Evaluating Cavity Pressure Variations Effect on Process Window

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Background

- The goal of a single cavity mold is to have a template that provides a platform where a stable, single cavity can produce nearly identical parts in each of the cavities.
Process Window Evaluation

• Process Window
  1. Guess / Experience

  2. Holding Pressure Experiment

  3. D.O.E.
Process Window Development

<table>
<thead>
<tr>
<th>S #</th>
<th>CP-A</th>
<th>CP-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3000</td>
<td>4500</td>
</tr>
<tr>
<td>2</td>
<td>4000</td>
<td>5500</td>
</tr>
<tr>
<td>3</td>
<td>5000</td>
<td>6500</td>
</tr>
</tbody>
</table>

Adjusting +/- 250 psi = flash or short shots

Data courtesy of Suhas Kulkarni

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Process Window Evaluation

Critical Dimension

8.85 +/- 0.025 mm

Cavity ID

8.7 8.725 8.75 8.775 8.8 8.825 8.85 8.875 8.9

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

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Artificially balanced
Equipment Utilized

- Part volume = 8.51 cm³ (1.49 mm nominal wall thickness)
- Runner volume = 3.32 cm³ (sprue, runner, gates)
- Model 9211 force sensors (Kistler Instrument Corporation)
Process Utilized

Mold = 8-Cavity Next Gen
Material = PC/ABS

Geometrically Balanced Runner vs. Rheologically Controlled Runner

- Fullest Cavity is 95% full
- Even Filling Pattern
- Increase Fill Volume by 6%
- Decrease in Fill Volume

Does This Matter?
Question

- Is the impact of rheological variations eliminated during packing?
Packing Pressure

- Post Gate Cavity Pressure Comparison
  - 4,000 psi pack pressure
Packing Pressure (4,000 psi)

Geometrically Balanced

Rheologically Controlled

Note: Uniform Pack Pressures
Packing Pressure

- Post Gate Cavity Pressure Comparison
  - 6,000 psi pack pressure

![Graphs showing Geometrically Balanced and Rheologically Controlled packing pressures](image)
Packing Pressure (6,000 psi)

Geometrically Balanced

Rheologically Controlled

Note: All Parts Full, Uniform & Higher Pack Pressures
Packing Pressure

- Post Gate Cavity Pressure Comparison
  - 8,000 psi pack pressure

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**Geometrically Balanced**

![Graph showing Geometrically Balanced packing pressure comparison](image)

- Peak Post Gate Press. – Inside Cavities
- Peak Post Gate Press. – Outside Cavities
- Fill Pressure

**Rheologically Controlled**

![Graph showing Rheologically Controlled packing pressure comparison](image)

- Note: All Parts Full, Uniform & Higher Pack Pressures

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Packing Pressure (8,000 psi)

Geometrically Balanced

Rheologically Controlled

- All Parts Full, Uniform & Higher Pack Pressures

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Lab Demonstration

- Results of this study of a Rheologically Controlled Runner System
  - Process window increased by 100%
  - Reduced variation in peak cavity pressures by 97%
  - Reduced cavity pressure integral variation by 81%
  - Reduced gate freeze time by 6% due to uniform gate seal
  - Increased pressure available to the cavity by 50%
  - Increased shot volume by 6%
  - Shear imbalance reduction of 20%
Industry Example 1

Critical Dimension

8.85 +/- 0.025 mm
Industry Example 1

- Identify Flow Groups.

Critical Dimension

8.85 +/- 0.025 mm

Cavity ID

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Industry Example 1

Critical Dimension

8.85 +/- 0.025 mm

Flow Group ID

1A (9) 1B (8) 1C (1) 1D (16) 2A (10) 2B (7) 2C (2) 2D (15) 3A (11) 3B (6) 3C (3) 3D (14) 4A (12) 4B (5) 4C (4) 4D (13)
Industry Example 1

- Dimensional Variations vs. Short Shot Analysis

![Graph showing dimensional variations and part weight analysis.](image-url)
Multi-Defect Analysis

- Use the mold maintenance and part quality data to create a history plot.

Table 1

Mold Maintenance Log Mold X100X

<table>
<thead>
<tr>
<th>Date</th>
<th>Inspector</th>
<th>Description of Problem</th>
<th>Cavity ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/22/2005</td>
<td>JTD</td>
<td>Broken core pin</td>
<td>6,7,11</td>
</tr>
<tr>
<td>6/30/2005</td>
<td>JTD</td>
<td>Short shots</td>
<td>4,9,13</td>
</tr>
<tr>
<td>8/10/2005</td>
<td>MDR</td>
<td>Short shots</td>
<td>1,4,5,13,16</td>
</tr>
<tr>
<td>10/4/2005</td>
<td>JTD</td>
<td>Heavy flash</td>
<td>6,7,10,11</td>
</tr>
<tr>
<td>2/22/2006</td>
<td>JTD</td>
<td>Flash K.O. pins</td>
<td>7,10,15</td>
</tr>
<tr>
<td>3/29/2006</td>
<td>JTD</td>
<td>Parts sticking</td>
<td>3,6,7,10</td>
</tr>
<tr>
<td>4/28/2006</td>
<td>MDR</td>
<td>Heavy flash</td>
<td>7,11,14</td>
</tr>
</tbody>
</table>
Multi-Defect Analysis

- Apply Flow Groups to troubleshoot and identify root causes / corrective actions.

Table 2
Industry Example 2
- Cavity Pressure & Temperature Development Comparison
  - 4 Cavity, Acetal (POM) Gear

Effective Melt Temperature

Conventional Control
Avg. $\Delta T = 38.3^\circ F$

Rheological Control
Avg. $\Delta T = 4.8^\circ F$

Concentricity

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Industry Example 2

- 4-cavity gear mold; fairly uniform wall thickness
- Material = Acetal (POM)
- DSC data = Latent Heat of Fusion is an indicator of percent crystallinity

<table>
<thead>
<tr>
<th>Sample</th>
<th>1st Heat $\Delta H_f$ (J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A-3B</td>
<td>155.6</td>
</tr>
<tr>
<td>4A-4B</td>
<td>164.4</td>
</tr>
<tr>
<td>Delta 3-4</td>
<td>8.8</td>
</tr>
<tr>
<td>1A-1B</td>
<td>161.5</td>
</tr>
<tr>
<td>2A-2B</td>
<td>159.1</td>
</tr>
<tr>
<td>Delta 1-2</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Thank You for Your Time

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Bonus Material

Eric Bowersox, ebowersox@beaumontinc.com, 814-899-6390 Ext. 153
Artificial Balancing Cold Runner Systems

- Even with the artificial fill balance:
  - Higher temperature material still flowing to the inside cavities
  - Intra-cavity imbalances

Temperature distribution @ 95% full

Intra-cavity imbalance

Artificially balanced runners (Ø0.102” vs. Ø0.094”)

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Artificial Balancing Cold Runner Systems

- Even with the artificial fill balance:
  - Pack pressure differences exist between the inside and outside cavities

Pressure distribution at 1.9 seconds

- Over 400 psi difference
- Remember...the magnitude is severely under predicted!

Artificially balanced runners (Ø0.102” vs. Ø0.094”)
Artificial Balancing Cold Runner Systems

- Even with the artificial fill balance:
  - Pack pressure differences exist between the inside and outside cavities

Pressure distribution at 3.7 seconds

- **500-1,300 psi** difference
- Remember…the magnitude is severely under predicted!
- Artificial balancing provides a fill balance only!

Artificially balanced runners (Ø0.102” vs. Ø0.094”)

Different temperature, viscosities, pressures = DIFFERENT PARTS!