Characterization of Polyethylene Terephthalate and Functionalized Polypropylene Blends by Different Methods

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ABSTRACT

The properties of polyethylene terephthalate (PET) and polypropylene (PP) blends and PET with functionalized PP blends were investigated. Two compatibilizers such as: polypropylene functionalized maleic anhydride (PP-MA) and polypropylene functionalized acrylic acid (PP-AA) have been used. Several combination methods were used to characterize the blends. The differences between the properties of the blends with PP and functionalized PP indicate that functionalization had some effects. The amount of functional group is the most important factor in determining the morphology and mechanical properties. An enhancement in morphology, thermal and mechanical properties were due to interaction and adhesion between the functionalized groups with PET end groups. FTIR Spectroscopy confirmed interaction of PET end groups with functionalized PP by shifts in absorption bands of OH and C=O groups to lower frequencies due to functionalization. Solubility test provided further evidence for improved affinity between the functionalized PP and PET compared with untreated compounds.

Key Words: blending, compatibilization, polyethylene terephthalate, polypropylene, functionalized PP

INTRODUCTION

Immiscible polymer blends are often preferred over the miscible types since they may combine some of the important characteristics of each blend component. Minimizing interfacial tension, and improving adhesion between the two phases \([1,2]\) usually attains satisfactory performance in immiscible blends.

Compatibility of immiscible blends may be improved by adding a third compatibilizing component (e.g., block or graft copolymers) or by adding suitable functionalized polymers capable of enhanced specific interactions and chemical reactions in reactive systems. A copolymer may be formed in situ during mixing, acting with similar manner as the above compatibilizer added separately.

Polymers under investigation are PET and PP which are not compatible and their blending will...\(^{193}\)
produce large phases with weak interfacial bonding and poor mechanical properties. Although these two polymers are major polymers, but literature studies show few works on this subject [3, 4], and besides there is no commercial polyolefin/polyester blend on the market. The work on PET/PP blends stemmed from our interests in recycling post-consumer plastics. Potential markets for recycled plastics are numerous e.g., geo-textiles, park benches, garbage cans and highway post [5].

The suitability of these polymers for blending can be assessed by their individual characteristics. The melting point $T_m$ and glass transition temperatures $T_g$ of PET (250 °C and 80 °C, respectively) are higher than PP (165 °C and 7–10 °C, respectively) [6]. Consequently PET could be expected to be capable of reinforcing the PP at higher temperatures. In any case, PET is generally stiffer than PP because of the presence of fewer methylene groups between the stiffening groups such as carbonyl and phenylene groups [7]. The properties of both PET and PP are reported in literature [8–11].

Since the permeability of PET to gases is much lower than PP and permeability to water is higher than PP, a blend could be expected to combine the barrier properties of both components. The polymers are also complementary in their resistance to solvent and chemical attack.

The structural differences which are responsible for the differences in resistance to solvent and chemical attack also result in different types of chemical modification. These various complementary features together with the limited extent to which studies on PET/PP blends have been reported in the literature and the economic importance of both types of polymer, it is suggested that these blends might make a suitable topic for investigation.

According to theoretical model of polymer blending the ability to control blend morphology and properties depends basically on the mixing process, the rheology of components and the interfacial properties [2,3,12,13].Compatibilization can be achieved by melt blending of two polymers containing functional groups that react with each other [14]. In such a case, a graft copolymer is formed in situ during melt blending. Recently, much attention has been directed towards functionalized PP (e.g., PP-MA and PP-AA) with polyester [4,15,16]. Although the processing conditions for blending PET with PP and the preparation of functionalized PP was reported in previous paper [17], in this work we compare a range of characterization techniques in order to investigate the mechanical and physical properties for the prepared blends, including tensile strength, impact strength, SEM, DSC, FTIR and Moula’s test.

EXPERIMENTAL

Materials
The sources and characterization of the materials are given in Table 1.

Blend Preparation
The materials were pre-dried (at 120 °C for 24 h). The blends compositions of 95/5, 90/10, 75/25, 60/40 and

Table 1. Sources and characterizations of materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Trade name</th>
<th>Supplier</th>
<th>Density*</th>
<th>Melt temp* (°C)</th>
<th>Molecular weight</th>
<th>MFR ASTM D1238</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>Kodapak 9901W</td>
<td>Eastman Chem.</td>
<td>1.4</td>
<td>250</td>
<td>52000</td>
<td>23.5 g/10 min</td>
</tr>
<tr>
<td>PP</td>
<td>Moplen X30S</td>
<td>Arak.P.C.C.Iran</td>
<td>0.92</td>
<td>165</td>
<td>232000</td>
<td>30 g/10 min</td>
</tr>
<tr>
<td>PP-MA</td>
<td>Excalor PO1015</td>
<td>Exxon Chem.</td>
<td>0.95</td>
<td>146</td>
<td>60000</td>
<td>150 g/10 min</td>
</tr>
<tr>
<td>PP-AA</td>
<td>Polybond 1001</td>
<td>Uniroyal Chem.</td>
<td>0.9</td>
<td>160</td>
<td>131600</td>
<td>43.63 g/10 min</td>
</tr>
<tr>
<td>phenol</td>
<td>—</td>
<td>Merck</td>
<td>1.071</td>
<td>40–42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetrachloroethane</td>
<td>—</td>
<td>*</td>
<td>1.598</td>
<td>54–56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Data for original supporting samples.
40/60 with and without functionalized PP were mixed with a mixture of 0.1% of antioxidants (Irganox 1098 and B-215) and carried out in an intensive batch mixer (Haake-Buchler Rheoehord 90). The operation conditions, which were obtained from previous work [17], was at a rotor speed of 80 rpm, wall temperature of 260 °C for a mixing time of 6 min. The blends were then removed from the mixer, passed between two metal plates and cooled to room temperature. The same procedure was used to produce samples of PET, PP, PP-MA and PP-AA in order to give the same thermal and shear history as for the blends.

Measurements
Test samples for mechanical properties were prepared on the Universal Testing Machine, Instron Model 6025, using ASTM D-638 for tensile testing and a Zwick Impact Tester Model 5102 (ASTM D-256) for impact testing. The surfaces of impact fractured samples were used for morphological investigations.

A Cambridge Stereoscan Model 360 scanning electron microscopy (SEM) was used to study the morphology of PET with PP and functionalized PP. Thermal analysis was performed by using PL-DSC differential scanning calorimeter. The samples were scanned at a rate of 10 °C/min from room temperature to 280 °C. The samples were held at 280 °C for 5 min, and cooled to room temperature at the same rate to obtain the crystallization thermograms. The second melting thermograms were obtained using the same heating conditions as the first samples.

The IR films for all the pure components and the blends were prepared by compression moulding using a Davenport 25 ton laboratory press. The conditions were kept constant (~1 mm thickness, at 265 °C and 150 psi for 5 min and then the films were cooled to room temperature by circulating water). A Bruker Model IFS-48 FTIR spectrophotometer was used to characterize the films at a resolution of 4 cm and three times scanning. Spectra were obtained over wavenumber 4000–500 cm⁻¹. Moulau’s test was applied to determine the solubility of PP and functionalized PP in the PET matrix during the blending process. Samples of each 0.5 g were dissolved in 5 mL of 60/40 w/w mixture of phenol and tetrachloroethane solvent in a test tube and heated in an oil bath above 120 °C. When the PET test tubes appeared to be clear, indicating that PET was being dissolved, the tubes were cooled to room temperature and were arranged in a rake and photographed.

RESULTS AND DISCUSSION
Mechanical Properties
The results of the mechanical testing of PET blends with functionalized and non-functionalized PP are shown in Figures 1–3. The impact strength values of the blends which are shown in Figure 1 decrease by the increased amount of PP or functionalized PP. The impact values of the blends at all compositions are poor because they are lower than that of pure PET and PP.

The tensile modulus of blends is given in
Figure 2. In the low range of PP, PP-MA and PP-AA (5–10%), the tensile modulus values are increased, showing positive blending effect, and then decreases to the same values of pure PP, PP-MA and PP-AA. The increases in the tensile modulus may be due to crystallinity of PET, which implies that the toughness is inferior when compared to that of the pure PET [18]. The highest modulus value corresponded to PET/PP-AA blend of 95/5. Surprisingly, the modulus at the ratio of 75/25 PET/PP-MA was found higher than the other blends for the same ratio. The modulus values for the components were in the order of:

PET/PP-MA > PET/PP > PET/PP-AA

Figure 3 shows the tensile strength at break of the blends for different compositions. It can be observed that the tensile strength for all blends reduce more than that of pure PET at low level (5%) of PP and functionalized PP, but it rises at 25% level to a maximum value. The changes in tensile strength, and modulus indicate that the sample of 5% blend was significantly more brittle than PET itself. A simple, overall interpretation is that blending lowered the resistance of PET to fracture. Electron microscopy confirmed that the PP or functionalized PP was present as droplets with a diameter of a number of millimicrons and provided evidence for little or no adhesion at the interface. Results of IR spectroscopy supported this finding. The mechanical testing results show that 25% of functionalized PP has more significant contribution in improvement of the tensile properties, suggesting that it gives more adhesion to PET. It can be seen that the PET/PP-MA blend shows good tensile and modulus properties even more effective than the others.

DSC thermograms show further evidence of these improved properties as described in the crystallinity study in the following paragraphs and by SEM as well. The differences between the properties of the blends with PP and functionalized PP indicate that functionalization has some advantages. The changes in melting point and crystallization temperature for PET caused by blending with the different types of PP provide evidence for interactions between the phases and the variations from one type of PP to another showing that the interactions depend on the type of PP.

**Morphological Properties**
Results obtained from morphological studies support the changes in mechanical properties. In comparison, PET/PP-MA and PET/PP-AA have better interfacial adhesion and fine particle morphology than PET/PP blends. In Figures 4–6 the blend ratio of 75/25 in which the continuous phase is composed of PET and the disperse phases are PP, PP-MA and PP-AA, respectively are shown. In PET/PP blends, there are
large particles and sharp boundaries which are not attached to the continuous phase. When the functionalized PP was used for compatibilizing with PET (Figures 5 and 6) the dispersed particles were reduced and the interfacial adhesion of the phases has been improved.

The results suggest that the functionalized PP has better compatibility with PET than PP. The enhanced compatibility of MA and AA functionalized PP with PET may confirm the interaction between PET and functionalized PP during melt mixing. The interaction and adhesion between the PET and PPMA and PP-AA phases are due to intermolecular dipole-dipole interactions between the carbonyl oxygen present in reactive maleic and acrylic acid groups and the hydrogen in the hydroxyl group of PET [18, 19]. At 75/25 blend ratio it can easily be seen that the blends have much smaller particle morphology and better interfacial adhesion than the other compositions. Similar morphologies have been observed by other authors [19–22].

Thermal Behaviour
Thermal properties analyzed by DSC for pure components and various blends are summarized in Tables 2–4. The T_m and T_c of pure PET and PP are 250, 198, 166 and 113.7 °C, respectively. These are in good agreement with the reported range for commercial polymers [23]. The T_m and T_c peaks of PET at 25–75% level of PP in the blends are similar to pure PET. This means that the blends are incompatible, but at 5–10% levels the T_m’s are shifted to lower values and T_c’s are shifted to higher values than that of pure PET. When the amount of PP is increased, the T_m of PP in the blends are shifted slightly to lower temperature (levelled at about 160.5–162 °C) and the T_c’s are shifted to higher temperatures. The percent crystallinity of PET slightly decreases when the amount of PP in the blend increases. While the percent crystallinity of PP increases by increasing the amount of PP in the blends. Surprisingly, in the 25% PP blend, the percent crystallinity of PP rises to 37.5 in comparison to other compositions.

The crystallization behaviour of the minor component in these blends has been suggested to be due to migration of nuclei across the interface and to nucleating agent-like behaviour of the already crystallized minor component, or to an altered chain mobility in the interface [6, 24].

According to the above mentioned arguments, the PP provides nucleation sites for crystal formation, with a consequent increase in the tensile modulus and decrease in the tensile strength of the compounds. The

Figure 5. SEM Micrograph of PET/PP-MA blend (75/25) at a magnification of 1500x.

Figure 6. SEM Micrograph of PET/PP-AA blend (75/25) at a magnification of 1500x.
Table 2. DSC Thermograms data of pure PET, PP and PET/PP blends.

<table>
<thead>
<tr>
<th>Ratio</th>
<th>PET T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>PET T&lt;sub&gt;c&lt;/sub&gt; (°C)</th>
<th>PET Crystallinity (%)</th>
<th>PP T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>PP T&lt;sub&gt;c&lt;/sub&gt; (°C)</th>
<th>PP Crystallinity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>249.9</td>
<td>198.0</td>
<td>28.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>95/5</td>
<td>245.0</td>
<td>203.3</td>
<td>28.7</td>
<td>-</td>
<td>122.0</td>
<td>31.8</td>
</tr>
<tr>
<td>90/10</td>
<td>245.9</td>
<td>203.4</td>
<td>28.3</td>
<td>-</td>
<td>122.8</td>
<td>30.3</td>
</tr>
<tr>
<td>75/25</td>
<td>249.4</td>
<td>198.0</td>
<td>26.0</td>
<td>160.4</td>
<td>120.5</td>
<td>37.7</td>
</tr>
<tr>
<td>50/50</td>
<td>249.9</td>
<td>198.4</td>
<td>27.7</td>
<td>160.5</td>
<td>117.0</td>
<td>30.8</td>
</tr>
<tr>
<td>25/75</td>
<td>249.9</td>
<td>196.2</td>
<td>28.6</td>
<td>162.0</td>
<td>119.4</td>
<td>36.0</td>
</tr>
<tr>
<td>0/100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>166.0</td>
<td>113.7</td>
<td>40.8</td>
</tr>
</tbody>
</table>

Table 3. DSC Thermogram data of PET/PP-MA blends.

<table>
<thead>
<tr>
<th>Ratio</th>
<th>PET T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>PET T&lt;sub&gt;c&lt;/sub&gt; (°C)</th>
<th>PET Crystallinity (%)</th>
<th>PP-MA T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>PP-MA T&lt;sub&gt;c&lt;/sub&gt; (°C)</th>
<th>PP-MA Crystallinity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>249.9</td>
<td>198.0</td>
<td>28.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>95/5</td>
<td>248.0</td>
<td>200.0</td>
<td>30.2</td>
<td>-</td>
<td>117.0</td>
<td>16.9</td>
</tr>
<tr>
<td>90/10</td>
<td>246.0</td>
<td>200.5</td>
<td>31.4</td>
<td>140.3</td>
<td>113.0</td>
<td>16.9</td>
</tr>
<tr>
<td>75/25</td>
<td>245.2</td>
<td>203.4</td>
<td>30.0</td>
<td>157.6</td>
<td>111.3</td>
<td>19.0</td>
</tr>
<tr>
<td>60/40</td>
<td>246.8</td>
<td>208.7</td>
<td>31.0</td>
<td>148.2</td>
<td>111.5</td>
<td>16.0</td>
</tr>
<tr>
<td>40/60</td>
<td>249.7</td>
<td>210.0</td>
<td>25.8</td>
<td>151.7</td>
<td>111.6</td>
<td>19.6</td>
</tr>
<tr>
<td>0/100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>145.9</td>
<td>106.6</td>
<td>38.9</td>
</tr>
</tbody>
</table>

Table 4. DSC Thermogram data of PET/PP-AA blends.

<table>
<thead>
<tr>
<th>Ratio</th>
<th>PET T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>PET T&lt;sub&gt;c&lt;/sub&gt; (°C)</th>
<th>PET Crystallinity (%)</th>
<th>PP-AA T&lt;sub&gt;m&lt;/sub&gt; (°C)</th>
<th>PP-AA T&lt;sub&gt;c&lt;/sub&gt; (°C)</th>
<th>PP-AA Crystallinity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>249.9</td>
<td>198.0</td>
<td>28.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>95/5</td>
<td>249.4</td>
<td>201.6</td>
<td>25.7</td>
<td>-</td>
<td>121.3</td>
<td>23.0</td>
</tr>
<tr>
<td>90/10</td>
<td>245.1</td>
<td>206.8</td>
<td>27.9</td>
<td>159.6</td>
<td>23.3</td>
<td>22.8</td>
</tr>
<tr>
<td>75/25</td>
<td>246.0</td>
<td>208.8</td>
<td>27.7</td>
<td>165.9</td>
<td>24.7</td>
<td>35.3</td>
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<tr>
<td>60/40</td>
<td>246.0</td>
<td>208.0</td>
<td>29.5</td>
<td>62.4</td>
<td>124.5</td>
<td>32.6</td>
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<td>204.5</td>
<td>34.2</td>
<td>162.0</td>
<td>125.0</td>
<td>45.4</td>
</tr>
<tr>
<td>0/100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>164.5</td>
<td>128.5</td>
<td>54.0</td>
</tr>
</tbody>
</table>

Thermal behaviour of PET with functionalized PP blends showed that the T<sub>m</sub> of PET in the PET/PP-MA and PET/PP-AA blends are decreased by increasing the amount of functionalized PP (from 5-40%), while the T<sub>m</sub> of functionalized PP increased by decreasing the amount of PET in the blends. The results show that the crystallinity of PET in the blends in the presence of PP-MA and PP-AA increases slightly at 5-10% levels of copolymer, then it levels with slight decreases at higher levels except for PP-AA, which is increased at high level. The crystallinity of PP in the blend increased when the concentration of functionalized PP increases. Surprisingly, in the 25% of PP-MA and PP-AA the percent crystallinity values are higher than other blend ratios.

**FTIR Analysis**

Application of infra-red spectroscopy in characterization of polymer blends is extensive. FTIR Spectroscopy is used to study hydrogen bonding as well as for...
identification of the mechanism of specific interactions in polymer blends [25, 26].

In the present study the most significant peaks for PET are in different positions from the PP peaks.

**Figure 7.** FTIR Spectra for PET at 4000–500 cm$^{-1}$.

**Figure 8.** FTIR Spectra for PP at 4000–500 cm$^{-1}$.
For PET there is strong and broad peak at 1738–1722 cm⁻¹ due to carbonyl group, a peak at 3550 cm⁻¹ for hydroxyl end groups and a peak at 3433 cm⁻¹ for the carbonyl overtone. At these positions there is no peak for PP (Figures 7–9). The peaks for PET/PP blend at the ratio of 75/25 appeared at the same positions as for pure PET. A reduction of peak intensity for PET in the blend is attributable to the decrease in amount of PET in the blend as it is replaced by PP.

The FTIR spectra for pure PET, PET/PP-MA and PET/PP-AA blends at various compositions in the region of 4000–500 cm⁻¹ are illustrated in Figures 10–12, and the characteristic absorption bands associated with PET, PET/PP-MA and PET/PP-AA blends are summarized in Tables 5 and 6.

In Figure 10, it can be observed that there are shifts of absorption band at 3433 cm⁻¹ to lower wavenumbers for all the blends with respect to pure PET.

Table 5. The absorption bands of FTIR spectra for PET and PET/PP-MA blends.

<table>
<thead>
<tr>
<th>PET/PP-MA Composition (% by w)</th>
<th>O–H stretching v (cm⁻¹)</th>
<th>C=O overtone v (cm⁻¹)</th>
<th>C=O stretching v (cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>3550</td>
<td>3433</td>
<td>1738–1712</td>
</tr>
<tr>
<td>95/5</td>
<td>3550</td>
<td>3431</td>
<td>1733–1708</td>
</tr>
<tr>
<td>90/10</td>
<td>3550</td>
<td>3431</td>
<td>1731–1708</td>
</tr>
<tr>
<td>75/25</td>
<td>3547</td>
<td>3431</td>
<td>1735–1712</td>
</tr>
<tr>
<td>60/40</td>
<td>3547</td>
<td>3431</td>
<td>1735–1712</td>
</tr>
<tr>
<td>0/100</td>
<td>—</td>
<td>3412</td>
<td>1713 &amp; 1860</td>
</tr>
</tbody>
</table>

Table 6. Absorption bands of FTIR spectra for PET and PET/PP-AA blends.

<table>
<thead>
<tr>
<th>Composition PET/PP-AA (% by w)</th>
<th>O–H stretching v (cm⁻¹)</th>
<th>C=O overtone v (cm⁻¹)</th>
<th>C=O stretching v (cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>3550</td>
<td>3433</td>
<td>1738–1712</td>
</tr>
<tr>
<td>95/5</td>
<td>3549</td>
<td>3431</td>
<td>1734–1713</td>
</tr>
<tr>
<td>90/10</td>
<td>3549</td>
<td>3431</td>
<td>1734–1712</td>
</tr>
<tr>
<td>75/25</td>
<td>3547</td>
<td>3431</td>
<td>1734–1712</td>
</tr>
<tr>
<td>60/40</td>
<td>3548</td>
<td>3433</td>
<td>1733–1716</td>
</tr>
<tr>
<td>0/100</td>
<td>—</td>
<td>3432</td>
<td>1719–1715</td>
</tr>
</tbody>
</table>
PET. These observations suggest that changes in the blend composition has a significant effect on the hydrogen bonding between PET end groups and the anhydride groups of functionalized PP.

In Figure 11, a large peak at 1726-1712 cm\(^{-1}\) was assigned to C=O group of aliphatic acid ester at 1720 cm\(^{-1}\) and a broader shoulder appeared at 1850 cm\(^{-1}\) which may be due to anhydride group, suggesting that this favourable interaction could contribute to some compatibilization of this blend system.

There is a shift of carbonyl group band in PET from 1726-1722 cm\(^{-1}\) to 1712-1708 cm\(^{-1}\) for all blends compositions. These suggested the chemical interactions between carbonyl groups of PET and the anhydride groups. The intensities of absorption peaks for C=O groups shifted from 1712 cm\(^{-1}\) for pure PET to 1708 cm\(^{-1}\) for functionalized PP of a 25 % level, but it did not change for 40 % of PP-MA in the blend composition.

Several topical reviews have been published \[14,27,28\] describing a number of possible interactions.
which may cause chain cleavage followed by recombination of the end-groups that results in random and/ or block copolymer.

In the case of PET/PP-AA blends, the same phenomenon were also observed. In Figure 12, the intensity of the OH at 3550 cm$^{-1}$ decreased when the concentration of copolymer was increased, while the intensity of the COOH peak at 3300 cm$^{-1}$ decreased when the copolymer concentration rose to 25%. This may be due to some bonding between the functionalized copolymer and blends or other chains of copolymer. At higher concentrations (40% of PP-AA) in the blends, the intensity of COOH peak increased.

From Table 6, it can be seen that the absorption peaks of OH groups shifted from 3433 cm$^{-1}$ to lower wavenumber 3431 cm$^{-1}$ by increasing the percent of functionalized PP.

**Molau’s Test**

In order to study qualitatively the miscibility of PP and modified polymers in the matrix PET during the blending process, the Molau’s test was applied [29, 30]. It can be seen from the photographs (Figure 13) that the test tube containing pure PET appears clear. It means that PET particles are dissolved completely in the solvent during the heating to above 120 °C, at 30 min, while in the other tubes containing pure PP and various compositions of PET/PP blends showed a clear solution with flake-like white particles floating on the top of solution. The undissolved particles confirm that they are just PP material having been phase separated by the mixture of phenol/ tetrachloroethane solvent which has dissolved the PET phase and the PP phase is remained undissolved. The same observation was made by other authors on blending non-compatibilized PA/PP, PA/EPR [31,32]. It suggests that Molau’s test were negative for these non-compatibilized blends.

In the case of functionalized PP in PET matrix

![Figure 15. Blends at different ratios of PET/PP-AA.](image-url)
(Figures 14 and 15), it can be seen that the test tube containing small quantities (1%) of functionalized PP in PET appears clear, indicating the complete solubility of functionalized PP in PET, whereas, in the other tubes (5–25%) of functionalized PP turbid solutions would result because of the formation of grafted copolymers/PET. The increasing turbidity from 5 to 25% indicates the presence of colloidal particles, as the content of the copolymer increased. The turbidity in the case of 25% copolymers/PET is completely apparent, suggesting partial compatibility of polymer blends. While in the case of compounds above 40% of functionalized blends, it showed a clear solution with flake-like particles floating on the top of the solution.

The undissolved particles confirm that they are the higher ratios of the functionalized PP, which are not dissolved in the selective mixture of solvents for PET. This suggests that the optimum condition for miscibility can be about 25% of functionalized PP.

CONCLUSION

In blending PET with PP and functionalized PP the following conclusions were drawn from the experimental observations:

-The mechanical properties of PET/PP blends were nearly all lower in value than for the separate polymers. The only exception was a small increase in tensile modulus on blending 5% of PP with PET. However, at this composition the tensile strength reduced by much more than would be expected from the pure PP. These effects are attributed to the PP disperse phase promoting the initiation and/or propagation of fracture because each particle of the PP disperse phase does not adhere to the PET continuous phase and forms an occupied hole, which appears as a defect. The increase in modulus is attributed to the PP disperse phase resisting deformation in the PET continuous phase because it could only be compressed and not stretched owing to lack of adhesion.

The blends with functionalized PP showed considerable improvement in mechanical properties over the blends with PP itself. These improvements in strength are believed to result from better adhesion with PET.

Impact strengths were lower for the blends with functionalized polymers than for the blends with PP and were lower than for either of the separate polymers. This might be that, PP is being replaced with a functionalized PP which has a higher modulus that provides less means of absorbing or dissipating energy.

-The morphology of PET/PP blends over the whole range of compositions shows poor interfacial adhesion and large dispersed phase particles. But most interesting is the correlation between morphology and the properties of the blends which are compatibilized with functionalized PP. The improvement in compatibility indicated by the finer dispersed morphology and good adhesion between the phases in the 75/25 blend ratio seems to enhance improvements to other compositions. It can be seen that functionalized PP are quite effective in controlling phase morphology.

One expects good adhesion at the interface is feasible but not entirely sufficient for improving mechanical properties. The compatibilization effect between PET and functionalized PP is probably based on the reaction between the OH end groups of PET and MA or AA groups in PP-MA and PP-AA. Also, the PET/PP-MA blends of being more effective than PET/PP-AA blends may be due to the anhydride groups reacting more readily than other polar groups.

-DSC measurements showed some evidence of interaction between the PET and PP phases. There was little effect on the melting points but the crystallization temperatures of both polymers were raised appreciably. The changes were larger for blends containing 5 to 10% PP than for other compositions. These interactions presumably resulted from the restrictions of chain configuration.

In functionalized blends the thermal behaviour of the blends provides further evidence of enhanced interactions. The lowering of T_m and raising of T_c and enhancement of the crystallinity of PET in the blends, when the amount of functionalized PP in the blends was increased, indicated some compatibility of the two components.

-FTIR Spectra of the PET/PP blend showed no extra
peaks for the blends, neither any shifts or changes in the absorption bands of carbonyl, hydroxyl and carboxylic groups of PET, nor any changes for PP, which indicate the absence of any specific interactions or chemical reactions between the phases. In the case of functionalized blends it confirmed some interactions of PET with functionalized PP by shifts in the absorption bands of the functionalized OH and C=O groups to lower frequencies. The shifts were consistent with the formation of block copolymers.

The solubility (Molau) test also showed no signs of affinity between PET and PP in the blends. While it provided further evidence for improved affinity between functionalized PP and PET. In line with these findings from the mechanical properties, the improvement was greatest at 75/25-blend ratio.

REFERENCES