SM1730-P: Simulation of Injection Compression and Compression Molding (Part II)

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More than 175 years of history

1836
Creation of Schneider at Le Creusot, France

19th century
Steel Industry

1975
Merlin Gerin joins Groupe Schneider

20th century
Power & Control

1991
Square D joins Groupe Schneider

1996
Modicon, historic leader in Automation, becomes a Schneider brand

2000
Acquisition of MGE UPS Systems

2003
Acquisition of T.A.C

2005
Acquisition of Power Measurement Inc.

2007
Acquisition of APC corp. and Pelco

2008
Acquisition of Xantrex

2010
Acquisition of Areva's distribution activity

2011
Acquisition of Telvent

2003-2008
Targeted acquisitions in wiring devices and home automation (Lexel, Clipsal, Merten, Ova, GET, etc.)

21st century
Energy Management
Schneider Electric at a glance
The global specialist in energy management

**Large company**

- 24 billion € of sales in 2012
- 41% of sales in new economies
- 140,000+ employees in 100+ countries
- 4–5% of sales devoted to R&D

**Diversified end markets**

- Utilities & Infrastructure: 25%
- Industrial & machines: 22%
- Data centres: 15%
- Non-residential buildings: 29%
- Residential: 9%

**Balanced Geographies**

- FY 2012 sales
  - Western Europe: 31%
  - North America: 25%
  - Rest of World: 18%
  - Rest of World: 27%

Year-end 2012 employees

- 28,300
- 44,200
- 42,600
- 22,000

FY 2012 Sales (billion €)

- Residential: 9%
- Utilities & Infrastructure: 25%
- Industrial & machines: 22%
- Data centres: 15%
- Non-residential buildings: 29%
- Residential: 9%
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 were 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

Mold Cracked Open 6 mm to 12 mm during Injection

A-Half of Mold (Fixed)

B-Half of Mold (Moving)
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

STL File Import
Injection-Compression, Test Case, Scandium 2014

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

Assign Injection Nodes

Assign Properties (Entire Part):
Compression Elements
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.
Polymer fill region

Time = 0.0722[s]
Theoretical Injection-Compression Part with Hole
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.
Polymer fill region

Time = 0.0884 [s]
Thermoset Compression Molding Validation – Test Case
We first show a graphical depiction of an actual compression molding process where a Thermoset BMC charge is compressed between two die halves.
External Initial Charge (Solid Model) placed at a finite distance from the 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.
External Initial Charge

Compression Elements
Notice that the charge does not touch this surface at the start of compression?

Notice that the upper Surface of the part is stretched in the Z direction to represent the upper die
Polymer fill region
Time = 0.3514[s]
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?
Polymer fill region
Time = 0.3514[s]
Q2R 2Pole Base, Compression Molded at Parkway, Mexico
Q2R 3Pole Base, Compression Molded at Parkway, Mexico
Q2R, 3Pole Base, Compression Molding Model/Mesh: Part & Charge Placement

External Initial Charge:
Volume: 20.6 cu. in.

Compression Elements:
Volume: 19.44 cu. in.
Q2R, 3Pole Base, Model/Mesh: Part & Charge Placement

This distance does not matter
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).

Core Block (upper moving side)

Cavity Block (lower stationary side)
Upper Die (A-half) Moving

Lower Die (B-half) Stationary

Charge is placed at the bottom of the B-half
Actual Mold temperature

A little above Room Temperature due to charge being heated by the mold prior to compression

Take defaults … Cure time will be entered later (approx. 3 min.)
Mold closing direction has to be plus or minus Z.

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.

Total mold close-to-mold open time is just over 3 minutes.
Thermoset Material: 
BMC 605
Max. Pressure
= 1,275 psi

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.
Q2R 3 Pole Base, Compression Molding
Upper Surface of the part is stretched in the Z direction to represent the upper die.
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”)

These holes do not exist at this stage of compression.
Polymer fill region
Time = 0.1521[s]
Polymer fill region
Time = 0.1521[s]
Polymer fill region

Time = 0.1521\,[s]
Short-Shots from Mold Trials of Q2R 3Pole Base conducted at Parkway, Mexico
Features on bottom of cavity block form first.
Ribs starting to fill.
Design of Experiment (DOE)

Method for the DOE

"Central Composite Design (Face-centered)".

Parameters not chosen for this experiment.

- Compression force,
- Cure time
- Charge weight

<table>
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<th>Compression speed (inch/sec)</th>
<th>Delay time (s)</th>
<th>Mold temperature (F)</th>
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<tr>
<td>15 – 16*</td>
<td>0.917</td>
<td>21</td>
<td>350</td>
</tr>
</tbody>
</table>

* Run 15 – 16 are at the same condition (nominal process); 5 parts for each run
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 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 predict what would be expected in 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.
Conclusions ...

• 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.

• 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 is quite good considering all the variables that influence shrinkage and warpage.
Conclusions ...

- 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.