ORIGINAL ARTICLE

Impact modification of a PET–PBT blend using different impact modifiers

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The performance enhancement of poly(ethylene terephthalate) (PET) and poly(butylene terephthalate) (PBT) blends using different impact modifiers was studied using various analytical tools. A comparison of the obtained impact resistance data was performed. A significant increase in toughness using 10% Elvaloy AC in a 60–40 PET and PBT blend was observed. In addition, a good combination of tensile strength and impact strength was observed in the 60–40 PET and PBT blend using polypropylene co-polymer B220 MN as an impact modifier. An attempt was also been made to investigate the chemical formulations of the constituent materials and the newly formed blends using the qualitative technique of Fourier transformed infrared studies. The results of the mechanical studies of the newly formed blends were also correlated with those of the morphological, structural and thermal analysis performed in the present investigation.

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INTRODUCTION

Toughened polymeric materials are receiving considerable attention. The role of this important group of additives is to improve impact strength, with the aim of overcoming inherent brittleness and improving the notch sensitivity of low-cost components with inferior properties. The key requirement of the impact modifier is the ability to bind chemically or mechanically with the matrix polymer. Studies on basic poly(ethylene terephthalate) (PET)–poly(butylene terephthalate) (PBT) blends have been carried out by various researchers in the last few decades. The theoretical compatibility of a 70/30 PET/PBT blend was established earlier by Mishra *et al.*¹ PET–PBT blends were studied by Aravinthan *et al.*² across almost their entire compositional range. The miscibility, rheology, structure and some mechanical features of these blends were reported by Aravinthan *et al.* This study suggests that the constituents of the blends are miscible and also that the properties are dependent on composition. The establishment of miscibility in other aryl resin materials, such as PET/poly(trimethylene terephthalate), belonging to the family of polyesters was carried out by Supaphol,³ and PBT/poly(trimethylene terephthalate) was studied by Kuo *et al.*⁴ and Dabgseetyb.⁵ These studies suggest a possible interaction between the constituents, which obey the Gordon–Taylor and Fox equations. These are the robust mathematical models of polymer solution thermodynamics. In addition to binary blends of polyesters, quaternary blends of PET/poly(trimethylene terephthalate)/PBT and PEI have been studied by Woo *et al.*⁶ The reported glass transition temperatures of these blends agree well with the Gordon–Taylor equation for this quaternary system. With respect

to the impact modification of polyesters, the deformation behavior of PET, PBT and PBT based thermoplastic elastomers has been studied by Stribeck *et al.*⁷ Small angle X-ray scattering studies and the observed small angle X-ray scattering patterns indicate an increase in chain flexibility from ethylene glycol for PET to TMG tetra-methylene glycol for PBT. Chaudhari *et al.*⁸ studied the impact modification of PET (recycled) using polyolefinic elastomer and reported a significant improvement in the impact strength of PET along with an improvement in percent elongation. The contribution of interfacial modification to the impact behavior of PET–polyolefin grafted maleic anhydride elastomer blends was studied by Chiu *et al.*⁹ They stated that with the increase in polyolefin grafted maleic anhydride content, significant improvement in the notched izod impact strength was observed. Loyens *et al.*¹⁰ studied an important toughening mechanism involving rubber toughened semicrystalline PET. This mechanism results in cavitations in the triaxial stress state ahead of a crack tip and produces dilatation, which in turn is responsible for void formation in the particle or particle–matrix interface. This is responsible for the dampening effect. A steep increase in the volume strain upon tensile loading confirmed the presence of a rubber voiding mechanism in PET/(EPR/E-GMA8) blends. In a developmental study on PET–PBT blend materials, different blended systems across the entire compositional range were synthesized and characterized in our pilot experimentation. To ascertain miscibility, the materials' mechanical, microstructural and bulk structural properties were evaluated. The results were consistent with those of earlier² related studies. Across the entire compositional range, the 60/40 PET/PBT blend

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labeled the D blend exhibited lower impact strength.¹¹ The modification of the PET-PBT blend so as to improve its impact strength and develop a scientific correlation between its properties was the aim of the proposed experimentation. Notably, studies related to the modification of PET-PBT (60–40) blends have not yet been reported in the literature.

EXPERIMENTAL PROCEDURE

Materials

Commercial grade PET was supplied by ASPET edge (South Asian Petrochem Limited, Kolkata, India) with IV $0.8 \pm 0.02 \text{ dl g}^{-1}$. PBT ultradur B 2550 grade with viscosity number $107 \text{ cm}^3 \text{ g}^{-1}$ (1.07 dl g^{-1}) was supplied by BASF Ultradur (Mumbai, India). Elvaloy 1224AC was supplied by Dupont Industrial Polymers (Shanghai, China). PP-cp with grade Repol B220MN was supplied by Reliance Industries Limited (Mumbai, India).

Blends

Samples using PET and PBT were prepared as per the compositional details mentioned in Table 1. Sample D was prepared using pristine resins with a blend ratio 60 PET/40 PBT. Elvaloy AC and PP-cp were used for impact modification of the D blend. Samples of all blends were prepared by melt extrusion using a single screw extruder. The constituent materials were thoroughly mixed and dried at 110°C for 4 h in an air circulating oven before melt extrusion. The temperature profiles maintained during extrusion were zone 1: 200°C , zone 2: 230°C , zone 3: 250°C and 260°C for the die zone. The screw speed was maintained at 40 r.p.m.

The extrudates were water cooled and palletized. These pallets were again dried before injection molding in the air circulating ovens at 110°C for 3 h. Standard American Society of Testing and Materials tensile and impact samples were molded using an Omega 80A 80W, Ferromatic Milacron, Gujarat, India, hydraulic injection molding machine. The temperature profiles were 220, 220, 240, 265°C for zone 1, zone 2, zone 3 and for the nozzle zone, respectively.

Analytical methods

Mechanical characterization. The tensile strength at yield at 23°C and elongation at break were measured using a universal tensile testing machine (8502/Instron, Chennai, India) as per American Society of Testing and Materials D638. The cross-head speed maintained was 50 mm min^{-1} .

The izod pendulum impact resistance of the blends was measured using a standard pendulum type hammer mounted on a standard machine (International Engineering Industries, Mumbai, India) as per American Society of Testing and Materials D 256. A micrometer-operated notch cutter was used to cut a standard 'V' notch. The average value of the five readings is reported in this work.

Thermal characterization. Differential scanning calorimetry was used to determine qualitative and quantitative information about physical and chemical changes that involve endothermic or exothermic processes or changes in the heat capacity of the sample. The melting and crystallization and related thermal studies of the blend were performed using differential scanning calorimetry (9PT24 M/Mettler Toledo, Powai, Mumbai). The scan procedure followed for thermal analysis performed by heating the sample from 25 to 260°C at a rate of $10^\circ\text{C min}^{-1}$ followed by quenching and reheating at the same rate up to 260°C during the second scan.

Morphological characterization. Scanning electron microscopy (SEM) was carried out using a 6380A/Jeol (Tokyo, Japan). Samples were fractured under cryogenic conditions for microstructural examination. Samples were observed after platinum coating before installation in the SEM chamber.

FTIR studies. Qualitative chemical analysis and the identification of functional groups in the blend sample were performed using a Perkin Elmer FTIR instrument (Perkin Elmer, Waltham, MA, USA). Solid sample material was used for FTIR studies of the blend.

X-ray diffraction studies. The crystallinity of the blend materials was evaluated using a PANalytical X ray diffractometer (Amlelo, The Netherlands) with a copper anode using $K\alpha$ radiation. The X-ray diffraction of the blends and pure materials was recorded at room temperature over a range of 2θ from 0° to 60° using a step size of 0.01° .

RESULTS AND DISCUSSION

Mechanical properties

The mechanical properties of the constituent materials¹¹ and the modified blends are shown in Table 2.

The addition of 2% Elvaloy AC in the D blend slightly lowers the tensile strength of the modified K blend, whereas impact strength is improved by 27%. Further increase in the modifier content to 10% in the D blend improves the impact strength by 163% in the L blend, which is the highest value of impact strength recorded for the L blend.

The addition of 2% PP-cp BMN220 improves the impact strength of the D blend by about 75%, which is comparatively lower (by about 50%) than the impact modification due to Elvaloy AC. With the increase in the PP-cp BMN220 content to 10%, the impact strength remains almost the same as that of the N blend. Higher percent elongation at break is observed in impact-modified blends than in the constituent material of the D blend. All of the impact-modified blends are semicrystalline in nature as observed from X-ray diffraction diffractographs. (The structural behavior of these blends is discussed in detail in section Morphological properties.) The crystalline region of the impact-modified blends may act as a reinforcement to enhance the percent elongation. Moreover, the amorphous portion of the semicrystalline polymer might have behaved similar to a rubbery phase to contribute a higher impact strength coupled with a slightly improved percent elongation.¹²

The addition of 10% impact modifier (both Elvaloy AC and PP-cp) significantly lowers the universal tensile strength by about 20%. Modification of the segmental structure, either in the form of branching or cross-linking, might have been responsible for lowering the universal tensile strength.¹³ Graphical representations of variations in the tensile strength and impact strength of the constituent materials and the blended systems are shown in Figures 1 and 2, respectively.

Both crazing and shear yielding involves the absorption of energy throughout a large volume of material other than just at the crack tip,¹⁴ and this phenomenon must have occurred in these formulated blends during impact loading.

Table 1 Impact modified blends and their composition

S. no.	Blend	Composition
1	K	2% ELVALOY AC in D
2	L	10% ELVALOY AC in D
3	N	2% PP-Cp B220 MN in D
4	P	10% PP-Cp B220 MN in D

Table 2 Mechanical properties of the modified blends and their constituent materials

Property	Elvaloy	PP-cp					
	C 1224	220 MN	D	K	L	N	P
Ultimate tensile strength (MPa)	>46	24	57	55	45	52	46
Elongation at break (%)	>48	53	6	8.2	8.9	10.1	7.9
Izod impact strength (J m ⁻¹)	>108	93	33	42	87	53	55

Morphological properties

The fine and uniform lamellar microstructure of the D blend is shown in Figure 3. SEM photomicrographs of the K and L blends modified using Elvaloy AC and N and P blends modified using PP-cp indicates immiscibility as shown in Figure 3. Co-continuity of the structure is

shown in the microphotograph of the L blend, which indicates the network formation of the dispersed phase. The reinforcing effect of the material having high impact strength might have enhanced the properties. It can be stated that to obtain co-continuity of the phase structure, the optimum weight percent of the impact modifier Elvaloy

Figure 1 Variation in the tensile strengths of the constituent materials and impact modified blends. A full color version of this figure is available at *Polymer Journal* online.

Figure 2 Variation in the impact strengths of the constituent materials and impact modified blends. A full color version of this figure is available at *Polymer Journal* online.

D Blend

K Blend

L Blend

N Blend

P Blend

Figure 3 Microphotographs of the constituent blend and the modified blends.

AC should be a maximum of up to 10% of the total weight of the blend. Similar morphological features indicating co-continuity and network formation of the phases of the impact modified blends were reported in the study of Paul *et al.*¹⁵ It was also observed in this study that blends showing this type of morphology exhibited the highest impact strength. The ductile fracture of the thermoplastics can also be attributed to the presence of smaller threads with thickenings at the end. The stretching of a macromolecule followed by its rupture causes it to recoil similar to a spring. This effect is pronounced at highly stressed fracture sites and produces nodular thickening at the end of macromolecules.¹⁶ A similar morphology is observed in SEM studies of N and P blends.

X-ray diffraction studies of impact modified blends

The D blend is amorphous in nature.¹¹ However, the appearance of both sharp and diffuse diffraction peaks in the X-ray diffraction pattern of the remaining modified blends supports the existence of crystalline domains between amorphous regions. The semicrystalline nature of the modified blends is shown in Figure 4. The crystallinity of the constituent materials and the extent of crystallinity induced in modified blends are reported in Table 3.

It was observed that the crystallinity of the Elvaloy AC is 25% and the addition of 2% Elvaloy AC in the K blend and 10% Elvaloy AC in the L blend induces 16% and 19% crystallinity, respectively, in these modified blends. The crystallinity of the K and L blends was found to be about 15–25% lower than that of its crystalline constituent Elvaloy AC. Blend L consists of 81% amorphous domain in its structure. Copolymerization might have reduced the linearity of the molecular structure, and, thus, the highest impact strength of L blend can be correlated with this asymmetrical branched molecular structure.¹⁷ The observed crystallinity value of PP-cp is 60% and the addition of 2%

Figure 4 X-ray diffractograms of impact modified blends. A full color version of this figure is available at *Polymer Journal* online.

Table 3 % Crystallinity of the constituent resins and impact modified blends

S. no.	Modified blends and constituent materials	% Crystallinity
1	D	—
2	K	16
3	L	19
4	N	6
5	P	10
6	Elvaloy AC	25
7	PP-cp	60

PP-cp to the N blend and 10% PP-cp to the P blend produces a gradual increase in crystallinity. For the same amount of added impact modifiers Elvaloy AC and PP-cp used to modify the D blend, higher crystallinity was observed in the blends featuring Elvaloy AC.

The addition of 2% Elvaloy to the D blend shifts the peak at 20.96° to a slightly lower angle of 20°, whereas the peak at 21.9° is not observed in the K blend, and entirely new peaks at 23° and 24.8° appear (Table 4). Structural modification due to the addition of a highly polar modifier is evidenced by this result. A similar shift in the peak position from 20.96° to 20.8° was observed for the L blend, and an additional peak at 23°, the same position as that of the K blend, is observed in the L blend. The nucleating effect of the impact modifiers is evidenced from the reported data.¹⁸ The parent peaks of PP-cp show well resolved peaks at 13.66°, 16.46° and 18.1°. The N blend modified with 2% PP-cp exhibited only one peak at 17°, whereas the modified P blend showed two peaks at 13.9° and 16.74°. These results indicate a positive shift in the peak position with respect to the parent peaks of PP-cp.

The crystallite size of the impact modifier and the crystalline phases of the modified blends were calculated using the Scherrer equation. The average crystallite size of the Elvaloy AC is reported to be 0.339 and 0.132 μm for PP-cp (Table 3). The crystallite sizes of the blends featuring Elvaloy AC are lower than those of PP-cp. These results suggest the fragmentation and dispersion of these modifiers during processing. Minor variation in the crystallite size of the K and L blends using Elvaloy AC and N and P blends using PP-cp was also observed.

FTIR studies of impact modified blends

The infrared (IR) spectra of the modified blends, where the peak position is plotted versus the percent transmittance, is shown in Figure 5.

The sharp peaks at 2848 and at 2916 cm^{-1} in Elvaloy AC (Table 5) can be attributed to C-H stretching. α -, β -unsaturated esters show C=O vibration in the region between 1715 and 1735 cm^{-1} , which is confirmed by the presence of a peak at 1736 cm^{-1} . Peaks at 1463 and 1376 cm^{-1} are identified in the spectrograph as C-H bending and C-H deformation of methylene, respectively. The peak at 719 cm^{-1} can be attributed to methylene rocking. The FTIR results indicate the presence of methyl acrylate in Elvaloy AC. The addition of 2% Elvaloy AC to the D blend indicates some deviation in the IR spectra from that

Table 4 X-ray diffraction peak positions of the constituent materials and impact modified blends

S. no.	Constituent materials and modified blends	Peak position (2 θ)	Crystallite size (μm)	Average crystallite size (μm)
1	D blend	—	—	—
2	Elvaloy AC	20.96°	0.396	0.339
		21.19°	0.283	
3	PP-cp	16.46°	0.178	0.132
		13.66°	0.196	
		18.1°	0.123	
4	K	20°	8.1	8.3
		23°	8.4	
		24.8°	8.3	
5	L	20.8°	9.9	8.5
		23°	7.1	
6	N	17°	9.9	9.9
7	P	13.9°	10.6	10.5
		16.74°	10.4	

of the D blend (Table 6). The C–C stretching vibration at 1103 cm^{-1} in the D blend is shifted to 1090 cm^{-1} . Similarly, additional peaks at 872 , 1207 and 1236 cm^{-1} in the region of the C–C stretch vibration are observed in the modified K blend. The positive shift from 1266 to 1288 cm^{-1} in this range for the C–C stretching vibration is also observed in the modified 'K' blend. A minor change in the C–O stretching vibration of the ester from 1356 to 1341 cm^{-1} is observed in the K blend, and an entirely new peak at 1388 cm^{-1} is observed in this range. Most of the bands for C=C aromatic stretching remains unchanged in the modified blend, except for a negative shift from 1454

to 1447 cm^{-1} . A negative shift in the case of the most characteristic C=O vibration of the ester is observed from 1720 to 1709 cm^{-1} because of internal conjugation. Extra peaks at 2282 and 2380 cm^{-1} are also observed in this region for the modified blended system. Shifting of the peak corresponding to C–H aliphatic stretching in the negative direction from 2905 to 2869 cm^{-1} is observed. Some complexity and modification in the structure, especially at the highly polar sites (COO) of the acrylate, are predicted from these results.

At a higher concentration of the impact modifier (10%) in the L blend, the intensity of the peaks further increases. For the characteristic C–C stretching mode, an additional peak at 1260 cm^{-1} in the form of shoulder of the parent peak 1271 cm^{-1} was observed. Two additional peaks at 1380 and 1420 cm^{-1} in the spectral region between 1350 and 1450 cm^{-1} are also noticed in the modified L blend. The peak position corresponding to 1420 cm^{-1} is absent in K the blend, which indicates further modification of the structure at higher concentrations of the impact modifier; this might be related to observed enhancement in mechanical properties. IR bands corresponding to aromatic C=C stretching, C=O stretching of ester, C–H aromatic stretching and C–H aliphatic stretching are located in the spectra of the 'L' blend with minor shifts in their positions with respect to those of the K blend.

The co-polymer moiety of PP-cp is not disclosed in the technical data sheet of PP-cp B 220 MN. The IR spectrograph of B220MN PP-cp shows strong peaks at 2913 and at 2837 cm^{-1} . These peak positions were reported as a spectral feature of EPDM. Hence, it can be inferred from these results that B220 MN may be the co-polymer of EPDM. The enhancement in the impact characteristics supports this assumption. The spectral position 721 cm^{-1} corresponds to C–H rocking; this bending (rocking) motion is associated with four or more CH_2 groups in the open chain commonly known as the long chain band, whereas the peak at 1376 cm^{-1} indicates C–H bending of the methyl pendent group of the polypropylene moiety. The addition of 2% PP-cp B 220

Figure 5 FTIR bands of impact modified blends. A full color version of this figure is available at *Polymer Journal* online.

Table 5 Infrared spectral position of constituent materials

Infrared blend D wave numbers (cm^{-1})		Elvaloy AC wave numbers (cm^{-1})		PP-cp B 220MN wave numbers (cm^{-1})	
727	Benzene ring (di substitution and C–H rocking)	719	C–H rocking	721	C–H rocking
894	C–C stretch ($800\text{--}300\text{ m}^{-1}$)	821	C–C stretch ($800\text{--}1300\text{ cm}^{-1}$)	808	C–C stretch ($800\text{--}1300\text{ cm}^{-1}$)
917		1017		841	
937		1160		973	
1019		1194		998	
1103		1376	C–H bending (methyl)	1167	
1173		1463	C–H def. (methyl)	1256	
1266		1736	C=O stretch (acrylate)	1376	C–H bending (methyl, CH_3)
1356	C–O stretching ester	2848	C–H stretch aliphatic	1387	
1387					
		2916		1410	
1409				1431	
1454	C=C stretch aromatic ($1450\text{--}1650\text{ cm}^{-1}$)			1455	Methylene (CH_2 bending)
1505				1610	C=C stretch
1524				1645	
1578				2837	EPDM spectral feature
1613				2852	C–H stretch aliphatic ($2850\text{--}2960\text{ cm}^{-1}$)
1720	C=O stretch ester ($1715\text{--}1730\text{ cm}^{-1}$)			2913	
1956				2950	
2543					
2905	C–H stretch aliphatic ($2850\text{--}2960\text{ cm}^{-1}$)				
2963					
3054	C–H stretch aromatic ($3000\text{--}3050\text{ cm}^{-1}$)				

Table 6 Infrared spectral positions of the modified blends

	<i>K</i> blend (cm ⁻¹)	<i>L</i> blend (cm ⁻¹)		<i>N</i> blend (cm ⁻¹)	<i>P</i> blend (cm ⁻¹)
Benzene ring (di substitution)	722	723	Benzene ring (di substitution)	722	723
	793			793	
C–C stretch (800–1300 cm ⁻¹)	872	873	C–C stretch (800–1300 cm ⁻¹)	872	873
	1015	1016		1015	1016
	1090	1091		1091	1092
	1207	1213		1236	1238
	1236	1237	C–O stretching ester	1340	1335
		1260		1360	
		1271		1407	1408
	1288				1430
C–O stretching ester	1341	1348	C=C stretch (aromatic; 1450–1650 cm ⁻¹)	1456	1460
	1388	1380		1544	1540
	1407	1408		1612	
C=C stretch (aromatic; 1450–1650 cm ⁻¹)	1447	1441		1708	
	1504	1520	C=O stretch internal conjugation	1722	1711
	1526			1960	
	1577	1578		2000	2005
	1612			2832	2844
	1626	1640	C–H stretch aliphatic (2850–2960 cm ⁻¹)	2855	2852
C=O stretch internal conjugation	1709	1712		2960	
	1955	1948	C–H stretch aromatic (3000–3050 cm ⁻¹)	3044	3042
	2282	2270			
	2380	2388			
C–H stretch aliphatic (2850–2960 cm ⁻¹)	2869	2852			
C–H stretch aromatic (3000–3050 cm ⁻¹)	2962	2960			
	3052	3055			

MN to the D blend indicates some deviation in the IR spectra from that of the D blend. The peak value corresponding to C–C stretching at 872 cm⁻¹ is observed in the N blend. This peak position represents a positive shift with respect to the corresponding band in PP-cp B 220 MN and a negative shift with respect to the corresponding band in the D blend. Similarly, the peak position 1091 cm⁻¹ of the N blend in this range represents a negative shift with respect to the peak at 1103 cm⁻¹ of the D blend. The peak corresponding to the C–O stretching of ester, C=C stretching (aromatic), characteristic C=O stretching of ester, C–H aliphatic and aromatic stretching was identified in both modified systems using PP-cp B 220 MN. Moreover, the addition of PP-cp B 220 MN is confirmed by the existence of peaks at 2832 and 2844 cm⁻¹ in the IR spectrum of EPDM. Additional peaks are observed at 793, 1236, 1360, 1544, 1708 and 2000 cm⁻¹ in the N blend and 1238, 1540, 2005 and 2844 cm⁻¹ in the P blend. Co-polymerization of the D blend with impact modifier is strongly indicated by these results, and the co-polymerization of the modified blend could have resulted in the modification of the blend's molecular structure, as evidenced by the presence of additional peaks.

Thermal studies of impact modified blends

The differential scanning calorimetry thermographs of the blends are shown in Figure 6. The glass transition temperatures of the immiscible systems of amorphous and crystalline polymers approach each other but do not coincide.¹⁹ The glass transition phenomenon is not evident in all of the blends featuring impact modifiers for the scan procedure adopted in this study, and only a very weak indication is observed in the P blend, which might be due to the effect of the D blend.

The reported glass transition temperatures of the various elastomers are all in the range of –20 to –90 °C^{20,21} and all the thermographs of the blends are indicative of glass transition temperatures well below

Figure 6 Differential scanning calorimetry thermographs of impact modified blends.

room temperature. Thus, glass transition temperatures below room temperature define the domains of the elastomers. The thermal data for the constituent materials and the modified blends are depicted in tabular form in Table 7.

Two endothermic melting peaks are revealed in the modified blends using impact modifiers. Co-continuity in the solidification of the PET and PBT phases of these blends might have resulted in the appearance of the two separate peaks in the thermographs. Besides these endotherms, weak and broad endothermic peaks at 118 and 124 °C are seen in the K and L blends featuring Elvaloy AC. Modification of the molecular structure and/or formation of a complex structure due to the reaction of PET/PBT with the highly polar acrylate moiety of Elvaloy AC might be responsible for the endothermic peaks observed

in thermal study. Blends using PP-cp as an impact modifier show an additional endotherm at 164 °C for the N blend and 161 °C for the P blend, which correspond to the PP-cp endotherm. Notably, similarly weak endotherms at 118 °C in all of the blends except the P blend and

at 158 °C are observed, which may be due to fragmentation of the molecular chains. The presence of separate endothermic melting peaks in all of the blends supports the existence of evenly distributed particles, which may be correlated with the morphological features, that is, the existence of the immiscible phases, of the blends. The broad endotherms also support the formation of a complex molecular structure.

Table 7 Thermal data of the constituent materials of the impact modified blends

S. no.	Blend constituents and modified blends	Glass transition temperature (T_g °C)	Melting temperature (T_m °C)	
			T_{m1}	T_{m2}
1	D blend	71	219	247
2	Elvaloy AC	—		94
3	PP-cp	—		168
4	K	—	224	256
5	L	—	225	250
6	N	—	226	251
7	P	—	216	247

Figure 7 Possible reaction in the impact modified blend using Elvaloy AC.

Conclusion

- The cumulative effect of property enhancement due to blending and the use of impact modifiers as additives in the blends were established in this study using Elvaloy AC and PP-cp.
- The effect of Elvaloy AC as an impact modifier was more pronounced than that of PP-cp.
- A linear increment in the impact strength from about 25–160% was observed in the study using Elvaloy AC for impact modification, and the highest impact resistance was observed for the L blend (increment by 163%). This was attributed to the formation of a three-dimensional network.
- A good combination of toughness and tensile strength was observed for the N and P blends using PP-cp B220MN as an impact modifier.

Figure 8 Possible structure of the B 220MN PP-cp. A full color version of this figure is available at *Polymer Journal* online.

Figure 9 Possible reactions and cross linking of the polyester matrix with B 220MN PP-cp. A full color version of this figure is available at *Polymer Journal* online.

- The reinforcement and network formation of the toughening additives was observed by SEM imaging; these features are responsible for the highest observed impact modification of the L blend using Elvaloy AC.
- FTIR analysis of the impact modified blend shows the characteristic peak positions of the different organic bonds of the macromolecules. The extra peaks and shifts in the IR peaks from the characteristic peak positions clearly indicate the complexity and modification of the molecular structure, especially at the highly polar sites (COO) of the acrylate. On the basis of the above observations, the reaction that is most likely when using Elvaloy AC can be predicted as shown in Figure 7.

On the basis of the results related to the use of PP-cp, it can be predicted that B220 MN PP-cp may be the co-polymer of EPDM. A diagrammatic representation of B 220MN PP-cp is shown in Figure 8.

This dipole bonding is not as strong as hydrogen bonding. Dipole-dipole bonding of the polyester and C–H group of EPDM, therefore, may lead to a strong physical interaction as shown in the Figure 9, which results in cross linking of the macromolecule.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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