ONE TEAM
EXTENSION
EMEA

Moldflow Insight Advanced Processes

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Agenda

- SMC Compression Molding
- Resin Transfer Molding
- Powder Injection Molding
- Microcellular & Chemical Foam Molding
Powder Injection Molding

- PIM = Powder Injection Molding
- MIM = Metal Injection Molding (Powdered Metal)
- CIM = Ceramic Injection Molding (Powdered Ceramic)
What is PIM?

- PIM merges two established technologies: plastic injection molding & powder metallurgy
- A mature process where powder is mixed with a binder for molding relatively small metal or ceramic parts
Why use PIM?

- Cost-effective manufacture of high volume complex parts
- Reduced production time compared with investment casting
- Net-shape manufacture with minimal material waste, more significant as materials costs rise
- Finer particle size, higher sintered density than casting products
- Mechanical properties superior to castings
- Properties equivalent to wrought alloys
Who invented it, when, and where?

1973
- Innovated by Parmatech in USA

1980s
- Developing in EUR and JPN

1990s
- The Product Line of MIM in Israel

Today
- Hottest Component Forming Technology
PIM Process

Wheat → Flour → Shaping → Baked
Feedstock

Feedstock = Binder + Powder

SEM Feedstocks

Wax Based

Paraffin Wax

Polymer

POM System

POM

Stearic acid

Gas atomization powder

Water atomization powder

SS particles

Binder

Binder

Wax

Polymer

POM

Stearic acid
Powder Dimension

- Size
  - Diameter: 1-30 μm

- Powder Loading
  - Volume fraction: About 60%
  - Weight fraction: About 90%

\[ \phi_v = \frac{V_{\text{powder}}}{V_{\text{suspension}}} = \frac{W_{\text{powder}}}{W_{\text{suspension}}} \frac{\rho_{\text{suspension}}}{\rho_{\text{powder}}} \]

Example:
- Stainless 316
- Solid Density: 7.9 g/cm³,
- Melt Density: 5.32 g/cm³
- \( \phi_f = 61.5\% \), \( W_f = 91\% \)
Viscosity

- Higher than conventional thermoplastic material
- The flow-related increase in pressure for filling narrow cross section gates is relatively small
PIM Products
Moldflow PIM Simulation

- Insight Standard
- 3D
- Fill + Pack
- No Warp
- DOE requires Insight Premium
- Finer mesh required above conventional
Process Modeling

- Keep the same Fill and Pack settings as for thermoplastic injection molding

- Advanced settings
  - Consider the following effects
    - Inertia
    - Gravity
    - Wall-slip
  - Time Step
    - Change the default 5% to 0.1%
Wall Slip (3D) – Slip Friction Coefficient

• “With friction”: a slip velocity model, with slip velocity being a function of shear stress, is applied
Powder Volume Concentration
Powder Concentration & Defects

Low concentration regions, possible black line defects
Powder Volume Concentration

Shear-rate gradients  Particle Migration  Powder Concentration

\[ \dot{\gamma} = \frac{du}{dy} = \frac{U}{h} \]

\[ \tau = \eta \cdot \dot{\gamma} \]
Powder Volume Concentration

- Powder Concentration
  - Shear-induced
  - Convection

\[
\frac{\partial \phi}{\partial t} + \mathbf{V} \cdot \nabla \phi = -\nabla \cdot \mathbf{j}_\perp
\]

\[
\mathbf{j}_\perp = \frac{2a^2}{9\eta_0} f(\phi) \nabla \cdot \Sigma_p
\]

\[
\Sigma_p = -\eta_0 \eta_n \dot{\gamma} Q
\]

\[
\eta_n = K_n (\phi/\phi_m)^2 (1 - \phi/\phi_m)^{-2}
\]

\[
Q = \begin{bmatrix}
\lambda_1 & 0 & 0 \\
0 & \lambda_2 & 0 \\
0 & 0 & \lambda_3 
\end{bmatrix}
\]

\[
\dot{\gamma} = \sqrt{2E:E}
\]

Suspension Balance Model
Powder Volume Concentration

Across thickness
Standard Test Procedures

Viscosity - Injection Moulding Rheometer

Mold Validation – Injection Moulding Machine

Shrinkage – Injection Molding Machine

Moldflow uses alternative test methods for MIM and CIM
Viscosity Testing

for MIM and CIM use Rosand RH-7
Plunger driven capillary rheometer

Rosand RH-7
Twin Bore Piston Rheometer
• Possible Replacement of :
  • piston tips
  • capillary dies
  • barrels
Thermal Conductivity Testing

K System:
- Maximum K values
  ~0.5 W/m/deg.C
- Not suitable for MIM and CIM

for MIM and CIM use: Laser Flash Thermal Diffusivity System
- sample preparation - 12.5 mm diameter disk
- test different samples at each temperature
  - 2 temperatures, solid state and one melt state
Samples are required: moulded parts [3mm thick]
# Powder Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder radius</td>
<td>0.01 mm [0.001:10]</td>
</tr>
<tr>
<td>Initial powder volume concentration</td>
<td>60 % [0:100]</td>
</tr>
<tr>
<td>Maximum powder volume concentration</td>
<td>68 % [0:100]</td>
</tr>
<tr>
<td>Particle stress coefficients</td>
<td></td>
</tr>
<tr>
<td>$K_n$</td>
<td>3 [0:100]</td>
</tr>
<tr>
<td>$\Lambda_1$</td>
<td>1 [0:1]</td>
</tr>
<tr>
<td>$\Lambda_2$</td>
<td>0.8 [0:1]</td>
</tr>
<tr>
<td>$\Lambda_3$</td>
<td>0.5 [0:1]</td>
</tr>
</tbody>
</table>
Validation Examples

- Material
  - Stainless 316L
- Dimension
  - 24.7mm x 18.525mm x 3.088mm
The Part - Meshed

- Meshed Type
  - Block: 3D Tetra
  - Runner: Beam Elements

- Meshed more finer around the Gate area
  - More accurate flow pattern around interface between the runner and part
# The Molding Process

## Filling Control

<table>
<thead>
<tr>
<th>Ram Position (mm)</th>
<th>Ram Speed (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>18</td>
<td>40</td>
</tr>
<tr>
<td>8.5</td>
<td>20</td>
</tr>
</tbody>
</table>

## Packing Control

<table>
<thead>
<tr>
<th>Duration (s)</th>
<th>Packing Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>0.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>
PIM Validation Results – Flow Pattern

- 20% Filled Volume
PIM Validation Results – Flow Pattern

- 38% Filled Volume
PIM Validation Results – Flow Pattern

- 52.8% Filled Volume
PIM Validation Results – Flow Pattern

- 76.1% Filled Volume
PIM Validation Results – Flow Pattern

- 86.1% Filled Volume
PIM Validation Results – Flow Pattern

- 97.7% Filled Volume
Powder Volume Concentration Validation

- Sintered Block
  - Cracks correspond to low powder concentration
  - Optical microscope
Example 2

<table>
<thead>
<tr>
<th>尺寸 (mm)</th>
<th>標準公差 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0</td>
<td>+/- 0.250</td>
</tr>
<tr>
<td>25.0</td>
<td>+/- 0.125</td>
</tr>
<tr>
<td>12.0</td>
<td>+/- 0.05</td>
</tr>
<tr>
<td>6.0</td>
<td>+/- 0.04</td>
</tr>
<tr>
<td>3.0</td>
<td>+/- 0.03</td>
</tr>
<tr>
<td>1.0</td>
<td>+/- 0.02</td>
</tr>
</tbody>
</table>
Jetting Prediction
1.38 s (51.82%)
1.54 s (58.84%)
1.72 s (66.10%)
1.84 s (71.19%)
2.01 s (78.21%)
2.19 s (85.47%)
2.36 s (92.98%)
Weld Line Position & Angle

Moldflow
Example 3

- Jetting prediction using wall slip & inertia effects