Study of Molded-in-Stress & Warpage behavior in an Injection-Compression Molded (2K) part

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Introductions

- Lead Engineer – (GApt) SABIC Innovative Plastics, India
  - CAE Simulations – providing solutions for development of applications in Automotive & Industrial segments, globally
  - Over 13 years of Industry experience – (also) worked as technical support engineer for Moldflow in India
  - Six-Sigma Green Belt Certified
  - Filed 5 patents and authored many internal reports for knowledge management & posterity
  - MS in Tool Engineering

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The SABIC Organization:

- Creating Long Term Success
- Innovative Solutions
- Material Sustainability
- Commitment to deliver
- Spirit of Ingenuity
- Actions not just words
The SABIC Organization:

We are 40,000 strong and have operations in over 40 countries around the world. World’s 2nd largest diversified chemicals Company
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Class Summary & Objective:

- Through this work we’ll get a basic understanding of Injection-Compression molding process
- Comparative performance b/w Injection molding & Injection-Compression molding
- Warpage behavior of a ICM part (insert molded)
- Use of DOE to get insights into the molding process (ICM)
- Understand the affect of variables on the key “Y” parameter
- Optimize the parameters to reduce the overall part warpage
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Understanding of Injection Compression Molding (ICM) v/s the Conventional Inj. Molding (CIM) process
The CIM Molding process:

- Mold is closed – resin is filled into a gap of part thickness - \( P_{THICK} \)
- Packing/Holding is from the Screw/Barrel System
- The pressure gradient across the part is (relatively) big
- Difficult to pack-out the extremities of the part – needs high pressure

Typical limitations in CIM process:

- Huge pressure gradient
- Limited by the gate freeze-off time
- Over Packing – higher residual stresses & molecular orientation
The ICM Molding process:

Key Characteristics of the ICM Process:

- Vertical sealing of the parting plane (all round)
- Filling into an enlarged cavity - Tool gap ($T_{GAP}$)
- Additional material is required to be injected

- Compression of the parting plane – Fills & Packs-out the part
- At the end of Compression – required part thickness is achieved
- Uniformity in application of Holding pressure on the part
Key Characteristics of the ICM Process: (contd.)

- Filling partially into an oversized mold
- Final part geometry is achieved at the end of Compression
- Compression stroke is used to fill the part & for shrinkage compensation
The ICM Process – Synergy of Technologies

A Successful ICM Process

- Mold Design Compatibility
  - 2-K rotary table with dual injection*
  - Vertical sealing plane in the tool
  - Tool alignment, matching & precision

- Molding Machine & Controls
  - Uniform Compression movement
  - Good control on Comp. stroke & repeatability of the process
  - Shut-Off nozzles to prevent flow-back of resin

- Understanding of the Process
  - Inter-play between the process variables \( \mathbf{C}_{\text{speed}}, \mathbf{C}_{\text{gap}}, \mathbf{C}_{\text{force}} \)
  - Part design compatibility, (t,3D profile, machine tonnage, etc)
As seen in the Process…
- Reduction in Clamping Force (~50%)
- Reduction in Injection Pressure (~40%)
- Improved venting

As seen in the Part…
- Lower residual stress & molecular orientation (birefringence)
- Improved Optical clarity
- Part warpage reduction
- Reduced material shear

Clamp force comparison of IM vs ICM
The ICM Process – Typical applications

Automotive Glazing, Side/Rear Windows, Panoramic Roof, etc.

Optical Parts – like CD/DVD, Lens,

Large Part molding (~1m² surface area) – like Hoods, Side Deflectors,

Structural Parts with Long Glass Fiber (LFT)

Also used for parts
- In-Mold Decoration
- Replication of micro ~ nano textures
The ICM Process – Limitations

- A (relatively) complicated molding process (ICM or 2K-ICM)
- Increased Mold & Machine cost
- Good repeatability in m/c controls & articulation required
- Part design compatibility – 3D profile or depth in parts can be difficult
- Compression motion has less effect on angular surfaces
- Reduced tool life – trimming of flash
Sequential ICM
- The tool is kept with a pre-set gap
- Resin is injected into a enlarged gap
- At the end of injection the tool is compressed to close
Simultaneous ICM

- Keep a pre-set gap
- As Injection is going on the tool is closed to Compress the resin...
Breathing ICM –

- Tool is closed & ready for Injection
- As Injection proceeds, cavity gets opened (free movement)
- Compression starts at Switch-Over point & closes the tool
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Why 2K – ICM as a process is required…?

Plastic parts scores over a metal part……

- Sheet metal system lacks “Design Freedom”.
- Visual appeal – limited aesthetics
- Intensive in secondary operations
- Integration of parts not possible
- “Near Net Shape” process….not really

Product Differentiation, Uniqueness - coming from ETP!
Why 2K – ICM …?

- Use of 2-Station with a central “swivel platen”
- Injection Unit on either side of the m/c.
- Over-Molding of 2nd shot over 1st Shot

2K or 2-Component system to derive the benefits….
- Part integration
- Creation of functional details (latches, bosses, etc)
- Mounting features, reinforcement details, etc.
- Over-molded with 2nd material to form the final “A” Class surface sub. assembly
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The 2K-ICM part – Case study:

1st Shot Part

The 1st shot part is molded using CIM process

2nd Shot Part

The 2nd shot part is molded using ICM process (over molded)

Final Part

Note: Part Dimensions:
1st Shot: 200x80x2mm
2nd Shot: 200x80x2.5mm
The 2K-ICM part – Case study:

1st Shot Part: The 1st part is molded using Cycoloy XCM830.

2nd Shot Part: The 2nd Shot is over-molded with Lexan LS2.

Final Part: During molding of 2nd Shot – the 1st shot is considered as plastic insert at 80 Deg. C.
Typical Process Parameters for ICM:

Melt Temperature – Deg. C
Mold Temperature – Deg. C
Injection Time – sec.

Vol. of resin injected - %
Initial Tool gap - mm

Compression Speed profile – mm/sec
Clamp Tonnage limit - Ton

This is the qty. of resin injected @ Switch-Over
The initial tool gap that is kept open
This is the speed at which Compression is done
This is the max. available Clamp force

Note: The ICM process used here is “Sequential method”
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Design of experiment (DOE) is a tool that allows you to obtain information about how factors (Xs) alone & in combination affect a process & its output (Y).

Face Centered Cube – FCC
- # of Factors (X): 4
- Levels for each Factor: 2
- # of Center points: 7
- Total # of Runs: 25
Insights into the Process – DOE Study:

Y (Minimum Part Deflection) = f(X1, X2, X3,....)

X1: Tool Gap
X2: Qty. of resin injected
X3: Compression Speed
X4: Distance

Design Space

<table>
<thead>
<tr>
<th>Tool Gap (mm)</th>
<th>Low</th>
<th>Med.</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Qty. of Resin Injected %</td>
<td>104</td>
<td>107.5</td>
<td>111</td>
</tr>
<tr>
<td>Comp. Speed (mm/sec)</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td>Distance</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Insights into the Process – DOE Study:

Feed System Details for ICM:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt Temp.</td>
<td>295 Deg. C</td>
</tr>
<tr>
<td>Mold Temp.</td>
<td>90 Deg. C</td>
</tr>
<tr>
<td>Injection Time</td>
<td>2sec</td>
</tr>
<tr>
<td>Max. Clamp F</td>
<td>25T *</td>
</tr>
</tbody>
</table>

All these above factors are kept as Constant while doing the experiments
Available Clamp Force : 25T
Insights into the Process – DOE Study:

Inputs to be provided – Moldflow® Interface

- Mold Temp. (K)
- Melt Temp. (K)
- Injection Time
- Constant

(X2 (Qty. of resin injected))
Insights into the Process – DOE Study:

Inputs to be provided – Moldflow® Interface

- **X1 (Tool gap)**
- **X3 (Comp. Distance)**
- **X4 (Comp. Speed)**
Insights into the Process – DOE Study:

Inputs to be provided – DOE Build in Moldflow® Interface

- **Variable Influences (Taguchi)**
  Calculate which variables have the greatest influence on part quality criteria. Generate a list in the DOE impact of each variable on quality. This list helps in determining the influence of each variable on part quality.

- **Variable Responses (Face Centered Cubic)**
  Calculate how sensitive each quality criterion is to input variables. Generate 2D/3D response surface plot for each criterion. Use this method to determine the sensitivity of each variable for each criterion.

- **Quality Criteria & Weightage**
  The Deflection, all effects Deflection is calculated. The goal is to minimize the variation of Deflection. Weight is 10, indicating the high importance of minimizing this variable.
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Insights into the Process – Key Results:

The relevant results from ICM process are shown:

- Part fills in 8.8 sec
- Max. Pressure: 22 MPa
- Flow Front Temp. drop: 20°C
- Press comes back by 1.95 mm
Insights into the Process – Key Results:

The relevant results from CIM process are shown:

- Part fills in 2.15sec
- Pressure @ Switch-Over 37MPa
- Max. Pressure: 37MPa
- Clamp Force: 49T

- As seen, there is a reduction of 40% in pressure required to fill the part
- The Clamp tonnage reduces by ~50%
Insights into the Process – Key Results:

Warpage Comparison b/w CIM & ICM

- Part fills in 2.15 sec
- Warpage Comparison b/w CIM & ICM

CIM Process:
- Max. Deflection: 4.5 mm
- Overall “pressure history” is lower in ICM process
- Response to Packing is more effective in ICM
- Residual stress is reduced – part warpage is lower in an ICM molded part

ICM Process:
- Max. Deflection: 2.3 mm
Insights into the Process – Key Results: Resin Inj: 107.5%

- Part Deflection vs Press Open dist.
- Press Comp. Speed at 0.5mm/sec
- Press Comp. Speed at 0.75mm/sec
- Press Comp. Speed at 1.0mm/sec
- Press Open Distance 1mm
- Press Open Distance 2mm
- Press Open Distance 3mm

Part Deflection vs Press Comp. Speed

Part Deflection vs Press Comp. Speed

Part Deflection vs Press Comp. Speed

Press Open Distance 1mm

Press Open Distance 2mm

Press Open Distance 3mm
Insights into the Process – Key Results:

- The response surface plot is shown here.
- Part Deflection (Z-axis) is shown as a response to the variation in Press Open distance (1mm ~ 3mm), Press Comp. Speed (0.5mm/s ~ 1mm/s), and Qty. of resin Injected (104% ~ 111%).

The optimized settings of “X” parameters for minimal “Y” (warpage) is given here.
Thank You