Solid-State Processing Approach to Enhance the Mechanical Properties of Polypropylene

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Abstract
Agenda: Background; Research Problem; Methodology; Results and Discussion; Conclusions.

Disciplines
Industrial Engineering | Mechanics of Materials | Operational Research

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Solid-State Processing Approach to Enhance the Mechanical Properties of Polypropylene

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Agenda

- Background
- Research Problem
- Methodology
- Results and Discussion
- Conclusions
Background

- **Isotactic Polypropylene (i-PP)**
  - Commercially available thermoplastic polymer
  - Packaging and labeling, textiles and stationery [1]
  - Optimal price-performance ratio, recyclability [2]
  - Inferior mechanical strength [3]
  - Solid-state processing to improve mechanical strength

- Polyethylene terephthalate, Polystyrene and Polyvinyl Chloride (Fig. 1 and Fig. 2) [4]
- Nucleating agents to enhance mechanical properties [5]

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Background

- Nucleating agents are additives
- Sorbitol-based derivatives such as 1, 3, 2, 4-dibenzylidene sorbitol (MDBS) [7]
- Melt blending or solubilizing [8]
- Difficult to attain uniform dispersion [9]


Fig. 3. Working mechanism of nucleating agents
Background

- Cryomilling - Solid-state grinding technique
- Mechanical attrition of particles - cryogenic environment (-196 °C)
- Induces molecular physicochemical changes [11]

Research Problem

- Can cryomilling homogeneously disperse small quantities (0.2wt%-1 wt.%) of MDBS within i-PP matrix?
- Does cryomilling PP/MDBS improve the mechanical properties of i-PP?
Methodology

Table 1. %MDBS

<table>
<thead>
<tr>
<th>Material</th>
<th>% MDBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.00</td>
</tr>
<tr>
<td>A2</td>
<td>0.20</td>
</tr>
<tr>
<td>A3</td>
<td>0.40</td>
</tr>
<tr>
<td>A4</td>
<td>0.60</td>
</tr>
<tr>
<td>A5</td>
<td>0.80</td>
</tr>
<tr>
<td>A6</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Fig. 5. Flowchart of experimental methods
X-Ray Diffraction

Fig. 6. XRD graph
Fig. 7. Cooling curve from DSC analysis

Table 2. DSC cooling and heating data

<table>
<thead>
<tr>
<th>Wt.% MDBS</th>
<th>T_m (1st) (°C)</th>
<th>T_m (2nd) (°C)</th>
<th>T_c (°C)</th>
<th>ΔH_m (J/g)</th>
<th>Crystallinity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>165.8</td>
<td>164.6</td>
<td>117.3</td>
<td>29.4</td>
<td>14.1</td>
</tr>
<tr>
<td>0.2</td>
<td>166</td>
<td>165.2</td>
<td>128.8</td>
<td>31.7</td>
<td>15.2</td>
</tr>
<tr>
<td>0.4</td>
<td>166.8</td>
<td>165.5</td>
<td>128.3</td>
<td>34.8</td>
<td>16.7</td>
</tr>
<tr>
<td>0.6</td>
<td>165.9</td>
<td>165.1</td>
<td>128.6</td>
<td>32.7</td>
<td>15.6</td>
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<tr>
<td>0.8</td>
<td>166.6</td>
<td>165.9</td>
<td>128.6</td>
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<td>16.1</td>
</tr>
<tr>
<td>1</td>
<td>166.4</td>
<td>165.4</td>
<td>129</td>
<td>38.6</td>
<td>18.5</td>
</tr>
</tbody>
</table>
Mechanical Properties

**Fig. 8.** Test setup and coupon

**Fig. 9.** Stress-Strain curve for PP/MDBS samples
**Table 3.** Tensile test data

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Description</th>
<th>Ultimate tensile stress (MPa)</th>
<th>Modulus of elasticity (MPa)</th>
<th>Elongation @ break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>PP</td>
<td>33.12 ± 0.67</td>
<td>1,109.36 ± 78.49</td>
<td>0.25 ± 0.00</td>
</tr>
<tr>
<td>A2</td>
<td>0.2%</td>
<td>36.65 ± 0.70</td>
<td>1,418.98 ± 78.59</td>
<td>0.06 ± 0.01</td>
</tr>
<tr>
<td>A3</td>
<td>0.4%</td>
<td>35.44 ± 0.33</td>
<td>986.53 ± 49.70</td>
<td>0.08 ± 0.01</td>
</tr>
<tr>
<td>A4</td>
<td>0.6%</td>
<td>35.52 ± 0.53</td>
<td>1,203.65 ± 55.77</td>
<td>0.07 ± 0.01</td>
</tr>
<tr>
<td>A5</td>
<td>0.8%</td>
<td>35.54 ± 0.70</td>
<td>1,141.42 ± 56.47</td>
<td>0.06 ± 0.00</td>
</tr>
<tr>
<td>A6</td>
<td>1.0%</td>
<td>38.02 ± 1.04</td>
<td>1,932.91 ± 44.45</td>
<td>0.04 ± 0.00</td>
</tr>
</tbody>
</table>

**Fig. 10.** Box plot of tensile strength and strain data
Conclusions and Broader Impacts

- Lower malleability
- Higher strength
- Broaden industrial applications
- Reduce cycle time
- Lower cost
- New processing technique
Questions?
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