Research Article

Recycled Polypropylene Improved with Thermoplastic Elastomers

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The use of recycled polypropylene (RPP) as raw material for various industries has been known. However, the mechanical and thermal properties of recycled products are lower than those of raw material. The objective of this study was to obtain and investigate the modified recycled polypropylene (RPP) with commercial elastomers for possible applications. The compounded RPP-based thermoplastic elastomers were investigated in order to determine their thermal properties (melt flow index (MFI), differential scanning calorimetry (DSC), VICAT softening temperature (VST), and heat deflection temperature (HDT)), structural characteristics (optical microscopy, atomic force microscopy (AFM), and X-ray diffraction (XRD)), and mechanical properties (tensile properties, density, and IZOD impact). The RPP compounded with 10% elastomer recorded higher tensile properties than the unmodified RPP. Also, IZOD impact strength increased from $4.3 \pm 0.2 \text{kJ/m}^2$ (registered for RPP) to $21.7 \pm 2.5 \text{kJ/m}^2$ for the PPR/SIS30 compound, while the degree of crystallinity decreased for all compounds. The obtained results recommend the RPP/elastomers compounds both for environmental remediation from postconsumer PP wastes and to realize new goods with high performance for various applications.

1. Introduction

It is known that most polypropylene (PP) materials show low resistance to impact especially at low temperatures, which limits its applications in engineering fields. The technical requirements for automobiles, appliances, and other commercial products applications of PP materials envisage good mechanical properties, easy processing, good aesthetics, and low weight and cost. In order to obtain these properties, usually PP is compounding with elastomer, resulting in polypropylene composites with improved properties [1]. Generally, the elongation, impact strength, and brittle/tough transition temperature represent the most important properties improved when PP is compounded with elastomer [2–8]. For example, [7] investigated the compatibilized PP/poly(ethylene glycol-co-cyclohexane-1,4-dimethanol terephthalate) blend with styrene-ethylene/butylene-styrene (SEBS), styrene-butadiene-styrene (SBS), and styrene-isoprene-styrene (SIS) and reported a remarkable increase in impact strength due to the addition of SIS, about 5 times as that of the uncompatibilized blends; the yield strength of the blends with SBS and SIS is enhanced from 33.6 to 39.6 and 37.6 MPa, respectively. A significant improvement on elongation at break from 35.9% to 91.2% and notched IZOD impact from 3.5 kJ/m² to 71.1 kJ/m² was obtained when PP was compounded with 10% SEBS [3].

However, the widespread use of PP in various domains results in a significant amount of plastic waste. Different
recycling methods have been used for PP wastes including land filling (causing a negative impact on the environment), mechanical [9,10] including dissolution/reprecipitation method [11], chemical method [12, 13], and incineration [14, 15]. By mechanical recycling, the PP wastes are separated from other resin types, washed to remove dirt and contaminants, and ground and crushed to reduce the plastics’ particle size, followed by extrusion by heat and reprocessing into new plastic goods. Chemical recycling leads to the conversion of plastic wastes to original monomers or other valuable chemicals, while, by incineration, energy is obtained. Among all recycling methods, mechanical and chemical recycling are the most used for PP wastes management.

The reuse and recovery rate of recycled PP materials are of great importance for the plastic industry, which depends on oil and has consequences on the environment and the economy. Therefore, the amount of energy and raw materials (such as propylene) required for the manufacturing of new products is reduced, large quantities of raw materials are returned to the economic circuit, and the amount of PP waste deposited at the landfill or incinerators is also diminished.

A large number of papers describe the modification of recycled polypropylene with different additives, fillers, or processing reinforcements for obtaining of wood plastic composites (WPC) with high added value [9,16–21], concrete [22], and a novel coupling agent for fibrous cellulose/polypropylene composite [23].

It is known that the mechanical properties of virgin materials are different from those of the corresponding recycled materials [10, 24]. For example, it showed that the tensile strength of the highly recycled polypropylene decreased by about 15% when it is compared to neat polypropylene [10]. In another paper, by investigating the mechanical properties of recycled PP/nylon compounded with SEBS elastomer, it was found that the impact strength was improved with the increase of SEBS content, while the tensile strength of PP/nylon blend was not enhanced by the addition of SEBS [25]. The same results were obtained by Jose and coworkers [26] that modified the PP wastes with rubber in a Brabender Plastograph. The effect of recycling on the molecular weight, rheological properties and the mechanical properties of the PP-based composites, and the deformation mechanisms were also investigated [24, 27]. The obtained results showed that thermomechanical recycling process led to decrease of the molecular weight, failure stress, and impact energy. Instead, the yield stress and the Young modulus increased until the fifth cycle of reprocessing due to increase of the crystallization rate taking place during the recycling process. Previous researches of our team indicated the incorporation of 10% elastomer as the optimum amount that leads to the improvement of the recycled polypropylene properties [28–31].

The aim of this work is to investigate the modified recycled polypropylene with commercial elastomers by thermal properties (MFI, DSC, VICAT, and HDT), structural characteristics (XRD, optical microscopy, and AFM), and mechanical properties (tensile properties, density, and IZOD impact) for possible applications.

2. Experimental

2.1. Materials and Methods. Polymeric matrix, recycled polypropylene (RPP) (in the granule form), comes from industrial postconsumer boxes processed by injection moulding technology. It is characterized by a density of 0.96–0.99 g/cm³, a melt flow index (190 °C, 5 kg) of 6 g/10 min, tensile strength break of 2.06 MPa, elongation at break of 2.83%, and IZOD impact strength at 23 °C of 6kJ/m². Three elastomers types with different contents of styrene were used:

1. Styrene-ethylene/butylene-styrene block-copolymer, Calprene H 6144 (SEBS), was acquired from Dynasol, Spain. It contains 31% styrene and is characterized by viscosity in 5.23% toluene, 30 cSt, Brookfield viscosity (10%, 25 °C), 400 cP, volatile matter, max. 0.5%, and shore hardness, 75°ShA.

2. Styrene-isoprene-styrene block-copolymer, D165P (SIS30), purchased from Kraton, USA, is characterized by tensile strength at break, 32 MPa, elongation at break, 1300%, shore A hardness, 48°ShA, and density, 0.93 g/cm³. SIS 30 contains 28.2–31.8% styrene.

3. Styrene-isoprene-styrene block-copolymer, D1660BT (SIS20) provided by Kraton, USA, contains 17.4–20.5% styrene and similar characteristics as SIS30.

Besides these materials, polyethylene grafted with maleic anhydride (PE-g-MA), 0.5 wt.% of maleic anhydride, provided by Sigma-Aldrich, was used as the compatibilizer between RPP and thermoplastic elastomers. It shows a viscosity at 140 °C 500 cP, density at 25 °C 0.92 g/mL, melting enthalpy (ΔH_m) 51.8 J/g, and melting temperature (T_m) 113 °C. Also, 2,6-ditert-butyl-4-methylphenol (Topanol OC) was used as an antioxidant for compounds containing SIS elastomer. It is characterized by a density of 1.03 g/cm³, melting temperature 70 °C, and water solubility at 25 °C 0.00006 g/100 mL.

2.2. Preparation of Polypropylene Compounds. Three kinds of compounds coded RPP/SEBS, RPP/SIS30, and RPP/SIS20 were prepared by compounding of RPP with each elastomer type in content of 10 wt.% by using of a SHJ-35 corotating twin-screw extruder (ø 35.6 mm, L/D 32, nine zones of temperature, and speed of screw 60–600 rpm) provided with pelletizing line. The RPP, PE-g-MA, and thermoplastic elastomers were premixed in appropriate ratios prior to compounding according to the formulations listed in Table 1.

PE-g-MA was introduced to RPP compounds preparation in order to improve the interfacial adhesion between RPP matrix and elastomer phase which signifies the increase of mechanical properties (tensile strength at break) of compounds. Other authors have also reported the use of compatibilizers containing maleic anhydride in order to increase the adhesion between phases of the polypropylene components of mixture [8, 32, 33]. The proposed mechanism that shows the compatibilizing action of PE-g-MA in RPP compounds is shown in Figure 1.

By melting the components it is assumed that interactions between PE-g-MA with elastomer and thermoplastic matrix
### Table 1: Composition of RPP compounds.

<table>
<thead>
<tr>
<th>Compound code</th>
<th>RPP, wt.%</th>
<th>PE-g-MA, wt.%</th>
<th>Elastomer, wt.%</th>
<th>Topanol OC, wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP/SEBS</td>
<td>85</td>
<td>5</td>
<td>10</td>
<td>—</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>84</td>
<td>5</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>84</td>
<td>5</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 1:** Proposed mechanism for compatibilizing action of PE-g-MA in RPP compounds. (a) RPP/SEBS compound; (b) RPP/SIS compound.

and also between elastomer and RPP exist. The interactions could take place through van der Waals bonding between the RPP chain and the olefinic segments of PE-g-MA. Also, dipolar interactions between PE-g-MA and elastomer phase probably could occur (Figure 1).

In order to avoid the degradation of RPP/SIS compounds, 1 wt.% antioxidant was premixed with RPP, PE-g-MA, and SIS. Each pellet mixture was then fed into the feed throat and the materials were melted, blended, and compatibilized in the extruder.

Compounding process was performed by using a mixing speed in the range 425–500 rot/min, a melt temperature at the die of 150°C, a pressure at the die of 13 MPa, and a feed rate of 250 rot/min. The temperature profile is summarized in Table 2.

The molten blend was then forced through a strand die, cooled in water at room temperature, and followed by the granulation process. Black pellets with cylindrical shape were obtained and dried at 105°C. The specimens for further characterizations are taken from sheets and films prepared by compression moulding of compounded samples by means of a laboratory press (FONTUNE) at 200°C, for 5 min, and at a maximum compressive load of 8 tons. RPP unmodified was pressed in the same conditions like RPP compounds and used as the control sample.

### 2.3. Microscopic Characterization.

Thin cross-microtome sections of the 1 mm thick sheets were examined with a Leica DM 2500 M microscope with a digital camera at 200x.

A 4000SPM MultiView/NSOM atomic force microscope system (AFM) (Nanonics Imaging, Ltd.) was used to investigate the surface morphology of the compounded recycled polypropylene. SPM images were acquired in air, noncontact mode (at a distance between 0.1 and 10 nm of sample). Analyzed surface area was 80 μm² and the measurement speed used was 12 ms/point. The needle used for surface analysis
where $\lambda$ is the wavelength of the radiation from the diffraction tube, FWHM is full width at half maximum of diffraction in the $2\theta$ scale (rad), and $\theta$ is diffraction Bragg angle.

$\phi = 1.54065 \, \text{Å}$ and $\Delta H_m$ is the melting enthalpy corresponding to 100% crystalline PP (190 J/g); $\Delta H_m^0$ is the melting enthalpy of sample; $\chi_c = \frac{\Delta H_m}{\Delta H_m^0 \times w} \times 100 \, \%$. (2)

The morphology images for the RPP compounds and unmodified RPP matrix led to a good dispersion of those within a continuous phase of the thermoplastic matrix, especially for RPP/SIS20 (Figure 2(d)).

3. Results and Discussion

The optical microscopic images of RPP and RPP/elastomers blends are shown in Figures 2(a), 2(b), 2(c), and 2(d). Optical microscopic images from Figure 2 reveal an inhomogeneous surface for RPP (Figure 2(a)) while the introduction of elastomers into RPP matrix led to a good dispersion of those within a continuous phase of the thermoplastic matrix, especially for RPP/SIS20 (Figure 2(d)).

The morphology images for the RPP compounds and unmodified RPP surfaces are presented in Figures 3(a)–3(d). The optical microscopic images for the RPP compounds and unmodified RPP matrix led to a good dispersion of those within a continuous phase of the thermoplastic matrix, especially for RPP/SIS20 (Figure 2(d)).

AFM analysis reveals the rough surface of the RPP/SEBS blends (Figure 3(a)) with many voids and relatively large depths (200 nm deep approximately) and peaks ranged from 150 to 200 nm (Figure 3(b)), while by incorporation of SIS into RPP matrix a relatively smooth surface can be noticed (Figures 3(c) and 3(d)) having fewest voids in material but also more pronounced peaks ranged from 20 to 170 nm.

2.7. Tensile Tests. The tensile tests were measured in accordance with ISO 527 using at least five rectangular test specimens with a thickness of 1 mm. The speed rate was of 50 mm/min.

2.8. IZOD Impact Test. Notched impact test was carried out using an IZOD-CHARPY Impact Tester (CEAST, Italy). The tests were performed for all specimens at 23°C. The rectangular shaped test specimens with $80 \times 10 \times 4$ mm dimensions and a 2 mm notch with an angle of 45° were tested in accordance with ISO 179. A hammer of 2 J was used for all measurements.

2.9. VICAT Softening Temperature (VST) and Heat Deflection Temperature (HDT). The VST and HDT tests were performed by means of a HDT/VICAT equipment (CEAST, Italy), as follows: VST test was conducted according to ISO 306, Method A50, load 10 N, and heating rate of 50 °C/h and HDT test was carried out according to EN ISO 75, using a load of 0.45 MPa and a heating rate of 120 °C/h. Specimens with thickness of 4 mm were used for both tests.

Table 2: Preset/achieved temperature [°C] for the compounding of recycled polypropylene with thermoplastic elastomers.

<table>
<thead>
<tr>
<th>Zone I</th>
<th>Zone II</th>
<th>Zone III</th>
<th>Zone IV</th>
<th>Zone V</th>
<th>Zone VI</th>
<th>Zone VII</th>
<th>Zone VIII</th>
<th>Zone IX</th>
</tr>
</thead>
<tbody>
<tr>
<td>140/136</td>
<td>147/147</td>
<td>158/174</td>
<td>165/162</td>
<td>175/166</td>
<td>175/169</td>
<td>171/158</td>
<td>171/169</td>
<td>165/169</td>
</tr>
</tbody>
</table>

Table 3: Roughness values for the samples calculated from AFM analysis.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>RMS [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>77.2</td>
</tr>
<tr>
<td>RPP/SEBS</td>
<td>189.5</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>32.4</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>33.2</td>
</tr>
</tbody>
</table>
From Table 3, it can see that the surface roughness values increase with introduction of SEBS into mixture (189.5 nm) which proved that the interface between the elastomer and RPP matrix is weaker due to the poor dispersion and compatibility and decreases for SIS elastomers (~32 nm) in comparison with RPP. This indicated a good compatibility between SIS elastomers and the RPP matrix. Also, it is assumed that the introduction of PE-g-MA improved the compatibility between SIS elastomers and RPP and increased the surface smoothness. From Table 3 it can also be observed that the surface roughness of RPP/SIS 30 slightly decreased when compared to that of RPP/SIS20, due to the increase of PS content.

The values for the density measured at 23°C and melt flow index (MFI) of granules samples are presented in Table 4.

The obtained compounds show the density and melt flow index values lower than unmodified RPP. RPP/SIS samples recorded high MFI values (~5 g/10 min) in comparison with RPP/SEBS compound (~3 g/10 min) indicating the decrease of melt viscosity. The easier flow behavior of the RPP/SIS samples is in correlation with their roughness values (reported in Table 3). Analyzing the roughness values from Table 3 and the melt flow index from Table 4 in the case of unmodified RPP and RPP/SIS compound it is observed that RPP possesses high RMS, but its melt viscosity is less than RPP/SIS. It is known that the viscosity depends on interfacial adhesion between the individual blend components [26]. In the case of the elastomer introduced in the RPP matrix, the interfacial adhesion increases. This is attributed to the immiscible styrene block from the elastomer introduced to the PP matrix making it difficult to flow resulting in an increase in viscosity. Due to the good compatibility of SIS with polymeric matrix, the surface roughness decreased compared with unmodified RPP.

Figure 4 shows the DSC curves recorded by RPP compounds and RPP. The thermal parameters, heat melting, $\Delta H_m$, melting temperature, $T_m$, and the degree of crystallinity for PP, ($X_c$), have been determined from DSC curves and they are reported in Table 5.

From Figure 4 and Table 5 two endothermic melting peaks are observed for investigated samples, the first being associated with polyethylene (PE) melting (~128°C) and the second with $\alpha$ crystals melting from RPP (~166°C). This suggests that the recycled polymers represent a mixture...
of different polymers as was reported by Martín-Alfonso and coworkers [36]. The obtained results indicate that the crystalline phase of PE remains separated in PP domains at microstructural level; these results validating the observations from other papers [37, 38]. From the first endothermic peak assigned to PE $T_m$, $\Delta H_m$, and $\chi_c$ (Table 5) were evaluated. The degree of crystallinity for PE was calculated using the melting enthalpy of a 100% crystalline PE of 290 J/g [38]. If it is assumed that the crystalline phases from PE are the same with the amorphous ones as Brachet and coworkers demonstrated [39], then the total amount of PE from recycled PP is $\sim$25%.

Introducing of elastomer into RPP matrix led to minor changes of the melting temperature ($T_m$) in comparison with RPP, while the degree of crystallinity ($\chi_c$) recorded a decrease compared to the RPP. Among all investigated elastomers,
Table 5: Thermal parameters for RPP samples evaluated from DSC thermograms, first heating scan.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>$\Delta H_{m}$, PE [J/g]</th>
<th>$T_{m}$, PE [°C]</th>
<th>$\Delta H_{m}$, PP [J/g]</th>
<th>$T_{m}$, PP [°C]</th>
<th>$\chi_{c}$, PP [%]</th>
<th>$\chi_{c}$, PE [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>36.81</td>
<td>129.8</td>
<td>34.8</td>
<td>166.6</td>
<td>18.3</td>
<td>12.7</td>
</tr>
<tr>
<td>RPP/SEBS</td>
<td>22.7</td>
<td>129.1</td>
<td>28.9</td>
<td>165.9</td>
<td>17.9</td>
<td>7.8</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>21.8</td>
<td>128.7</td>
<td>25.1</td>
<td>166.1</td>
<td>15.7</td>
<td>7.5</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>25.1</td>
<td>128.3</td>
<td>25.8</td>
<td>166.0</td>
<td>16.1</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Figure 4: DSC curves for RPP and RPP/elastomer compounds containing 10% elastomers.

Table 6: Average crystallite sizes (nm) for RPP compounds and unmodified RPP.

<table>
<thead>
<tr>
<th>Code sample</th>
<th>Average crystallite size [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>37.58</td>
</tr>
<tr>
<td>RPP/SEBS</td>
<td>48.55</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>41.80</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>46.41</td>
</tr>
</tbody>
</table>

SEBS elastomer shows the smallest change in the degree of crystallinity (17.9%) with respect to RPP (18.3%). This behavior in the crystallinity is assigned to the compatibility between the continuous phase of RPP matrix and the ethylene-butylene phase from SEBS that does not disturb the lattice structure of RPP. Compounds based on RPP and SIS elastomers recorded a decreased degree of crystallinity due to the good compatibility with the matrix in comparison with SEBS elastomer. In the case of RPP/SIS compounds, due to the decreased degree of crystallinity and smooth surfaces (Table 2) it is expected to show an improvement on the tensile properties and IzOD impact.

Figure 5 shows the X-ray diffraction patterns of the RPP reference and RPP/elastomer samples. The average of crystallite sizes for RPP compounds and unmodified RPP is given in Table 6.

The elastomers influence on the crystallite sizes of RPP compounds is higher than those of RPP. It is expected that high dispersed particles of elastomers were made at RPP compounding. The increase of the crystallite sizes caused disturbances of the microcrystalline network formation, its effect being recorded by DSC analysis (Table 5). However, the incorporation of SEBS elastomer into RPP matrix exhibited the highest increase of the crystallite sizes in comparison with compounds containing SIS. This can be explained by the high viscosity of SEBS and poor compatibility with polymeric matrix (Table 4) that lead to increasing the tendency for the agglomeration of the crystallite size.

Influence of the elastomer type on the tensile strength at break and elongation at break of RPP compounds compared with RPP is shown in Table 7.

Tensile strength of RPP/elastomer compounds increased with the introduction of the elastomer in RPP polymer matrix, Table 7. This increase is due to the effect of PE-g-MA, which increases interaction between RPP matrix and elastomer. RPP/SIS30 sample recorded the highest value of tensile strength at break ($11.7 \pm 0.77$ MPa), followed by RPP/SIS20 sample ($8.9 \pm 2.2$ MPa) and RPP/SEBS ($7.33 \pm 0.7$ MPa). These values of tensile strength are in good agreement with the degree of crystallinity (Table 5). The smooth surface for RPP/SIS compounds (Table 2) is also responsible for the increased tensile strength at break. From Table 7 it is also observed that the elongation at break increased by about 5 times for all RPP compounds compared to RPP, due to the
Table 7: Tensile properties for RPP/elastomer compounds and RPP.

<table>
<thead>
<tr>
<th>Code compound</th>
<th>Tensile strength at break [MPa]</th>
<th>Elongation at break [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>2.06 ± 0.20</td>
<td>2.83 ± 0.11</td>
</tr>
<tr>
<td>RPP/SEBS</td>
<td>7.33 ± 0.70</td>
<td>12.89 ± 4.20</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>11.70 ± 0.77</td>
<td>10.96 ± 2.25</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>8.90 ± 2.20</td>
<td>11.03 ± 4.08</td>
</tr>
</tbody>
</table>

Table 8: Izod impact strength of RPP blends.

<table>
<thead>
<tr>
<th>Code sample</th>
<th>Izod impact [kJ/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>4.35 ± 0.23</td>
</tr>
<tr>
<td>RPP/SEBS</td>
<td>8.55 ± 2.14</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>21.78 ± 2.58</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>16.91 ± 2.52</td>
</tr>
</tbody>
</table>

Table 9: VST and HDT properties for the unmodified RPP and RPP blends.

<table>
<thead>
<tr>
<th>Code sample</th>
<th>VST [°C]</th>
<th>HDT [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>162.0 ± 1.0</td>
<td>87.0 ± 6.5</td>
</tr>
<tr>
<td>RPP/SEBS</td>
<td>162.3 ± 2.3</td>
<td>73.0 ± 2.0</td>
</tr>
<tr>
<td>RPP/SIS30</td>
<td>160.0 ± 4.3</td>
<td>64.6 ± 3.5</td>
</tr>
<tr>
<td>RPP/SIS20</td>
<td>157.6 ± 2.5</td>
<td>67.5 ± 0.7</td>
</tr>
</tbody>
</table>

elastomer component that favors the flow and mobility of RPP. There is no noted difference on elongation at break between all used elastomers.

IZOD impact strength for the RPP and RPP/elastomer compounds performed on notched specimens is shown in Table 8.

As is shown in Table 8, the IZOD impact strength increased for all compounds compared to that for RPP (4.35 ± 0.23 kJ/m²) with a spectacular increase in the case of RPP/SIS30 (21.78 ± 2.58 kJ/m²). This increase is attributed to the elastomeric phase that absorbs and transfers the force at impact from the continuous phase of RPP matrix [26]. In addition, the flexible interface between elastomer and RPP prevents the development of cracks. Consequently, the impact resistance of RPP compounds is significantly improved, in good agreement with the decrease of the degree of crystallinity reported in Table 5.

The influence of the used elastomers on the VICAT softening temperature (VST) and heat deflection temperature (HDT) properties of the RPP blends is shown in Table 9.

As compared with control sample (unmodified RPP), the VST and HDT values show almost the same value for RPP/SEBS and a slow decrease for RPP/SIS30 compound (a decrease ∼2°C) and RPP/SIS20 compound (a decrease ∼5°C). The HDT values recorded the same trend as VST values. The decrease in VST and HDT values is in good accordance with the increase of elongation at break.

From three elastomers types used to improve the RPP properties it can be remarked that the SIS with 30% styrene content is a better impact modifier for RPP, reflecting the better properties (smooth surface, melt flow, tensile strength, and impact resistance).

4. Conclusions

The postconsumer polypropylene (RPP) was compounded with SEBS, SIS30, and SIS20, respectively, and characterized in terms of mechanical and thermal properties and structural characteristics in order to establish the best elastomer for improvement of RPP properties.

Generally all prepared compounds showed good properties compared with unmodified RPP, suitable for obtaining new goods for various applications, which proves that the mechanical recycling of polypropylene wastes is also a good strategy for management of waste.

DSC analysis revealed that the degree of crystallinity ($\chi_c$) registered a decrease for all compounds compared with RPP control, while the melting temperature ($T_m$) showed only minor changes.

The tensile strength at break of compounds increased by about 5 times compared to RPP due to incorporation of PE-g-MA in mixture. A significant increase for elongation at break and IZOD resistance was recorded for all compounds.

However the investigated elastomers had a quite different effect on the RPP properties due to their structures.

The RPP compatibilized with SEBS revealed high root surface and melt viscosity while those compounded with SIS showed a smooth surface and low melt viscosity.

Although by incorporation of SEBS elastomer into RPP matrix the lattice network of polymeric matrix is not much disrupted, its crystallite sizes increased in comparison with compounds containing SIS.

Based on the obtained results it can be concluded that SIS30 was the best modifier for RPP properties leading to the highest increase of mechanical properties of RPP compound, by about 5 times for tensile strength and IZOD impact, respectively.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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