ABSTRACT

In this study, polypropylene (PP) and polyethylene terephthalate (PET) were blended using a single screw extruder and then fibre formation was carried out through the spinneret. The effects of PET content and PP-g-GMA as a compatibilizer were also investigated. The morphology and mechanical properties of uncompatibilized and compatibilized PP/PET fibres were comprehensively assessed utilizing scanning electron microscopy (SEM) and tensile experiments. Likewise, the drawabilities of both compatibilized and uncompatibilized systems using hot and cold methods were evaluated. It was observed that the optimum fibrillar distributed morphology would be achieved at 8 wt% of PET. Furthermore, addition of compatibilizer showed no significant morphology changes and mechanical performance improvement, although applying 3.5 wt% PP-g-GMA would result in higher crystallinity in fibres due to the nucleating effect of compatibilizer in these blends. However, the total results suggest that the fibre blend system would be improved using suitable amount of compatibilizer with proper grafting of GMA onto PP. Finally, in order to investigate the effect of compatibilizer, a sample of PP/PET blend was compatibilized with PP-g-MA as well. Mechanical properties data have shown that the PP/PET blend compatibilized with PP-g-GMA has a significant performance compared to other systems.

INTRODUCTION

Blending polyolefins with engineering plastics is a commonly used method to improve the mechanical properties of polymeric materials [1]. However, most polymer blends are thermodynamically immiscible, thus blending immiscible polymers which is widely considered as a viable and economical technique would result in polymeric products with poor mechanical properties. Polymer blends would take the advantages of desirable properties of the constituents and have the ability to be recycled after the initial product has served its purpose [2-5].

In general, effective factors on
the morphology of immiscible blends include composition of the blends, interfacial tension, differences in viscosity and elasticity of constituents, and processing conditions, i.e., temperature, residence time, shear rate, shear stress, and total strain [6-8]. Synthetic fibres based on fibre-forming polymer blends are specified as a special fibre group in which the variation of properties in fibres can be reached by using two or more components in the fibre-forming polymer blends [8,10]. Fibres from poly (ethylene terephthalate) (PET) and polypropylene (PP) blends are mainly used in general purpose and engineering textiles. These blends can lead to fibres with improved chemical resistance and moisture properties, impact strength, tensile strength, and flexural modulus [9,11].

Several studies have been devoted to the development of phase morphology and mechanical properties of PP/PET blends using reactive [12] or non-reactive additives such as PP-g-MAH [13] or PP grafted itaconic acid [14]. Due to the grafting probability of glycidyl methacrylate (GMA) onto PP and its reactivity with end groups of PET in the blend, this reactive compatibilizer has been under investigation during the last two decades [15]. During these years, the formation of polymer blends that result in a fibrillar phase morphology has been extensively investigated.

In the present study, the mechanical and structural properties of PP/PET fibres were investigated as a function of PET content and compatibilizer addition. The effect of PET content in the range of 2 to 10 wt% was studied on the properties of produced fibres. Later on, the fibres were developed in the presence of PP-g-GMA as a new compatibilizer and the effect of compatibilizer on the thermal and mechanical behaviour of the fibres was examined. Drawability of blend fibres was assessed with hot and cold drawing methods.

EXPERIMENTAL

Materials
Commercial fibre grade isotactic PP, known as V30S was provided by Arak Petrochemical Co., Iran. PP had a melt flow Index (MFI) of 16 (g/10 min), density of 0.92 (g/cm³) and melting point (T_m) of 165°C. PET fibre grade was purchased from Noyvalesia Co., Italy. It has intrinsic viscosity (IV) of 0.64 (dL/g) and T_m of 256°C. PP-g-GMA and PP-g-MA were synthesized in our laboratory with a GMA content of 2.69 phr and MA content of 2.37 phr. The full method of synthesis would be found elsewhere [13,16]. Irganox B215 (Ciba-Geigy, USA) was used as antioxidant with constant amount of 0.5 wt% in all polyblends.

Melt Spinning of Blend into Fibre
Melt spinning was performed using a single-screw (L/D=30) melt extruder with two different types of spinneret with 2 mm and 2.3 mm orifice diameters, respectively.

Temperatures of different zones of the extruder were set as 190, 235, 255 and 225°C, for feed, metering, die, and spinneret sections, respectively. The screw was run at fixed screw speed of 11 rpm. Undrawn filament was collected at a take-up speed of 160 m/min. The fibre blends were obtained by melt blending of PP with 2, 5, 8 and 10 wt% PET. The PET granules were dried in a vacuum oven for 24 h at 110°C before melt spinning [17].

Drawing Machine
While melt spinning was completed by an orifice of 2.3 mm diameter, some samples were drawn with a fibre drawing system operating with two rotating rolls with different speeds of 18 and 100 rpm, at room temperature and 110°C, respectively.

Scanning Electron Microscopy
The morphology of fibres was studied using Philips scanning electron microscope, XL30 model at 20 KV accelerating voltage. SEM micrographs were taken from fractured surfaces of polyblends specimens after immersion in liquid nitrogen. The surfaces were coated with a layer of gold before testing.

Mechanical Testing
Tensile test was performed at room temperature at cross-head speed of 50 mm/min and gripper gap of 5 cm.

Thermal Analysis
Thermal behaviour of drawn fibres was measured
using DSC. Specimens of 3-5 mg were encapsulated in aluminium pans and heated at the rate of 10°C/min from room temperature to 300°C. The degree of crystallinity, $X_c$, of PP was calculated from the following equation:

$$X_c = \frac{\Delta H_m}{x\Delta H_m^*} \times 100$$  

Where, $\Delta H_m^*$ = 50 cal/g is the fusion enthalpy of crystalline PP [18], and $x$ is the weight fraction of PP in the polyblend fibres.

RESULTS AND DISCUSSIONS

Structural and Mechanical Properties

Uncompatibilized PP/PET Blend

Tensile strength, Young’s modulus, and elongation-at-break of fibres at different contents of PET are illustrated in Figures 1a-1c. As it is shown, increasing the amount of PET in PP matrix up to 8 wt% increases the modulus, elongation-at-break, and tensile strength of blend fibres. However, for the higher percentage of PET, these properties decrease. Several studies showed that by increasing PET content in PP results in improvement of the tensile strength because PET functions as a reinforcing agent in PP matrix [17].

In addition, the decrease in mechanical properties of the sample containing 10 wt% of PET could be attributed to the blend morphology (Figure 2). As shown in Figure 2, because of low concentration of dispersed phase, the morphology of sample with 2 wt% of PET (Figure 2a) is similar to pure PP. There is a discontinuity around all the interfaces in blends containing 5 wt% PET (Figure 2b). More improvements in properties of sample with 8 wt% of PET are due to formation of nearly uniform distributed fibrils of PET through the matrix (Figure 2c).

On the contrary, SEM micrograph of sample with 10 wt% of PET shows a strong segregation of phases, which is assumed to be due to the enlargement of particle size of dispersed phase more than the other samples. This could be an indication of weak adhesion at the interphases of PP/PET components (Figure 2d) leading to the deterioration of the tensile properties of the blend relative to PP fibres [12,15].

Compatibilized PP/PET Blend

SEM Micrographs of compatibilized samples are...
demonstrated in Figure 3. In this system, due to the presence of PP-g-GMA as a compatibilizer, interfacial adhesion between two phases is obviously improved through the placement of compatibilizer at the interface.

Furthermore, by increasing compatibilizer content from 0.5 to 3.5 wt% for the system containing 8 wt% of PET, both orientation and interfacial adhesion are improved, whereas for the sample consisting 3.5 wt% compatibilizer, the fibrillar structure is dominant (Figure 3c).

**Figure 2.** SEM Micrographs of PP/PET fibre blends at: (a) 2, (b) 5, (c) 8, and (d) 10 wt% of PET.

**Figure 3.** SEM Micrograph of compatibilized fibres with: (a) 0.5, (b) 2, and (c) 3.5 wt% of PP-g-GMA (2000x).
Figures 4a-4c show the tensile properties of compatibilized systems with different amounts of PP-g-GMA (0.5, 2 and 3 wt%) and PP-g-MA just for 2 wt%. As it is illustrated in these figures, tensile properties of compatibilized systems except modulus are nearly lower than those of the uncompatibilized samples and hardly differ by changing the amount of PP-g-GMA.

This behaviour in tensile properties may be attributed to the residual orientation in PET phase that remains unreleased during fibres discharge through the die. Therefore, it quickly reaches the strain hardening domain and tends to have more brittle behaviour [10]. Therefore, brittleness has caused some decreases in elongation-at-break of compatibilized samples. However, the modulus of fibres has
increased in comparison with uncompatibilized samples which indicate the formation of fibrillar structure and interfacial adhesion improvements in compatibilized systems. According to these results, sample containing 3.5 wt% of compatibilizer has better tensile properties. It is interesting to mention that with the same amount of compatibilizer content, the properties of fibre blends compatibilized with GMA-based compatibilizer are significantly higher than MA-based compatibilizer. This is due to more reactivity of PP-g-GMA macroradicals interacting with PET chains end group rather than PP-g-MA active sites.

**Drawing Effects on Mechanical Properties**

The results of tensile test on uncompatibilized sample with 8 wt% PET and compatibilized system with 3.5 wt% PP-g-GMA are compared in Figures 5a-5c for undrawn, hot-drawn, and cold-drawn samples. From these figures, it is obvious that drawing of both compatibilized and uncompatibilized fibres would result in a significant increase in tensile strength and modulus values. This is due to the stress-induced orientation and crystallinity in fibres. In hot-drawn samples, due to higher chain mobility and thus higher orientation within the samples, mechanical properties were improved significantly. In other words it is interesting to note that hot-drawn compatibilized fibres show more enhanced tensile strength than uncompatibilized system. This is partially due to the release of residual orientation in dispersed phase during simultaneous action of tension and heat. The Young’s modulus of drawn fibres showed the same trend as tensile strength.

Elongation-at-break results exhibit a dramatic decline for drawn fibres, which obviously is the result of stretching of the polymer molecules on drawing.

**Differential Scanning Calorimetry**

The amount of crystallinity in uncompatibilized and compatibilized systems containing 8 wt% PET was evaluated using DSC curves of polyblends which are given in Figure 6. The results of crystallinity measurements are tabulated in Table 1. From the results it can be concluded that the melting temperature of PP in polyblend fibres is rather decreased compared with the neat PP fibres.

![Figure 6. DSC Thermograms of drawn fibres of: (a) 92/8/0 and (b) 88.5/8/3.5 of (PP/PET/PP-g-GMA).](image)

According to the obtained results, it is evident that crystallization temperature is shifted towards lower values by addition of compatibilizer, and therefore the degree of crystallinity is increased. To explain this result, it may be suggested that the compatibilizer serves as the nucleating agent due to the higher interfacial interaction in compatibilized system, thus, leading to the increase in crystallinity percentage.

**Table 1. DSC Results of hot drawn fibres of PP pure sample uncompatibilized PP/PET blend, and compatibilized system by PP-g-GMA.**

<table>
<thead>
<tr>
<th>Sample composition</th>
<th>Xc (%)</th>
<th>Tc (°C)</th>
<th>Tm (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP/PET (92/8)</td>
<td>41.7</td>
<td>117.56</td>
<td>165.04</td>
</tr>
<tr>
<td>PP/PP-g-GMA/PET (88.5/3.5/8)</td>
<td>53.3</td>
<td>108.96</td>
<td>166.95</td>
</tr>
</tbody>
</table>
CONCLUSION

Investigation of the morphological and mechanical aspects of PP/PET blends as a function of PET content suggests that fibre properties are optimum at about 8 wt% of dispersed PET in PP matrix, where below this value, the morphology is heterogeneous and beyond this value the particle size of dispersed phase is rather large. In compatibilized fibre blends, SEM micrographs show that by increasing the amount of PP-g-GMA as compatibilizer from 0.5 to 3.5 wt% the orientation is significantly improved due to the enhanced interfacial adhesion.

Tensile test results suggest that fibrillar morphology remains unchanged during compatibilization. Drawing both compatibilized and uncompatibilized fibres has led to significant improvement in tensile strength and modulus due to stress-induced orientation and crystallinity in fibres. Hot drawing of compatibilized sample further enhanced the tensile strength in comparison with uncompatibilized system. The results of crystallinity measurements, using DSC, illustrate lower crystallization temperature and higher degree of crystallinity in compatibilized system.

REFERENCES

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