AN EXTRUSION STUDY: EXAMINATION OF THE IMPROVED PROCESSING CHARACTERISTICS OF A PLA IMPACT MODIFIED BLEND

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Presentation Outline

- Introduction
  - Review of Prior Work
    - PLA
    - Physical Properties

- Experimental
- Discussion of Results
- Summary / Conclusion
Introduction

Prior Work

**Modification of PLA for Improved Processing and Properties**

Dr. Barry Morris – Dupont
Donavon Kirschbaum, NatureWorks, LLC

- Observations with the addition of 2 - 5% by wt. IM in PLA

- Improved mechanical properties & appearance
  - Tensile and flexural properties
  - Impact strength at room and cold temperature
  - Good Contact Clarity at low levels (1-5 wt%)

- Processing Characteristics
  - Lower Amps
  - Higher Energy Efficiency - kg/hr-kw
  - Lower Melt Temperature
Polylactic Acid - PLA

Attributes
- 100% Renewable Source (e.g. Corn)
- Meets EC 2002/72 & FDA for Food Packaging
- Meets EN 13432 & ASTM 6400 for biodegradability Standard
- Great Clarity

Applications
- Thermoformed cups, containers,
- Non-wovens
- Oriented Films
- Molding
Polylactic Acid

Physical Properties

- Very Stiff and Brittle
  - Can result in splitting and other handling problems during sheet manufacturing.
  - Amorphous PLA, $T_g = 57$ Deg C making it unsuitable for many packaging applications
Physical Properties

PLA + IM (120) 1-5 %

- Impact Modifier – petroleum-based ethylene acrylate copolymer that has good compatibility with PLA
- AT 1-2 % loading, it has been found to significantly improve toughness without decreasing transparency

No Breakage of PLA strip contained 2% or more Biomax® Strong
Experimental
Experimental

Materials

- PLA - 2002D
- PLA + 2 % IM 120
- PLA was dried for 4 hrs – 90 Deg C and the IM was added using a Colortronic feed system

![Graph showing apparent viscosity vs. apparent shear rate for different IM concentrations.]

- 0% IM
- 2% IM
- 4% IM
- 100% IM
Experimental (Cont.)

Equipment
- 63.5mm, (2.5 in) 30:1 L/D highly instrumented
- EDI Ultraflex Sheet Die
  - 40cm wide, Die Gap = 1.5mm
- Data Acquisition System
  - Pressure and Melt temperature measurements - 50 HZ
- Screw Design DSBM® Barrier Screw

<table>
<thead>
<tr>
<th>L/D Depth (mm)</th>
<th>Feed</th>
<th>Trans.</th>
<th>Barrier</th>
<th>Meter</th>
<th>Mixer</th>
<th>Meter</th>
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<tbody>
<tr>
<td>F+5</td>
<td>1</td>
<td>15.5</td>
<td>3</td>
<td>2</td>
<td>2.5</td>
<td></td>
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<tr>
<td>12.1</td>
<td>-</td>
<td>U/C = 0.64</td>
<td>4.8</td>
<td>U/C = 0.64</td>
<td>4.8</td>
<td></td>
</tr>
</tbody>
</table>
Experimental (Cont.)

Operating Conditions and Recorded Parameters

- Barrel Temperature Profile
  - 179, 190, 190, 190 199 deg C
  - Die / Adapter – 191 deg C

- Screw Speed Range
  - 50, 75, 100, 125 RPM

- Recorded Parameters
  - Output rate
  - Melt Temperature
  - Motor Power
  - Heat Flux in each barrel zone
  - Pressure along the length of the barrel
    - Cross channel pressure gradients in each zone of the screw design
Results
Output Rate and Extrudate Temperature vs. Extruder Speed

- **Extrudate Temperature, °C**
  - 2002D Natural
  - 2002D + IM

- **Extruder Speed, RPM**
  - 50
  - 75
  - 100
  - 125

- **Output Rate, kg/hr**
  - 0
  - 40
  - 80
  - 120
  - 160
  - 200

Legend:
- 2002D Natural
- 2002D + IM
Extruder Motor Power vs. Extruder Speed

- Extruder Motor Power, KW
- Extruder Speed, RPM

- 2002D Natural
- 2002D + IM
Barrel Heat Flux (KW) vs. Extruder Speed

Extruder Speed, RPM

Total Barrel Heat Flux, KW

- 2002D Nat
- 2002D+ IM
Efficiency - kg/hr/kw vs. Screw Speed

Extruder Speed, RPM

- 2002D Nat
- 2002D+ IM
Axial Pressure Generation
Cross Channel Pressure Gradients

Feed Zone

Melt Film / Solid Bed Interface

Melt Film / Barrel Wall Interface

Mechanical Deformation

Conductive Melting w/ Forced Melt Removal

Feed Zone

Pressure (Mpa)

Time (s)

PLA

IMB (PLA + IM)
Cross Channel Pressure Gradients
Melting Zone

Solid Channel
Melt Channel
Solids
Melt Film Thickness
Barrel Wall

Cross Channel Pressure Gradients

Melt Channel

PLA
IM (PLA + IM)

Pressure (Mpa)

29.1 29.2 29.3 29.4 29.5 29.6 29.7

Time (s)

0 5 10 15 20 25 30
Conclusion
Working Mechanism of IM

- Early melting of IM resulted in
  - Feed Zone
    - Lower frictional coefficient
    - Reduced axial pressure generation
    - Lower cross channel gradient
    - Reduced heat removal from barrel
  - Melting Zone
    - Reduced viscosity of melt film
    - Less viscous energy dissipation, (VED)
    - Lower cross channel pressure gradient
    - Reduced heat removal from barrel
- Balanced the solids conveying and melting rate
Conclusion

As a Result, Addition of 2% IM
- Decreased throughput 6-8%
- Lowered Melt Temperature 3.3 – 3.9 Deg C
- Reduced Power consumption 15.6 – 23.7 %
- Increased Energy Efficiency 9 – 21%
- Decreased Heat removal 36 – 46%
- Lower axial pressure generation
- Reduced cross channel gradients in feed and melting zones