

Studies on Binary and Ternary Blends of Polypropylene with SEBS, PS, and HDPE. II. Tensile and Impact Properties

A. K. GUPTA and S. N. PURWAR, *Centre for Materials Science and Technology, Indian Institute of Technology, New Delhi 110016, India*

Synopsis

Studies are reported on tensile and impact properties of several binary and ternary blends of polypropylene (PP), styrene-*b*-ethylene-co-butylene-*b*-styrene triblock copolymer (SEBS), high-density polyethylene (HDPE), and polystyrene (PS). The blend compositions of the binary blends PP/*X* were 10 wt % *X* and 90 wt % PP, while those of the ternary blends PP/*X*/*Y* were 10 wt % of *X* and 90 wt % of PP/*Y*, or 10 wt % *Y* and 90 wt % PP/*X* (PP/*Y* and PP/*X* were of identical composition 90:10); *X*, *Y* being SEBS, HDPE, or PS. The results are interpreted for the effect of each individual component by comparing the binary blends with the reference system PP, and the ternary blends with the respective binary blends as the reference systems. The ternary blend PP/SEBS/HDPE showed properties distinctly superior to those of PP/SEBS/PS or the binary blends PP/SEBS and PP/HDPE. Differences in the tensile yield behavior of the different samples and their correlation with impact strength suggested shear yielding as the possible mechanism of enhancement of impact strength. Scanning electron microscopic study of the impact fractured surfaces also supports the shear yielding mechanism of impact toughening of these blends.

INTRODUCTION

Studies on the blends of isotactic polypropylene (PP) with a recently commercialized elastomer styrene-*b*-ethylene-co-butylene-*b*-styrene (SEBS), reported in our previous publications,¹⁻³ have revealed some interesting effects of blend composition on the melt rheology,¹ impact¹ and tensile² properties, crystallization of the PP component,² and shear band formation during tensile yielding³ of the blend. Blending with SEBS produced, in general, improvement in the melt rheological properties and melt fracture behavior desirable for better processability. Tensile strength and yield stress of PP decreased on blending with SEBS, whereas the impact strength was considerably improved. The stress concentration parameter, evaluated from the blend composition dependence of the tensile properties, suggested the occurrence of considerable effect of discontinuity in stress transfer at high SEBS content (i.e., above 10 wt %) and almost no stress concentration at the lower SEBS content of this two-phase blend.³

Though PP and SEBS form two-phase incompatible blend, some degree of interphase adhesion may be expected from the possible affinity of the polyolefinic middle block EB of the elastomer SEBS and the PP, owing to their sufficiently close values of solubility parameter.¹ The effect of incorporations of a third component to PP/SEBS blend using high density polyethylene (HDPE) or polystyrene (PS) as the third component has been stud-

ied.⁴ Use of a third component to improve the compatibility of two-phase binary blends has been studied on various other systems.^{5,6} Studies⁴ on melt-rheological properties and melt-fracture behavior of various binary and ternary blends of PP, SEBS, HDPE, and PS have shown some advantages of using HDPE as a third component in PP/SEBS blend. The rheological data and the melt-fracture behavior of the various binary and ternary blends have also enabled us to determine a specific relationship for the dependence of melt-fracture behavior on melt viscosity and melt elasticity of the blend.

In this article we present studies on the tensile and impact properties of the various binary and ternary blends of PP, SEBS, HDPE, and PS. The major component of the blends was PP, which forms the matrix phase, while the dispersed phase was any one of the other three components in binary blends, and SEBS plus any one of the last two (i.e., HDPE and PS) in ternary blends. Blend compositions of the binary blends PP/*X* or ternary blends PP/*X*/*Y* were chosen that the former represent addition of 10 wt % *X* to PP, while the latter represent 10 wt % addition of *X* or *Y* to PP/*Y* or PP/*X* blend of composition 90:10 by weight, *X*, *Y* being SEBS, HDPE or PS.

Studies include tensile properties at ultimate breaking as well as at small deformation (viz., yield behavior), the Izod impact strengths, and the scanning electron microscopic studies of impact fractured surfaces. The correlation of impact strength with yield behavior and the effect of notch angle on the impact strength are discussed to ascertain the origin of impact toughening in these blends.

Experimental

Materials

Isotactic polypropylene (PP): Koylene M3030 (MFI = 3.0) of Indian Petrochemicals Corp. Ltd. High density polyethylene (HDPE): Hostalene GD 1730 (MFI = 1.7) of Polyolefine Industries Ltd. Polystyrene (PS): HCG-100 of Hindustan Polymers Ltd. The elastomer styrene-*b*-ethylene-co-butylene-*b*-styrene (SEBS): Kraton G-1652 of Shell Chemical Co. were used.

Preparation of Blends

The blends were prepared by mixing the appropriate amounts of two or three components through melt blending in a single-screw extruder (Betol BM-1820) using temperature profile 200°C, 210°C, 220°C of first, second, third, and the die zones, respectively, and screw speed 40 rpm. Compositions of the various blends and the sample designations are shown in Table I. The unblended PP was also passed through the same process of extrusion so as to give it a history identical to the blend samples.

The thick strands of the samples received from the extruder were cut into small chips or granules, which were then washed and dried. These were then compression-molded into sheets of about 1 mm thickness (for tensile testing) and 5 mm thickness (for impact testing) on a Carver Laboratory Press at 220°C and 5000 psi pressure. Molding time varied from 10

TABLE I
Composition of the Various Samples

Sample designation	Composition (wt %)			
	PP	SEBS	HDPE	PS
PP	100	—	—	—
PP/SEBS	90	10	—	—
PP/HDPE	90	—	10	—
PP/PS	90	—	—	10
PP/SEBS/ HDPE	80	10	10	—
PP/SEBS/PS	80	10	—	10

to 50 min, depending on the thickness of the sheet and nature of the blend, so as to achieve good homogeneity and removal of flow lines in the molded sheets. Test specimens of appropriate dimensions and shapes were punched out of the compression-molded sheets conforming to the ASTM standards: dumbbell-shaped for tensile testing (ASTM-D-638) and rectangular bars for impact testing (ASTM-D-256). Edges of the cut samples were smoothed with a fine emery paper. Notches in the impact test specimens were cut using a sharp tool cutter of appropriate angles, viz., 30° and 60°, and notch depth 2.5 mm.

Tensile Testing

Tensile measurements at ambient temperature were made on an Instron Universal Tester (Model 1121) using 5 cm gauge length and 1 cm or 20%/min rate of extension. At least five samples were tested in each case, and the deviation of the data around mean values was less than 5%.

Impact Testing

Izod impact strength of notched samples was measured on a falling hammer type impact testing machine (Model FIE-0.42). Impact energy was calculated from the difference of the potential energy of the falling hammer before and after the impact. Impact energy per unit breadth of the sample is expressed as the impact strength. Measurements were done on at least five specimens in each case and the deviation of results was less than 5%.

Scanning Electron Microscopy

Scanning electron micrographs of the fracture surfaces of the impact fractured specimens were obtained on a Stereoscan S4-10 (Cambridge Instruments, Ltd.) scanning electron microscope.

RESULTS AND DISCUSSION

Tensile Strength

Stress-strain curves of these samples, presented in Figure 1, show quite prominent yield peak in all the cases. Differences in the yield peak de-

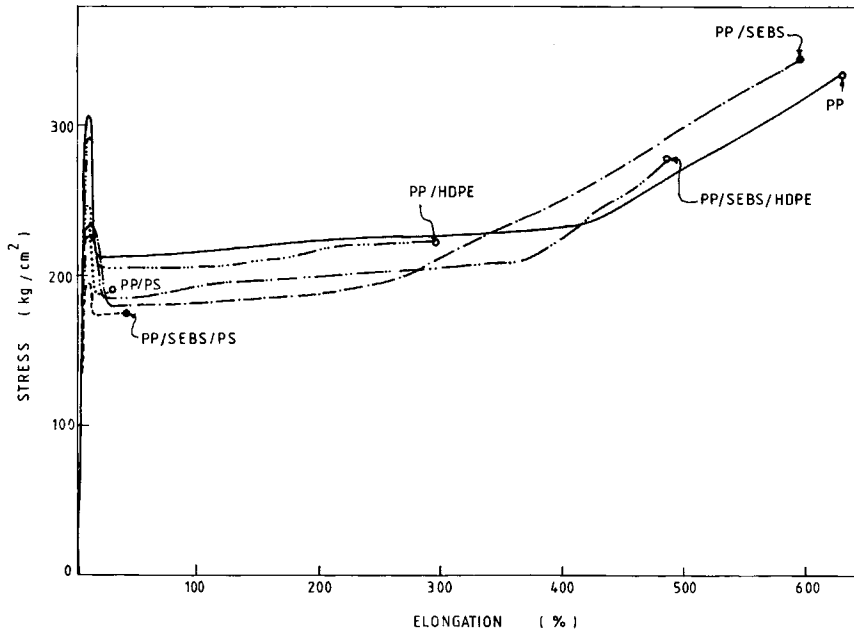


Fig. 1. Stress-strain curves of the various samples.

pending on the nature of the blend are apparent, which will be discussed in detail in the subsequent section. Beyond the yield peak, the curves for most of these blends show quite similar general features but widely different positions of ultimate breaking point. The similarity of shapes of these stress-strain curves is apparently the effect of PP being the major component which constitutes the matrix phase of all these blends. The role of the other components constituting the dispersed phases of the blend on the yield behavior and the ultimate breaking is quite significant in these blends.

Values of tensile strength, elongation at break and modulus are shown in Table II. These results indicate the following:

(1) In the case of binary blends: (i) The addition of SEBS produces very little change in the tensile strength and elongation at break of PP, while

TABLE II
Tensile Strength, Modulus, Elongation at Break, and Area under Stress-Strain Curve of the Various Binary and Ternary Blends

Sample	Modulus (kg/cm ²)	Tensile strength (kg/cm ²)	Elongation at break (%)	Area under stress-strain curve (arbitrary units)
PP	95	320	645	299
PP/SEBS	58	330	578	274
PP/HDPE	125	327	297	138
PP/PS	98.5	188	19	8
PP/SEBS/HDPE	70	279	510	204
PP/SEBS/PS	56	180	36	16

the modulus decreases; (ii) the addition of HDPE or PS produces significant decrease in tensile strength and elongation at break of PP, while the modulus increases significantly in PP/HDPE and very slightly in PP/PS.

(2) In the case of ternary blends: (i) Tensile strength, modulus and elongation at break are higher for PP/SEBS/HDPE than the PP/SEBS/PS blend; (ii) the tensile strengths of both binary and ternary blends containing PS (viz., PP/SEBS/PS and PP/PS) are quite close to each other, whereas the modulus of PP/SEBS/PS is considerably lower than that of PP/PS; (iii) in case of blends containing HDPE the tensile strength of PP/SEBS/HDPE was closer to that of PP/SEBS blend but higher than that of PP/HDPE blend, while the modulus of both PP/SEBS/HDPE and PP/SEBS is lower than that of PP/HDPE.

This suggests that SEBS in combination with HDPE plays a distinctly different role in improving tensile strength of ternary blend than SEBS in combination with PS. Both HDPE and PS were chosen for this study with the hope of achieving improvements in properties owing to the possible affinity with one or both components of the PP/SEBS blend; PS with polystyrene blocks of SEBS and HDPE with both PP and the polyolefinic block EB of SEBS. Furthermore, these results also suggest that if HDPE or PS were to be used only for the purpose of dilution (for cost reduction), then HDPE would be more appropriate choice from the point of view of tensile strength.

Tensile Yield Behavior

Stress-strain curves in the yield region for the various samples are presented in Figure 2. The initial linear increase of stress with strain proceeds with gradual change of slope up to the position of the yield peak. Thereafter, the stress decreases with increasing strain up to the point called the tip of the yield peak. Beyond the tip of the yield peak, the stress increases very slightly with strain. The stress and strain corresponding to the peak position

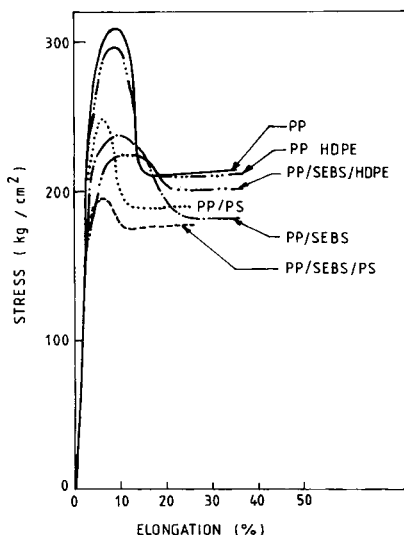


Fig. 2. Stress-strain curves in the yield region of the various samples.

TABLE III
Properties Related to Tensile Yield Behavior of the Various Binary and Ternary Blends

Sample	σ_y (kg/cm ²)	ϵ_y (%)	ϵ_{yt} (%)	Area under yield peak (arbitrary units)
PP	305	10	13	264
PP/SEBS	234	10	21	323
PP/HDPE	294	9	14	250
PP/PS	245	7	11	155
PP/SEBS/ HDPE	224	12	20	304
PP/SEBS/PS	194	7	10	117

are denoted as yield stress (σ_y) and yield strain (ϵ_y), and the strain at the tip of the yield peak is denoted as ϵ_{yt} .

Effect of blending on the yield peak of PP is apparent in variations of yield stress, yield strain, and width of the yield peak (or the analogous parameter ϵ_{yt}) through their values shown in Table III. The area under the yield peak from origin to the tip of the yield peak, as shown by the limits drawn in Figure 3, is a measure of "work of yield" or the energy absorbed in the process of yielding.

Yield peak of the binary blend PP/HDPE does not differ much from that of PP, while a considerable broadening in case of PP/SEBS and narrowing in case of PP/PS blends is clearly apparent. The peak width of the two SEBS containing blends, viz., PP/SEBS and PP/SEBS/HDPE is distinctly greater, whereas that of the other SEBS containing blend (viz., PP/SEBS/

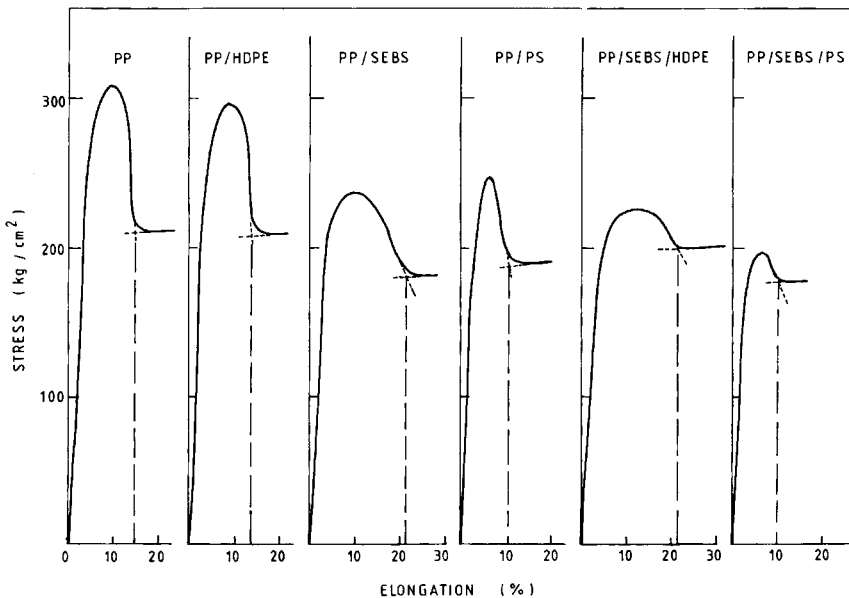


Fig. 3. Yield peaks with the limits marked with broken vertical lines used for calculation of work of yield.

PS) is smaller than that of PP. This suggests that SEBS has a tendency to increase the width of yield peak, and in the case of the ternary blends this tendency is not operative in presence of PS as the third component of the blend.

The mutual resemblance of the yield peaks of PP and PP/HDPE as well as that of their counterparts containing SEBS, viz., PP/SEBS and PP/SEBS/HDPE, suggests no significant role of HDPE in the broadening of yield peak. The lower peak heights and broader peaks in the latter two cases imply a similar role of SEBS in the yield behavior of PP as well as PP/HDPE blend. On the other hand, in case of the blend containing PS, the addition of SEBS produces a decrease in the height of yield peak and some narrowing of the peak. Thus it may be stated that, among these two ternary blends, the yield behavior is predominantly affected by the SEBS component in case of PP/SEBS/HDPE and by the PS component in case of PP/SEBS/PS.

Values of the various parameters describing yield behaviour of these samples are given in Table III. These results show the following:

(1) In the case of binary blends: (i) The addition of HDPE does not produce any notable change in yield stress, yield strain, and work of yield of PP; (ii) the addition of SEBS increases work of yield and yield strain and decreases yield stress of PP; (iii) the addition of PS decreases considerably yield stress, yield strain, and work of yield of PP.

(2) In the case of ternary blends (when viewed as the addition of HDPE or PS to the binary blend PP/SEBS): (i) The addition of HDPE produces slight decrease in the work of yield and yield stress and no significant change in the yield strain; (ii) the addition of PS produces a considerable decrease in the work of yield, yield stress, and yield strain.

(3) In the case of ternary blends (when viewed as the addition of SEBS to PP/HDPE or PP/PS blend): (i) Addition of SEBS to PP/HDPE blend produces substantial increase in work of yield and yield strain and a decrease in yield stress; (ii) addition of SEBS to PP/PS blend produces decrease of work of yield, yield stress, and yield strain.

These results thus suggest that, in the two ternary blends, the role of SEBS in the yield behavior is predominant only in PP/SEBS/HDPE, whereas in PP/SEBS/PS the PS phase seems to play a predominant role. The increase of work of yield is accompanied by the increase in yield strain (as well as the ϵ_{yt} and broadening of yield peak), and this effect occurs mainly in the blends containing the SEBS elastomer. This suggests that, during the yielding process, a part of the energy will be absorbed by the SEBS domains which can undergo sufficient elongation before fracture. The PS domains, on the other hand, may not account for such absorption of energy owing to their hard, brittle, or glassy character. Further discussion about the role of SEBS, HDPE, and PS domains in these blends will be presented below on the basis of scanning electron microscopic observations of the morphology of these blends.

The observed lowering of yield stress and increase of work of yield may have some relevance with the enhancement of impact strength, as will be discussed subsequently.

Impact Strength

Izod impact strength of these samples measured at two notch angles, viz., 30° and 60°, are given in Table IV. In spite of the notch sensitivity in certain cases, which will be discussed later, the impact strength at both of the notch angles shows identical trends of variation with the nature of the blend. Effects of the various components of the blend on the impact behavior apparent from these results are as follows:

(1) In binary blends: (i) The addition of SEBS produces considerable increase of impact strength of PP; (ii) the addition of HDPE as well as of PS produces only a slight increase of impact strength of PP.

(2) In ternary blends (when viewed as addition of HDPE or PS to the binary blend PP/SEBS): (i) The addition of HDPE produces an increase, while the addition of PS produces a decrease of impact strength; (ii) this role of the addition of HDPE or PS in the case of these ternary blends is different from that stated above for the case of the binary blends.

(3) In ternary blends (when viewed as addition of SEBS to the PP/HDPE or PP/PS blend): (i) The addition of SEBS to the PP/HDPE blend produces greater increase in impact strength than the addition of SEBS to PP; (ii) the addition of SEBS to PP/PS blend produces an increase in the impact strength; however, this increase is much smaller than that produced by the addition of SEBS to PP.

Thus it may be stated that, as regards the impact strength of these ternary blends, the use of HDPE as a third component is advantageous, whereas the use of PS as the third component is disadvantageous. A similar disadvantage of using PS, in comparison to HDPE, is noted also in the respective binary blends. This indicates the detrimental role of PS in the impact resistance of these blends. SEBS, on the other hand, clearly enhances the impact strength of PP, as well as of the PP/HDPE blend. On the basis of these results, the use of HDPE as a diluent in PP/SEBS blend may be preferable not only from the point of view of cost reduction but also for improvement of impact toughness.

These measurements of impact strength at the two notch angles show distinctly greater notch sensitivity of impact strength in some samples (viz., PP/SEBS and PP/SEBS/HDPE) than the others (Table IV). With decreasing notch angle the impact strength decreases. PP and PP/SEBS/PS show almost negligible notch sensitivity while PP/HDPE and PP/PS show slight notch sensitivity.

TABLE IV
Izod Impact Strength of the Various Binary and Ternary Blends

Sample	Impact strength (J/m)	
	Notch angle 60°	Notch angle 30°
PP	11.0	10.6
PP/SEBS	24.9	18.2
PP/HDPE	12.2	10.7
PP/PS	12.3	10.7
PP/SEBS/HDPE	29.5	22.3
PP/SEBS/PS	15.3	15.5

As stated by Bucknall,⁷ the impact energy falls rapidly with decreasing notch radius because the presence of a sharp notch drastically reduces the extent of plastic yielding, and, furthermore, the notch sensitivity of fracture resistance is more striking in ductile materials than the brittle. Though PP, which constitutes the matrix phase of these blends, is a ductile material at room temperature, the notch sensitivity of the unblended PP is quite low. The increased ductility, as evident from the decrease in yield stress, and increase of work of yield, is accompanied by the considerably high notch sensitivity in PP/SEBS and PP/SEBS/HDPE blends. This suggests that there exists a critical limit of ductility at which the notch sensitivity of the impact strength becomes appreciable. The lower notch sensitivity of the blends containing PS might be due to the brittle nature imparted to the blend by the PS domains. The notch sensitivity of PP/HDPE blend is comparable to that of the PP, as is also the case with the ductility or yield stress of these two systems.

The above-stated effect of the notch sensitivity implies greater degree of plastic yielding in the samples showing high notch sensitivity, viz., PP/SEBS and PP/SEBS/HDPE. These are the samples which show also considerably enhanced impact strength values. This suggests a role of plastic yielding in the enhancement of impact strength of these blends. The yielding occurs prior to the impact fracture, accounting, therefore, for a higher impact energy of these samples, owing to the dissipation of a part of the energy through the process of yielding. The increased ease of yielding (or increased ductility) of PP/SEBS blend with increasing SEBS content has been reported previously,³ where the presence of SEBS domains gave rise to greater tendency of shear band formation during tensile stretching.

Unlike the rubber toughening of glassy polymers, where microcrazing is considered as the principal mechanism for increase of impact energy, the present blends show plastic shear yielding as the mechanism of their impact toughening, presumably owing to the ductile nature. Probably, if the tests were carried out at temperatures below the glass transition temperature of PP, one could have expected the microcrazing as the predominant cause of impact toughening of these blends. Some authors⁸ have suggested that formation of shear bands or microcrazing can occur in the same system, depending on the environmental pressure around the elastomer domains caused by the dilation of the matrix phase during deformation, which in turn governs the magnitudes of the critical stresses for microcrazing (σ_{mc}) and for shear band formation (σ_{sb}), and have discussed the conditions under which $\sigma_{sb} < \sigma_{mc}$ or vice versa. From the present results it appears that not only the ductile or glassy nature of the matrix but also the blend constitution influence the competition between shear band formation and microcrazing processes, or in other words the relative magnitudes of σ_{sb} and σ_{mc} .

The possibility of occurrence of microcrazing before the impact failure is not quite ruled out even in the case where $\sigma_{sb} < \sigma_{mc}$; microcrazing in such cases may occur after the yielding and before the fracture. Occurrence of microcrazing in the shear yielding type materials has been reported by some authors⁹ and attributed to the propagation of cracks by way of intermixed zones.

Impact strength at both the notch angles varies linearly with yield stress

in the case of four of these six samples (viz., PP, PP/HDPE, PP/SEBS and PP/SEBS/HDPE), as shown in Figure 4. The other two samples, whose data points fall away from the straight lines shown in Figure 4, are the ones which contain PS as a component of the blend (i.e., PP/PS and PP/SEBS/PS). The decrease of yield stress accompanied by the observed peak broadening implies the increase of ductility. Thus the linear variation represented by Figure 4 indicates an increase of impact strength with increasing ductility of the system; this provides support to the aforesaid shear yielding mechanism of impact toughening of these blends. However, in case of the two blends containing PS, the low impact energies, owing to reasons attributable to the PS domains, seem responsible for the this lack of correlation in Figure 4.

The work of yield and work of rupture, which are proportional to the areas under stress-strain curve under yield peak and up to the breaking point respectively, vary with impact strength in a manner shown in Figure 5. With the exclusion of the two samples containing PS, these plots show (i) sufficiently linear variation of work of yield with impact strength and (ii) poor linearity of the variation of work of rupture with impact strength. This lack of correlation in the latter case might be due to the effects of large deformation which are not present in the yielding behavior and impact strength, which are measured at small deformations. Large deformation mechanism of these two- or three-phase systems might be more complex than the small deformation mechanism.

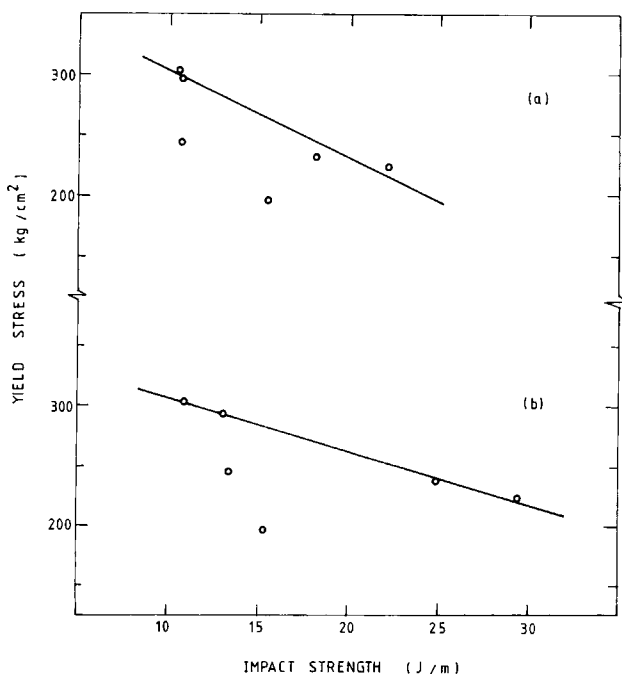


Fig. 4. Variation of yield stress with Izod impact strength measured at notch angle (a) 30° and (b) 60°. The two points in the middle represent data on the blends containing PS.

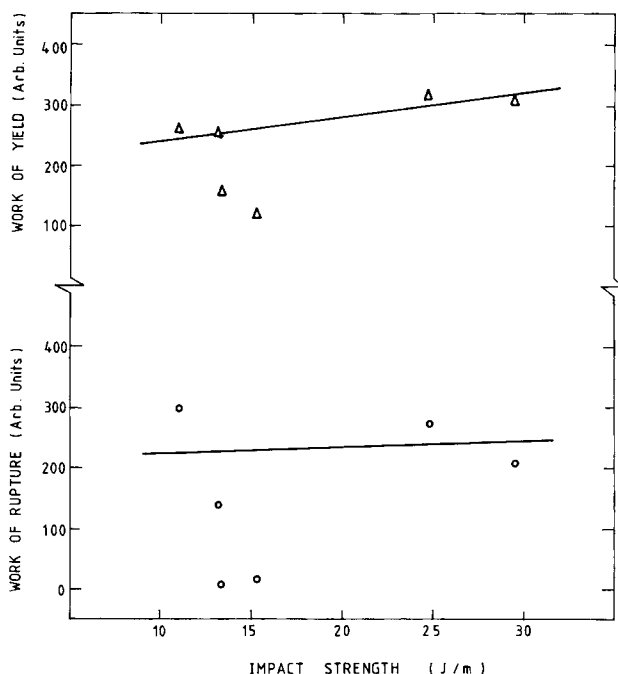


Fig. 5. Variations of work of yield and work of rupture with Izod impact strength at notch angle 60° . The two points in the middle correspond to the data on the blends containing PS.

Possibility of a New Relationship

Although it looks strange to expect a relationship between melt flow properties and impact strength, these data show a relationship of the following type. Values of melt viscosities of these samples, from a previous publication⁴ are shown in Table V at two shear stresses. Variation of the melt viscosity (η_{app}) with impact strength at both the notch angles and both the shear stresses are shown in Figure 6. These variations are sufficiently linear, with the exception of the sample PP (which is incidentally a single-component system). This linear variation in the case of the blends indicates some similarity of the roles of disperse phase domains in melt flow behavior

TABLE V
Melt Viscosity of the Various Samples

Sample	Melt viscosity $\eta_{app} \times 10^{-3}$ P	
	a	b
PP	1.05	0.68
PP/SEBS	5.47	3.94
PP/HDPE	3.92	2.56
PP/PS	3.84	2.61
PP/SEBS/HDPE	5.92	4.30
PP/SEBS/PS	5.47	3.94

^a Shear stress 1.47×10^6 dyn/cm².

^b Shear stress 1.96×10^6 dyn/cm².

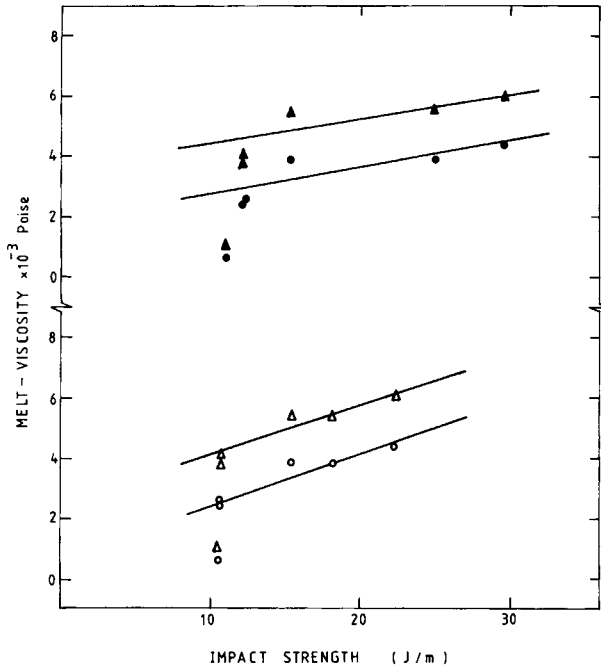


Fig. 6. Variation of melt viscosity with Izod impact strength at notch angle (a) 60° (\blacktriangle , \bullet) and (b) 30° (\triangle , \circ) and at shear stress (dyn/cm^2) 1.47×10^6 (\blacktriangle , \triangle) and 1.96×10^6 (\bullet , \circ). The points on extreme left correspond to the data on PP.

and the passage of impact fracture in the blends. This correlation deserves further investigation, in order to achieve greater insight into the similarity of the origins of the two processes.

Scanning Electron Microscopy

Micrographs at two magnifications of impact-fractured surfaces are shown in Figures 7-12. The characteristic coarse morphology of fracture

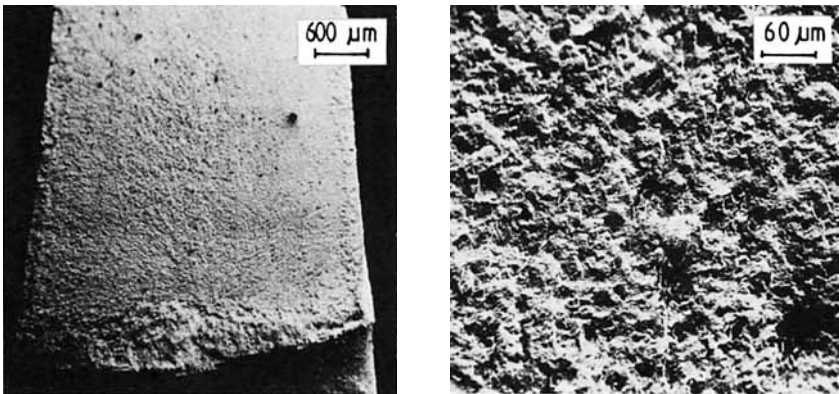


Fig. 7. Scanning electron micrographs of impact fractured surface of PP.

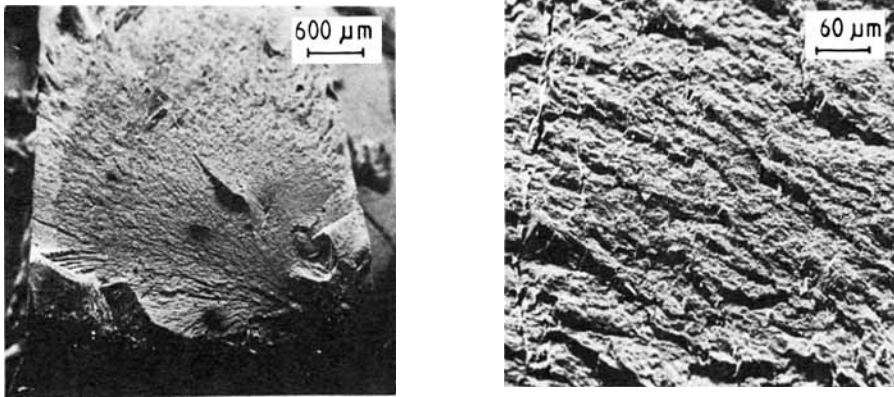


Fig. 8. Scanning electron micrographs of impact fractured surface of PP/HDPE.

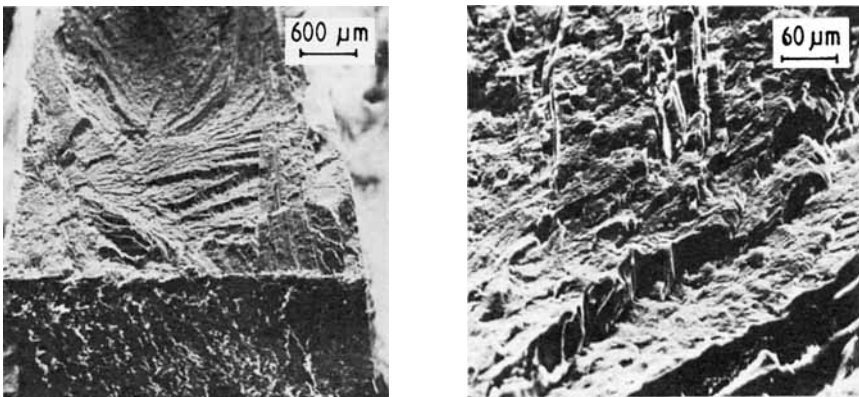


Fig. 9. Scanning electron micrographs of impact fractured surface of PP/SEBS.

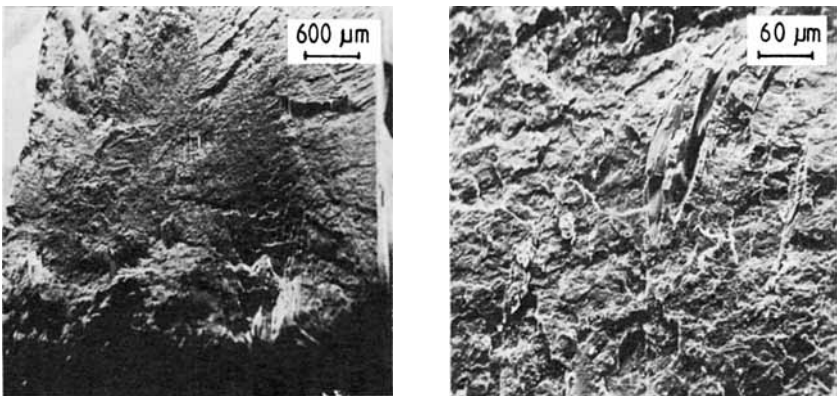


Fig. 10. Scanning electron micrographs of impact fractured surface of PP/SEBS/HDPE.

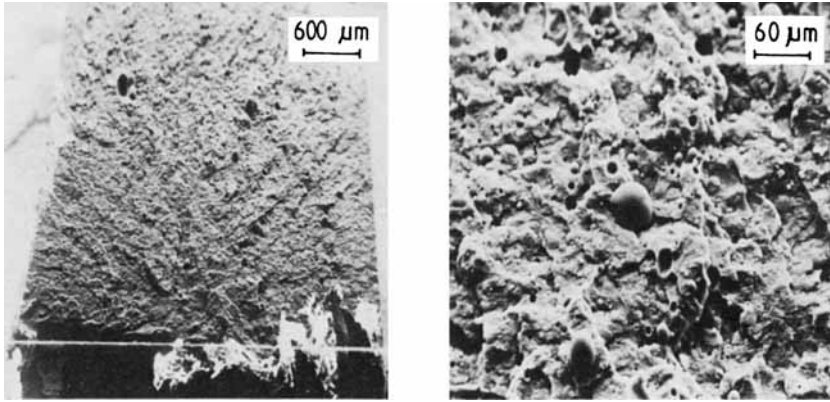


Fig. 11. Scanning electron micrographs of impact fractured surface of PP/PS.

surface of PP matrix is visible in these samples. There are, however, some differences of surface coarseness, which are apparently due to the multiphase character of these blends. HDPE seems to reduce the coarseness of the fracture surface as apparent from the greater smoothness of fracture surface of PP/SEBS/HDPE than PP/SEBS and also of PP/HDPE than PP. This implies some role of HDPE in energy dissipation mechanism in these blends.

Transverse contraction, which is recognized⁹ as the effect of shear yielding, is apparent in most of these samples. This is in support of the shear yielding mechanism of enhancement of impact strength discussed above.

Some crazelike structures are also apparent in these fracture surfaces, but their unidirectional growth from one rubber particle to the next is not clearly ascertainable. Hence it is difficult to say whether these are the crazes usually described for PP at temperatures below glass transition,¹⁰ or some kinds of crazes created by way of intermixed zones⁹ or the shear bands.⁷ Possibility of these being shear bands seems quite likely owing to the large size of these crazelike structures, as well as their nonperpendicular alignment with the direction of their propagation. Formation of stress-whitened shear bands at angles about 60° to the direction of stress was seen in tensile deformation of PP/SEBS blend.³ These micrographs show almost similar

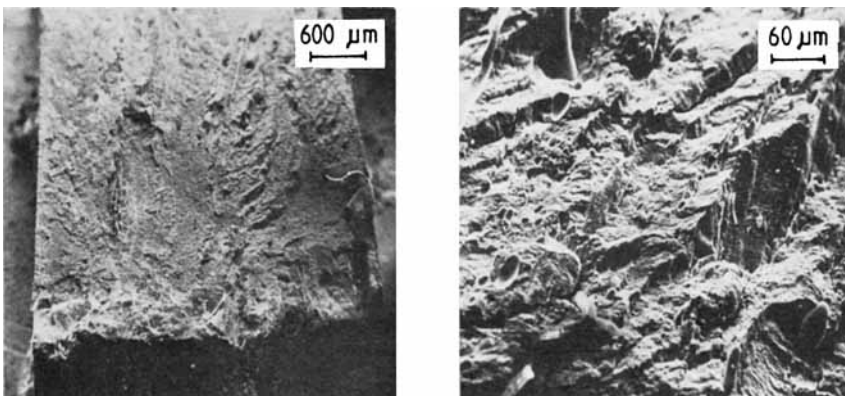


Fig. 12. Scanning electron micrographs of impact fractured surface of PP/SEBS/PS.

alignment of the bands with the direction of stress. Furthermore, a similar surface morphology of shear bands in tensile fractured surfaces is shown in another system (*viz.*, HIPS/PPO blend).¹¹

Blends containing PS, *viz.*, PP/PS and PP/SEBS/PS, show sufficiently great coarseness of the fracture surface. The occurrence of transverse contraction clearly supports the occurrence of shear yielding in these samples also. The observed low enhancement of impact energies in these samples might be partly due to the lower work of yield and partly due to the weak bonding at the interface of PS domains; the uprooted PS domains are apparent on these fracture surfaces.

Micrographs at higher magnifications, shown in Figures 7–12, show the morphology of the PP matrix developed after plastic deformation, owing to a large amount of applied force before fracture. There are some differences in the surface morphology of PP and PP/HDPE (Figs. 7 and 8); the former shows granular while the latter shows a somewhat layerlike morphology. Coarse granular morphology of impact-fractured surface of PP is apparently relevant with the coarse fibrillar¹² morphology of tensile fractured surfaces of PP. Voids created by uprooted domains of PS and SEBS are distinctly apparent as black regions of characteristic shapes. PS domains are small and sufficiently spherical while the SEBS domains are large of irregular nonspherical shapes. This uprooting of the domains implies the insufficient adhesion between the domain and the matrix for the specified energies of impact. The lower impact strengths of the samples containing PS clearly imply lower adhesion of PS domains with PP matrix than of SEBS domains with PP. This difference of the interphase adhesion might be due to the possible affinity of polyolefinic block EB of SEBS with PP, as described¹ on the basis of their solubility parameters. Furthermore, the higher impact strength of PP/SEBS/HDPE than PP/SEBS implies a better degree of interphase adhesion in presence of HDPE, which might be indicative of the compatibilizing role of HDPE due to its possible affinity with both PP and the EB block of SEBS.

CONCLUSION

In conclusion, it may be stated that blending with SEBS produces improvement in impact strength of PP. The impact strength of PP/SEBS blend can be further enhanced by incorporation of HDPE as a third component in the blend. This addition of a third component, however, also produces a decrease in tensile strength while the modulus is slightly increased. On the other hand, the incorporation of PS as a third component in PP/SEBS blend produces reduction not only in tensile strength and modulus but also in the impact strength. Some advantages of PP/SEBS/HDPE blend over the PP/SEBS/PS blend were found⁴ also in the melt rheological properties and extrudate distortion behavior.

Mechanism of impact toughening at room temperature in these blends is principally the shear yielding of PP. The interphase adhesions of PS with PP are sufficiently weak to sustain the stress at the ultimate impact fracture and therefore, the progress of the impact fracture is accompanied by uprooting of the disperse phase domains.

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