Comparative Study of Micro Powder Injection Molding (µPIM) and Simultaneous Micro Powder Injection Compression Molding (µPICM)

E.Honza, M.Kruchem, V.Piotter, K.Plewa
Karlsruhe Institute of Technology (KIT)
elvira.honza@kit.edu

Outline of the talk

I. Introduction and Motivation
II. Injection Compression Molding
III. Performing of simultaneous Micro Powder Injection Compression Molding (µ-PICM)
IV. Reproduction of micro structures by simultaneous µ-PICM
V. Investigation of sequential µ-PICM
VI. Summary and Outlook
Introduction and Motivation

Advantages of Injection Compression Molding (ICM):

Processing:
- Reduction in injection pressure, clamping force and cycle time
- Uniformly acting holding pressure
- Compensates shrinkage by compressing the melt by clamping movement
- Less material shear

Molded parts:
- Minimization/elimination of sink marks and warpages
- For long-fiber-reinforced thermoplastics: reduction of fiber degradation in parts
- For transparent parts: improvement of dimensional accuracy thus optical properties

Motivation

- Flaws due to incomplete filling at µ-PIM

- Design of the ICM process for powder material and investigation of the influence on accuracy reproduction of micro structure by use of design of experiments (DoE)
Injection Compression Molding (ICM)

Versions of Injection Compression Molding Process

<table>
<thead>
<tr>
<th>Coining axis</th>
<th>Main axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Secondary axis</td>
</tr>
<tr>
<td></td>
<td>Combined main and secondary axes</td>
</tr>
<tr>
<td>Direction of coining</td>
<td>Clamping coining</td>
</tr>
<tr>
<td></td>
<td>Opening coining</td>
</tr>
<tr>
<td></td>
<td>Combined opening/closing coining</td>
</tr>
<tr>
<td>Temporal sequence</td>
<td>sequential</td>
</tr>
<tr>
<td></td>
<td>simultaneous</td>
</tr>
</tbody>
</table>


E. Honza - Comparative Study of μ-PIM and μ-PICM

Injection Compression Molding (ICM)

Mold concepts for injection compression molding

Vertical flash face

Stamping frame

Stamping plug

E. Honza - Comparative Study of μ-PIM and μ-PICM
Injection Compression Molding (ICM)

- Mold moving to compression gap
- Melt injection into a cavity (80-90% cavity volume)
- Compression by clamping movement of the machine
- Cooling, opening and ejection

Performing of Simultaneous Micro Powder Injection Molding (µ-PICM)

- Mold with shearing edges
- Commercial injection molding machine (ARBURG® Allrounder 420C)
- Machine control allows for individual programming of µ-PIM and µ-PICM
- Design of Experiments (DoE): full two-level four-factorial (2⁴)

<table>
<thead>
<tr>
<th>Process parameter</th>
<th>Low level</th>
<th>High level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression force [kN]</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Compression speed [mm/s]</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Compression starting time [s]</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Holding time [s]</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Other process parameters
- Tool temperature [°C] | 75
- Injection speed [mm/s] | 95
- Hold time [s] for µ-PIM | 2.3
- Cooling time [s] | 30
Performing of Simultaneous Micro Powder Injection Molding (µ-PICM)

- Tool insert with micro structures produced by LIGA (Lithography, Electroplating and Molding)

- Feedstock: yttria stabilized zirconium powder (TZ-3YS-E) with binder system (Polyethylene, wax, stearic acid)
Performing of Simultaneous Micro Powder Injection Molding (µ-PICM)

- Investigation of replication quality especially in the area with micro structures of high aspect ratio
- Qualitative rating by use of binary evaluation and arithmetic average of each structure
- Influence of the position of micro structure (near and far to the gate)

Reproduction of micro structures

<table>
<thead>
<tr>
<th>Optimum process parameters of DoE for simultaneous µ-PICM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression force [kN]</td>
</tr>
<tr>
<td>Compression speed [mm/s]</td>
</tr>
<tr>
<td>Compression starting time [s]</td>
</tr>
<tr>
<td>Holding time [s]</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between quality and process parameters with significant variables highlighted.](image)
Reproduction of micro structures

- Comparative analysis between µ-PIM and simultaneous µ-PICM (optimum process parameters) show marginal improvement of the replication.
- Increasing of the significant parameters at µ-PICM: compression force (600kN) and compression speed (6mm/s).
- Comparison between µ-PIM and simultaneous µ-PICM:

![Image of micro structures comparison]

Flow direction of feedstock

Green parts

µ-PIM

µ-PICM

Sintered parts

µ-PIM

µ-PICM

E. Honza - Comparative Study of µ-PIM and µ-PICM
Reproduction of micro structures

Green parts

Sintered parts

Near to gate

Far from gate

E. Honza - Comparative Study of µ-PIM and µ-PCIM
Reproduction of micro structures

- Investigation of the unfilled areas by use of white light interferometer

- µ-PIM: 101.1 µm

- µ-PICM: 63.6 µm

Investigation of sequential µ-PICM

- Machine, mold, structured insert and feedstock unchanged
- DoE: full two-level four-factorial ($2^4$)

<table>
<thead>
<tr>
<th>Process parameter</th>
<th>Low level</th>
<th>High level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression force [kN]</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>Compression speed [mm/s]</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Compression gap [mm]</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Holding time [s]</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Other process parameters

- Tool temperature [°C] 75
- Injection speed [mm/s] 95
- Cooling time [s] 30

- Significant influence: compression force
Investigation of sequential µ-PICM

Green parts

Sintered parts

Near to gate

Far from gate

Summary and Outlook

- Successful implementation of the simultaneous µ-PICM
- First significant process parameters were appointed
- Obvious improvement of micro structure near to the gate with µ-PICM
- Future: further optimization of simultaneous µ-PICM (variothermal processing)