HIPS phase in these blends.

The results also show that compatibilization decreases the continuity index in particular at low HIPS content blends. This is due to the reduced interfacial tension and better stress transfer during compounding which in turn lead to decrease the domain size of HIPS phase and effective encapsulation of HIPS phase by PE phase [compare Fig. 13(a,c)]. SEBS compatibilized blends display lower continuity index than SBS compatibilized blends. This result confirms the results of morphological studies by means that SEBS has more efficiency of compatibilization.

CONCLUSION

Rheology and morphology of HIPS/HDPE blends in a wide range of composition were studied. The effect of compatibilization using SBS and SEBS were also studied. The obtained results were conducted to the following conclusions:

The results of linear viscoelastic properties showed that low HIPS content blends displayed negative deviation behavior of viscosity and elasticity at low frequencies, while high HIPS content blends showed positive deviation. The negative deviation was related to the poor interfacial interaction between PE matrix and two different types of dispersed particles (homo-PS surrounded PB particles and individual homo-PS particles). On the other hand, the positive deviation of viscosity and elasticity for high HIPS content blends was attributed to the interfacial and hydrodynamic interactions between dispersed PE and PB particles. It was found that compatibilization increased the viscosity and elasticity in particular at low frequencies representative of increased interfacial interaction.

The results of morphological studies showed that when PE acted as a matrix phase, the dispersed phase exhibited bimodal size distribution corresponding to the presence of two different types of dispersed particles as mentioned earlier. When HIPS was the major phase, although the PE particles displayed broad size distribution, but bimodality was not clear as those observed for high PE content blends.

The co-continuous and/or semi co-continuous morphology was observed in a wide range of composition because of the presence of less deformable PB rubber particles in all the blends.

Compatibilization using SBS and SEBS decreased the dispersed particles size in both PE-matrix and PE-dispersed blends, while the bimodality of particle size distribution remained unchanged in the case of PE-matrix blends. The former related to decreasing of the interfacial tension and therefore increasing the interfacial interaction by adding compatibilizer and the latter was correlated to the less-deformable nature of PB particles. Using compatibilizer only decreased the thickness of homo-PS layer around the PB particles.

SEBS had more efficiency of compatibilization than SBS, due to the presence of ethylene block in the structure of SEBS and its lower molecular weight than SBS. Using both compatibilizers decreased the HIPS continuity index and SEBS had more efficiency than SBS.

Higher volume contraction of PE than HIPS, in solidification process, and different mechanical properties of HIPS and PE led to different fracture behavior of PE-matrix and PE-dispersed blends. When PE acted as a matrix, the interfacial adhesion increased during solidification process due to the higher contraction of PE than HIPS, whereas, when HIPS acted as a matrix, higher contraction of PE decreased the interfacial adhesion. HIPS is much brittle than PE particularly at cryo-fracturing conditions. Therefore HIPS particles have more tendencies to fracture than PE particles.

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