

Effect of EPDM on Morphology, Mechanical Properties, Crystallization Behavior and Viscoelastic Properties of iPP+HDPE Blends

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Summary: Blends of isotactic polypropylene (iPP) and high density polyethylene (HDPE) with and without ethylene-propylene-diene (EPDM) terpolymer as compatibilizer were systematically investigated to determine the influence of the EPDM on blends properties. The morphology was studied by Scanning Electron Microscopy (SEM). Mechanical properties of investigated systems: tensile strength at break, elongation at break, yield stress and Izod impact strength were determined. Crystallization behavior was determined by Differential Scanning Calorimetry (DSC). Dynamic Mechanical Analysis (DMA) was used to determine the storage modulus (E'), loss modulus (E''), and loss tangent ($\tan \delta$). The PP+HDPE blend revealed poor adhesion between PP and HDPE phases. Finer morphology was obtained by EPDM addition in PP+HDPE blends and better interfacial adhesion. Addition of HDPE to PP decreased tensile strength at break, elongation and yield stress. Decrease of tensile strength and yield stress is faster with EPDM addition in PP+HDPE blends. Elongation at break and impact strength was significantly increased with EPDM addition. The addition of EPDM in PP+HDPE blends did not significantly change melting points of PP phase, while melting points of HDPE phase was slightly decreased in PP+HDPE+EPDM blends. The EPDM addition increased the percentage of crystallization (X_c) of PP in PP+HDPE blends. The increase of X_c of HDPE was found in the blend with HDPE as matrix. Dynamical mechanical analysis showed glass transitions of PP and HDPE phase, as well as the relaxation transitions of their crystalline phase. By addition of EPDM glass transitions (T_g) of HDPE and PP phases in PP+HDPE blends decreased. Storage modulus (E') vs. temperatures (T) curves are in the region between E'/T curves of neat PP and HDPE. The decrease of E' values at 25 °C with EPDM addition in PP+HDPE blends is more pronounced.

Keywords: differential scanning calorimetry (DSC); EPDM; mechanical properties; morphology; PP+HDPE blends

Introduction

Polypropylene (PP)^[1] and polyethylene (PE) represent one of the principal commodity thermoplastics. Major plastic components of plastic waste are PP and PE. Separation of plastic waste into individual polymers is costly and complete sorting is

some times impossible. Plastic waste can be recycled easily by converting it into the form of polymer blends. Polymer waste recovery is providing greatly increased motivation for improving the properties of polymer blends.^[2] A significant portion of the high density polyethylene (HDPE) on the market finds its way into blow-molding applications for articles like milk jugs, water jugs, and detergent bottles. A problem arises when attempts are made to recycle these parts. Very often, the spout or the closure on these bottles is produced

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from injection-molding-grade PP. Thus, the HDPE waste stream from blow-molding applications will likely have some contamination from PP.^[3,4] Unfortunately, PP and PE are highly immiscible resulting in a blend with poor adhesion among its phases, coarse morphology and consequently poor mechanical properties. Several methods exist to improve the interfacial adhesion of immiscible polymers. One is by chemical modification carried out by reactive extrusion. Peroxide is added to the melt blend in the extruder. In the case of a gross viscosity mismatch, peroxides can reduce the viscosity of the PP phase through chain scission and increase the viscosity of the PE phase through crosslinking, as has been shown by Yu et al.^[5] Another option is to add a third component that can act as a polymeric surfactant, situating itself at the interface of the two polymers.^[6] By the addition of the third component, it is possible to obtain finer morphology, better particles dispersion and reduction of its size, higher interfacial adhesion and reduction of interfacial tension. To modify the poor impact toughness of PP+HDPE blends various elastomers can be added as a compatibilizer, such as ethylene-propylene (EP) copolymer,^[7–10] ethylene-propylene-diene (EPDM) terpolymer,^[11–14] ethylene/vinyl acetate copolymer (EVA),^[6,15–18] styrene-butadiene-styrene (SBS) block copolymer^[19] and styrene-ethylene/butylene-styrene (SEBS) triblock copolymer.^[16] Many papers have been focused on investigations of PP+PE blends as well as compatibilized PP+PE blends. Jose et al.^[2] investigated the phase morphology, crystallization behavior and mechanical properties of isotactic PP (iPP) and HDPE blends. The morphology of PP+HDPE blends showed two phase structure and the domain size of the dispersed phase increased with increasing concentration of that phase due to coalescence. Their crystallinity studies showed that blending of these two polymers has not much effect on the crystalline melting point of PP and HDPE, and the crystallization enthalpy and heat of fusion values of HDPE and PP in the blend were decreased

as the amount of the other component increased. They obtained poor mechanical properties of PP+HDPE blends due to incompatibility of these components. Li et al.^[20] investigated miscibility and isothermal crystallization of PP and PE. The crystallization rate of PP was decreased in the PP and linear low density polyethylene (LLDPE) blends, but in PP and low density polyethylene (LDPE) blends and PP+HDPE blends, was similar to that of the pure PP. The differential scanning calorimetry (DSC) and hot-stage optical microscopy (HSOM) showed that the PP was miscible with the LLDPE, at elevated temperatures at a PP composition of 20%, while the PP was immiscible with the HDPE and LDPE at the same temperatures. Transmission electron microscopy (TEM) showed phase separation in the PP+LDPE (20+80) blend, although the droplets were much finer. Kim and Chun^[21] studied the effect of HDPE addition and testing temperatures on the mechanical and on morphological properties of PP+EPDM blends. Modulus of elasticity was decreased as the EPDM content increased regardless of the testing temperatures, while modulus of elasticity of PP+HDPE+EPDM blend increased compared to PP+EPDM blend when tested at -30 and -60 °C. At more than 30 wt. % EPDM content, ternary blends showed higher impact strength compared to binary blends. Dispersed EPDM and HDPE phase could form skin-core microstructures and the PP matrix was partly connected by the extended HDPE attachment within the dispersed EPDM+HDPE particles. Hemmati et al.^[17] studied the morphology of PP+HDPE+EPDM blends. They obtained a core-shell-type morphology for HDPE encapsulated by rubber. Their investigations showed that the torque ratios affected only the size of the dispersed phases and have no influence on the type of morphology. Blom et al.^[6,15] studied the compatibilizer effect of EPDM and EVA used in PP+HDPE blends. EPDM was more effective at improving the impact strength and gate puncture resistance of a 90+10 PP+HDPE blend.

Mechanical properties were improved with EPDM addition. Choudhary et al.^[18] studied the effect of EPDM on the crystallization behavior and morphology of iPP+HDPE blend, by means of DSC and X-ray diffraction. The DSC and X-ray diffraction showed that overall crystallinity decreased as the weight percentage of EPDM was increased in the iPP+HDPE blends. By scanning electron microscopy (SEM) they revealed a random distribution of EPDM throughout the iPP matrix, and existence of composite inclusions of EPDM-HDPE in an iPP matrix. Effect of EPDM on melt rheology, morphology and mechanical properties of PP+HDPE (90/10) blend was also studied by the same authors.^[22] They concluded that EPDM (5–10 wt. %) helped in the compatibilization of iPP+HDPE (90 + 10) binary blend. At higher EPDM content, agglomerates of EPDM lead to the formation of larger domains thereby increasing the viscosity of the blend. Addition of EPDM improved impact strength. Souza and Demarquette^[16] studied the effect of three types of compatibilizer: EPDM, EVA and SEBS in PP+HDPE blends. They concluded that EPDM was more efficient as an emulsifier for PP+HDPE blend than EVA or SEBS. It was also shown that EPDM was more efficient to decrease the interfacial tension than the others.

In our study, we tried to evaluate the effect of EPDM as compatibilizer on morphology determined by means of SEM, on tensile and impact properties, on crystallization behavior and on viscoelastic properties of PP+HDPE blends. The influence of the amount of EPDM in PP+HDPE blends was also investigated. The aim was to find the correlation between morphology and investigated properties of PP+HDPE+ EPDM blends.

Experimental Part

Materials

The following materials were used to prepare the PP+HDPE blends with and without EPDM as compatibilizer:

Isotactic polypropylene (iPP), HC206TF, supplied by Borealis, MFR 5 g/10 min. (2.16 kg/230 °C); high density polyethylene (HDPE), Lupolen 5031L, supplied by Basel, MFR 6.5 g/10 min. (2.16 kg/190 °C). Ethylene-propylene-diene (EPDM) terpolymer, Nordel IPNDR 4520, supplied by Dupont Dow Elastomers, has a content of ethylene 49–51%, propylene 43.7–47%, and ethylene norbornene 4–5.30%. Mooney viscosity of EPDM was 16–24 at 125 °C.

Preparation of the Blends

A sample of neat polymers and blends of PP+HDPE with and without a compatibilizer were prepared by Haake Record 90 twin screw extruder with intensive mixing profile, Haake TW 100, with the zone temperatures of 180/190/195/205 °C and at 60 rpm. After the extrusion, dumbbell test specimens were prepared by injection molding with Zwick injectometer at 230 °C, the injection rate of 200 mm/s and the mould temperature of 40 °C. The compositions of the prepared PP+HDPE blends were 100 + 0, 80 + 20, 40 + 60 and 0 + 100 wt %. Five percent and seven percent of EPDM were added to iPP+HDPE blends. For example, a blend containing 80 g of iPP, 20 g of HDPE and 5 g of EPDM, has the following notation: PP+HDPE+EPDM 80 + 20 + 5.

Scanning Electron Microscopy (SEM)

The samples of PP+HDPE and PP+HDPE+EPDM blends were fractured in liquid nitrogen and sputtered with thin gold layer to prevent charging. The fracture surfaces were observed by SEM microscope (JSM 5800, Jeol), using secondary electrons detector.

Mechanical Properties

The measurements of tensile properties, tensile strength at break, elongation at break and yield stress of dumbbell shape samples were carried out by an Instron 1185 tester according to standards ISO 527-1: 1993 and ISO 527-2: 1993, at a crosshead speed of 50 mm/min. The Izod impact strength was measured according to ISO

180; 1993. For each analysis five specimens were tested and the average values were reported.

Crystallization behavior was determined by Differential scanning calorimetry (DSC),^[23] DSC 2910, TA Instruments, according to ASTM D-3418-82 standard. A sample size 7–10 mg was used. The sample was heated from 30 °C to 230 °C at heating rate of 10 °C/min and was maintained at 230 °C for 10 min. After that, the sample was cooled from 230 °C to 30 °C at cooling rate of 10 °C/min. Sample was kept for 10 min under that temperature and then heated again from 30 °C to 230 °C. The sample was kept for 10 min at 230 °C and after that cooled from 230 °C to 30 °C.

Dynamic Mechanical Analyzer 987 (DMA), TA Instruments, used to determine the viscoelastic properties of samples.^[23] The measurement was carried out at constant frequency of 1 Hz, temperature range from –150 °C to +150 °C, amplitude 0.2 mm and heating rate of 5 °C/min.

Results and Discussion

The SEM micrographs of PP+HDPE and PP+HDPE+EPDM blends are presented in the Figure 1. In PP+HDPE 80 + 20 blend two-phase morphology was observed (Figure 1a). The HDPE phase is dispersed in PP matrix and the voids as results of pull out effect of HDPE phase were visible. This emphasize on low interfacial adhesion. With the addition of EPDM (5 and 7 pph) better homogeneity of the system was obtained and the HDPE particles were incorporated in PP matrix (Figure 1b and 1c). The blend of PP+HDPE with 7 pph EPDM revealed better miscibility of PP and HDPE phases.

The tendency for EPDM to envelop HDPE, rather than vice versa, in a PP matrix is reasonable from interfacial energy considerations.^[24] The HDPE-within-EPDM structure (HDPE core-EPDM shell structure) will be thermodynamically favorable over an EPDM-within-HDPE structure if $\gamma_{PP-EPDM} < \gamma_{PP-HDPE}$, where γ is the interfacial energy.

In PP+HDPE 40 + 60 blend co-continuous morphology was visible (Figure 1d). Coalescence of HDPE phase is observed, what is usual morphology for HDPE-rich phase blends.^[2]

Upon addition of 5 pph of EPDM SEM micrograph revealed also co-continuous morphology and no higher improvement of homogeneity (Figure 1e). The 7 pph of EPDM improved the homogeneity of the system (Figure 1f).

The size of the HDPE phase increased in PP+HDPE 40 + 60 blends. This is due to the coalescence phenomenon. Coalescence, the recombination of particles, is known to take place during the mixing process.^[25] From SEM micrographs (Figure 1) it is evident that the size of HDPE domain is smaller when PP is the major phase. This observation can be explained in terms of viscosity difference between the two polymer phases.

Molten PP has high viscosity which can be lowered significantly by addition of a polymer crystal (PLC).^[26] Being more viscous, PP matrix hinders the diffusion of HDPE domains, so it is difficult for HDPE domains to diffuse through the PP matrix and this limits the number of effective collisions. Hence the phenomenon of coalescence becomes minimum when PP is the matrix. On the other hand it is comparatively easy for the PP domains to diffuse through the less viscous HDPE matrix. So the rate of collisions and therefore the coalescence is greater when HDPE is the matrix.

D'Orazio et al.^[27] observed that EPDM acts as an interfacial agent which can promote the interfacial bonding between the PP and HDPE.

The mechanical properties of PP+HDPE and PP+HDPE+EPDM blends are presented in Figure 2. Tensile strength at break of neat PP was the highest and with the addition of HDPE to PP was reduced (Figure 2a). The values of tensile strength of binary and ternary blends were between the values of the neat homopolymers (Figure 2a). Addition of EPDM (5 and 7 pph) reduced the values of tensile strength

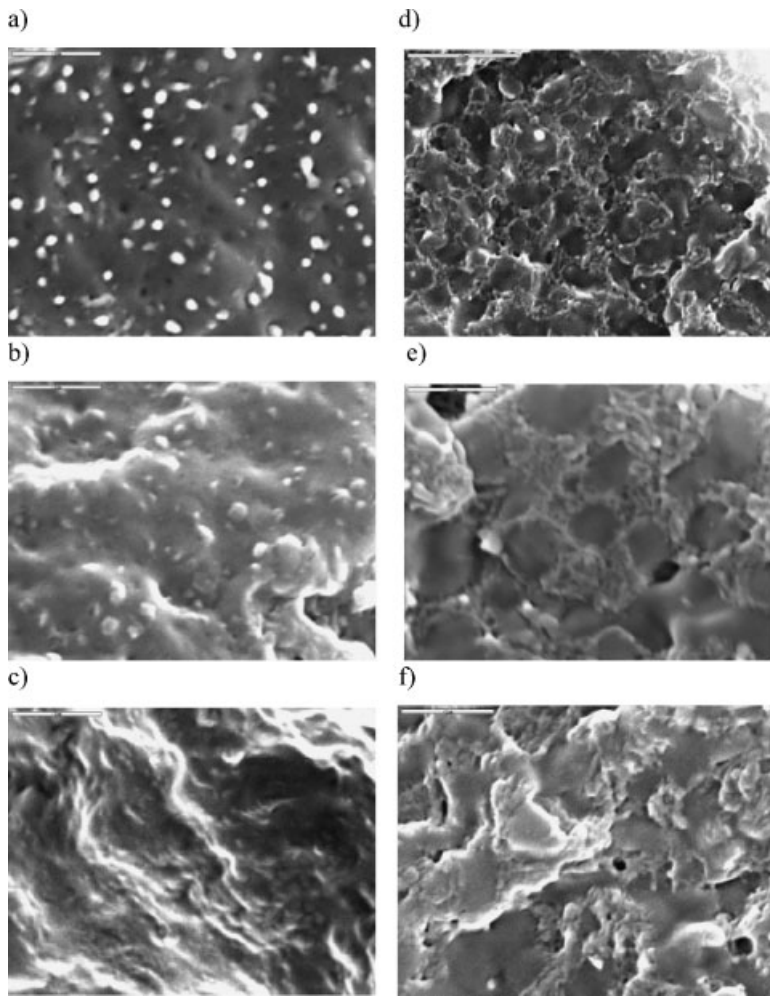


Figure 1.

SEM micrographs of PP+HDPE+EPDM blends: a) 80 + 20, b) 80 + 20 + 5, c) 80 + 20 + 7 d) 40/60, e) 40 + 60 + 5 and f) 40 + 60 + 7.

in PP+HDPE blends and this effect was more pronounced in PP-rich phase blend and with higher EPDM content (Figure 2a). It is in agreement with better homogeneity of PP+HDPE+EPDM blends obtained by SEM micrographs (Figure 1). The highest value of the elongation at break had the neat HDPE (Figure 2b). The non compatibilized blends showed very low values of elongation at break, as a consequence of the poor interfacial adhesion. The addition of EPDM increased the values of elongation at break in PP+HDPE blends, especially in PP-rich phase blend and in blends

with higher EPDM content (Figure 2b). Improvement of elongation at break for PP+HDPE 40 + 60 blends upon EPDM addition was not so expressed. The highest value of yield stress had the neat PP and the lowest had neat HDPE (Figure 2c). Addition of HDPE to PP reduced the yield stress. EPDM slightly decreased the yield stress in PP+HDPE blends. Decrease of yield stress was higher with 7 pph of EPDM (Figure 2c). The values of yield stress of binary and ternary blends were between the values of the neat homopolymers (Figure 2c). Addition of HDPE to PP

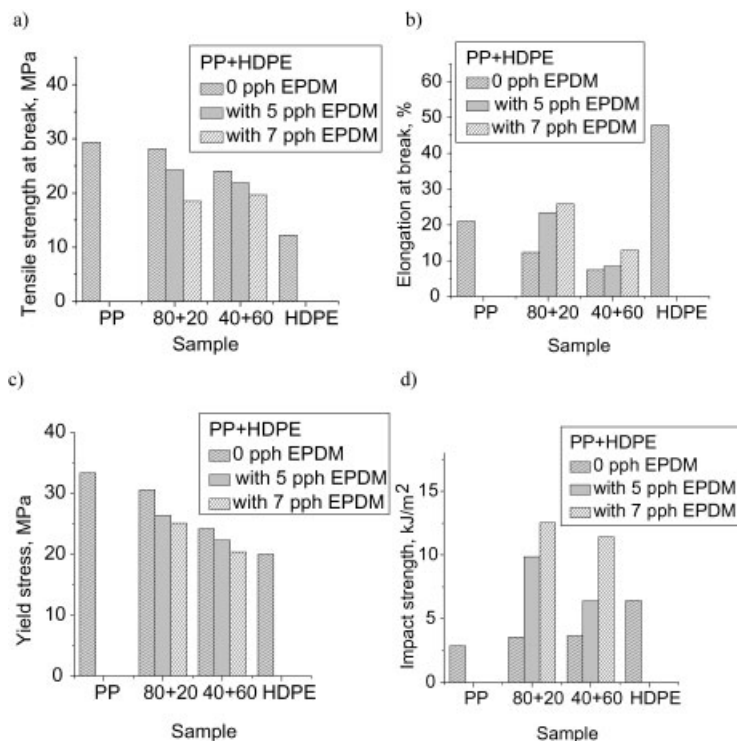


Figure 2.

Mechanical properties of PP+HDPE blends: a) Tensile strength at break, b) elongation at break, c) yield stress and d) impact strength.

slightly increased the values of impact strength (Figure 2d). The SEM micrographs (Figure 1a and 1d) showed non compatible PP and HDPE phases, which lead to cracks and fracture at interphase boundaries.^[2] Addition of EPDM (5 and 7 pph) in PP+HDPE blends drastically improved impact strength and the values were higher even than the neat HDPE (Figure 2d). Effect of impact strength improvement upon EPDM addition was much more expressed in PP – rich phase blend and with higher EPDM content, what together with SEM micrographs indicated better compatibility of PP+HDPE blend.

Figure 3 a shows DSC melting curves of pure polymers and their blends. The values of melting endotherms (T_m) are presented in Table 1. The melting endotherms (T_m) of neat PP and neat HDPE were 161.56 °C and 130.63 °C (Table 1). In PP+HDPE blends and PP+HDPE+EPDM blends two melt-

ing endotherms, which corresponded to PP and HDPE phases, were observed (Figure 3a). T_m of PP phase and T_m of HDPE phase in PP+HDPE blends were slightly decreased compared to neat PP. Addition of EPDM in PP+HDPE blends did not show significant change in melting points of PP phase.

In PP+HDPE 80 + 20 blend upon addition of EPDM slightly decreased T_m of HDPE phase, while in PP+HDPE 40 + 60 blend T_m of HDPE phase slightly increased upon EPDM addition.

The crystallization thermograms of PP+HDPE blends with and without EPDM, as well as the thermograms of neat PP and HDPE are shown in Figure 3b and the values of crystallization points are presented in Table 1. The crystallization point, T_c , of PP and HDPE from crystallization thermograms were 118.47 °C and 114.70 °C (Table 1). In PP+HDPE blends

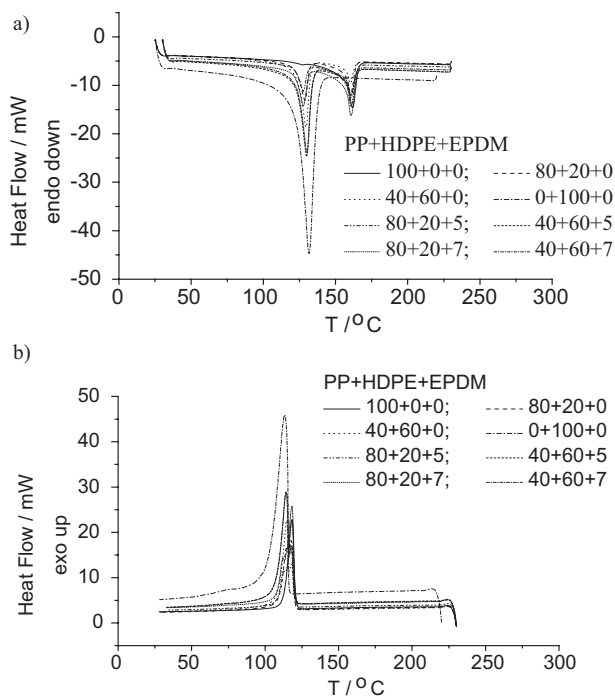


Figure 3.

(a) DSC heating curves and (b) DSC cooling curves of PP+HDPE blends.

T_c of PP phase and T_c of HDPE phase were not significantly changed. Addition of EPDM in PP+HDPE 80+20 blends, slightly increased T_c of PP phase, and T_c of HDPE phase was decreased. Addition of 7 phh EPDM decreased the T_c of HDPE phase for 3.19 °C. Again, effect of EPDM addition on T_c was more expressed for HDPE phase, than for PP phase. The reason is the morphology of blends explained earlier.

In PP+HDPE 40+60 blends, the EPDM addition did not have effect on T_c

of PP phase and T_c of HDPE phase (Table 1).

The percentage of crystallization (X_c) of HDPE and PP in blends, compared to 100% crystalline HDPE and PP, calculated using the relationship:

$$\% \text{ crystallinity} = (\Delta H_f^{\text{obs}} / \Delta H_f^{\circ}) 100,$$

Where ΔH_f^{obs} is the observed heat of fusion values and ΔH_f° is the heat of the fusion value for 100% crystalline HDPE (278 J/g) or PP (207 J/g).^[2]

Table 1.

Melting and crystallization behavior of PP+HDPE blends.

PP+HDPE+EPDM	PP phase		PE phase		PP phase	PE phase
	$T_m/^\circ\text{C}$	$T_c/^\circ\text{C}$	$T_m/^\circ\text{C}$	$T_c/^\circ\text{C}$	$X_c/\%$	$X_c/\%$
100 + 0 + 0	161.56	118.47	/	/	31.28	/
80 + 20 + 0	160.38	117.64	128.85	114.84	19.39	15.55
40 + 60 + 0	160.19	117.61	129.57	114.65	8.84	24.75
80 + 20 + 5	160.72	118.04	127.62	112.39	26.20	9.21
40 + 60 + 5	160.51	117.74	129.94	114.31	11.75	29.43
80 + 20 + 7	160.74	118.34	127.70	111.65	21.10	10.18
40 + 60 + 7	160.60	117.75	130.25	114.40	11.92	32.01
0 + 100 + 0	/	/	130.63	114.70	/	62.06

The percentage of crystallization (X_c) of neat HDPE and neat PP are found to be 62.06% and 31.28% (Table 1). X_c of HDPE phase in the PP+HDPE blends were decreased as the amount of the PP phase increased and vice versa (Table 1).

The X_c of PP phase in PP+HDPE 80+20 blends upon addition of EPDM (5 and 7 pph) was higher than X_c of PP phase in PP+HDPE blend without EPDM addition (Table 1). The X_c of HDPE phase in PP+HDPE 80+20 blends upon addition of EPDM (5 and 7 pph) was decreased in comparison with X_c of HDPE phase in non compatibilized 80+20 blend (Table 1). EPDM addition hampered the process of crystallization of HDPE, as a result of HDPE and EPDM composite particles morphology.

In PP+HDPE 40+60 blends with EPDM addition X_c of PP phase was

increased, as well as the X_c of HDPE phase (Table 1). In this blend, the higher increase of X_c was obtained for HDPE phase.

In DMA relaxation spectra's several relaxation maximums were observed (Figure 4a). The neat HDPE has two relaxation maximum, one at negative temperature (-152.3°C), γ relaxation, and is believed to be associated with segmental motion of as few as three or four methylene groups in the carbon-carbon backbone in the amorphous phase, and is considered the primary glass transition of PE,^[28] and at positive temperature (61.53°C), α relaxation, and is related to the onset of molecular motion in the crystalline phase.^[28]

According to McCrum et al.^[29] PP exhibited three relaxations peaks, α , β and γ relaxation maximum. β relaxation maximum is believed to correspond to the glass transition temperature (28.72°C), and

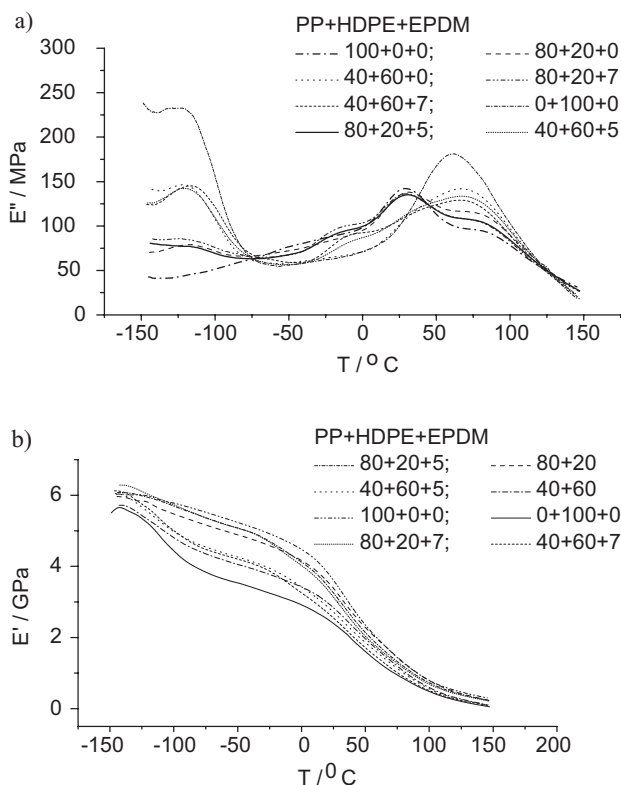


Figure 4.

DMA spectra's of PP+HDPE blends: (a) loss modulus (E'') vs. temperatures (T) and (b) storage modulus (E') vs. temperatures (T).

α -relaxation, which looks like a shoulder (74.26 °C), is related to a slip mechanism of polymer chains in the crystallites. The γ -peak is due to motions of small-chain groups like methyl and methylene, and is present at negative temperature.

The neat EPDM has glass transition temperature (T_g) at -40.08 °C (Table 2).

In DMA spectra of PP+HDPE 80 + 20 blend (Figure 4a, Table 2) was observed γ relaxation of HDPE (-118 °C), β relaxation of PP (30.20 °C), α relaxation of PP (77.62 °C). α relaxation maximum of HDPE was overlapped with α relaxation maximum of PP. Since the PP is matrix in this blend, α relaxation maximum of PP was more expressed in DMA spectra than α relaxation maximum of HDPE.

In PP+HDPE 80 + 20 blends the addition of EPDM (5 and 7 pph) slightly decreased T_g value of PP. α relaxation of PP in PP+HDPE 80 + 20 blends upon EPDM addition was shifted to lower values (Table 2, Figure 4a). T_g of HDPE phase in PP+HDPE 80 + 20 blends upon EPDM addition (5 and 7 pph) was shifted to lower values (Table 2, Figure 4a). By EPDM addition (5 and 7 pph) in PP+HDPE 80 + 20 blends new relaxation was observed

in DMA spectra's at negative temperature (Figure 4a, Table 2). The new relaxation maximum was more expressed with higher EPDM content and its values were noted in Table 2 as T_g of EPDM phase in PP+HDPE+EPDM blends.

In DMA spectra of PP+HDPE 40 + 60 blend two relaxation maximum were observed (Figure 4a). First maximum was at negative temperature (-121.3 °C) which correspond to T_g of HDPE. Second broad relaxation was at positive temperature (65.69 °C). It suggested that there was overlap of PP T_g and HDPE α relaxation. The usual shoulder of PP α relaxation in PP+HDPE 40 + 60 blend was not observed. We suppose that it was also overlap with HDPE α relaxation maximum. Addition of EPDM in PP+HDPE 40 + 60 blend shifted T_g values of HDPE at higher temperatures and the shift was more pronounced with higher (7 pph) EPDM content. The response from PP β relaxation and HDPE α relaxation was broader with EPDM addition. The temperature value of HDPE α relaxation was shifted to higher temperature in PP+HDPE 40 + 60 blend with 5 pph EPDM, and with 7 pph of EPDM was shifted to lower value. Also in

Table 2.

Glass transition temperatures (T_g) and intensity (I) of loss modulus (E'') of PP+HDPE blends.

PP+HDPE+EPDM	PP phase		EPDM phase		PE phase	
	$T_g/^\circ\text{C}$	$I\beta, \alpha_c$	$T_g/^\circ\text{C}$	$I\alpha$	$T_g/^\circ\text{C}$	$I \gamma, \alpha_c$
	E'', β peak	E''/MPa	E''/MPa	E''/MPa	E'', γ peak	E''/MPa
	E'', α_c peak				E'', α_c peak	
100 + 0 + 0	28.72	142.7				
	74.26	96.67	/	/	/	/
80 + 20 + 0	30.20	138.2			-118.0	79.43
	77.62	114.7	/	/	/	/
40 + 60 + 0	/	/	/	/	-121.3	146.4
	/	/	/	/	65.69	142.1
80 + 20 + 5	29.74	135.8			-121.7	77.57
	74.47	107.3	-9.906	96.14	/	/
40 + 60 + 5	/	/	-9.564	81.43	-120.2	142.9
	/	/	/	/	67.71	133.6
80 + 20 + 7	29.10	136.7			-125.7	85.33
	75.94	106.7	-11.63	100.7	/	/
40 + 60 + 7	/	/	-11.19	90.48	-117.8	145.7
	/	/	/	/	64.95	129.5
0 + 100 + 0	/	/	/	/	-125.3	233.1
	/	/	/	/	61.53	182.0
0 + 0 + 100	/	/	-40.08	42.14	/	/

Table 3.
Storage modulus (E') values of PP+HDPE blends.

PP+HDPE+EPDM	E' /GPa	
	$-100\text{ }^{\circ}\text{C}$	$25\text{ }^{\circ}\text{C}$
100 + 0 + 0	5.78	3.67
80 + 20 + 0	5.48	3.38
40 + 60 + 0	4.81	2.81
80 + 20 + 5	5.69	3.29
40 + 60 + 5	4.98	2.69
80 + 20 + 7	5.73	3.14
40 + 60 + 7	5.01	2.55
0 + 100 + 0	4.44	2.40

PP+HDPE 40 + 60 blends with 5 and 7 phh of EPDM was observed new relaxation at negative temperature (in Table 2 noted as T_g of EPDM phase). With higher EPDM content relaxation maximum of EPDM was more pronounced.

The highest value of storage modulus had the neat PP and the lowest value was observed in the neat HDPE (Figure 4b, Table 3). Addition of HDPE to PP decreased the values of storage modulus in PP+HDPE blends. The curves of storage modulus (E') vs. temperatures (T) of PP+HDPE and PP+HDPE+EPDM blends were between the E'/T curves of neat homopolymers (Figure 4b). Upon addition of EPDM in PP+HDPE blends the storage modulus was increased at negative testing temperature ($-100\text{ }^{\circ}\text{C}$). This increase of E' is more expressed with higher content of EPDM (Figure 4b, Table 3). At positive testing temperature ($25\text{ }^{\circ}\text{C}$) addition of EPDM decreased the values of storage modulus. It is more reduced with higher EPDM content (Figure 4b, Table 3). The storage modulus at negative testing temperature in ternary blends was higher than those in binary blends since testing temperature is below T_g of the EPDM, thus the EPDM is in a glassy state and results in a higher modulus.^[21] At positive testing temperature EPDM is in rubbery state,^[21] so the modulus of PP+HDPE+EPDM blends were decreased.

Conclusion

The present work showed that EPDM act as compatibilizer in PP+HDPE blends.

SEM micrographs of PP+HDPE blends revealed poor adhesion between PP and HDPE phases. Finer morphology was obtained by EPDM addition in PP+HDPE HDPE blends and better interfacial adhesion. Addition of HDPE to PP decreased tensile strength at break, elongation and yield stress. Decrease of tensile strength and yield stress is faster with EPDM addition in PP+HDPE blends. Elongation at break and impact strength significantly increased with EPDM addition. The addition of EPDM in PP+HDPE blends did not significantly change melting points of PP phase, while melting points of HDPE phase was slightly decreased in PP+HDPE+EPDM blends. The EPDM addition increased the percentage of crystallization (X_c) of PP in PP+HDPE blends. The increase of X_c of HDPE was found in the blend with HDPE as matrix. Dynamical mechanical analysis showed glass transitions of PP and HDPE phase, as well as the relaxation transitions of their crystalline phase. By addition of EPDM glass transitions of HDPE and PP phase in PP+HDPE blends decreased. Storage modulus (E') vs. temperatures (T) curves are in the region between E'/T curves of neat PP and HDPE. The decrease of E' values at $25\text{ }^{\circ}\text{C}$ with EPDM addition in PP+HDPE blends is more pronounced.

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