Investigation of the properties of PBT/ABS-g-GMA blends modified with epoxy resin of mid-molecular weights

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Abstract: Middle molecular weight epoxy resin was used to modify the properties of polybutylene terephthalate (PBT) and glycidyl methacrylate-functionalized acrylonitrile-butadiene-styrene (ABS-g-GMA) blends. Rheological tests showed that the complex viscosity and storage modulus of PBT increased with the addition of epoxy resin due to the chemical reactions. PBT displayed non-Newtonian fluid behaviour when epoxy resin content was 10wt% or higher. SEM results showed there was no obvious difference between the morphology of PBT/ABS-g-GMA blends when epoxy resin content was low, however, agglomeration of ABS phase took place when epoxy resin content was 10wt% or higher due to the complicated reactions. DSC results showed that the addition of epoxy resin to PBT/ABS-g-GMA blends improved the compatibility according to Tₘ depression criterion and DMA test further testified the improved compatibility. Mechanical tests showed impact strength of 902J/m and yield strength of 42MPa was achieved when 20wt% ABS-g-GMA and 5wt% epoxy resin were used, which displayed supper-toughness and much stiffer properties.

Introduction

Blends of polybutylene terephthalate (PBT) and acrylonitrile-butadiene-styrene (ABS) are of both scientific and commercial interests because of they inherit superior combination of impact strength, modulus, heat, chemical and abrasion resistance from their homopolymers [1]. PBT/ABS blends with super-toughness property can be achieved with a proper choice of materials and processing conditions even without use of any compatibilizers [2, 3]. On the other hand, reactive compatibilization using in situ reactive copolymers have more often been utilized to prepare PBT/ABS blends. In these studies compatibilizers were focused on the epoxy–functionalized copolymers [4-10], such as styrene-acrylonitrile-glycidyl methacrylate (SAG) and methyl methacrylate-glycidyl methacrylate-ethyl acrylate (MGE) copolymers. These copolymers contain epoxy groups that can react with PBT end groups (-COOH or –OH) to form block or graft copolymers at the matrix/dispersed phase interface through in situ reactions. This process reduces the interfacial tension between the blend components and retards dispersed phase coalescence via steric stabilization [11-14].

In PBT/ABS blends, the influence of ABS properties (such as ABS content, core-shell ratio, AN content and grafting degree), dispersed phase morphology, compatibilizer

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content, chemical reactions and PBT viscosity on the mechanical properties had been studied in detail [3-10]. In order to obtain super-tough PBT/ABS blends, the inter-particle distance ($\tau$) between the disperse phase has to be less than the $\tau_c$ [15]. That is the disperse phase content has to exceed the critical value and with the increase of disperse phase content, the toughness further improves usually [16-20]. However, the achievement of super-tough properties by increasing the disperse phase content sacrifices the stiffness of PBT, so how to obtain PBT blends with super-tough and stiffer mechanical properties becomes very meaningful.

In the present paper, the properties of PBT matrix was modified by middle molecular weight epoxy resin. Epoxy resin has been used as chain extension agent of polyesters and compatibilizers of polyester blends successfully [21-23]. However, the influence of epoxy resin on mechanical properties of rubber toughened polymer blends has seldom been studied in detail. In this study, glycidyl methacrylate (GMA) functionalized ABS (ABS-g-GMA) was used as toughener to improve the impact strength since its excellent toughening effect as discussed in the previous paper [24]. The influence of epoxy resin on the properties of PBT/ABS-g-GMA blends was investigated by rheological test, scanning electron microscopy (SEM), differential scanning calorimetry (DSC) and dynamic mechanical analysis (DMA). The mechanical properties were measured by means of notched impact and tensile tests and PBT/ABS-g-GMA blends with super-tough and stiffer properties can be obtained with the introduction of epoxy resin.

**Result and discussion**

**Rheological properties**

The relationship between complex viscosity and time in PBT/epoxy resin blend measured at 240 °C is shown in Figure1. It can be seen from Figure1 that the complex viscosity increases with time (stage1) and maintains at a steady value from 900 to 1500s (stage2) and then increases again (stage3). Similar reactions have been studied by Xie and his coworkers [25-26]. The increase of complex viscosity with time

![Figure 1. Relationship between complex viscosity and time in PBT/epoxy resin blend measured at 240 °C.](image-url)
is due to the chemical reactions between PBT and epoxy resin. Stage 1 was reaction-controlled since the diffusion rate of epoxy resin was faster than the reaction rate and the reaction took place mainly at the interface. As the reaction proceeded, the interfacial layer became saturated and the complex viscosity remained steady such as in stage 2. When the epoxy resin penetrated through the interface layer, the chemical reactions proceeded again and the complex viscosity increased such as in stage 3. However, only the reaction between the carboxyl and epoxy groups was considered for PBT/epoxy resin blend in Xie’s study. Actually, the hydroxyl groups of PBT can react with epoxy groups too though the reaction rate is rather lower than the chemical reaction between carboxyl and epoxy groups.

In Figure 2 the relationship between the complex viscosity and angular frequency of the PBT/epoxy resin blends is reported. It can be seen from Figure 2 that there is no obvious change of complex viscosity with the angular frequency for pure PBT which displays the Newtonian fluid behavior. Compared to PBT, PBT/epoxy resin blends display much higher complex viscosity during the whole angular frequency range and the much epoxy resin content in the blends the higher viscosity can be found. The increase of complex viscosity of the PBT/epoxy resin blends is due to the chemical reactions between the two phases that can form PBT-co-epoxy and PBT-co-epoxy-co-PBT copolymer. At the same time, it can be seen that PBT/epoxy resin blends display Newtonian fluid behavior when epoxy resin content is lower than 10wt%, otherwise, PBT/epoxy resin blends show non-Newtonian fluid behavior. The reactions between epoxy resin and PBT belongs to chain-extension reactions including esterification of the carboxyl end groups and etherification of the hydroxyl end groups; the secondary hydroxyls formed in these reactions may further react with epoxy resin, leading to branching or crosslinking. So the non-Newtonian fluid behavior of PBT blends may be due to the branching or crosslinking reactions between PBT and epoxy resin.

![Figure 2](image-url)

**Figure 2** Plots of complex viscosity versus angular frequency for the PBT and PBT/epoxy resin blends measured at 240 ºC.
Figure 3 displays the relationship between storage modulus and angular frequency of the PBT/epoxy resin blends. It can be seen that the storage modulus of PBT blends increases with angular frequency and the blends with much higher epoxy resin content show much higher storage modulus values during the whole angular frequency range. The increased complex viscosity with non-Newtonian behavior in the low frequency region and higher storage modulus testify the chemical reactions between PBT and epoxy resin and similar conclusions have been made by other studies[21-23].

![Figure 3 Plots of storage modulus versus angular frequency for the PBT and PBT/epoxy resin blends measured at 240 °C.](image)

**Morphology**

The morphology of the PBT blends was investigated by scanning electron microscopy (SEM). The holes left on the surface of the PBT matrix in Figure 4 reflect the morphology of the dispersed phase. As for the PBT/ABS-g-GMA blends, ABS can disperse in PBT matrix uniformly since the compatibilization effect due to the chemical reactions between PBT and epoxy groups of GMA. From Figure 4, it can be seen that ABS can disperse in PBT matrix uniformly when epoxy resin content is lower than 10wt% and there are no obvious differences can be found between the morphology, however, for the PBT/ABS-g-GMA blends with 10wt% epoxy resin addition, some ABS particles agglomerate together and several big and irregular phase domain can be found which is due to the complicated chemical reactions in PBT/ABS-g-GMA/epoxy resin blends.

In PBT/ABS-g-GMA blends, compatibilization and crosslinking reactions take place simultaneously which have been discussed in previous paper [24]. Compatibilization reactions involve reactions between epoxy groups of ABS-g-GMA and carboxyl and hydroxyl end groups of PBT. As for the crosslinking reactions one involves the secondary hydroxyl groups present on the copolymers of PBT-co-ABS formed at the interface and the other is based on the bifunctionality of the PBT matrix. The two reactions are competitive and affect by the epoxy groups content. When the epoxy content is low compatibilization reactions is the main reactions.
Figure 4 Effect of epoxy resin on the morphology of PBT/ABS-g-GMA
The addition of epoxy resin to PBT/ABS-g-GMA blend makes the chemical reactions in this system more complicated. Epoxy resin can influence the blends morphology by two possible reactions. One lies in the competitive chemical reactions between PBT/epoxy resin and PBT/ABS-g-GMA blends. The reactions between PBT and epoxy resin as discussed in the above section may decrease the reactions ratio between PBT and ABS-g-GMA. Compared to ABS-g-GMA, epoxy resin has much lower melt viscosity, so the reaction between PBT and epoxy resin is much faster. Another reaction may come from the epoxy resin, PBT and hydroxyl groups on ABS phase. The hydroxyl groups come from the preparation progress of ABS as pointed out in the previous paper [4] The chemical reaction between epoxy resin, PBT and hydroxyl groups on ABS can improve the compatibility between PBT and ABS since the formation of PBT-co-epoxy resin-co-ABS, however, much higher epoxy resin content may lead agglomeration morphology showed in Figure4e due to the crosslinking reactions between epoxy resin and ABS which list in scheme 1.

\[\text{ABS} + \text{OH} + \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{Epoxy resin} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{ABS} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{Epoxy resin} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{OH} \rightarrow \text{OH} \rightarrow \text{ABS} \]

Reaction 1

\[\text{ABS} \rightarrow \text{OH} + \text{C} \rightarrow \text{C} \rightarrow \text{Epoxy resin} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{ABS} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{Epoxy resin} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{C} \rightarrow \text{ABS} \rightarrow \text{OH} \rightarrow \text{OH} \rightarrow \text{ABS} \]

Reaction 2

Scheme 1 Crosslinking reactions between epoxy resin and functionalized ABS.

Figure 5 illustrates the evolution of the torque as a function of the mixing time for PBT blends. PBT/ABS has the lowest torque value since there is no chemical reaction between PBT and ABS. The chemical reactions between PBT and ABS-g-GMA induce higher melt viscosity and torque value. The epoxy resin content influences the viscosity of PBT/ABS-g-GMA blends. The torque value of the blends decreases in some degree with time when the epoxy resin content is lower than 5wt%, however, the torque increases again after some minutes if the epoxy resin content is higher than 5wt% and the content of epoxy resin is much higher the time interval of torque increase is shorter. The further increase of torque value of the blends may act as a proof of the complicated reactions in PBT/ABS-g-GMA/epoxy resin blends. The reaction degree is affected by the epoxy resin content and the much of the epoxy resin content is the much serious reactions can be achieved. So PBT/ABS-g-GMA/epoxy resin blends display agglomeration morphology such as Figure 4e.
**Figure 5** Evolution of torque with time in PBT/ABS and PBT/ABS-g-GMA blends with different epoxy resin content.

**DSC and DMA analysis**

Figure 6 displays the influence of epoxy resin on the second DSC melting behavior of PBT/ABS-g-GMA blends. In the DSC thermogram, PBT displays one main melting peak with a small melting peak. The first small melting peak could attribute to the partial melting of the less perfect crystals. The second main melting peak could attribute to the melting of original and recrystallized crystals. With the addition of epoxy resin to PBT/ABS-g-GMA blends, the main melting temperature of PBT shifts.

**Figure 6** DSC melting behavior of PBT/ABS-g-GMA blends with different epoxy resin content (1-0wt%, 2-1wt%, 3-3wt%, 4-5wt%, 5-7wt%, 6-10wt%).
to lower temperature which indicates the chemical reactions between PBT, ABS-g-GMA and epoxy resin can induce the increase of viscosity of PBT/ABS-g-GMA/epoxy resin blends that is not beneficial to the crystallization of PBT phase. On the other hand, the shift of melting temperature to lower temperature indicates that the compatibility between PBT and ABS-g-GMA is improved according to the $T_m$ depression criterion [24, 27].

Figure 7 shows the DMA curves of PBT and its blends. The compatibility of PBT and ABS has been improved by introduction of GMA as discussed in the previous paper [24]. The addition of epoxy resin to PBT/ABS-g-GMA blends makes the $T_g$ of PBT phase shift to higher temperature as showed in Figure 7. The much content of epoxy resin is the much higher $T_g$ can been achieved. There may be two reasons which make the increase of $T_g$ of PBT phase. One lies in the improvement of the compatibility between PBT and ABS-g-GMA. The chemical reactions between epoxy resin, PBT and ABS-g-GMA induce the formation of PBT-co-epoxy resin-co-ABS which achieves higher $T_g$ of PBT phase and higher compatibility. The second reason may lie in the branching or crosslinking reactions between PBT and epoxy resin, especially when the epoxy resin content is high. These chemical reactions limit the movement of PBT chains and induce the shift of $T_g$ to higher temperature.

![Figure 7 Loss tangent curves of PBT and its blends](image)

**Figure 7** Loss tangent curves of PBT and its blends

**Mechanical properties**

The addition of epoxy resin can influence the mechanical properties of PBT matrix and the PBT/ABS-g-GMA blends. The mechanical properties of PBT/epoxy resin blends are shown in Table 1. The addition of epoxy resin does not affect the impact strength of PBT obviously and all the blends fracture in brittle way. The yield strength of PBT can be affected by epoxy resin and which increases with the increase of epoxy resin content. The increase of PBT yield strength is due to the chain-extension since the chemical reaction between PBT and epoxy resin. The chain-extension leads to the increase of entanglement density of PBT matrix that induces the improvement of yield strength. The PBT/epoxy resin blends show very high
elongation at break values when epoxy resin content is lower than 10wt%, however, the elongation at break decreases with further increase of epoxy resin content which may be due to the branching or crosskinking reactions between PBT and epoxy resin.

**Table 1 Mechanical properties of PBT/Epoxy blends**

<table>
<thead>
<tr>
<th>PBT/Epoxy resin</th>
<th>Impact strength (J/m)</th>
<th>yield strength (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>47</td>
<td>49</td>
<td>335</td>
</tr>
<tr>
<td>99/1</td>
<td>57</td>
<td>49</td>
<td>425</td>
</tr>
<tr>
<td>97/3</td>
<td>56</td>
<td>51</td>
<td>378</td>
</tr>
<tr>
<td>95/5</td>
<td>54</td>
<td>51</td>
<td>370</td>
</tr>
<tr>
<td>93/7</td>
<td>50</td>
<td>53</td>
<td>366</td>
</tr>
<tr>
<td>90/10</td>
<td>48</td>
<td>54</td>
<td>315</td>
</tr>
<tr>
<td>85/15</td>
<td>47</td>
<td>56</td>
<td>165</td>
</tr>
<tr>
<td>80/20</td>
<td>44</td>
<td>57</td>
<td>132</td>
</tr>
<tr>
<td>70/30</td>
<td>42</td>
<td>60</td>
<td>34</td>
</tr>
</tbody>
</table>

The notched impact strength of PBT and PBT/ABS20 are 50J/m and 134J/m, respectively. As for the PBT/ABS-g-GMA20 blend, the impact strength reaches 688J/m which improves the toughness of PBT by a factor of 14 and the blend fractures in ductile mode. On the other hand, the impact strength of PBT/ABS-g-GMA blends further increases with the addition of epoxy resin as seen from Figure 8. The impact strength of 902J/m is achieved when the epoxy resin content is 5wt% which displays the super-toughness, however, the impact strength of PBT blends decreases with the further increase of epoxy resin when its content is beyond 5wt%.

![Figure 8 Effect of epoxy resin content on the notched impact strength of PBT/ABS-g-GMA blends.](image)
The brittle-ductile transition temperature curves of PBT/ABS20 and PBT/ABS-g-GMA20 blends with different epoxy resin content are shown in Figure 9. All the blends display higher impact strength with the increase of temperature. PBT/ABS20 blend fractures in brittle way between the temperature range and the other blends display obvious brittle-ductile transition. With the introduction of epoxy resin the brittle-ductile transition temperature shifts to lower temperature for PBT/ABS-g-GMA20 blends and lowest temperature (-10°C) was achieved when the epoxy resin content was 5wt%. Further increase of epoxy resin in the blends induces the shift of brittle-ductile transition temperature to higher temperature. So from Figure 8 and 9 it can be concluded that 5wt% epoxy resin is optimum to improve the toughness of PBT/ABS-g-GMA20 blends.

![Figure 9 Brittle-ductile transition temperature of PBT/ABS and PBT/ABS-g-GMA blends with different epoxy resin content.](image)

For comparison, PBT/ABS-g-GMA30 blend was prepared and impact strength of 916 J/m was achieved, however, this blend showed a relatively low yield strength value of 34 Mpa since the higher ABS-g-GMA content. As for PBT/ABS-g-GMA20 blend with 5wt% epoxy resin addition, impact strength of 902 J/m and yield strength of 42 Mpa was achieved. So the PBT blends with super toughness and higher stiffness can be obtained with the introduction of epoxy resin.

The chemical reactions between PBT and epoxy resin may induce the change of chain structure of PBT matrix and which can affect the chain entanglement and the yield properties of the matrix. So the change of the molecular chain interaction and yield behaviour of PBT matrix may induce the change of crack initiation and plastic deformation propagation of the PBT blends during the impact test process. The deformation mechanisms are cavitation of rubber particles of ABS and shear yielding of PBT matrix [24]. The addition of epoxy resin changes the properties of PBT matrix and the compatibility which will influence the deformation process of the blends and the ultimate impact properties. The detailed discussion about the reasons for toughness improvement of PBT/ABS-g-GMA blends with the addition of epoxy resin will be discussed in another paper.

The stress-strain curves of PBT and its blends can be seen from Figure 10. Pure PBT shows higher yield strength and elongation at break values. The addition of ABS to
PBT matrix induces the decrease of tensile properties due to the elastomeric nature of ABS and the poor interfacial strength between PBT and ABS. As for the PBT/ABS-g-GMA blend, the tensile strength and elongation at break increase obviously compared to PBT/ABS blend since the compatibilization reactions between PBT and epoxy groups of GMA. On the other hand, the introduction of epoxy resin to PBT/ABS-g-GMA blends leads to the further increase of yield strength. The blends show higher elongation at break values when epoxy resin content is lower than 5wt% and which decreases obviously with the further increase of epoxy resin due to the complicated reactions.

![Figure 10 Stress-strain curves of PBT and its blends](image)

**Figure 10 Stress-strain curves of PBT and its blends**

**Conclusion**

Middle molecular weight epoxy resin was used to modify the properties of PBT/ABS-g-GMA blends. The chemical reactions between PBT and epoxy resin induced the increase of complex viscosity and storage modulus of PBT matrix. ABS-g-GMA dispersed in PBT matrix uniformly when epoxy resin content was lower than 10wt%, otherwise, agglomeration of dispersed phase occurred due to the crosslinking reactions between epoxy resin and ABS-g-GMA. DMA and DSC results showed the compatibility between PBT and ABS-g-GMA was further improved by the introduction of epoxy resin due to the complicated reactions. The addition of epoxy resin can further improve the mechanical properties of PBT/ABS-g-GMA20 blends. Impact strength of 902J/m and yield strength of 42MPa were achieved when 5wt% epoxy resin were used and which displayed supper-toughness and much stiffer properties than PBT/ABS-g-GMA30 blends.
Experimental

Materials

The poly(butylene terephthalate) (PBT) was purchased from Engineering Plastics Plant of YIHUA Group Corp, China. The hydroxyl and carboxyl end-group concentrations are 44μeq/g and 20μeq/g, respectively and \([ \eta ] = 1.22 \text{dL/g}\), measured in a 1/1 w/w phenol/tetrachloroethane solvent, 25°C. Middle molecular weight epoxy resin, trademark: EPO 1691-410(E-03 609, diglycidyl ether of bisphenol-A), epoxy equivalent weight: 2400-4000(g/eq), supplied by Diandong Branch Plant of Shanghai Resin Plant, China. The chemical structures of PBT and epoxy resin are list as follows.

The ABS and ABS-g-GMA materials were synthesized by emulsion polymerization method and the preparation process has been described in the previous paper [24]. The GMA content in the ABS-g-GMA copolymer was set as 1wt%. The polybutadiene content of ABS and ABS-g-GMA was set at 60wt%.

Blending and molding procedures

The blending was carried out in a co-rotating twin-screw extruder and the composition of the blends was list in Table 2 and Table 3. The temperature along the extruder were 220, 230, 240, 240, 240, 240, 240°C and the rotation speed of the screw was 60rpm. The strap of blends were cooled in a water bath and then pelletised.

The blends were dried in a vacuum oven at 80°C for 24h then were injection molded to prepare Izod impact specimens and tensile specimens. The injection temperature was 240°C and the mold temperature was set at 60°C.

<table>
<thead>
<tr>
<th>Table 2 Composition of PBT/Epoxy resin blends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (wt%)</td>
</tr>
<tr>
<td>PBT</td>
</tr>
<tr>
<td>Epoxy resin</td>
</tr>
</tbody>
</table>
Table 3 Composition of the PBT/ABS and PBT/ABS-g-GMA/epoxy resin blends.

<table>
<thead>
<tr>
<th>Designation</th>
<th>PBT (wt%)</th>
<th>ABS or ABS-g-GMA (wt%)</th>
<th>Epoxy resin (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBT/ABS20</td>
<td>80</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA30</td>
<td>70</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA20</td>
<td>80</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA/E1</td>
<td>79</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA/E3</td>
<td>77</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA/E5</td>
<td>75</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA/E7</td>
<td>73</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>PBT/ABS-g-GMA/E10</td>
<td>70</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Rheological properties

PBT plates were prepared by hot compression molding method under 10 MPa at 240 °C for 5min. After that, the PBT plates were cut with a razor blade to form a diameter of 25mm. Then the epoxy resin was sandwiched between two PBT plates. The complex viscosity of the blend was monitored with time at temperature of 240 °C. The strain amplitude was 0.01 and the frequency was 1Hz.

The torque measurements of PBT blends were performed on a Thermo Haake mixer. The rotating speed was set at 50rpm and the temperature was set at 240 °C.

Morphology

The dispersed phase morphology of the PBT blends was characterized by scanning electron microscopy (SEM) (model Japan JSM-5600). The sample surface was cut at low temperature with a glass knife until a smooth surface was obtained. Then the samples was etched with tetrahydrofuran for 5h at room temperature to remove dispersed phase and coated with a gold layer for SEM observation.

DSC analysis

DSC measurements were conducted using a Perkin-Elmer DSC-7. The samples were taken from the injection molded specimens and had a normal weight of about 6mg. The samples were heated from 0 up to 260 °C at 10 °C/min under a nitrogen atmosphere, maintained for 2min to remove thermal history, and cooled at a rate of 10 °C/min to 0 °C to obtain the crystallization properties. The cooled samples were then reheated at a rate of 10 °C/min to 260 °C to obtain the melting properties.

DMA analysis

Dynamic mechanical thermal analysis was performed on a Netzsch DMA242 which provided the tanδ as a function of temperature. The scans were carried out in single cantilever mode at a constant heating rate of 3 °C/min and at a frequency of 10Hz. The measurement was performed over a temperature range of 0 to 150 °C.

Mechanical properties

Notched Izod impact tests of PBT blends were performed at 23±2 °C according to ASTM D256 on a XJU-22 apparatus. The samples with dimensions 63.5×12.7×6.35mm³ were obtained from injection molded specimens. The notch was milled in having a depth of 2.54mm, an angle of 45° and a notch radius of 0.25mm. The uniaxial tensile tests were carried out at 23±2 °C on a Shimadzu AGS-H tensile tester at a cross-head speed of 50mm/min according to the ASTM D638. For both mechanical tests at least five samples were tested and their results averaged. The samples were dried overnight prior to testing until the measurement were performed.
Acknowledgment
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