“Simulation of Injection-Compression and Compression Molding”

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Introduction

- For the last three years, Schneider Electric has been working extensively with Autodesk/Moldflow to jointly develop 3D Thermoset Injection-Compression and Compression Molding simulation software.
- In today’s presentation, I will give you some examples of idealized “Test-Cases” that we created to demonstrate the Injection-Compression & Compression Molding processes. These models were used to evaluate the software and provide feedback to Moldflow.
- We also had the opportunity to conduct mold trials of an actual Compression Molded Circuit Breaker casing, Q2R 3Pole Base at one of our mold vendors in Mexico. Part of these mold trials included a Design of Experiment (DOE) where we were able to evaluate the effect of varying 3 different molding parameters on Shrinkage.
- We then performed a Compression Molding Simulation of the Q2R 3Pole Base using the latest release of Moldflow Scandium 2014. Results are presented along with correlations between the Analytical predictions and the outcome of the Mold Trials.
Thermoset Injection-Compression (Test Case)
Injection Unit

A-Half of Mold (Fixed)

B-Half of Mold (Moving)

Mold Cracked Open 6 mm to 12 mm during Injection
Finished Part
Finished Part
(cut in half)
Two Steps prior to Mold Shutting Off
One Step prior to Mold Shutting Off
Window forms only when Mold shuts off completely
Theoretical Injection-Compression Part without Hole – Analyzed using Scandium 2014
Injection - Compression Molding Analysis - Moldflow Synergy Scandium 2014

STL File Import
Assign Injection Nodes

Assign Properties: Part 3D
(1” Dia. x 3” Tall)

Assign Properties (Entire Part):
Compression Elements
Injection-Compression, Test Case, Scandium 2014
BMC 605 (Bulk Molding Compound, Mineral Filled, Glass Fiber reinforced Polyester)
Notice that the lower surface of the part is stretched in the -Z direction to represent the lower moving die.
Theoretical Injection-Compression Part with Hole – Analyzed using Scandium 2014
In order to simulate the model with a hole, we need to model the hole as a thin area (with thickness of around 0.010” – 0.020”).
Notice that the lower surface of the part is stretched in the -Z direction to represent the lower moving die.
Thermoset Compression Molding Validation – Test Case

November 15, 2012
We first show a graphical depiction of an actual compression molding process where a Thermoset BMC charge is compressed between two die halves.
As the A-half starts to move down the upper surface of the charge is penetrated by any protrusion that may exist on the upper die. This displaces some of the volume and the charge starts to deform.
As the A-half moves down, the charge is further deformed. Notice that other than the protrusion on the upper die, the rest of the tool has not made contact with the charge.
At this stage of movement of the A-half, notice that the entire upper surface of the charge comes into contact with the die. Material starts to bulge into the cut-out in the upper surface of the cavity.
At this stage of compression, notice that the charge has come into contact with most of the upper surface of the cavity. However, it has not completely filled the U-shaped cut-out on the B-half.
As the A-half moves down further, the upper surface of the charge has completely contacted the upper die. The U-shaped cut-out on the lower die is almost filled, while the polymer has started to move down the edges of the B-half to form the side walls.
At this stage of compression, the lower surface of the A-half and the upper surface of the B-half are completely in contact with the charge and the polymer has moved down significantly to form the side walls. Notice the thickness of the side walls are larger than the final part side wall thickness.
The polymer has now been squeezed all the way to the parting line. The only portion of the cavity yet unfilled are the flanges on the bottom.
End of compression. A-half shuts off on B-half at the Parting Line. Notice that only at this stage, the wall thicknesses have the dimensions of the final part.
We then performed a Thermoset Compression Molding simulation with Moldflow Scandium. The solid model of the part and external initial charge were pulled into Moldflow Scandium.
This picture shows how a charge of Thermoset BMC is typically placed on top of the B-Half of the mold prior to compression.
External Initial Charge: Volume = 6" x 6" x 2" = 72 cu. in.

Compression Elements: Volume = 71.7256 cu. in.
Compression, Test Case, Scandium 2014

External Initial Charge

3"

Compression Elements
Notice that the upper Surface of the part is stretched in the Z direction to represent the upper die.

Notice that the charge does not touch this surface at the start of compression?
In order for the charge to touch the upper surface of the die, the bottom surface of the initial charge should follow the contour of the lower die.
Notice that with the shaped charge the polymer touches this surface right from the start of compression?
Q2R 2Pole Base, Compression Molded at Parkway, Mexico
Q2R 2Pole Compression Molding Trials Video
(CompressionTrials_Q2R-2P-Base_condensed.wmv)
BASE Q2R 3Pole Base, Compression Molded at Parkway, Mexico
External Initial Charge:
Volume: 20.6 cu. in.

Compression Elements:
Volume: 19.44 cu. in.

Q2R, 3Pole Base, Compression Molding
Model/Mesh: Part & Charge Placement
This distance does not matter
Q2R, 3Pole Base, Model/Mesh: Part & Charge Placement

In the X & Y direction, the charge placement location does matter
Clips from Video showing how material is loaded into the cavity half (lower stationary side).
Parkway, Mexico, Processing Conditions

- Actual Mold temperature
  - Mold surface temperature: 350°F
  - Melt temperature: 95°F
  - A little above Room Temperature due to charge heating by the mold prior to compression

- Take defaults .... Cure time will be entered later (approx. 3 min.)
Time during which the mold is closed (roughly 3 min.). This is where we account for the cycle time.

Actual Press closing speed after Core Half comes into contact with charge.

Take Defaults:

Mold closing direction has to be plus or minus Z.

Total mold close-to-mold open time is just over 3 minutes.
Parkway, Mexico, Processing Conditions

Thermoset Material: BMC 605

Mold material: Tool Steel H-13
With BMC 605, results of our analysis showed that the Compression Pressure required to fill the part would be 1,275 psi. Shown on the next Slide is the actual hydraulic pressure measured off a dial gauge at the press.
Pressure Gauge on the machine showed roughly 1,700 psi Hydraulic Pressure during the cure cycle. However, we do not have sufficient information from the molder as to how this pressure translates to Compression Force on the platen of the mold.
Scandium 2014 - Q2R 3 Pole Base, Compression Molding Results
‘q2r_charge3_comptime180_slow_sideassign3_Scandium_NewBMC’
Scandium 2014 - Q2R 3 Pole Base, Sectioned Part
Upper Surface of the part is stretched in the Z direction to represent the upper die.
These holes do not exist at this stage of compression.

To avoid the holes at the start of compression, a thin web needs to modeled over each of the holes (thickness: 0.010” – 0.020”)

Polymer fill region
Time = 0.1521[s]
Polymer fill region
Time = 0.1521[s]
Polymer fill region
Time = 0.1521[s]
Features on bottom of cavity block form first.
Ribs starting to fill.
Design of Experiment (DOE)

Note: We used "Central Composite Design (Face-centered)" method for the DOE.
Parameters (such as compression force, cure time, and charge weight) were not chosen for this experiment.

* Run 15 – 16 are at the same condition (nominal process); 5 parts for each run

<table>
<thead>
<tr>
<th>Molding Run</th>
<th>Compression speed (inch/sec)</th>
<th>Delay time (s)</th>
<th>Mold temperature (F)</th>
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<td>16</td>
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<td>14</td>
<td>0.917</td>
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<td>370</td>
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<tr>
<td>15 – 16*</td>
<td>0.917</td>
<td>21</td>
<td>350</td>
</tr>
</tbody>
</table>
Distances Measured

Note: No Gauges were inserted into the open end while cooling. Measurements were taken after parts had cooled down.
Notice that the Distance AB, measured at the Top of the part, varies from 4.369” to 4.426” (a range of 0.057”). The steel dimension is 4.454”. This implies that the shrink factor ranges from 0.006 – 0.019 in/in. The shrink factor applied in the tool was 0.002 in/in for BMC 605. The measured shrinkage for AB at the Top is roughly 3 to 10 times the recommended shrinkage for BMC 605. The variations in shrinkage were widely scattered between the various design parameters and it was difficult to draw conclusions regarding any one process variable that could be used to minimize shrinkage.
Notice that, even for Run 16, performed at Nominal Processing Conditions (Compression Speed: 0.917 in/sec, Delay Time: 21 sec, Mold Temp: 350 F), the variation in the distance measured for AB in Cavity 1 was 0.019”. Since all measurements were from the same cavity at the same processing conditions, one explanation is that it may be related to variations in weight and placement of the charge in the cavity. Also, variations in Compression Force can also cause variations in Shrinkage. Another explanation is that dimensions across the open end of the part vary a lot more than at the closed end of the part. Note: Gauges were NOT inserted into the open end while the part was cooling.
Notice that the Distance AB, measured at the Bottom of the part, varies from 4.401” to 4.408” (a range of 0.007”). This range of variation at the closed end is much tighter than at the open end. The steel dimension is 4.416”. This implies that the shrink factor ranges from 0.002 – 0.003 in/in. The shrink factor applied in the tool was 0.002 in/in for BMC 605. The measured shrinkage for AB at the Bottom is in line or just a little higher than the recommended shrinkage for BMC 605.
Notice that the Distance AE, measured at the Top of the part, varies from 6.471” to 6.483” (a range of 0.012”). This range is fairly tight for the longest dimension measured in the part (along the length, at the top of the side wall). The steel dimension is 6.483”. This implies that the shrink factor ranges from 0 – 0.002 in/in. The shrink factor applied in the tool was 0.002 in/in for BMC 605. The measured shrinkage for AB at the Bottom is in line or a little lower than the recommended shrinkage for BMC 605.
Warpage predicted was roughly 0.011” in the X-direction at the top of one of the side walls. Actual warpage measured in the molded parts was roughly 0.017”. Therefore, the predicted warpage is roughly 35% lower than the measured warpage. These predictions are on the same order of magnitude of what was measured and is quite good considering all the variables that influence shrinkage and warpage.
Conclusions

• The filling pattern predicted by Moldflow Scandium 2014 for both the Injection-Compression and Compression Molding Test Cases seemed to reasonably predicted what would be expected in a the real world.

• The filling pattern predicted for the Compression Molding of the Q2R 3Pole Base matched the short-shots rather well.

• From our DOE we found that the variations in shrinkage were widely scattered among the various design parameters and it was difficult to draw conclusions regarding any one process variable that could be used to minimize shrinkage.

• Measurements taken along the open end of the part indicated that the shrinkage varied as much as 10 times the expected shrinkage for BMC. Measurements taken at the closed end and along the length of the part were pretty much in line with what was expected.

• One explanation for the wide variation in shrinkage observed for measurements taken on multiple shots from a single cavity, all processed at the same conditions, is that it may be related to variations in weight and placement of the charge in the cavity. Also, variations in Compression Force can also cause variations in Shrinkage. Another explanation is that dimensions across the open end of the part vary a lot more than at the closed end of the part. Note: Gauges were NOT inserted into the open end while the part was cooling.
Conclusions … (continued)

- Warpage predictions were roughly 35% lower than measurements taken at the mold trial. These predictions are on the same order of magnitude of what was measured and this discrepancy is not uncommon for Flow simulations.

- Rather than model the two halves of the mold and compress the charge in between, similar to the actual Injection-Compression and Compression Molding Process, Moldflow has taken the approach of moving the entire upper surface of the part upward by a finite distance to mimic the A-half of the mold. Since the CAD model of the part is more readily available than the die halves, this makes it easier on the user to perform simulations.

- Because of this approach, the charge is modeled as an external block placed above the part, rather than inside the die halves. The upper surface of the part then moves downward to mimic the compression of the charge. As a result of this, holes, shut-offs etc., appear as openings right from the start of compression, rather than appear only when the two halves of the die are completely closed.

- In order to overcome the appearance of holes at the start of compression, the user needs to create a thin web of material over the holes/openings in the part. This may prove to be cumbersome for complicated parts.