Enhanced Orientation of PVC Pipe Using Acrylic Processing Aids

Manoj Nerkar, John Cornetta, Ted Price, Steve Rapacki, Ian Drake, Ramesh Iyer
Agenda

Background
• PVC-O Technology
• PVC-O Market Review

Fundamental PVC-O Material Properties
• Tensile Testing
• Effect of temperature and speed on orientation
• PVC-O in-house capabilities

Acrylic Process Aids
• Melt strength
• Melt Processing

Summary
Oriented PVC (PVC-O) Technology

Picture courtesy of PVC-O molecular orientation, Molecor
PVC-O Market Opportunity

Estimate of PVC-O installed capacity growth (kT) 2017-2022

- 2022 global installed PVC-O capacity projections
- 5 Year CAGR of 14% ('17-22)

Global number of PVC-O lines

- 60 PVC-O lines globally
- # of lines tripled since '08
- Prior 10 year CAGR of 13% ('08-'18)

1. Molecor published estimate from Pipes and Profile Extrusion Magazine Oct. 2018
2. Andre Nijland (Wavin) Pipes in Infrastructure Conference, London April 2018
Learning from Material Test: Tensile Property

• To understand the temperature effect on the PVC-O process, extruded PVC material property is evaluated at different temperature
• As temperature increases, PVC changes from elastic plastic to hyperelastic material behavior
Effect of Temperature on PVC Tensile Strain Limit

- For the PVC-O process, it is better to maintain the temperature where material can achieve highest strain and relatively lower modulus.
Tensile Testing: Effect of Pulling Rate

Base PVC-O Formulation:
- Modulus increases with increasing expansion rate
- Max strain decreases
- Failure in hoop expansion predicted at increased expansion rate
PVC Tensile Testing

Pulling Speed: 2 in/min

T=50 °C

T=100 °C

T=130 °C

Effect of Temperature

Effect of Pulling Speed
In-house Lab Scale PVC-O Set-up

- Pre-extruded pipe is tested for the PVC-O process by a solid mandrel
- Temperature, pipe expansion and lubrication is controlled in this test
- Expansion force is measured during the PVC-O expansion process
• As indicated from material test, force measurement from tensile test confirms that Temperature has a significant effect on the pipe expansion
• A few degree temperature drop can lead to significant force increase
Improved Material Properties: Effect of Processing Aids

100° C and 50 in/min

- PVC pipe compound baseline fails at 300%
- New Dow Processing Aid at 5phr 21527-XP (6515-5) shows higher strain limit
Improved Material Properties: Effect of Processing Aid (PA)

100°C, 20 in/min

Process Aid Loading (PHR)

Engineering Strain Limit (%)

- K120ND: Generic PA
- 21527-XP: PVC-O PA
- T-50: Reactive PA
How Acrylic Processing Aid Works?

**PVC**
- Short stiff chains
- Low molecular weight

**Acrylic Processing Aid**
- Long flexible chains
- Ultra high molecular weight

- MMA-rich, acrylic copolymers with Mw typically >1MM
- Highly compatible with PVC
- Promotes fusion / gelation of rigid PVC
- Without PAs, rigid PVC fusion and melting can be VERY slow under typical processing conditions

**PVC chains entangled with processing aid chains**

- Enhances melt strength and rheology, enabled by their high compatibility, flexibility and Mw, orders of magnitude greater than the PVC
- Rheology control has become the primary function of PA, driving exact selection and usage level

No Effect on Color and Clarity
### Haake Rheocord: Melt Strength Evaluation

<table>
<thead>
<tr>
<th>Haake Rheocord</th>
<th>Screw Speed:</th>
<th>10 RPM</th>
<th>Feeder Speed:</th>
<th>10 RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt Strength Tester</td>
<td>Height:</td>
<td>75 mm</td>
<td>Gap:</td>
<td>0.6 mm</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Haake Extruder</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>AD</th>
<th>Die</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (° C)</td>
<td>150</td>
<td>155</td>
<td>165</td>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>
• Higher level of processing aid increase melt strength, however, its critical to monitor torques and pressures in extruder and die
Choosing Right Processing Aid

- 21527-XP gives higher melt strength at lower loading level

<table>
<thead>
<tr>
<th></th>
<th>K120ND 2 PHR</th>
<th>21527-XP 2 PHR</th>
<th>K120ND 0.85 PHR</th>
<th>21527-XP 0.85 PHR</th>
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</thead>
<tbody>
<tr>
<td>Torque (m*g)</td>
<td>2807</td>
<td>2800</td>
<td>2760</td>
<td>3060</td>
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<tr>
<td>Barrel Pressure (PSI)</td>
<td>1140</td>
<td>1175</td>
<td>1108</td>
<td>1292</td>
</tr>
<tr>
<td>Die Pressure (PSI)</td>
<td>834</td>
<td>901</td>
<td>843</td>
<td>982</td>
</tr>
</tbody>
</table>

Max. Velocity (mm/s)
In-house Biaxial Orientation

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Biaxial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Soak Time (Min)</td>
<td>8</td>
</tr>
<tr>
<td>Temperature (° C)</td>
<td>100</td>
</tr>
<tr>
<td>Distance TD</td>
<td>3X</td>
</tr>
<tr>
<td>Distance MD</td>
<td>2X</td>
</tr>
</tbody>
</table>

- 21527-XP sustained increased (doubled) orientation speed

2X increase in rate

35 to 70 mm/s in TD and MD

21527-XP

Generic PA
Summary

• PVC-O process was evaluated from material perspective
• Maximum elongation was achieved at lower pulling rate
• Optimum temperature (100°C) is critical to get maximum orientation
• Higher elongation was achieved by addition of acrylic process aid (PA)
• 21527-XP improved biaxial orientation as demonstrated by tentering frame data
• Improved melt strength was attributed to specifically designed 21527-XP
• Right acrylic PA can improve PVC-O process and productivity