Introduction to injection molding
Injection molding machine

Figure 1.1 Schematic of a typical injection-molding machine
Injection molding cycle

• Injection of the melt into the mold

• Holding pressure and plasticating
  – Additional melt is injected to compensate for contraction due to cooling
  – As the melt cools and solidifies, the pressure should be high enough to avoid sinkmark

• Ejection
## Injection molding cycle

<table>
<thead>
<tr>
<th>t=0</th>
<th>Screw pushed forward</th>
<th>Hold time</th>
<th>Screw recovery</th>
<th>Soak time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold filling</td>
<td></td>
<td>Part cooling</td>
<td></td>
<td>Part ejected</td>
</tr>
<tr>
<td>Mold closed</td>
<td></td>
<td></td>
<td></td>
<td>Mold open</td>
</tr>
</tbody>
</table>
Characteristics

- Expensive molds – for large production runs
- Low assembly cost
- High pressure – limits the size of the product
- Long products require multiple gates
- Part thickness less than 5mm – limits the cooling time
- Part thickness larger than 0.5mm – premature solidification
- Cycle time is money
Clamping

Clamping force pushes the mold halves together, while the pressure of the melt inside the mold pushes the mold halves apart.

Figure 1.16  The main components of the clamping system
Mold

Sprue: entry channel of the mold

Figure 1.19 A runner system for a four-cavity mold
Mold

Figure 1.21 Example of a three-plate mold
Polymer Processing
The objective is to have the plastic reach all gates at the same time.
Flow into the mold

Figure 1.28  Illustration of fountain flow into a mold cavity

high degree of orientation of the surface layers
significant gradient in orientation and morphology
Weldline

Figure 1.31  Formation of a weld line
Important process parameters

• Product parameters
  – Product dimension, weight, appearance

• Main process parameters
  – Cavity pressure, injection pressure, fill time

• Additional process parameters
  – Melt temperature, mold temperature, hold pressure, cooling time, total cycle time, barrel temperature, screw speed, power consumption (screw, barrel heater)
CAE

(Concurrent engineering)

Polymer Processing
MOLDFLOW
- MF/VIEW : Pre/post processing
- MF/FLOW : Mold filling analysis
- MF/PACK : Packing analysis
- MF/COOL : Cooling analysis
- MF/GAS : Gas-assisted injection molding, PFP
- MF/FIBER : Fiber orientation analysis
- MF/WARP : Shrinkage/Warpage analysis
- MF/STRESS : Structural/stress analysis

C-MOLD C-SET: Reactive molding

ANSYS : Structural analysis

CAD S/W : AUTO-CAD, Pro-engineer
### CAE Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>W/m/deg C</td>
</tr>
<tr>
<td>Specific heat capacity</td>
<td>J/kg/deg C</td>
</tr>
<tr>
<td>Density</td>
<td>kg/cu.m</td>
</tr>
<tr>
<td>Shrinkage Coefficients</td>
<td></td>
</tr>
<tr>
<td>No flow constant</td>
<td></td>
</tr>
</tbody>
</table>

### PVT Data

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>deg C</td>
</tr>
<tr>
<td>Pressure</td>
<td>MPa</td>
</tr>
<tr>
<td>Specific volume</td>
<td>cu.cm/g</td>
</tr>
<tr>
<td>Tensile modulus parallel</td>
<td>MPa</td>
</tr>
<tr>
<td>Tensile modulus perpendicular</td>
<td>MPa</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td></td>
</tr>
<tr>
<td>Solid density</td>
<td>kg/cu.m</td>
</tr>
</tbody>
</table>

### Viscosity Data

<table>
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<tr>
<th>Property</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Temperature</td>
<td>deg.C</td>
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<tr>
<td>Shear rate</td>
<td>1/s</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Pa.s</td>
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</table>

### Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile modulus parallel filler</td>
<td>MPa</td>
</tr>
<tr>
<td>Tensile modulus perpendicular filler</td>
<td>MPa</td>
</tr>
<tr>
<td>Poisson ratio filler</td>
<td></td>
</tr>
<tr>
<td>Shear modulus, Fiber length</td>
<td></td>
</tr>
<tr>
<td>Fiber diameter, Fiber volume fraction</td>
<td></td>
</tr>
</tbody>
</table>

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**Polymer Processing**
Modeling

- FEM

Polymer Processing
Polymer Processing
- Stable (non-buckling) warpage
- Unstable (buckling) warpage

- X-Y-Z
- (Residual strain)
Polymer Processing
- Constant volume filling/packing
- Constant pressure filling/packing

- shut off
- delay
- Sink mark
- leakage, blow-through
Polymer Processing
- flow leader
- thicker
- shorter
- longer

Polymer Processing
Polymer Processing
Weld line about to form

Melt line about to form

Polymer Processing
Polymer Processing
Solvent vapor exposure
Multi-Live Feed injection molding
Push-Pull molding
In-mold Reciprocating pins
Sequential gating
Adapted from Robert A. Malloy. Plastic Part Design for Injection Molding (1994)
Sink mark
void
Gusset

Overview

"Shot short"  "Full short"

Full short process
- PVT