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

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More than 175 years of history

Steel Industry

Power & Control

Energy Management

19th century

20th century

21st century

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+

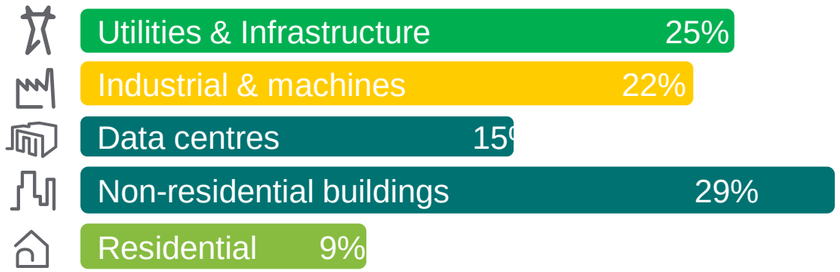
employees in 100+ countries

4–5%

of sales devoted to R&D

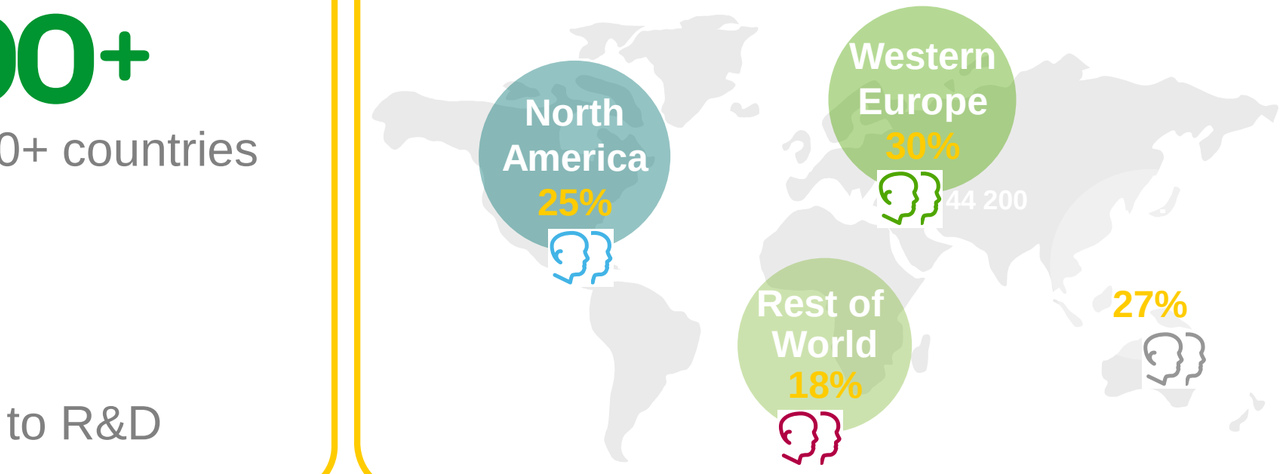
Diversified end markets

FY 2012 Sales (billion €)



Balanced Geographies

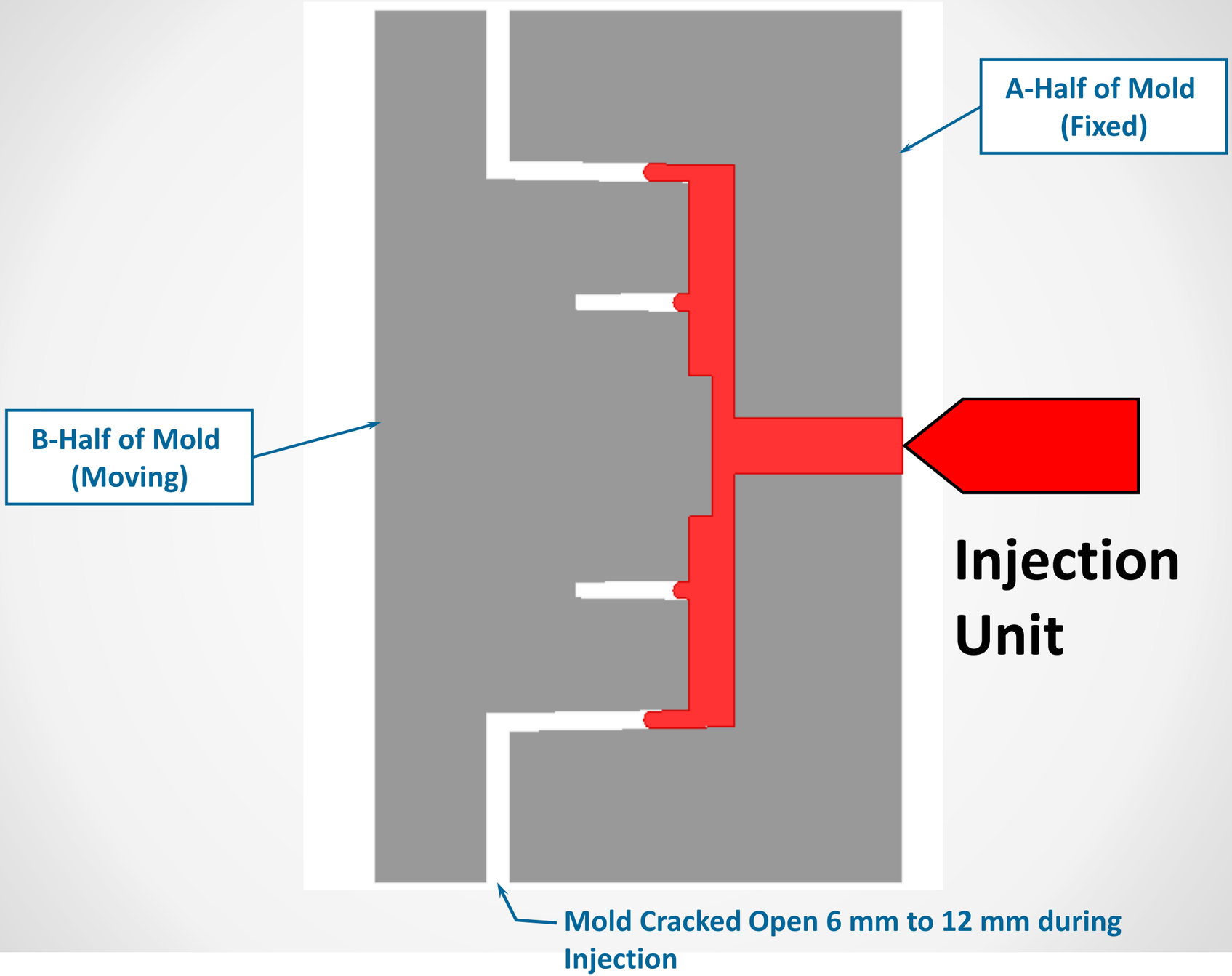
FY 2012 sales
Year-end 2012 employees

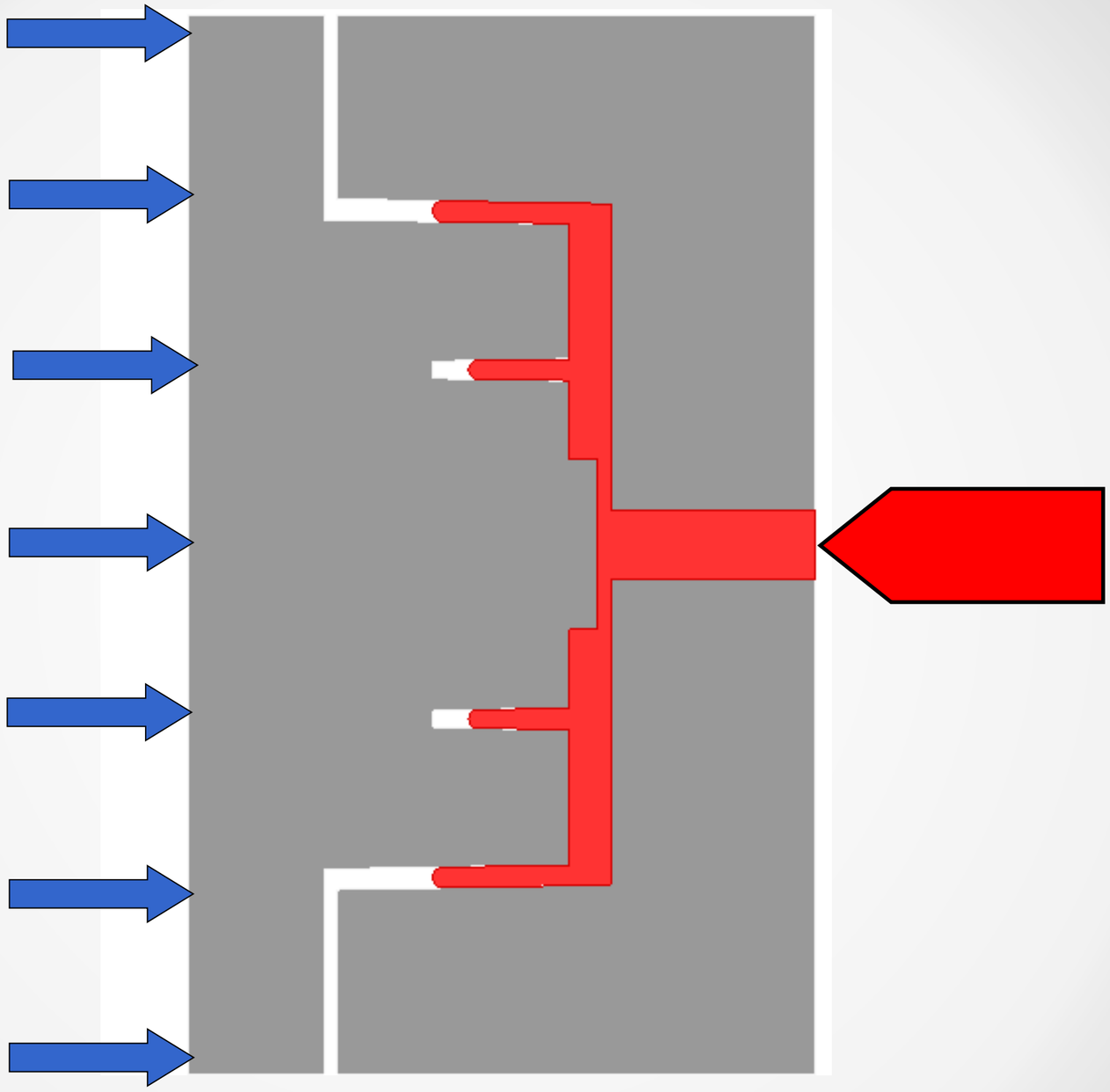


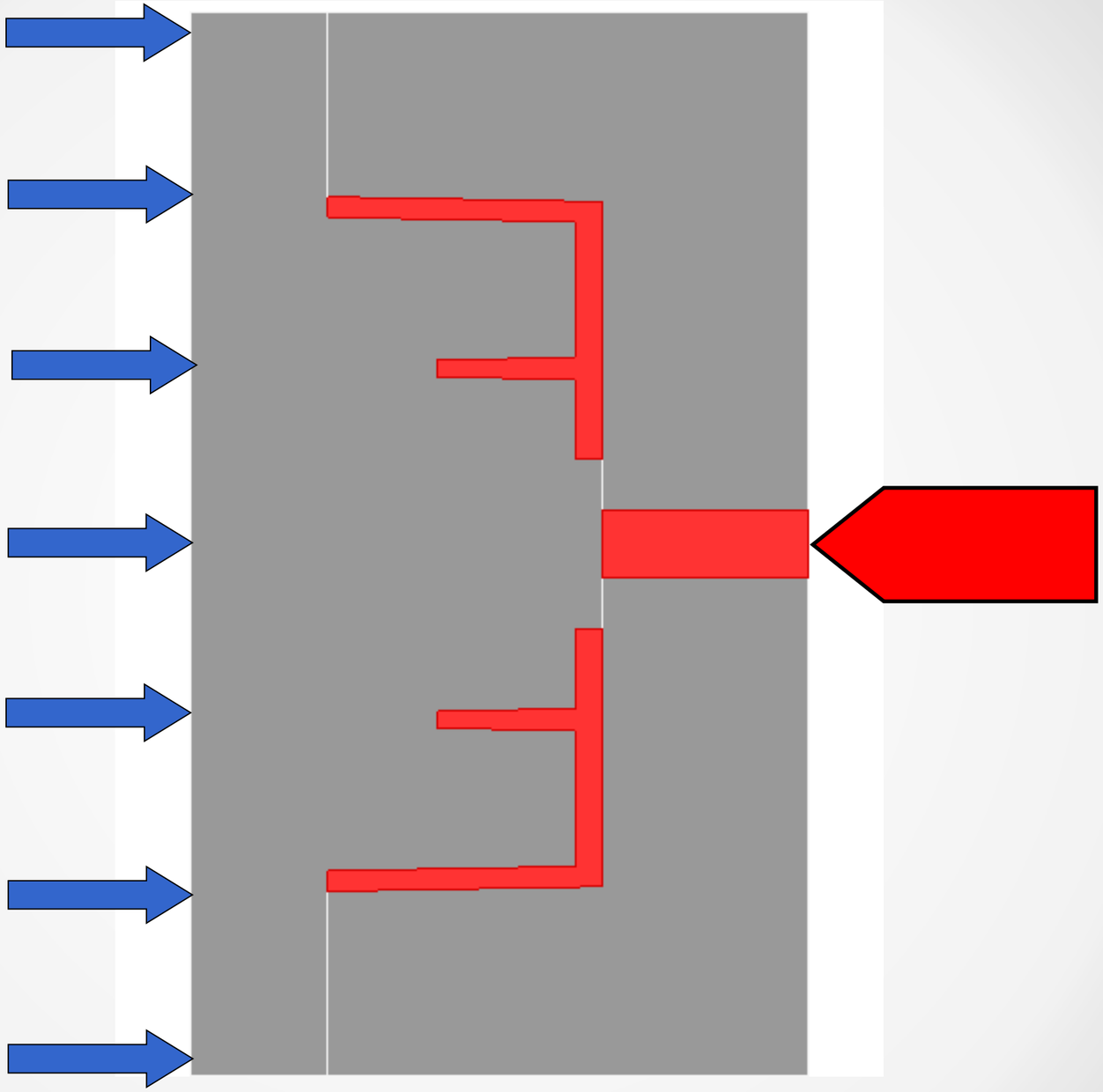
Introduction

- 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.

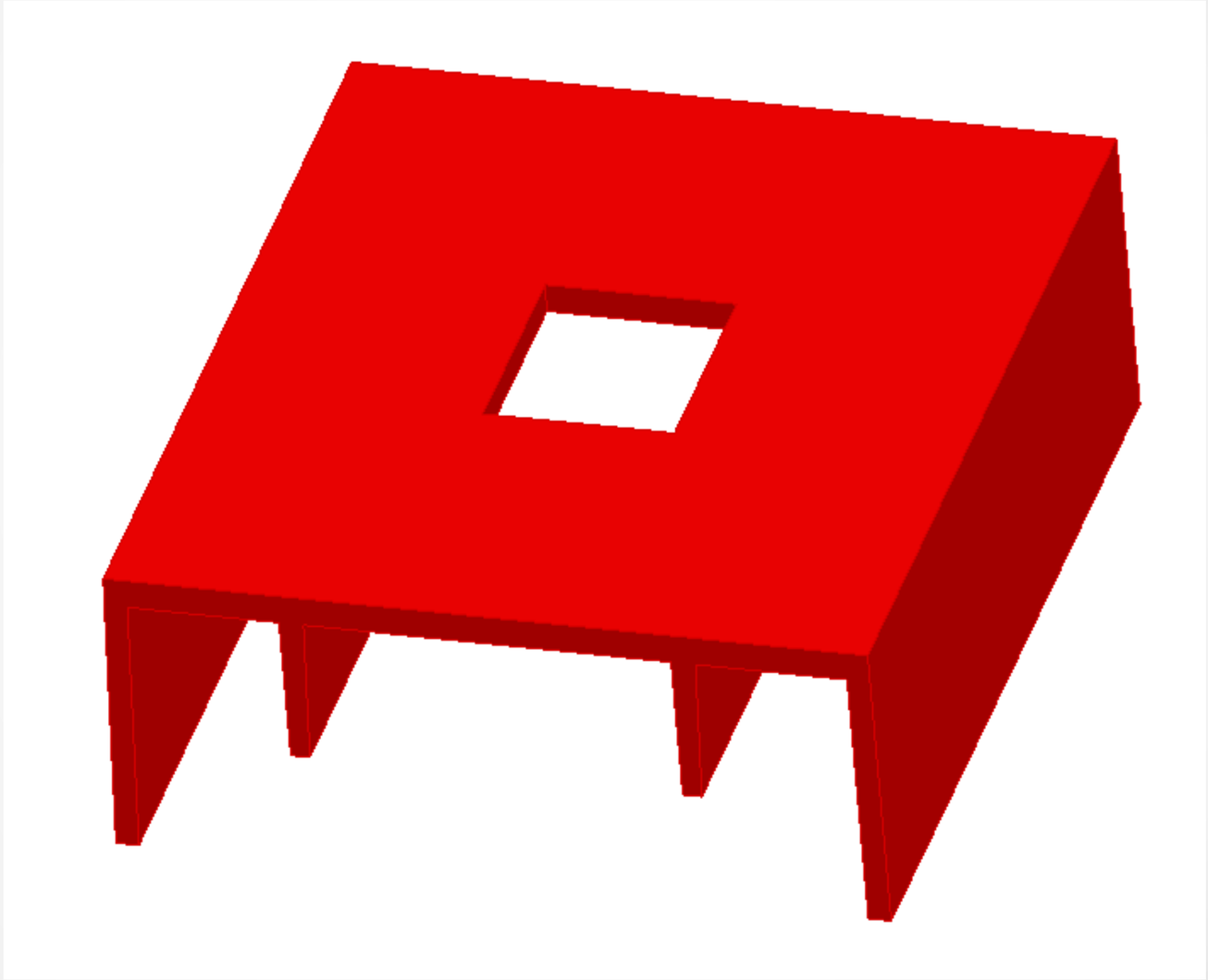
Thermoset Injection-Compression (Test Case)


A-Half of Mold
(Fixed)
B-Half of Mold
(Moving)
Injection
Unit
Mold Cracked Open 6 mm to 12 mm during
Injection

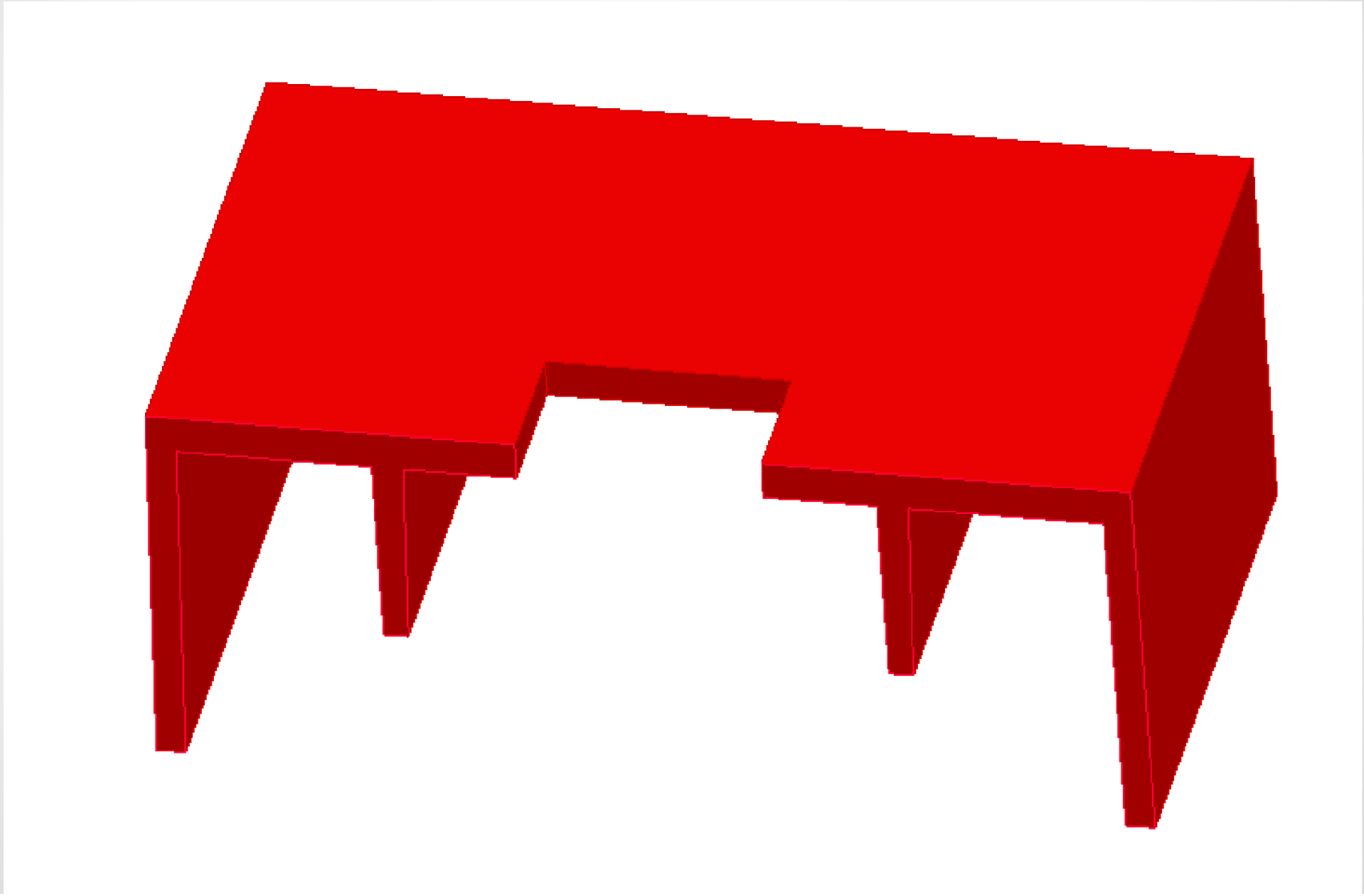




Finished Part

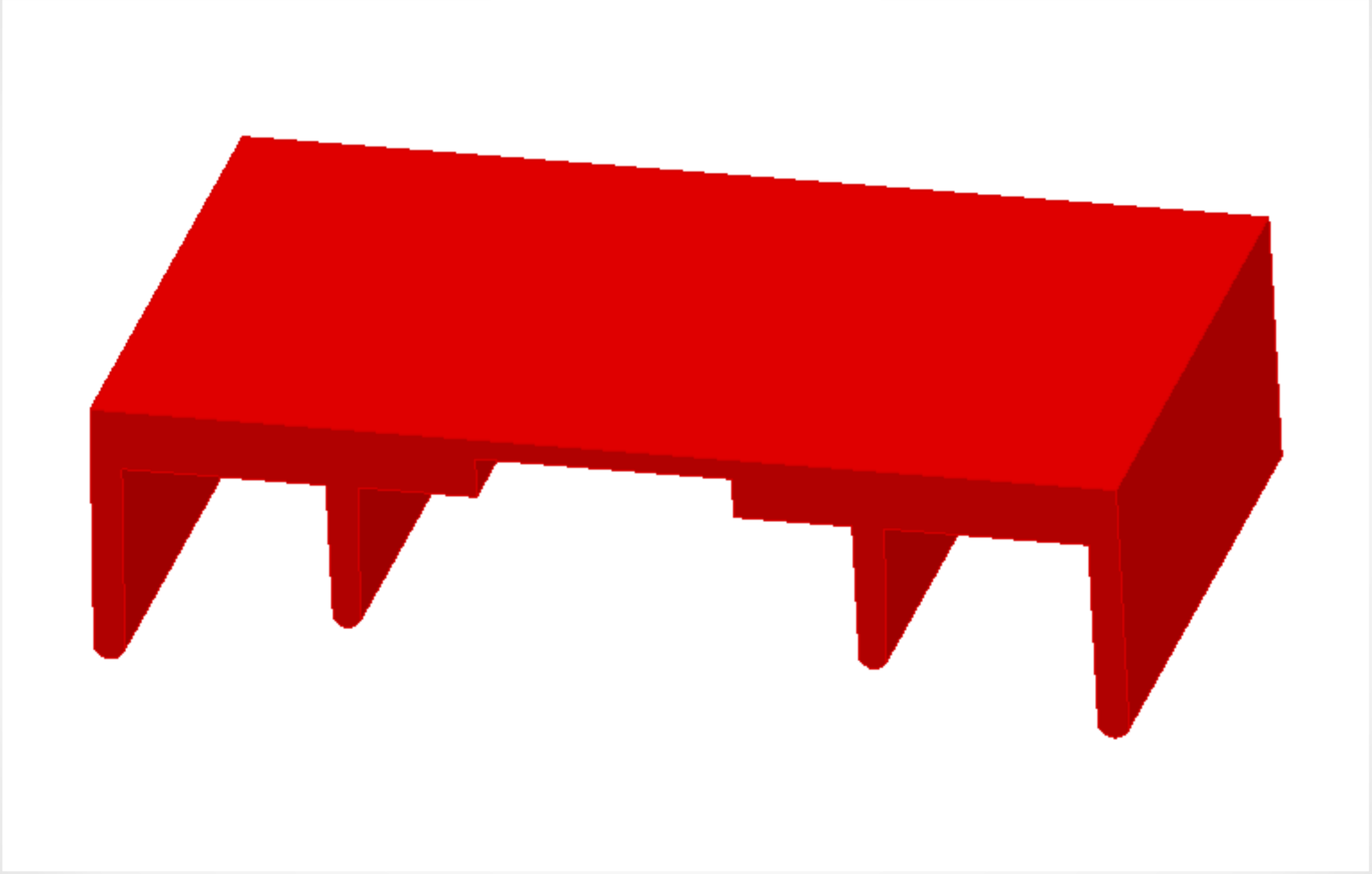


Finished Part (cut in half)

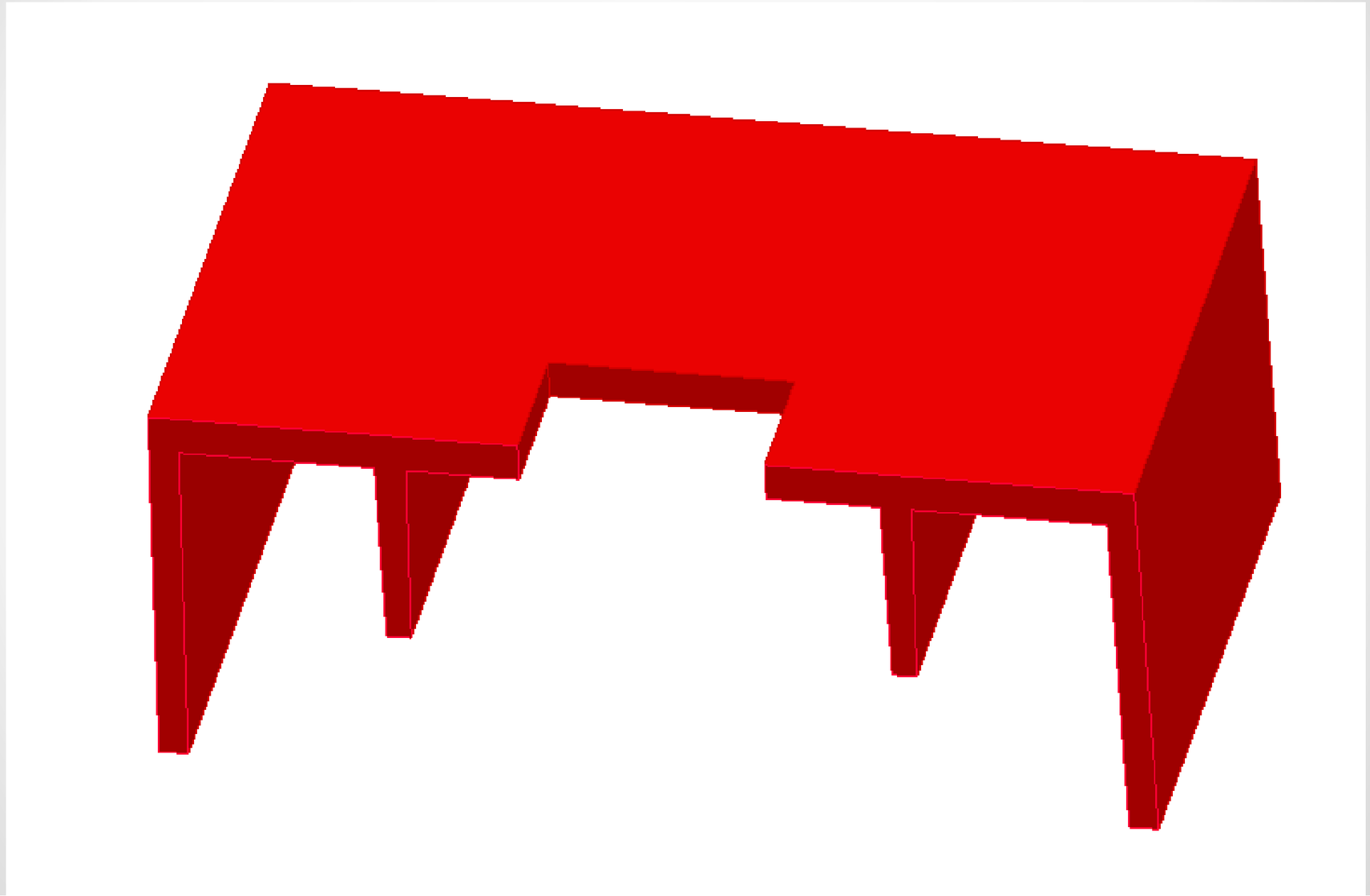


Two Steps prior to Mold Shutting Off

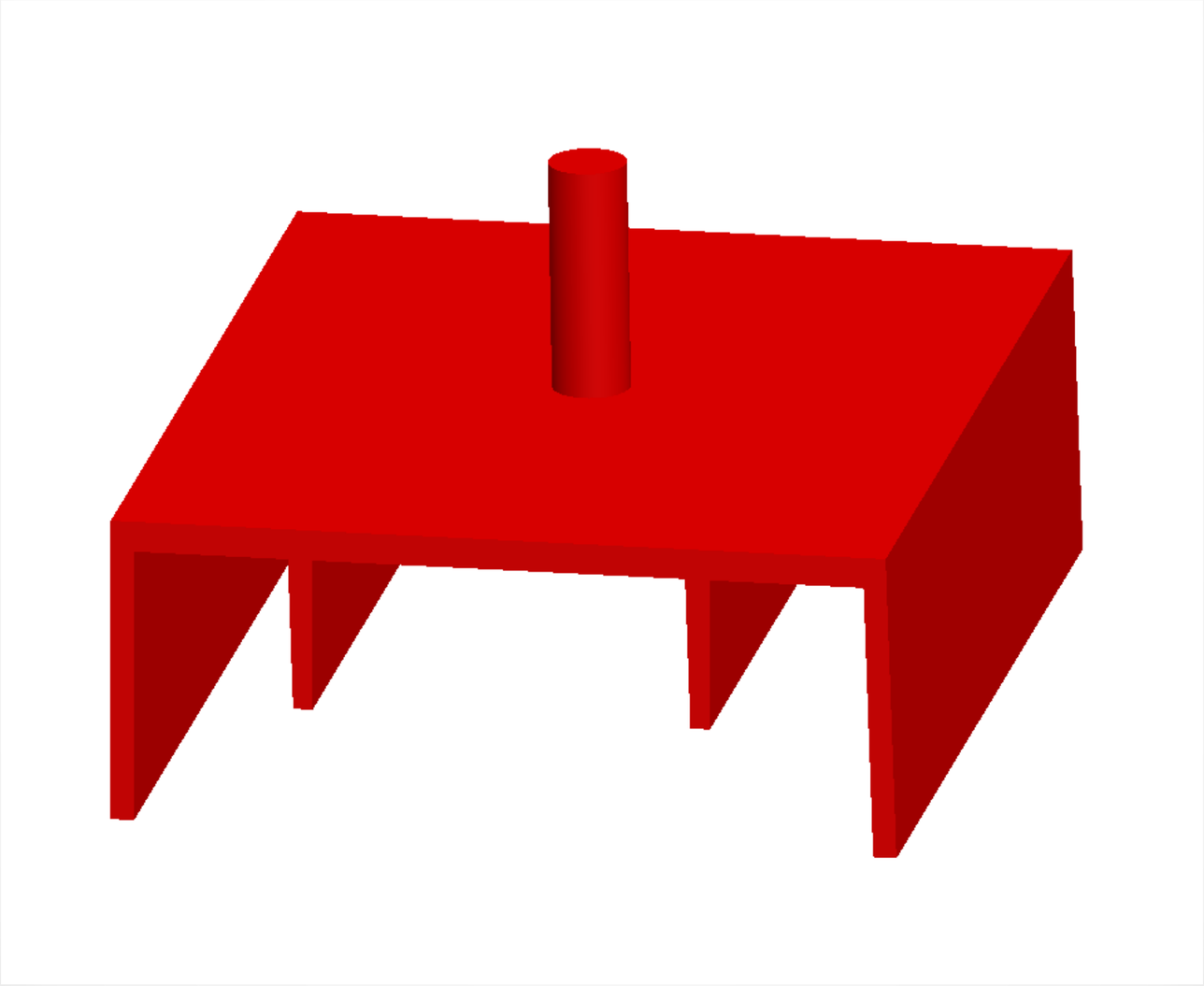
One Step prior to Mold Shutting Off



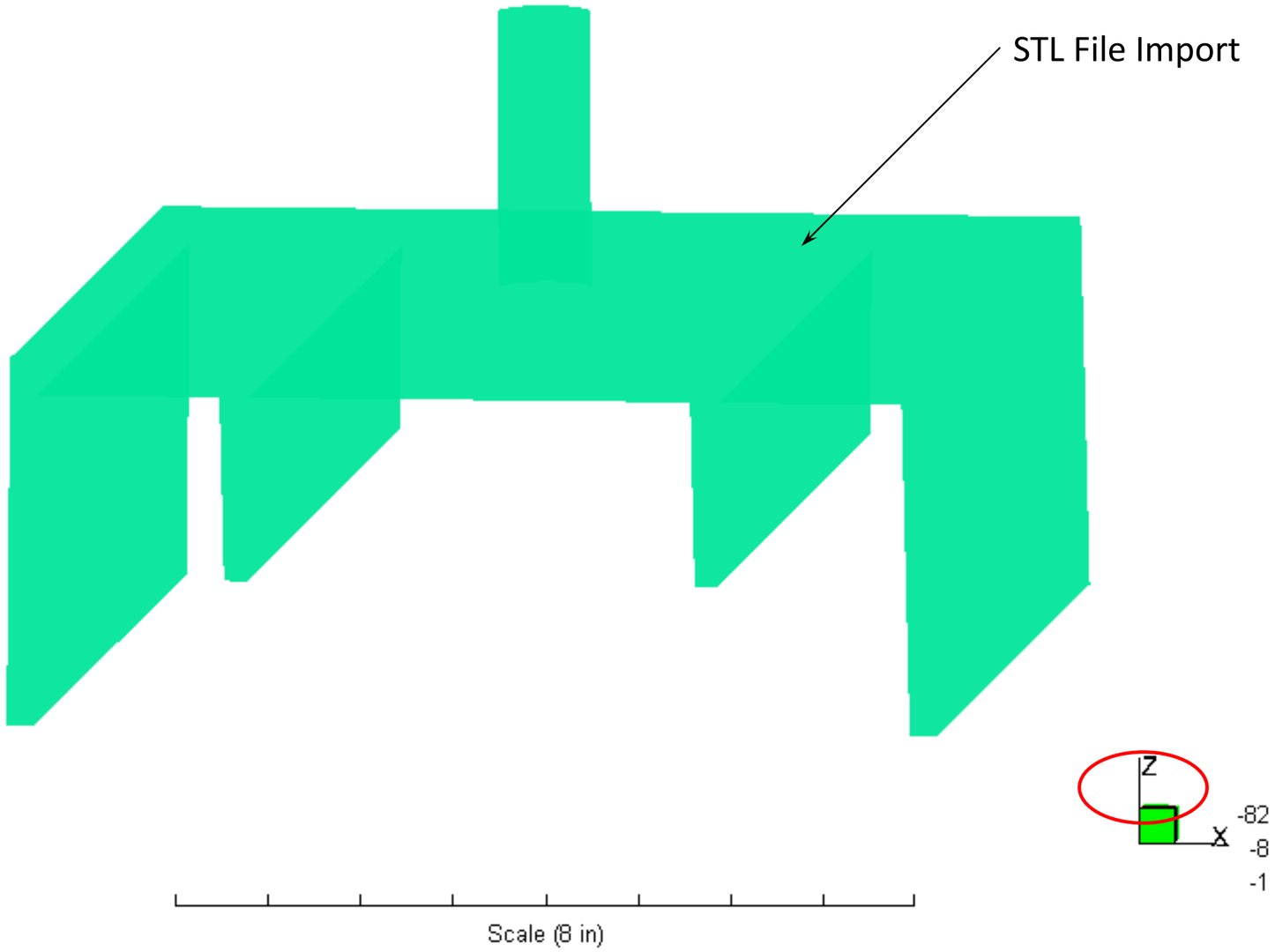
Window forms only when Mold shuts off completely



Theoretical Injection - Compression Part without Hole – Analyzed using Scandium 2014

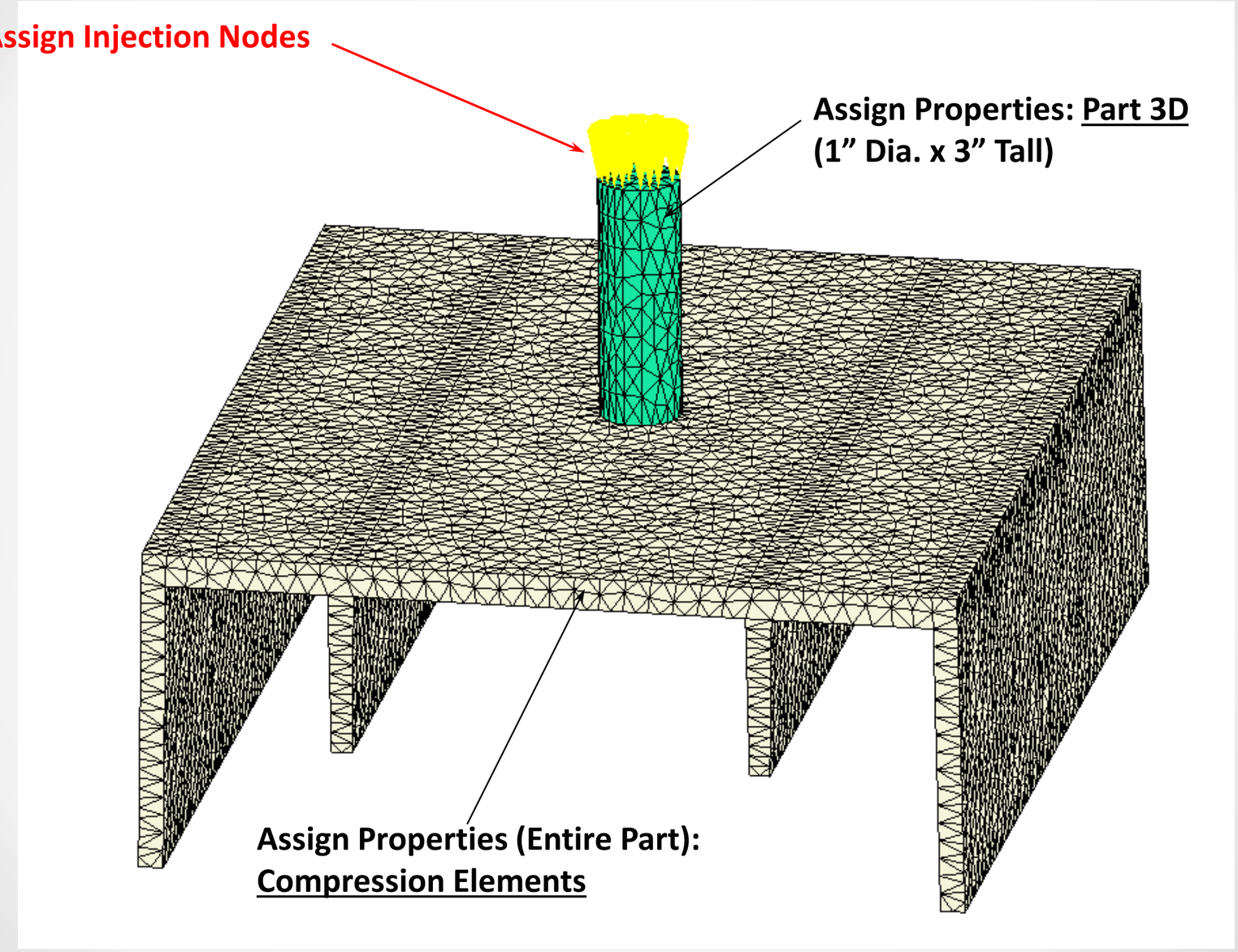


Injection - Compression Molding Analysis



Autodesk SIMULATION MOLDFLOW INSIGHT

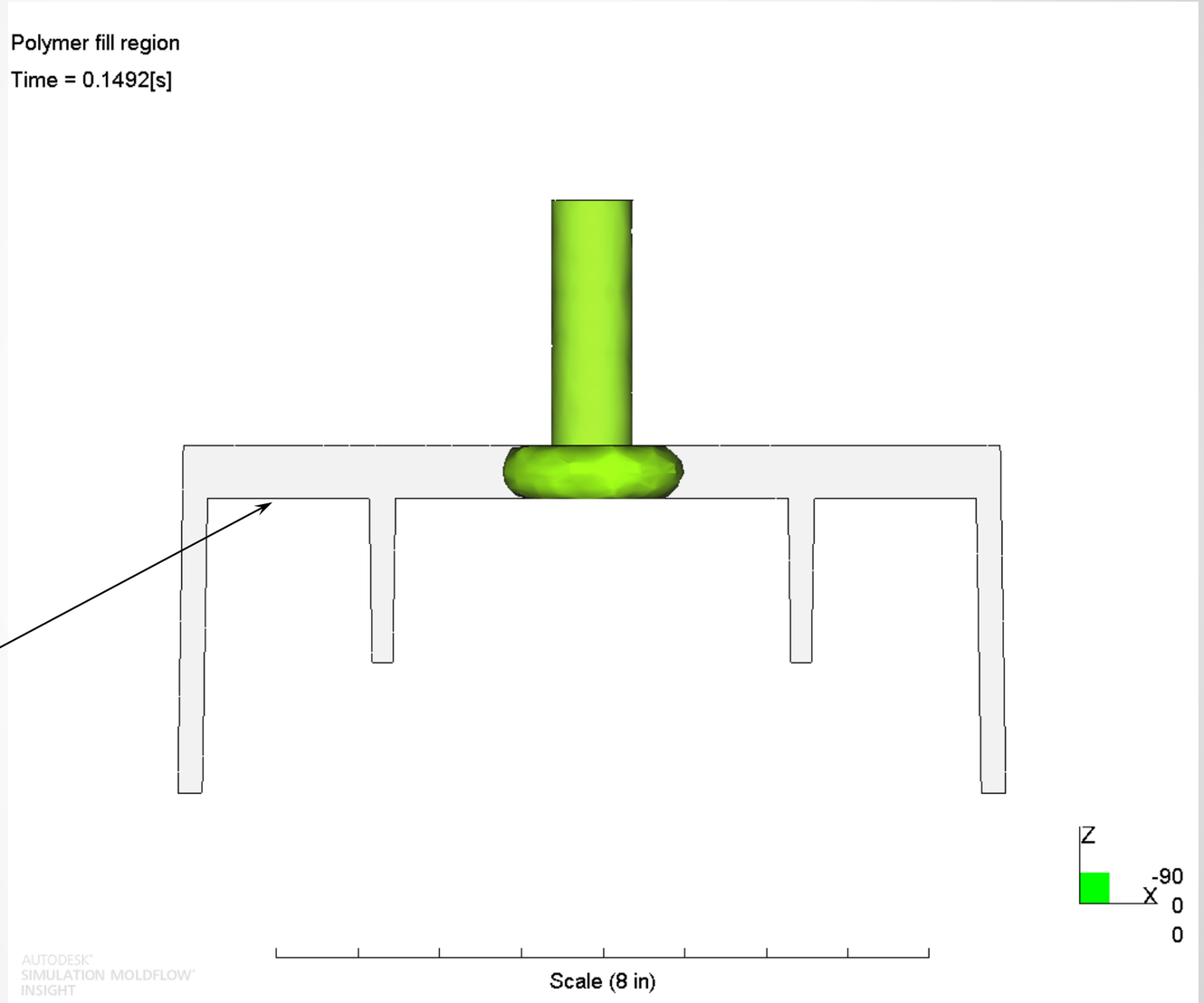
Injection-Compression, Test Case, Scandium 2014

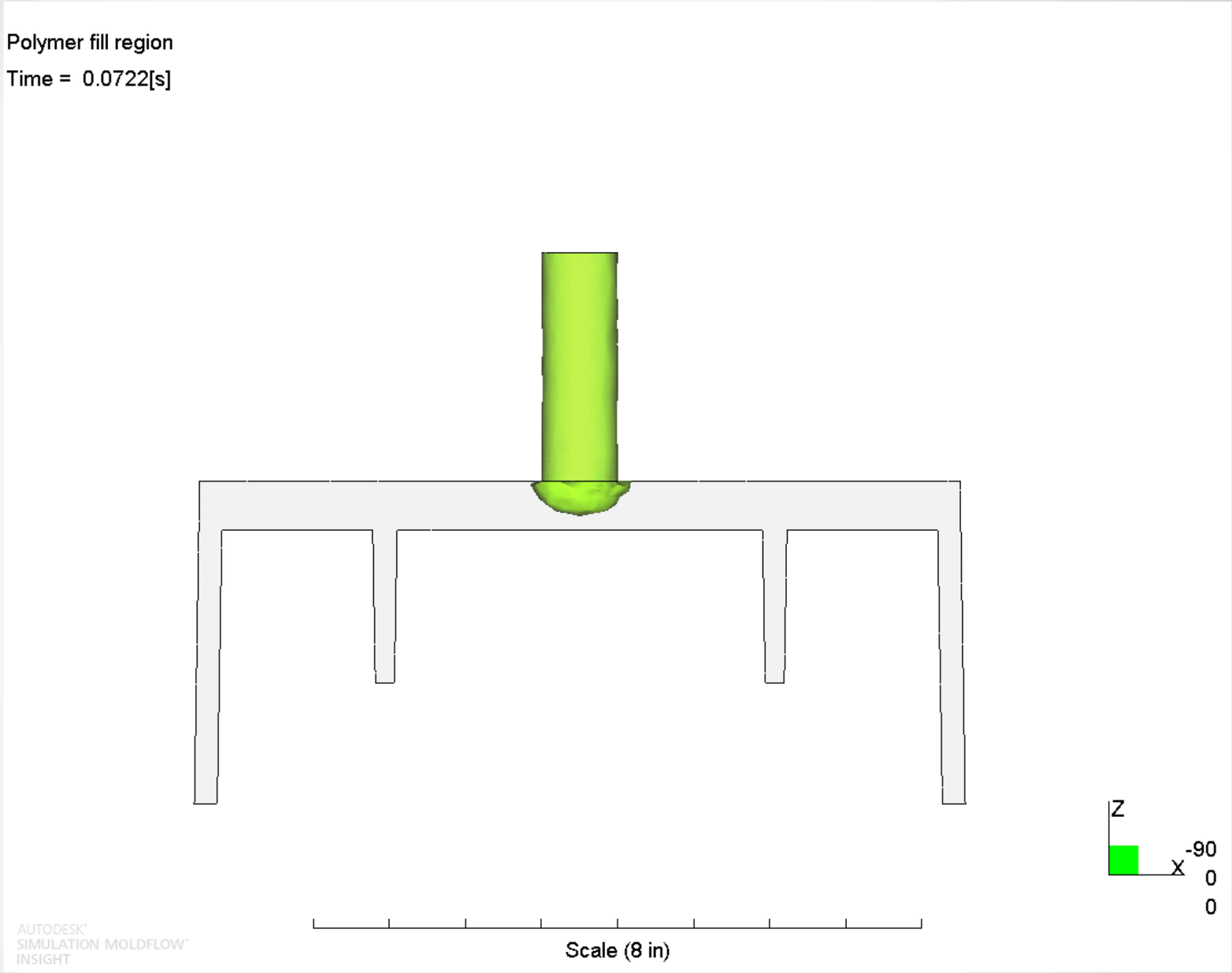


BMC 605 (Bulk Molding Compound, Mineral Filled, Glass Fiber reinforced Polyester)

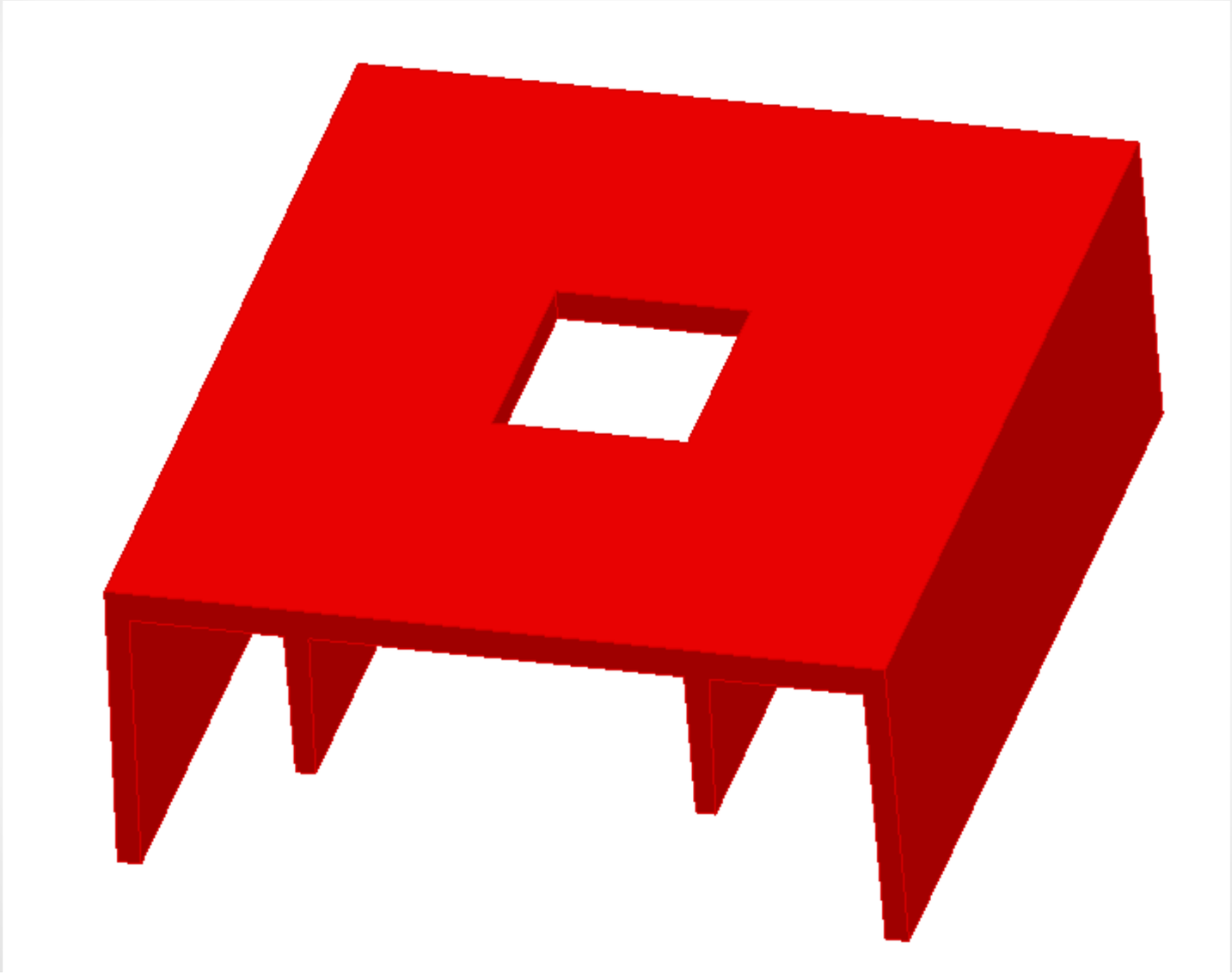
Injection-Compression, Test Case, Scandium 2014

Notice that the lower surface of the part is stretched in the -Z direction to represent the lower moving die

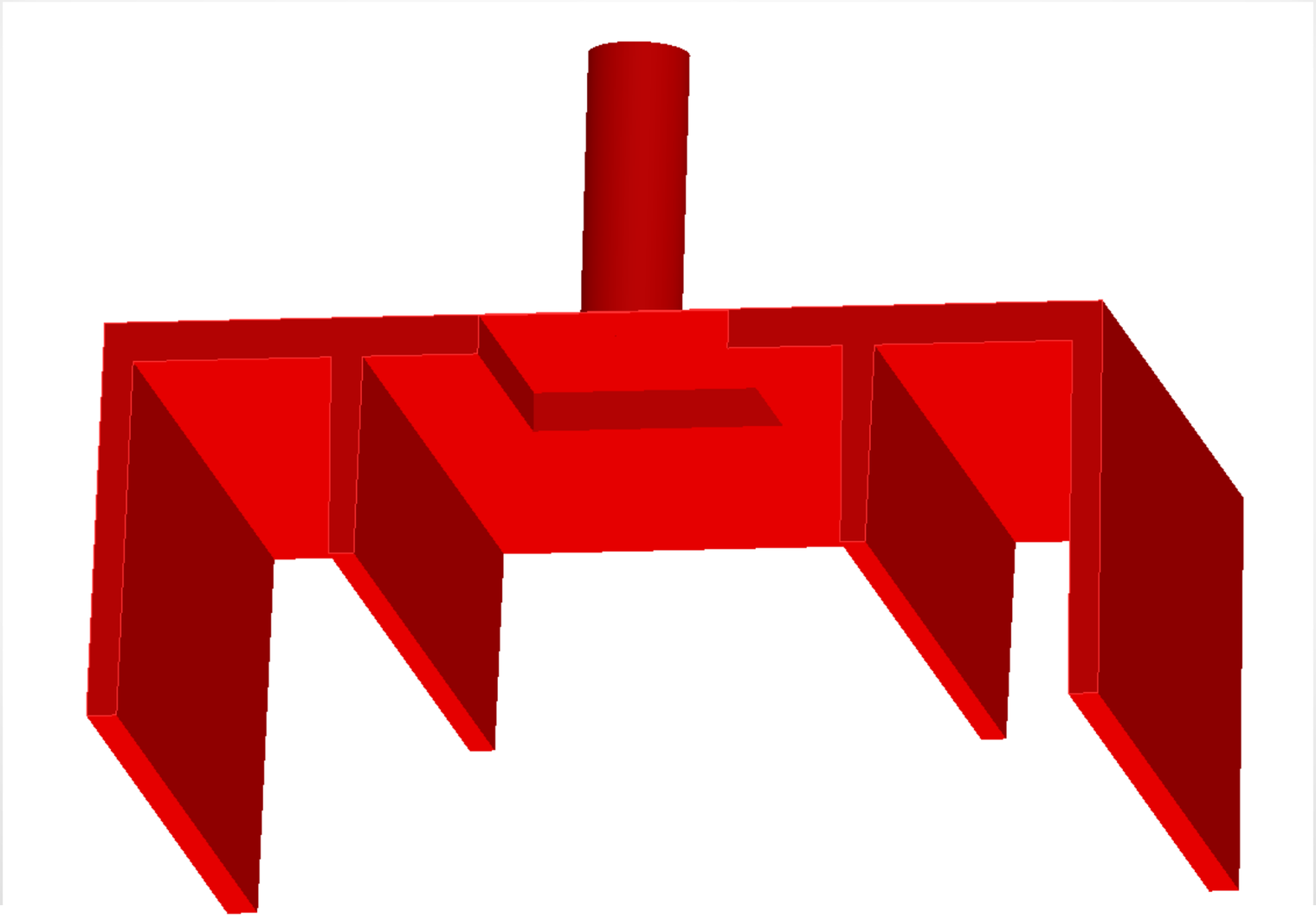



Polymer fill region
Time = 0.0722[s]
Z
X
-90
0
0
AUTODESK
SIMULATION MOLDFLOW
INSIGHT
Scale (8 in)

Theoretical Injection-Compression Part with Hole

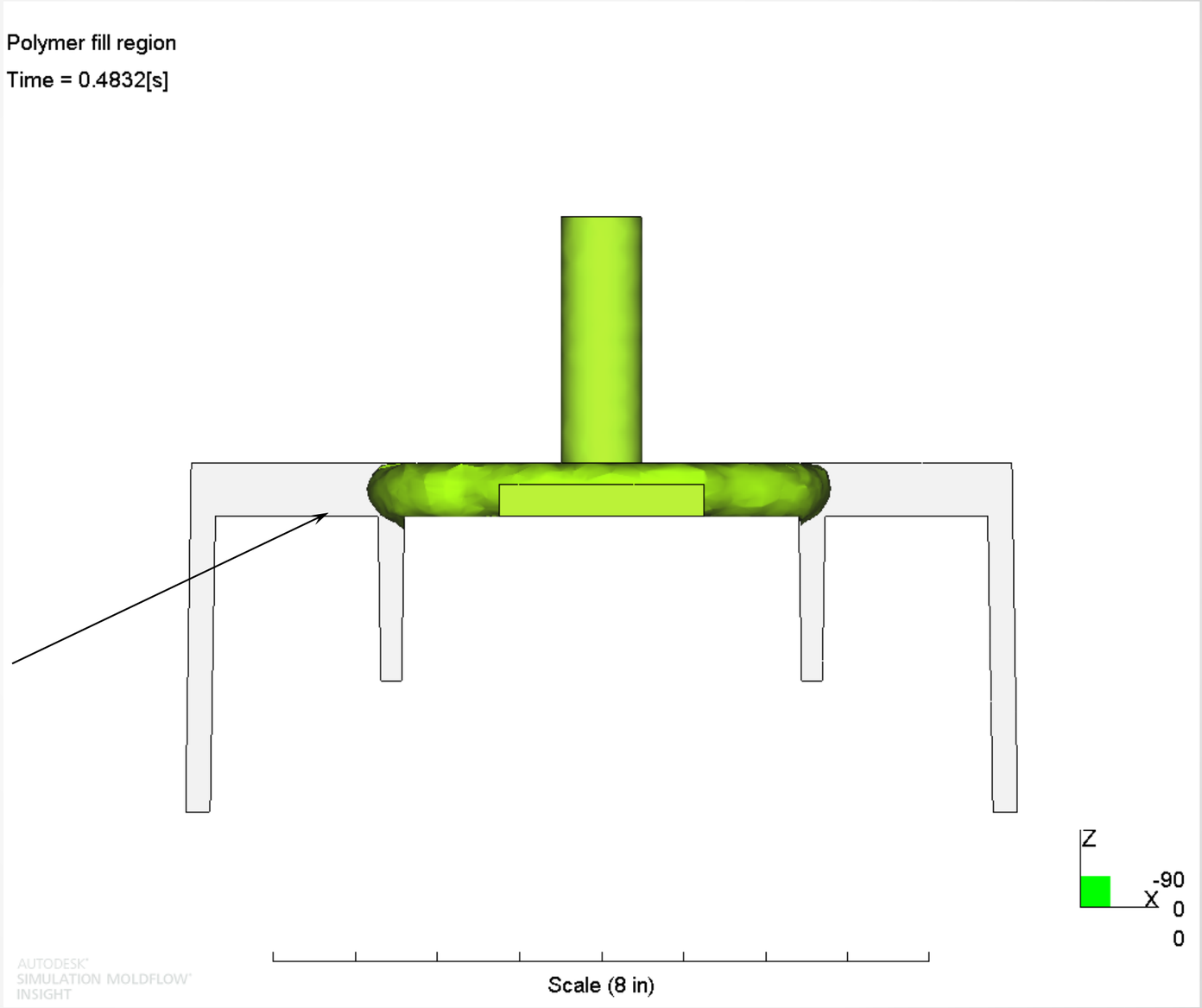


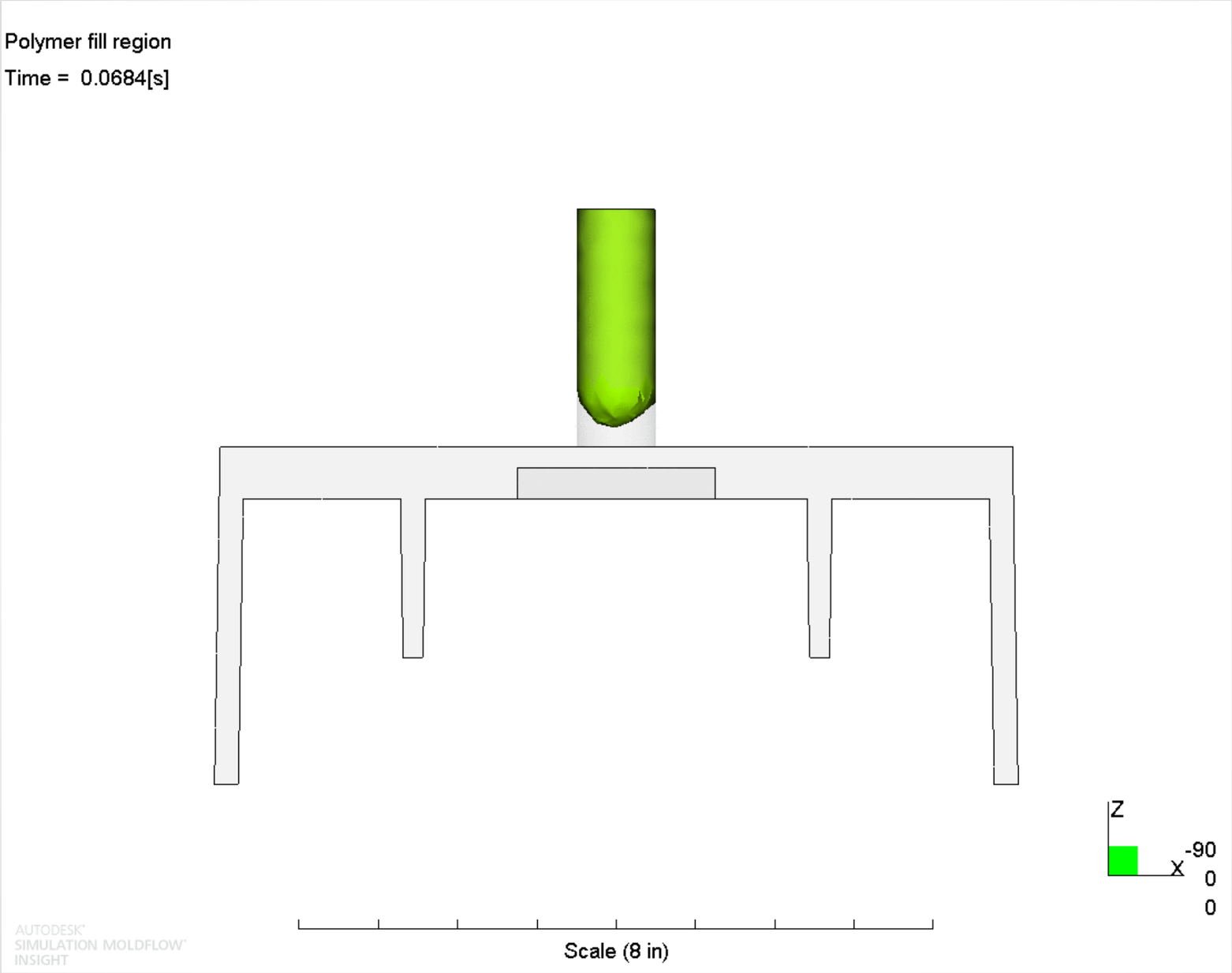
In order to simulate the model with a hole, we need to model the hole as a thin area (with thickness of around 0.010” – 0.020”).



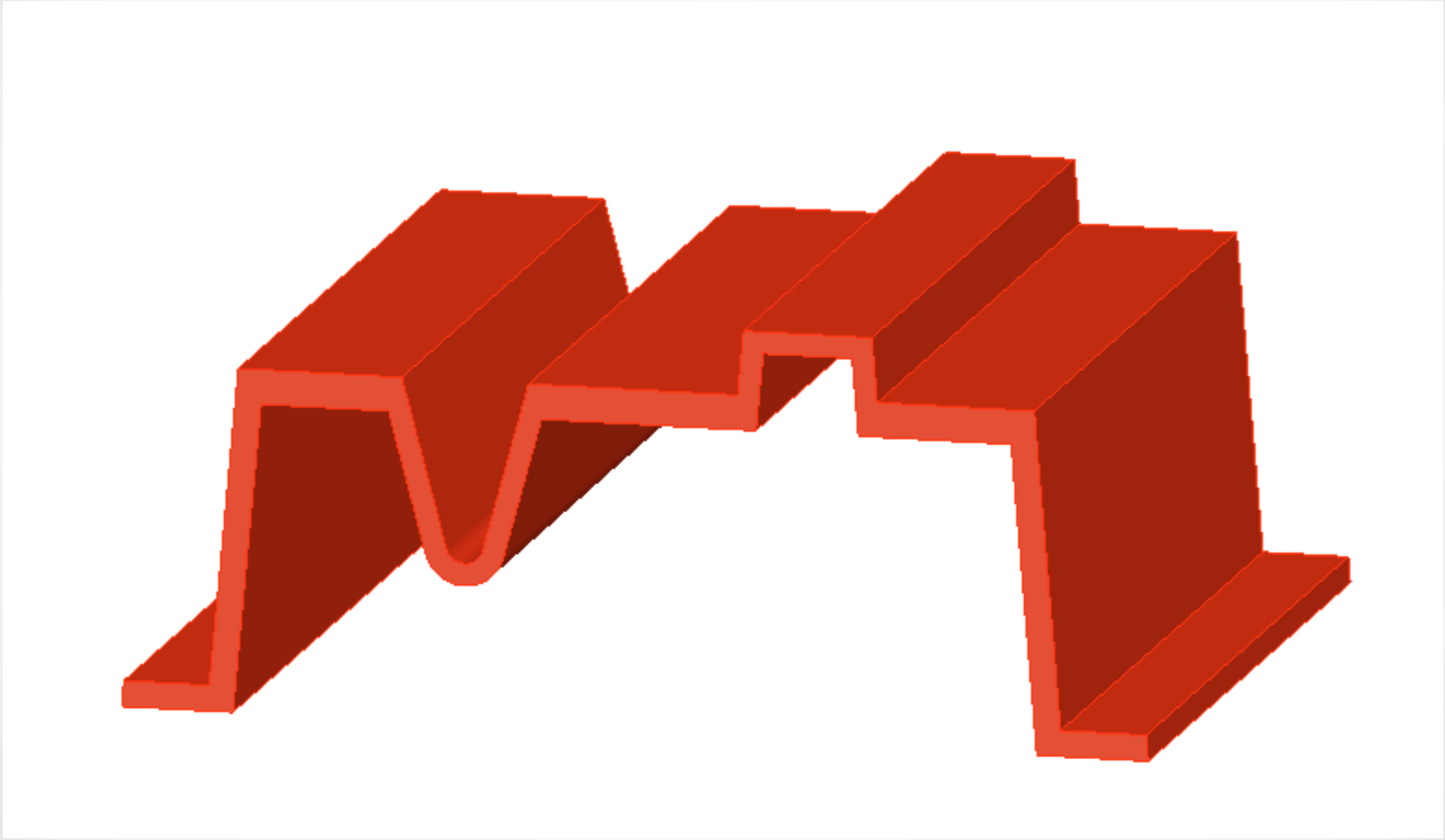
Injection-Compression, Test Case w/Hole, Scandium 2014

Notice that the lower surface of the part is stretched in the -Z direction to represent the lower moving die

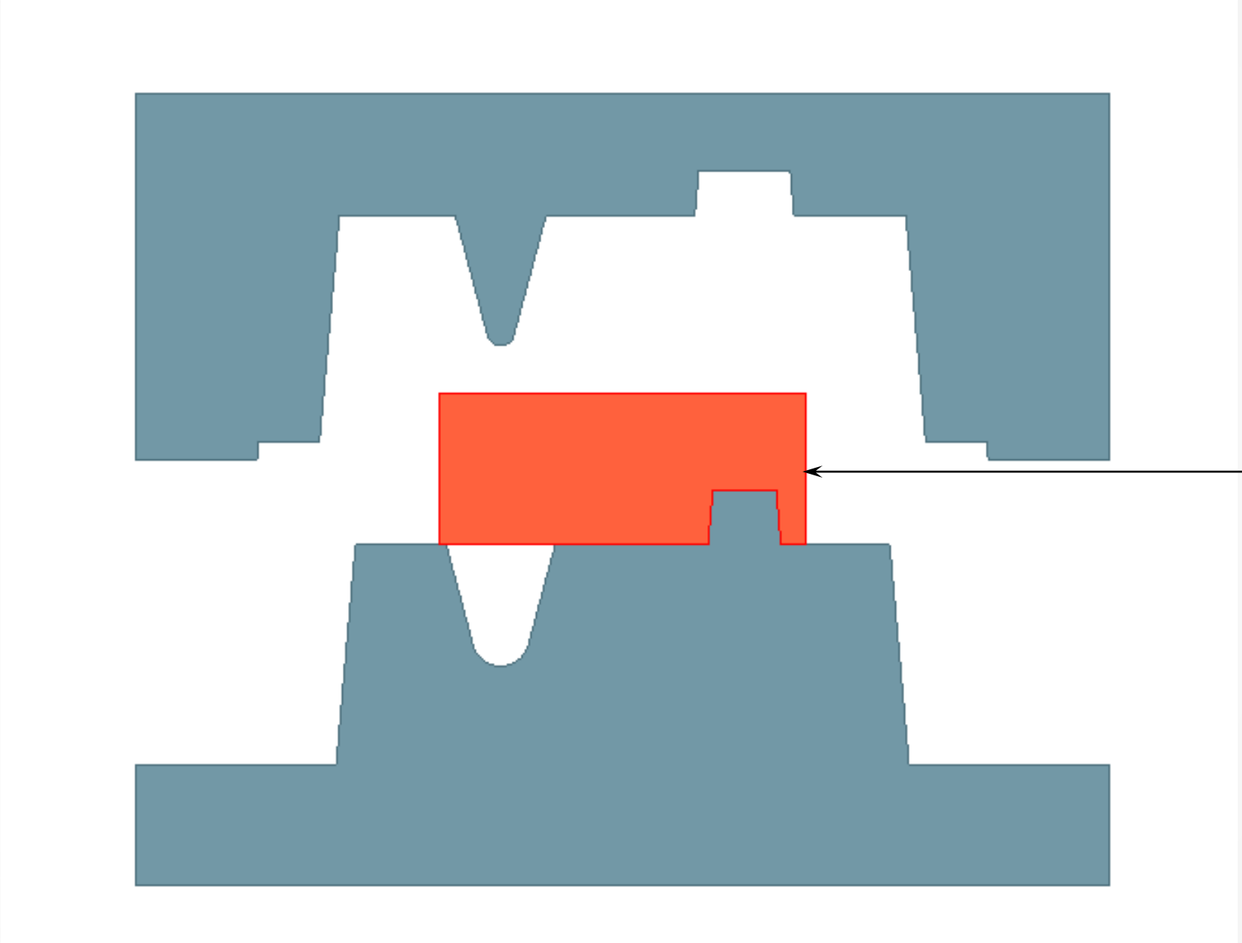



Polymer fill region
Time = 0.0684[s]
Z
X
-90
0
0
Scale (8 in)
AUTODESK
SIMULATION MOLDFLOW
INSIGHT

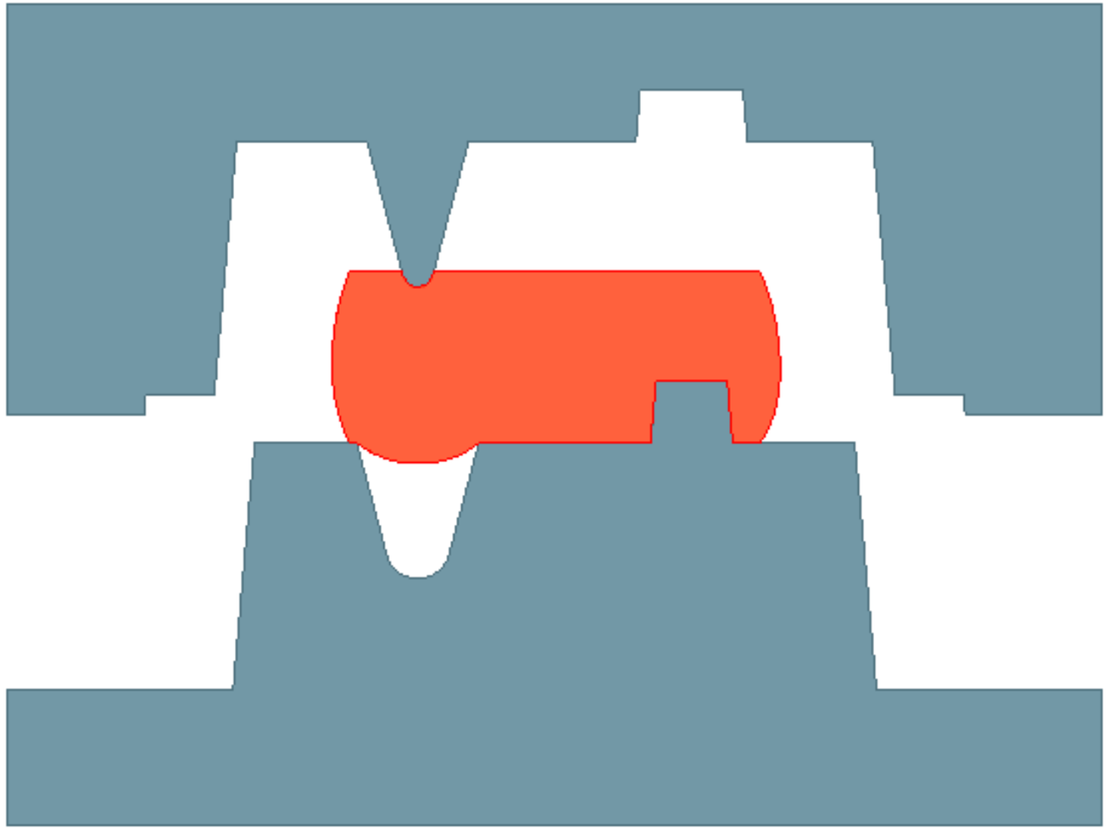
Thermoset Compression Molding Validation – Test Case

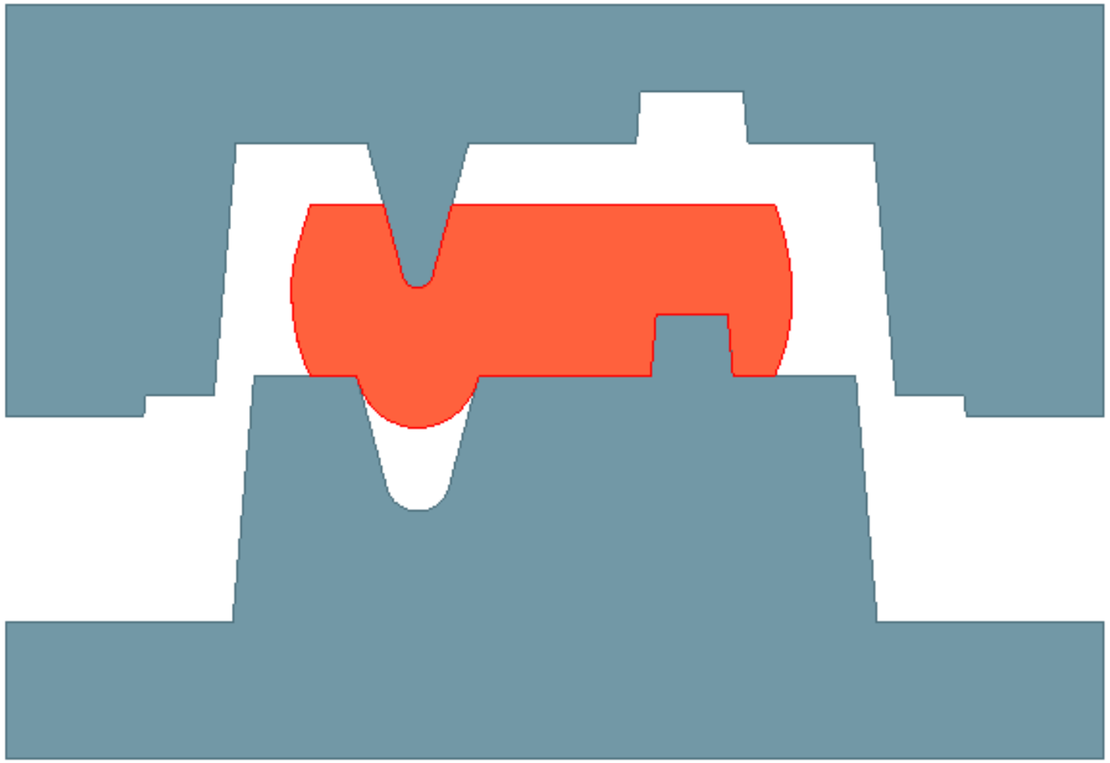


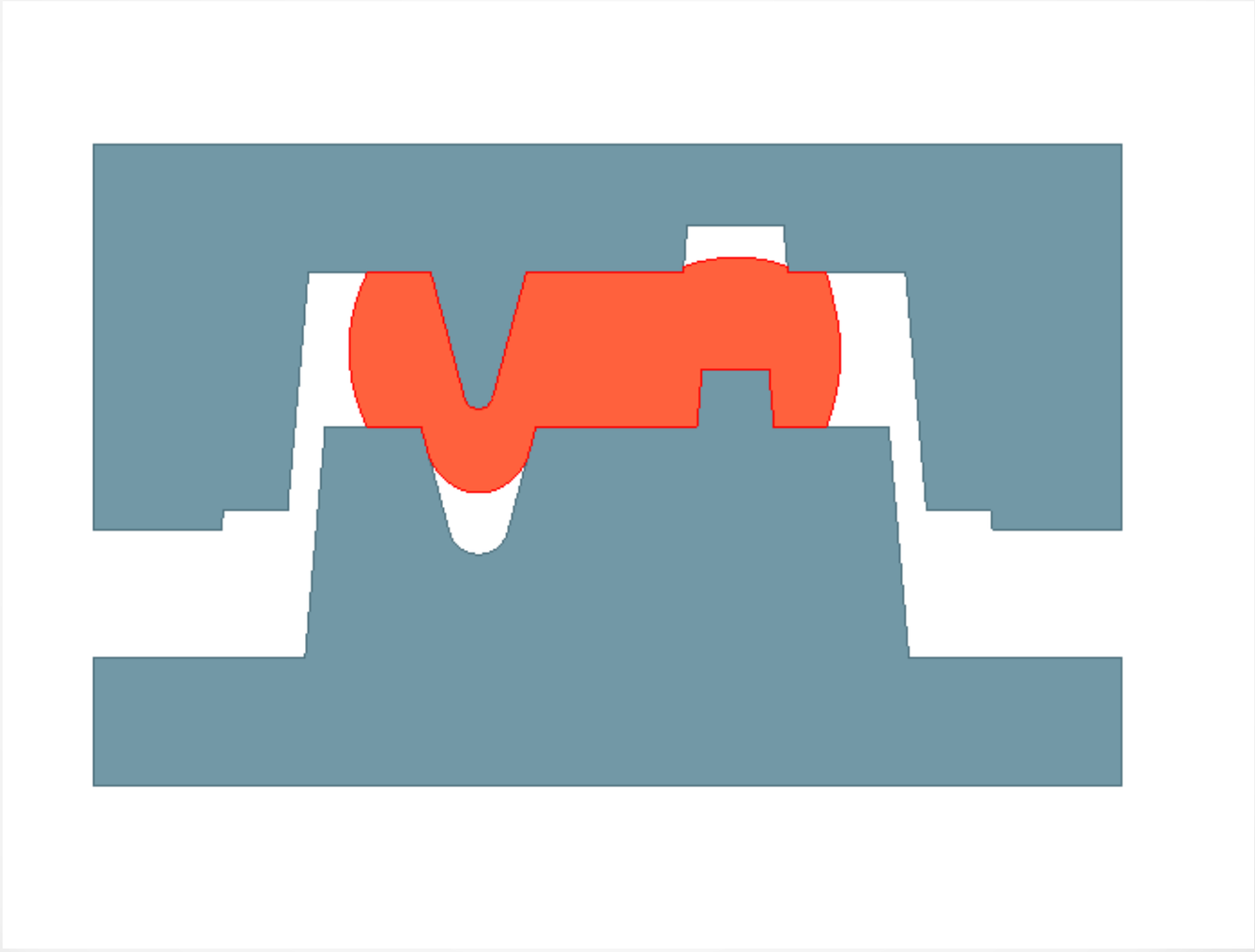
Thermoset Compression Molding Representation – Test Part

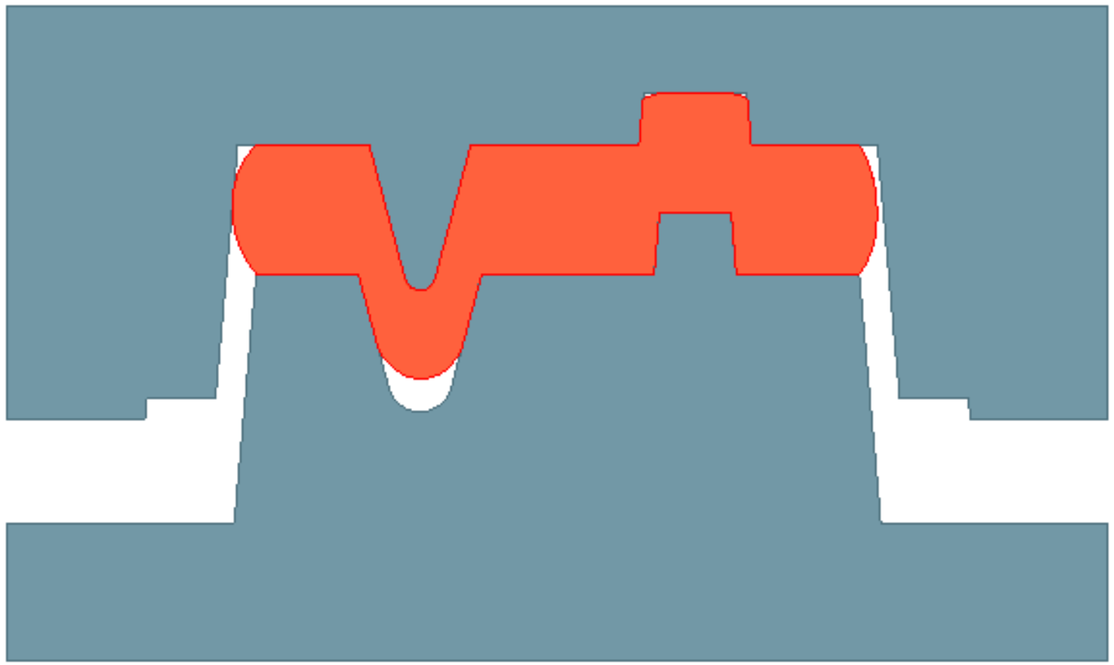


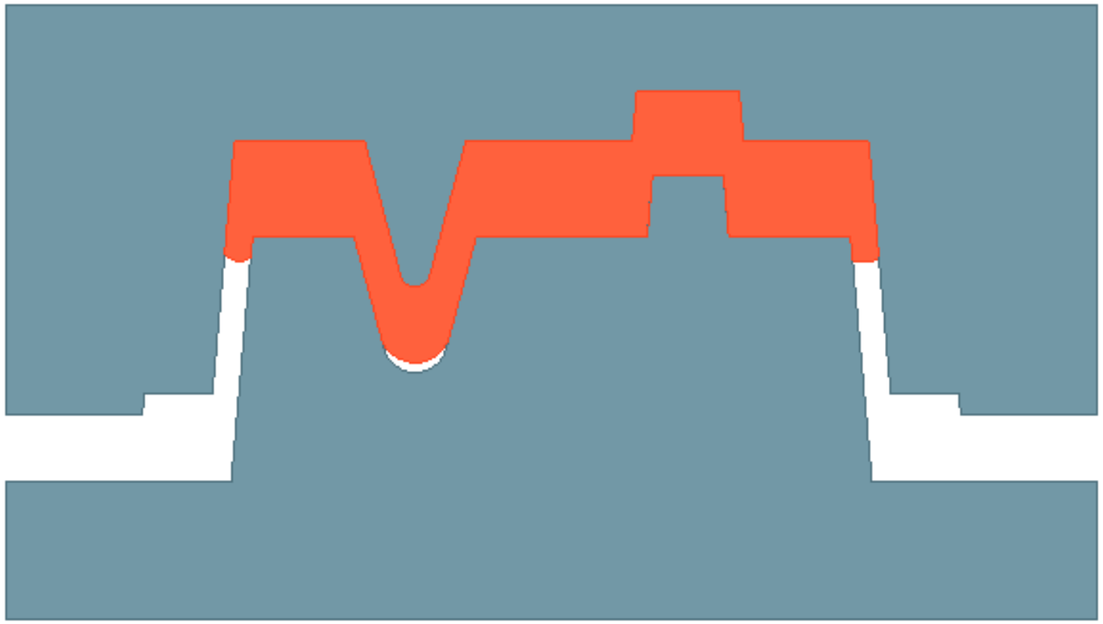
We first show a graphical depiction of an actual compression molding process where a Thermoset BMC charge is compressed between two die halves.

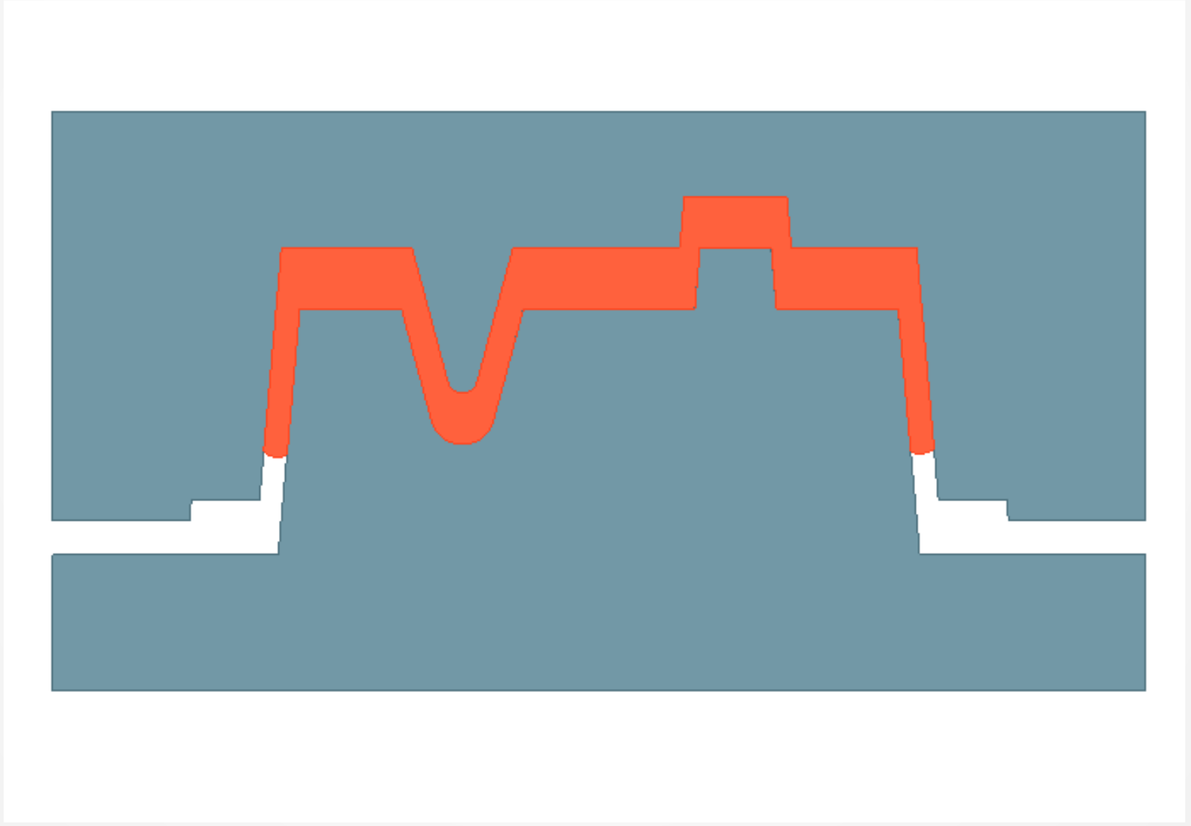


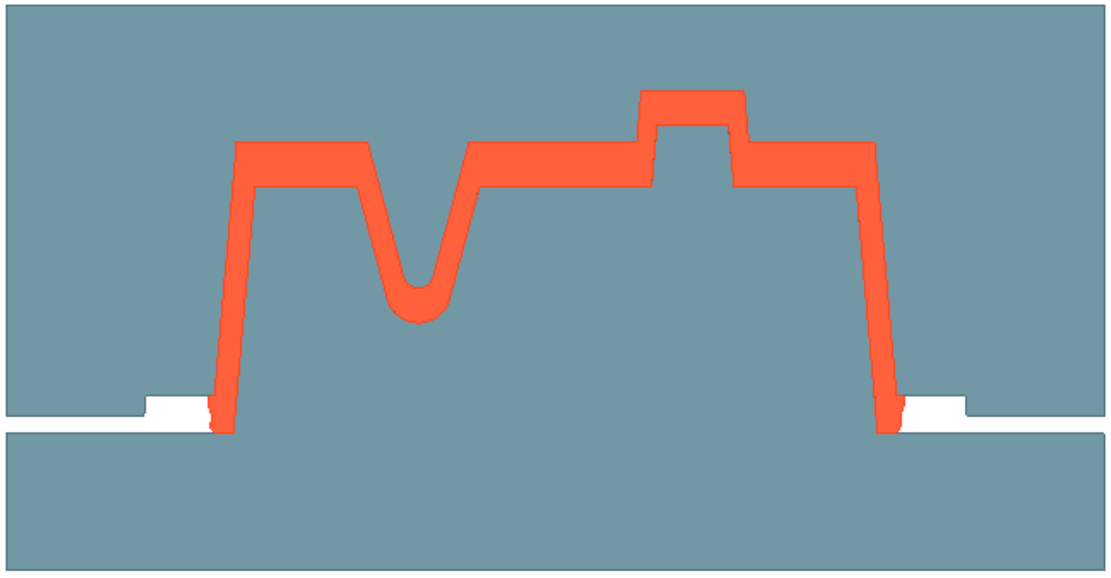


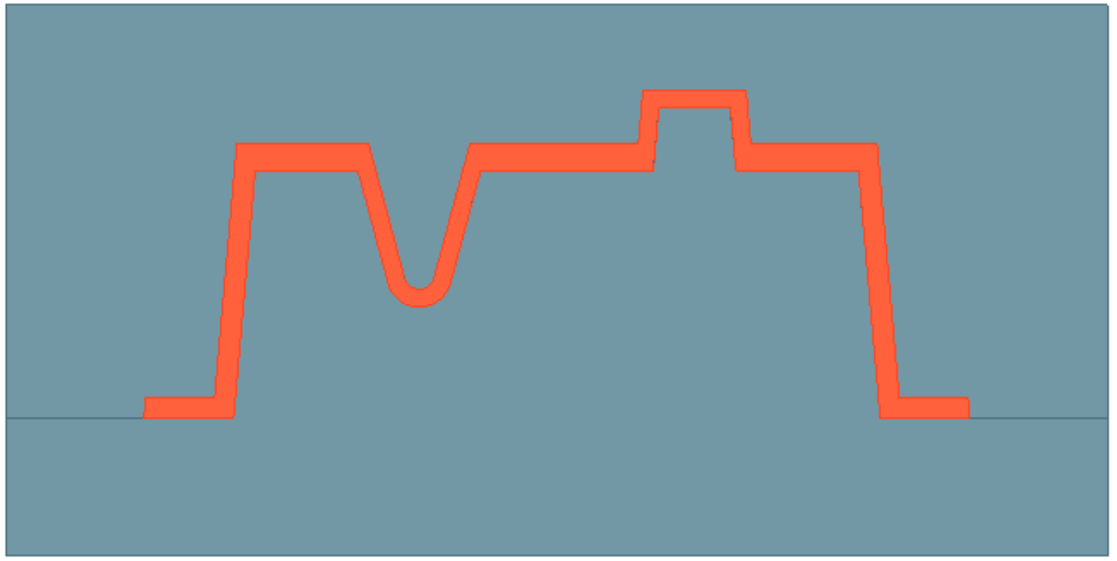








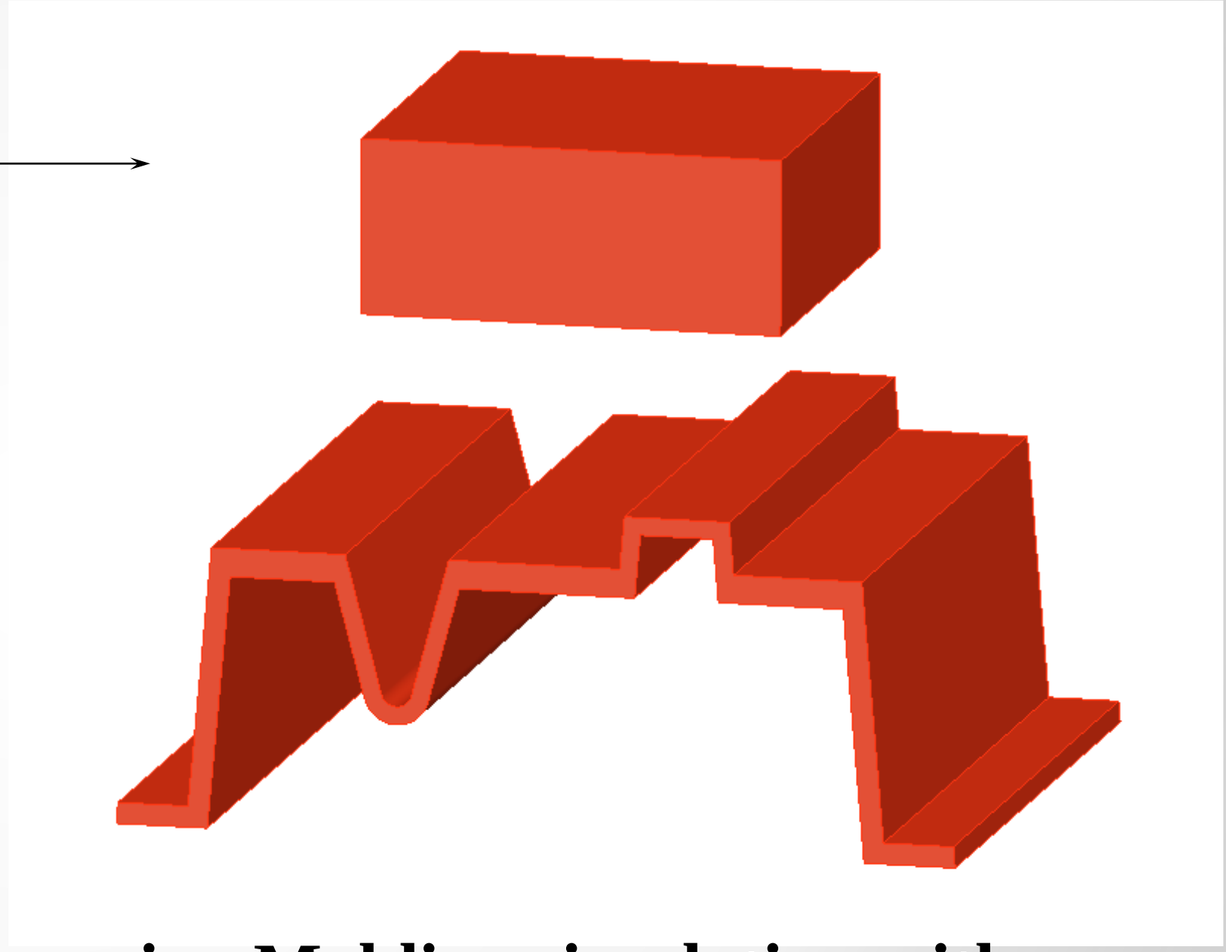




Moldflow Synergy Scandium 2014 - Thermoset Compression Test Case

External Initial Charge (Solid Model) placed at a finite distance from the part

Part Solid Model



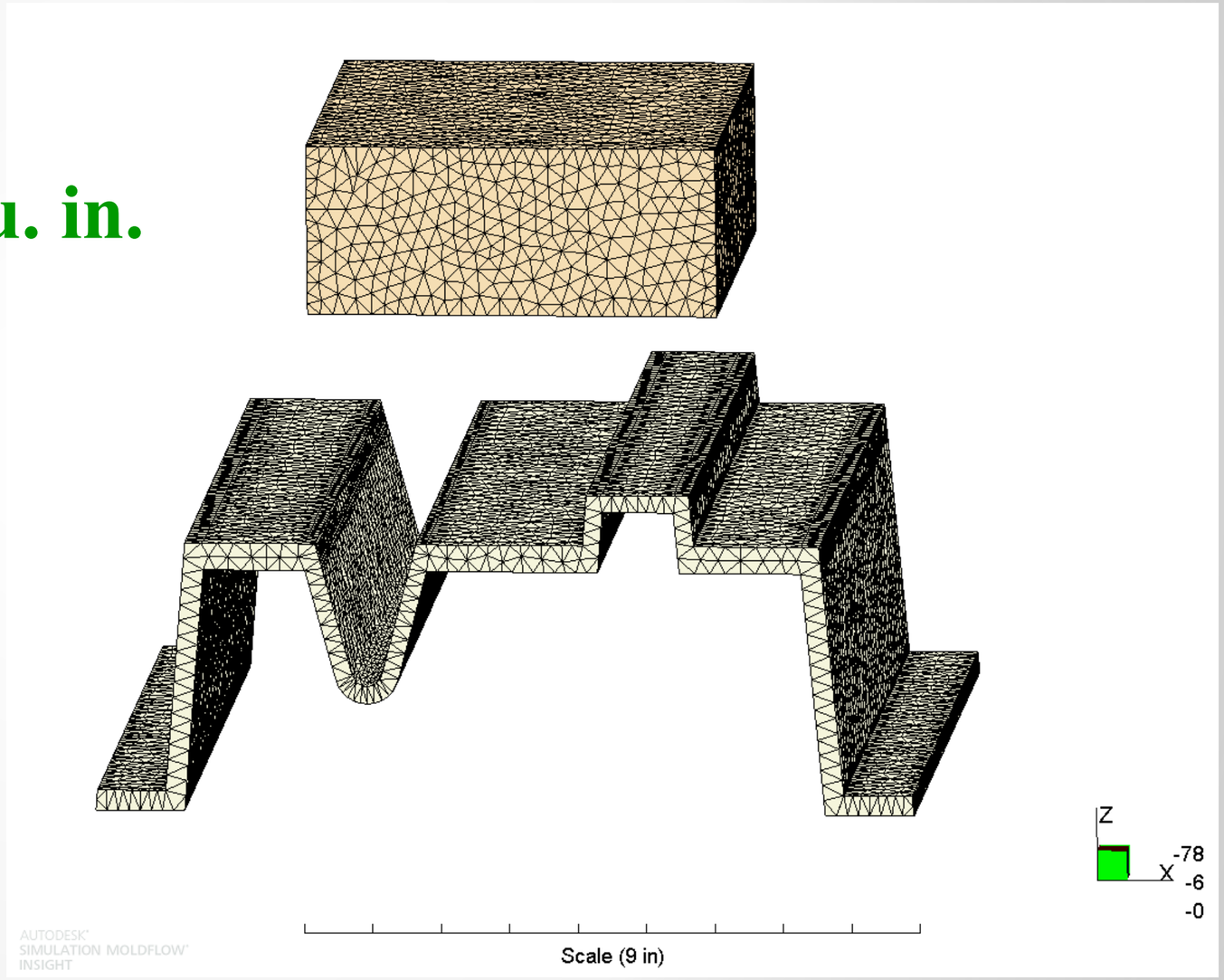
We then performed a Thermoset Compression Molding simulation with Moldflow Scandium. The solid model of the part and external initial charge were pulled into Moldflow Scandium.

This picture shows how a charge of Thermoset BMC is typically placed on top of the B-Half of the mold prior to compression.

Compression, Test Case, Scandium 2014

External Initial Charge:
Volume = 6” x 6” x 2” = 72 cu. in.

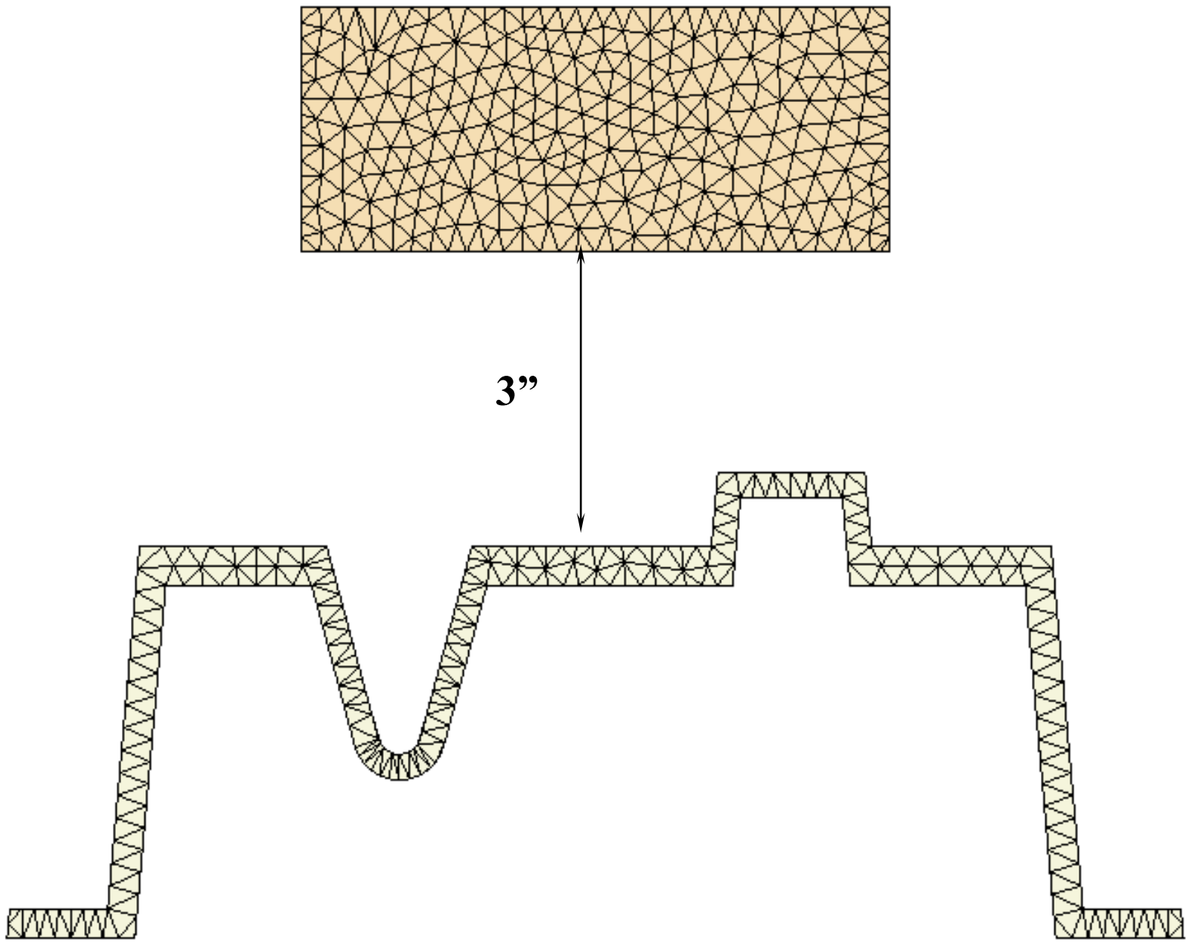
Compression Elements:
Volume = 71.7256 cu. in.



Compression, Test Case, Scandium 2014

External Initial Charge

Compression Elements

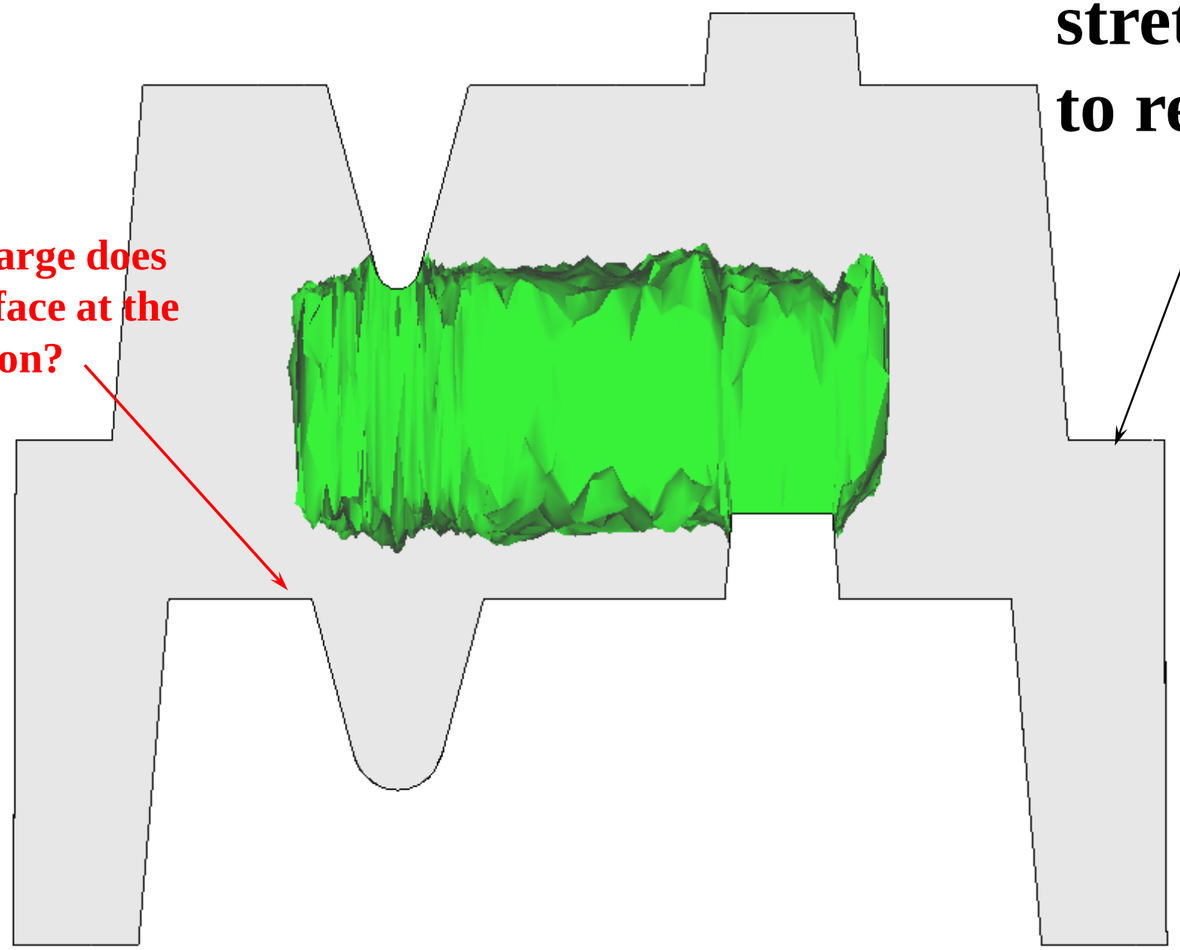


Polymer fill region

Time = 0.3514[s]

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?



Z

X

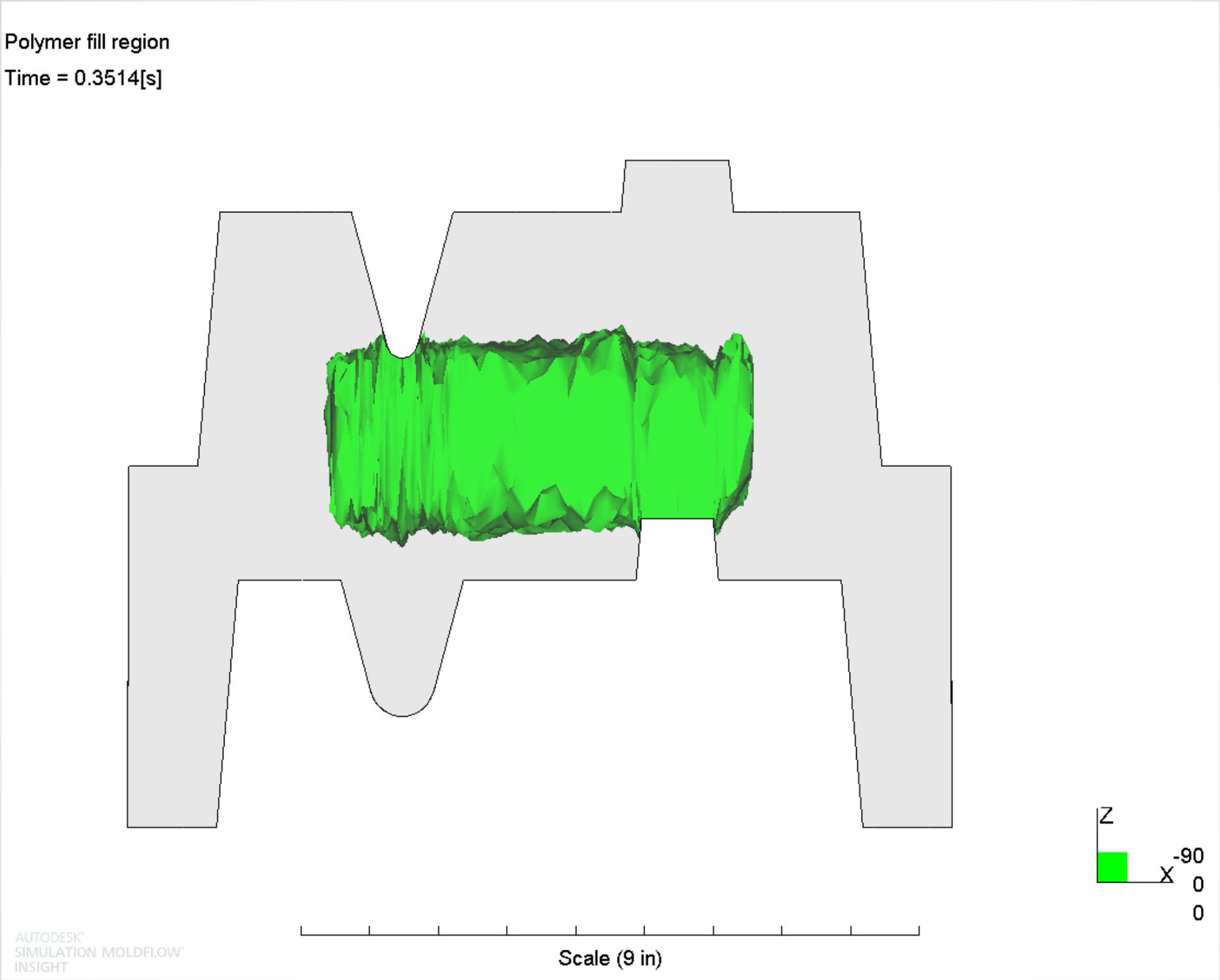
-90

0

0

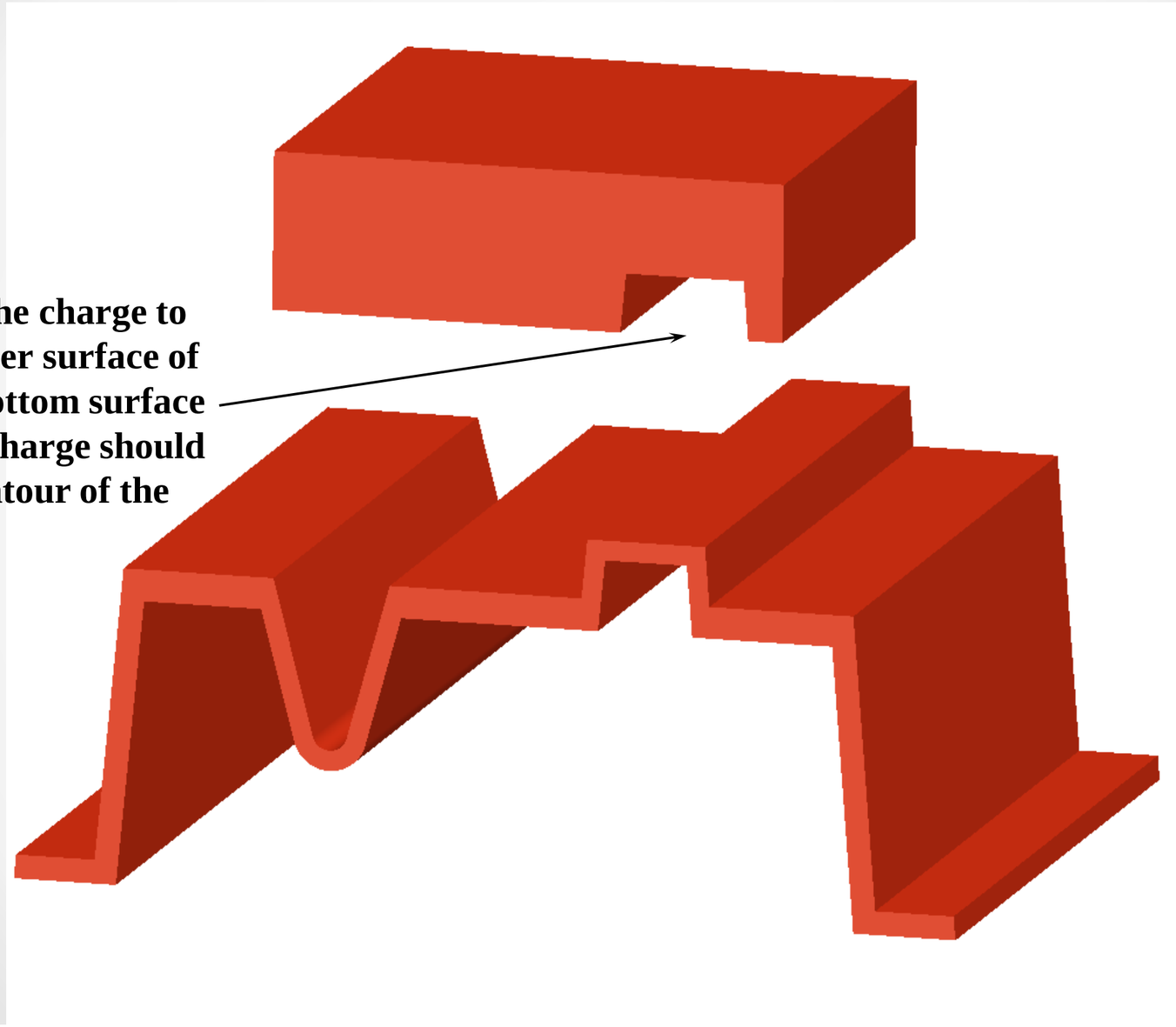
Scale (9 in)

AUTODESK SIMULATION MOLDFLOW INSIGHT


Polymer fill region
Time = 0.3514[s]
Z
X
-90
0
0
Scale (9 in)
AUTODESK
SIMULATION MOLDFLOW
INSIGHT

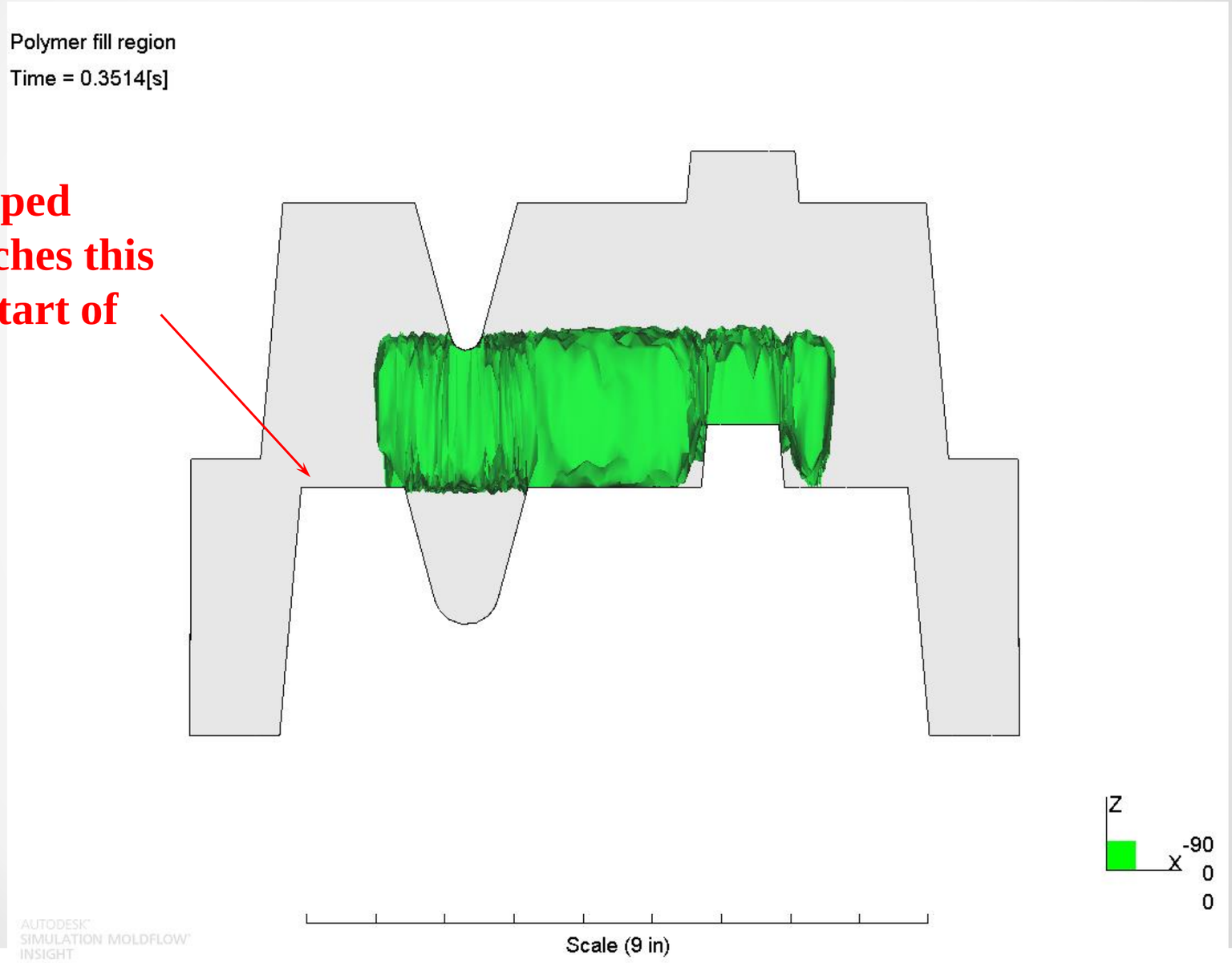
Compression, Test Case with Shaped Charge, Scandium 2014

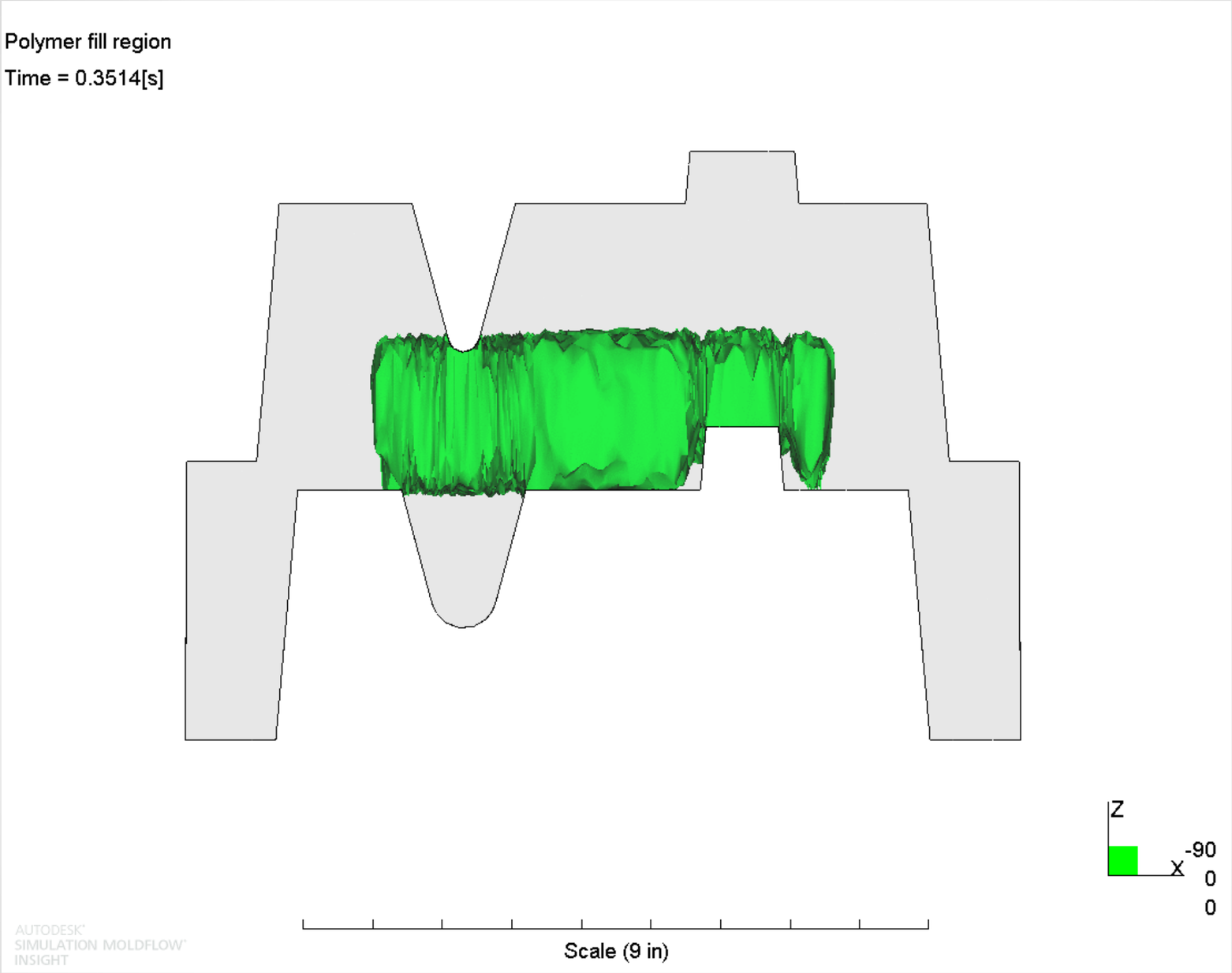
In order for the charge to touch the upper surface of the die, the bottom surface of the initial charge should follow the contour of the lower die



Compression, Test Case with Shaped Charge, Scandium 2014

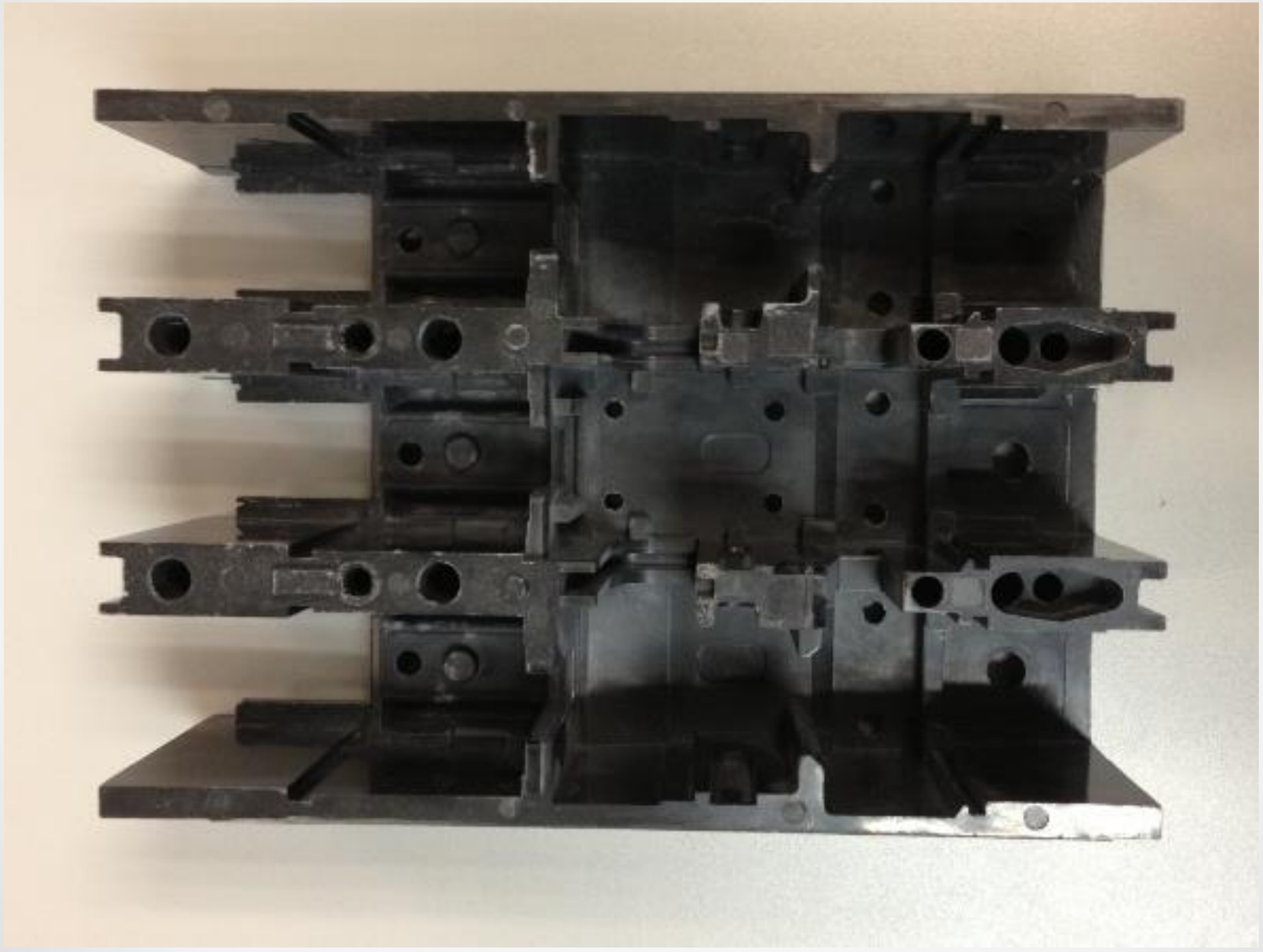
Notice that with the shaped charge the polymer touches this surface right from the start of compression?

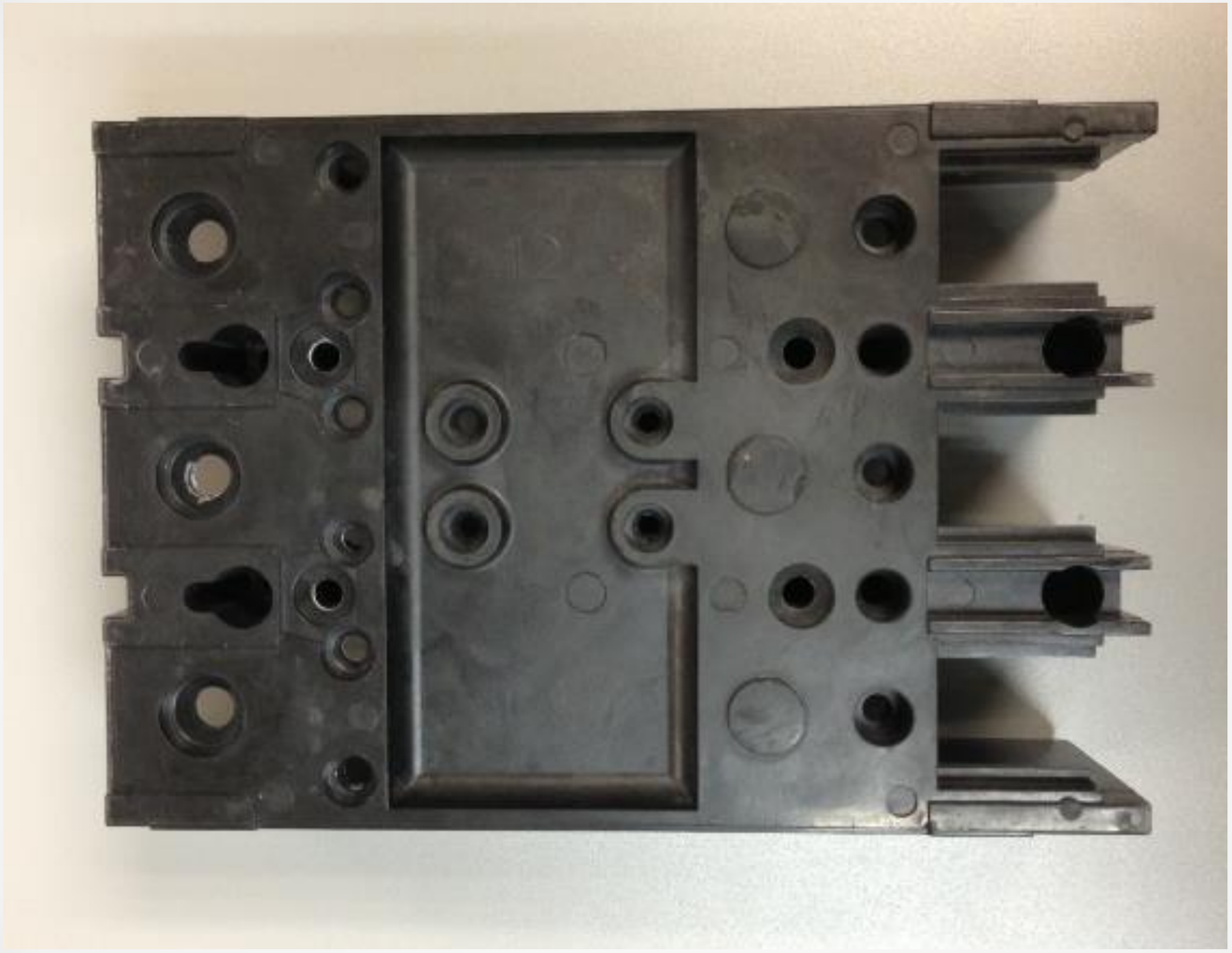



Polymer fill region
Time = 0.3514[s]
Z
X
-90
0
0
Scale (9 in)
AUTODESK
SIMULATION MOLDFLOW
INSIGHT

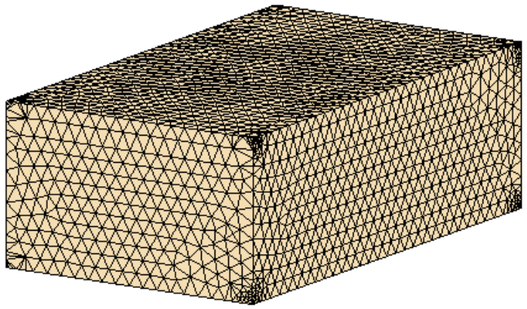
Q2R 2Pole Base,
Compression Molded at Parkway, Mexico

Q2R 3Pole Base,
Compression Molded at Parkway, Mexico





Q2R, 3Pole Base, Compression Molding Model/Mesh: Part & Charge Placement

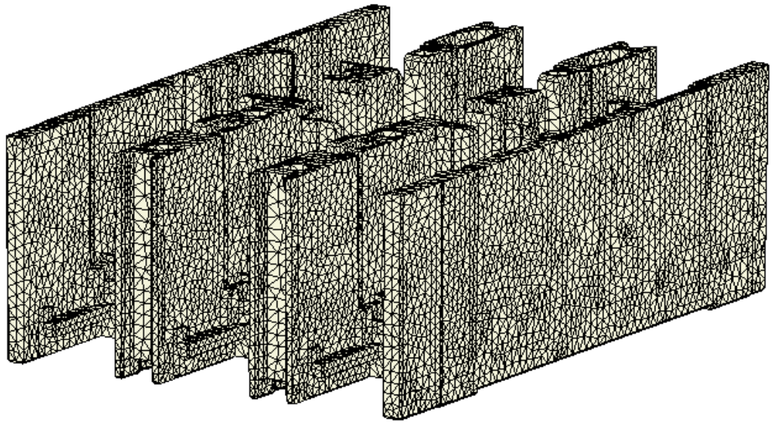


External Initial Charge:

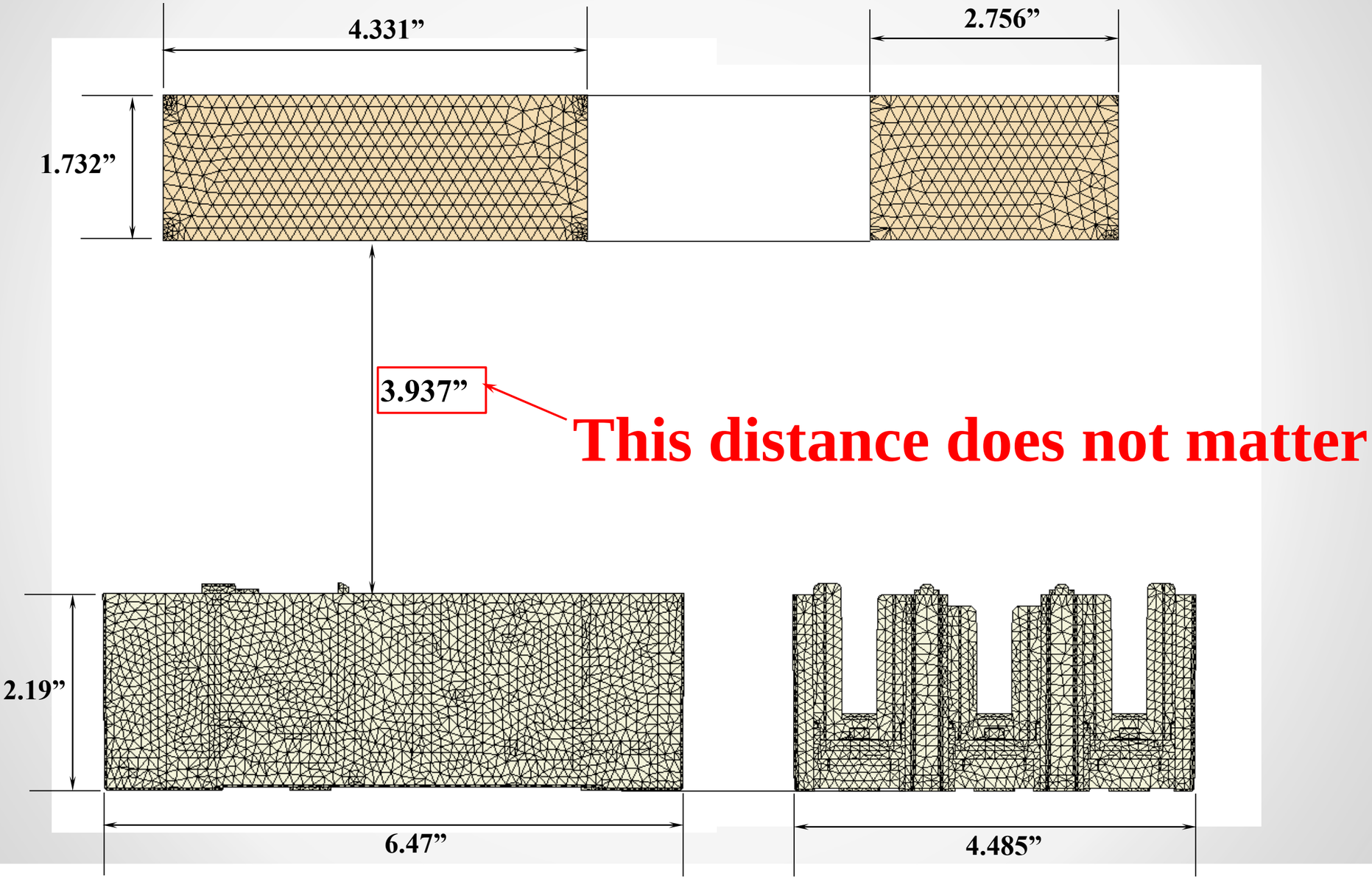
Volume: 20.6 cu. in.

Compression Elements:

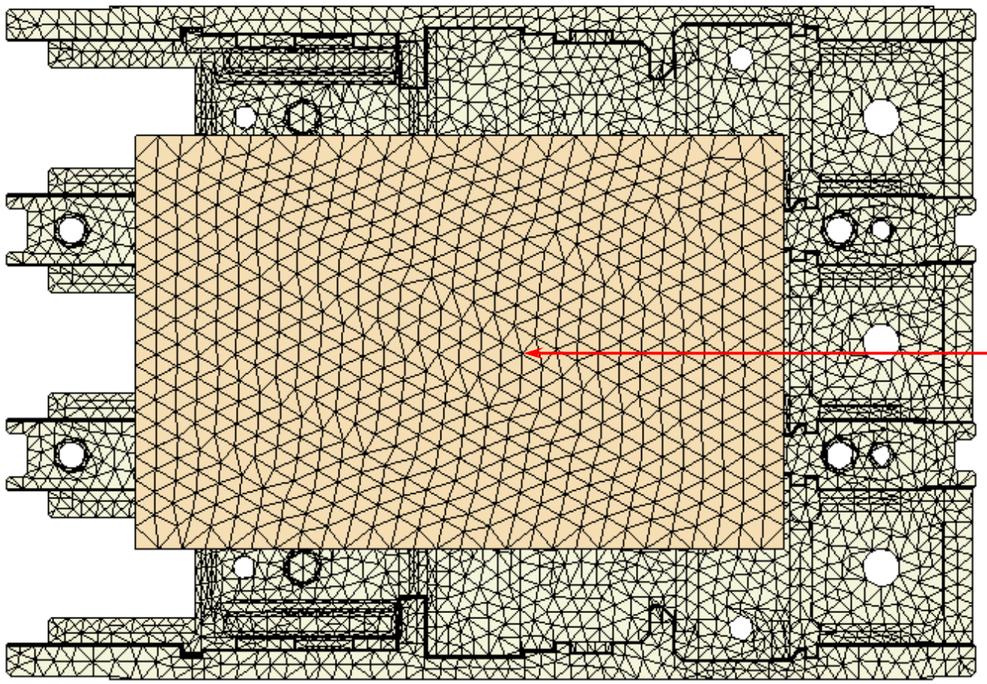
Volume: 19.44 cu. in.



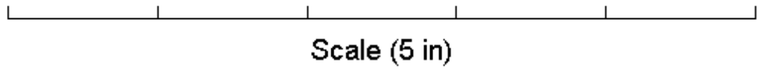
Q2R, 3Pole Base, Model/Mesh: Part & Charge Placement

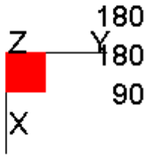


Q2R, 3Pole Base, Model/Mesh: Part & Charge Placement



In the X & Y direction, the charge placement location <u>does</u> matter

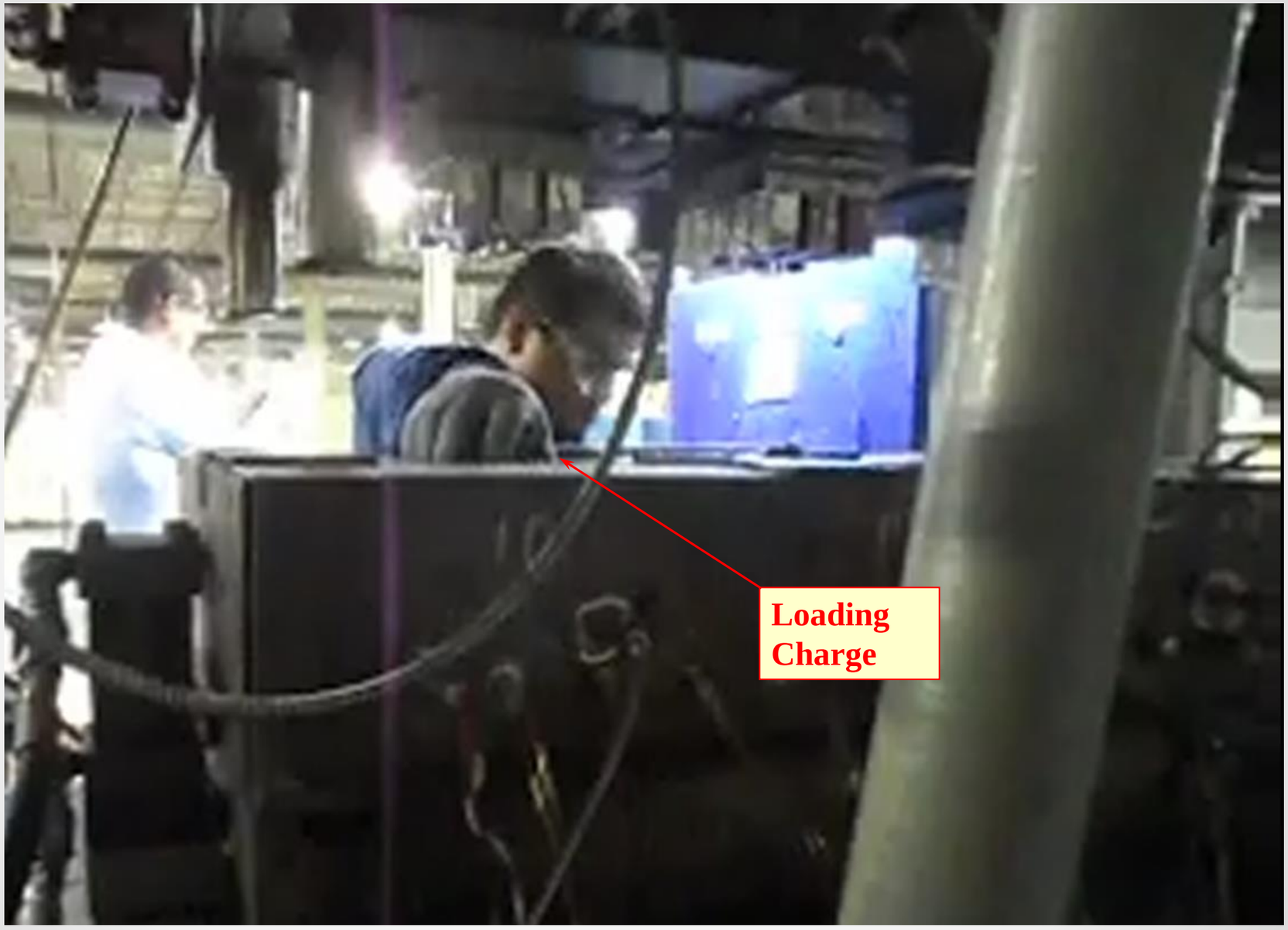


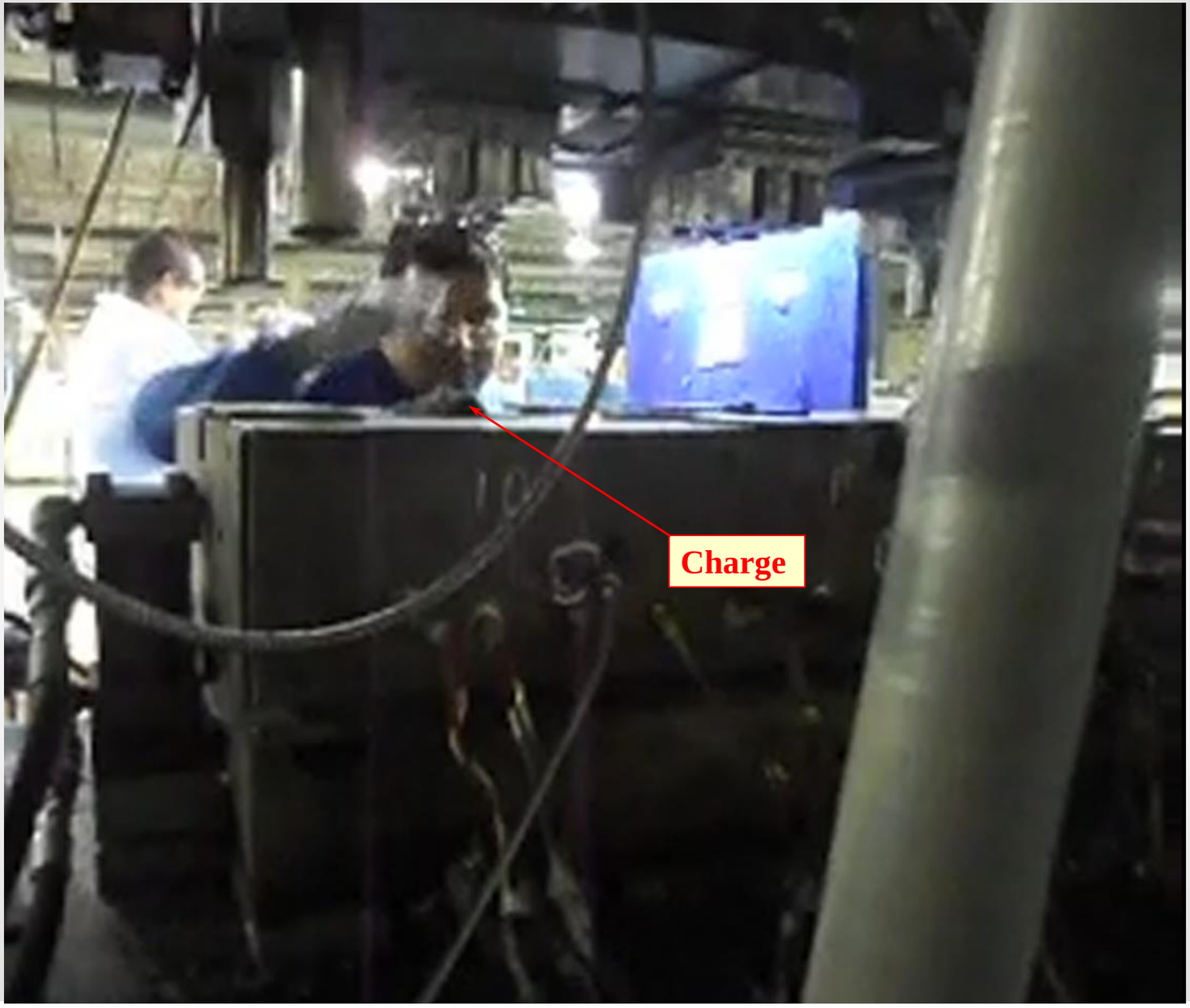


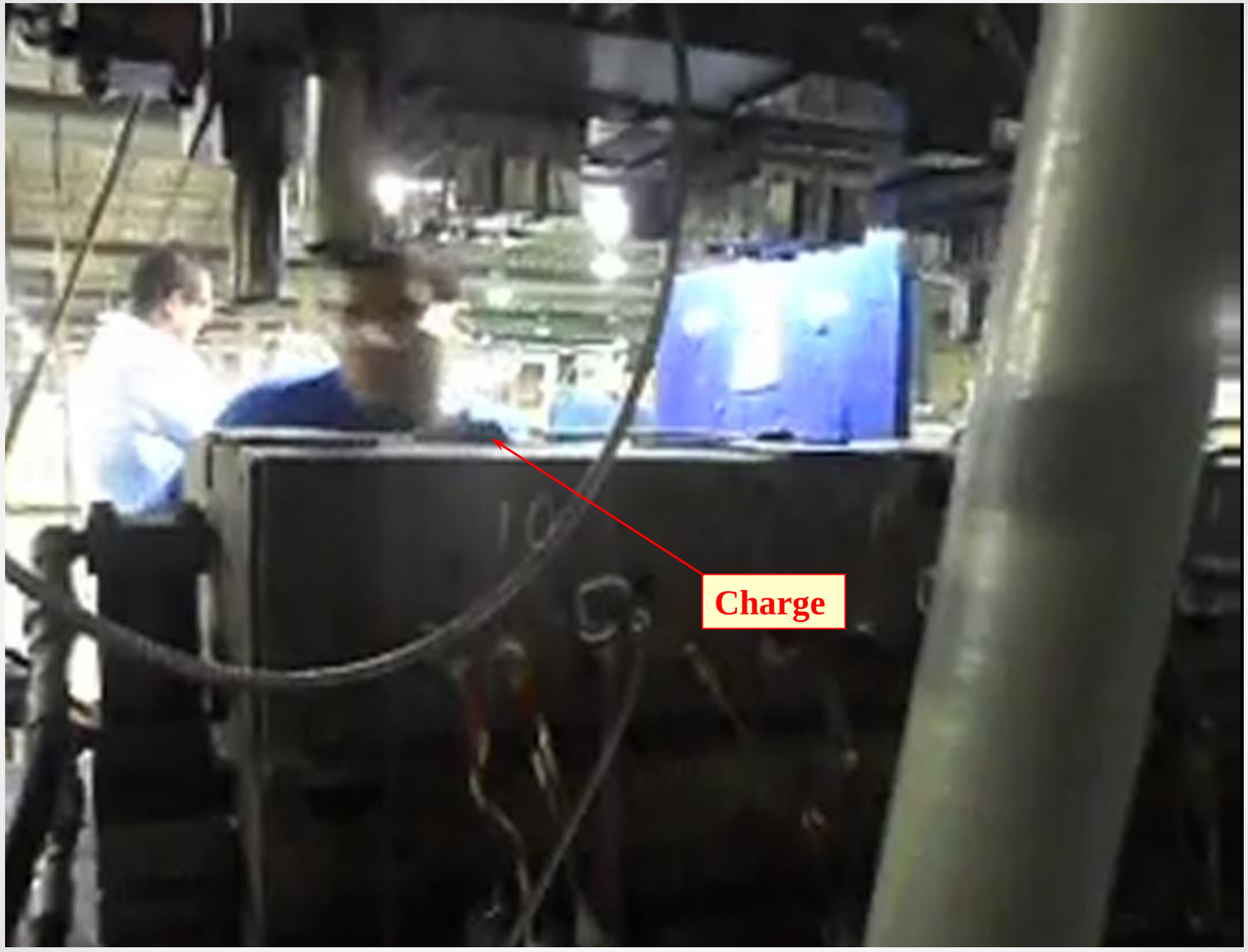
AUTODESK
SIMULATION MOLDFLOW
INSIGHT

Clips from Video showing how material is loaded into the cavity half (lower stationary side).

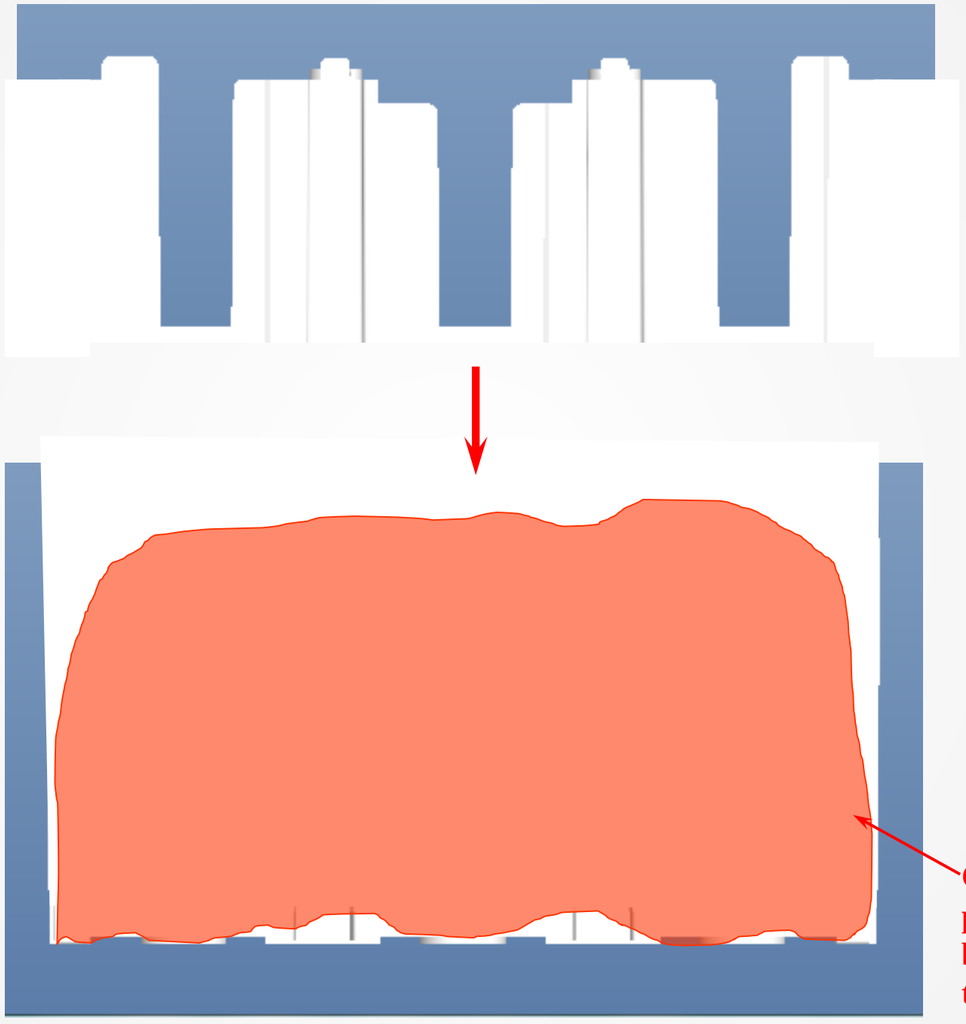

Loading
Charge


Loading
Charge


Charge


Charge

Upper Die (A-half)
Moving



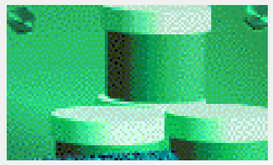
Lower Die (B-half)
Stationary

Charge is placed at the bottom of the B-half

Scandium 2014 Compression Molding Study Q2R 3Pole Base

Parkway, Mexico, Processing Conditions

Process Settings Wizard - RIM Settings - Page 1 of 4

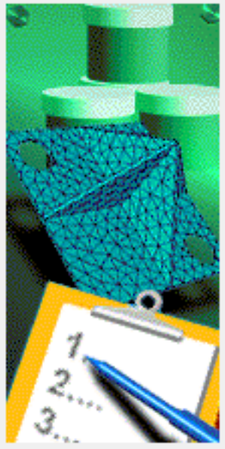


Mold surface temperature	350	F
Melt temperature	95	F

Actual Mold temperature

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

Process Settings Wizard - Reactive Molding Settings - Page 2 of 4



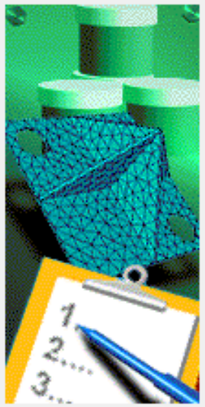
Melt initial conversion	0	[-1:1)
Curing time	0	s [0:]
%Air mass	0	% [0:0.01]

Preconditioning analysis

No preconditioning analysis

Take defaults … Cure time will be entered later (approx. 3 min.)

Process Settings Wizard - Compression Settings - Page 3 of 4



Compression direction: -Z

Mold closing direction has to be plus or minus Z

Pure compression press open distance option

Automatic

Press compression time	180	s [0:1200]
Press speed cap	39.37	in/s (0:393.7)
Press compression force cap	165.406	ton(US) (0:77191.9)

Time during which the mold is closed (roughly 3 min.). This is where we account for the cycle time.

Press compression speed vs distance (compression is along z-axis)

	Distance in [0:196.8]	Press compression speed in/s [0:39.37]
1	0.003937	0.9173
2	0.3937	0.9173
3		
4		

Take Defaults

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

Switch to press force control

By % nodes filled at 99 % [0:100]

Compression force after switch to press force control

Relative to the value at switch over

Edit values...

Advanced options...

Values

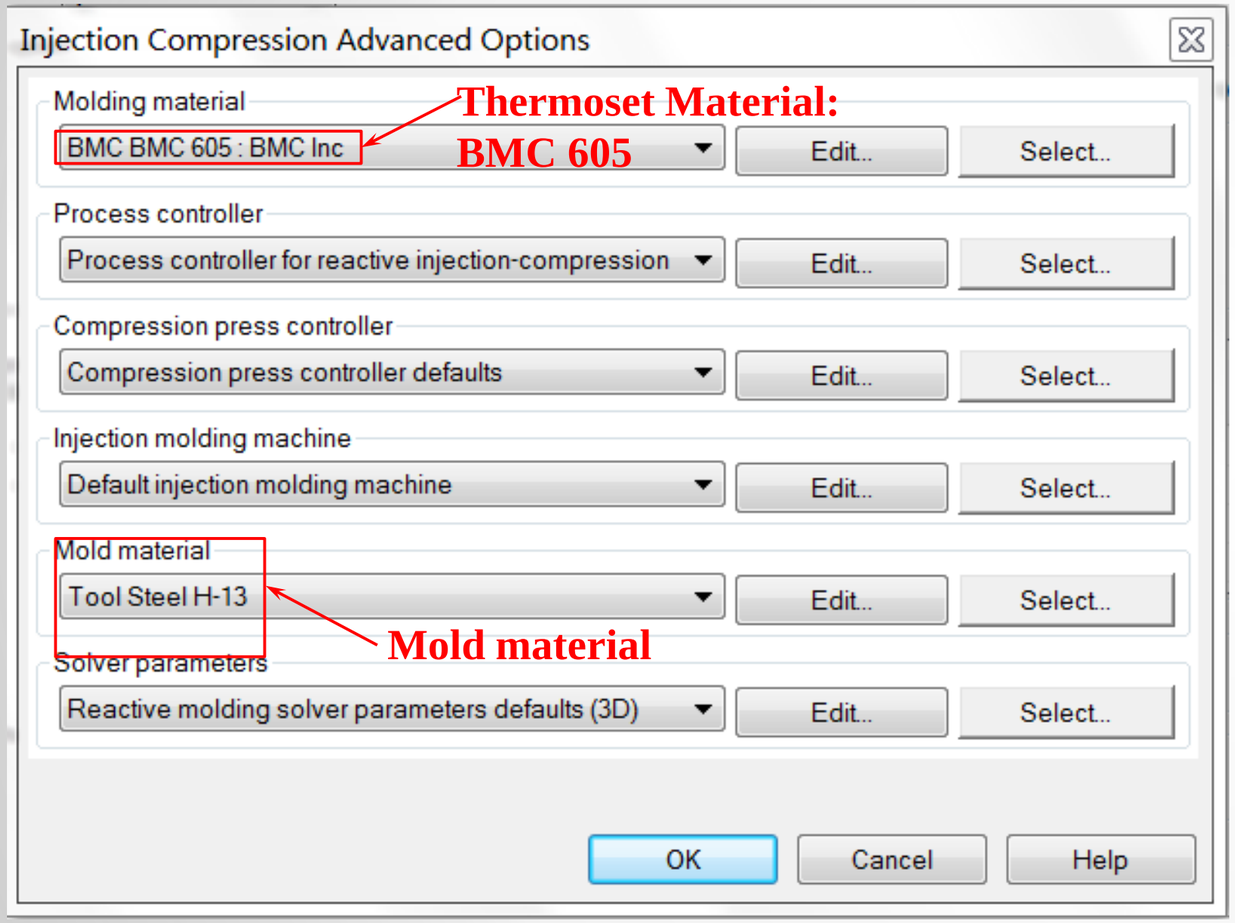
Press compression force (relative) vs duration

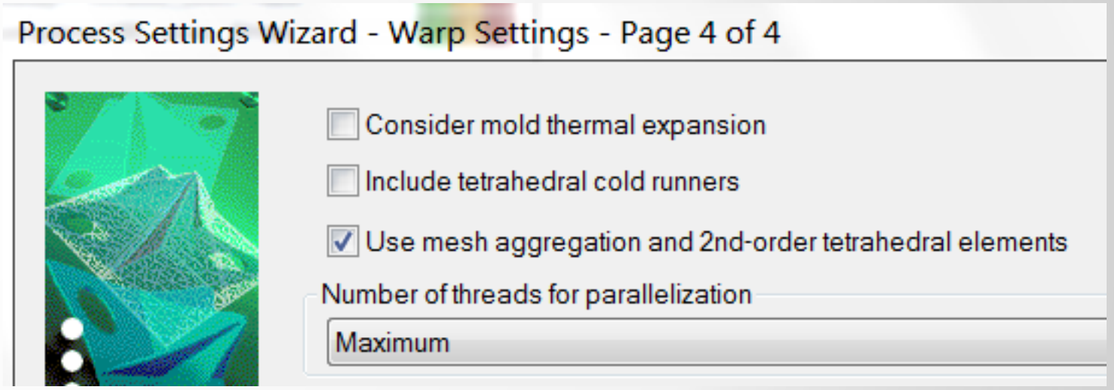
	Duration s [0:3000]	Relative press compression force % [0:3000]
1	0	100
2	190	100
3		
4		

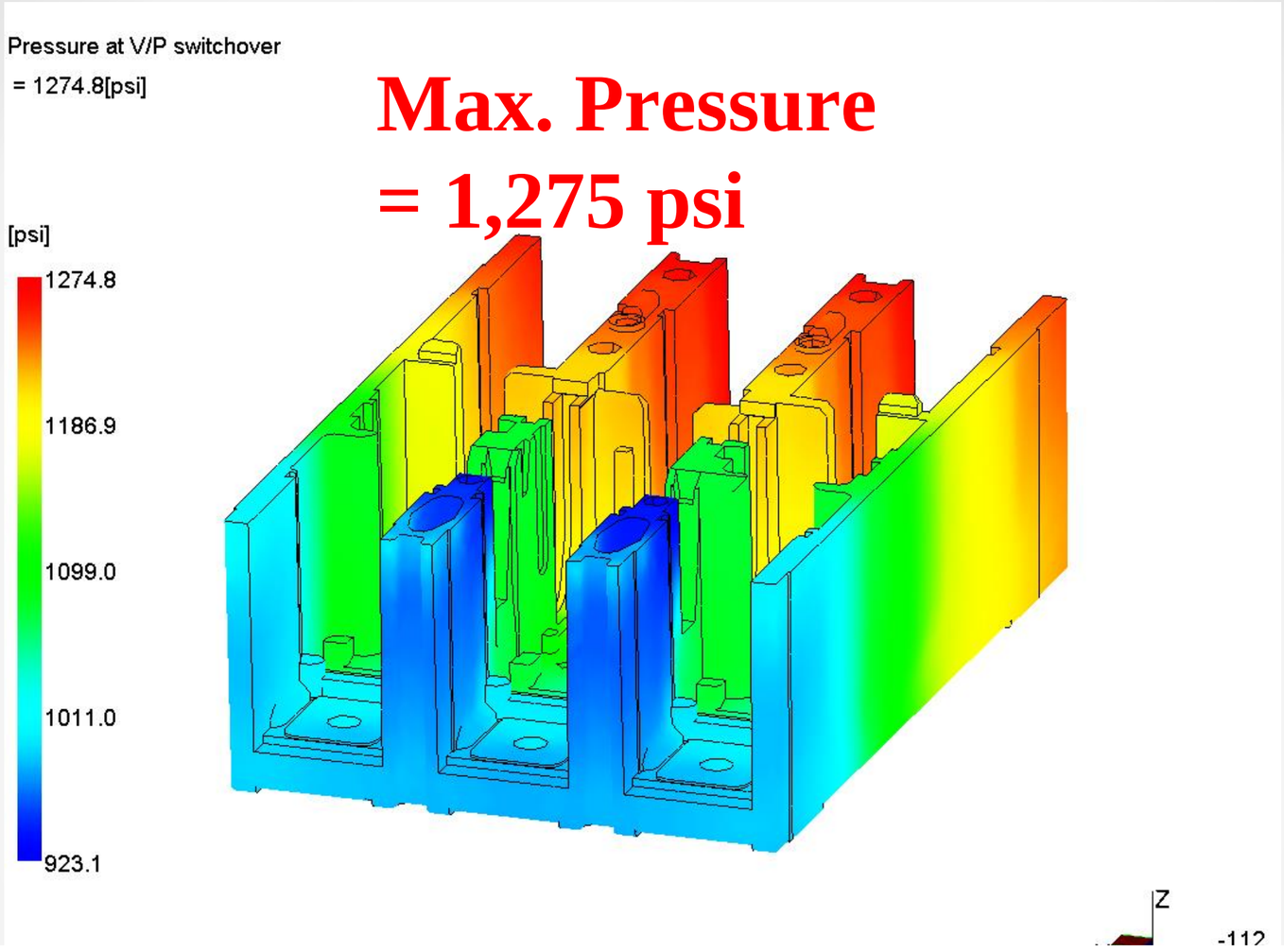
Total mold close-to-mold open time is just over 3 minutes.

OK Cancel Help

Parkway, Mexico, Processing Conditions





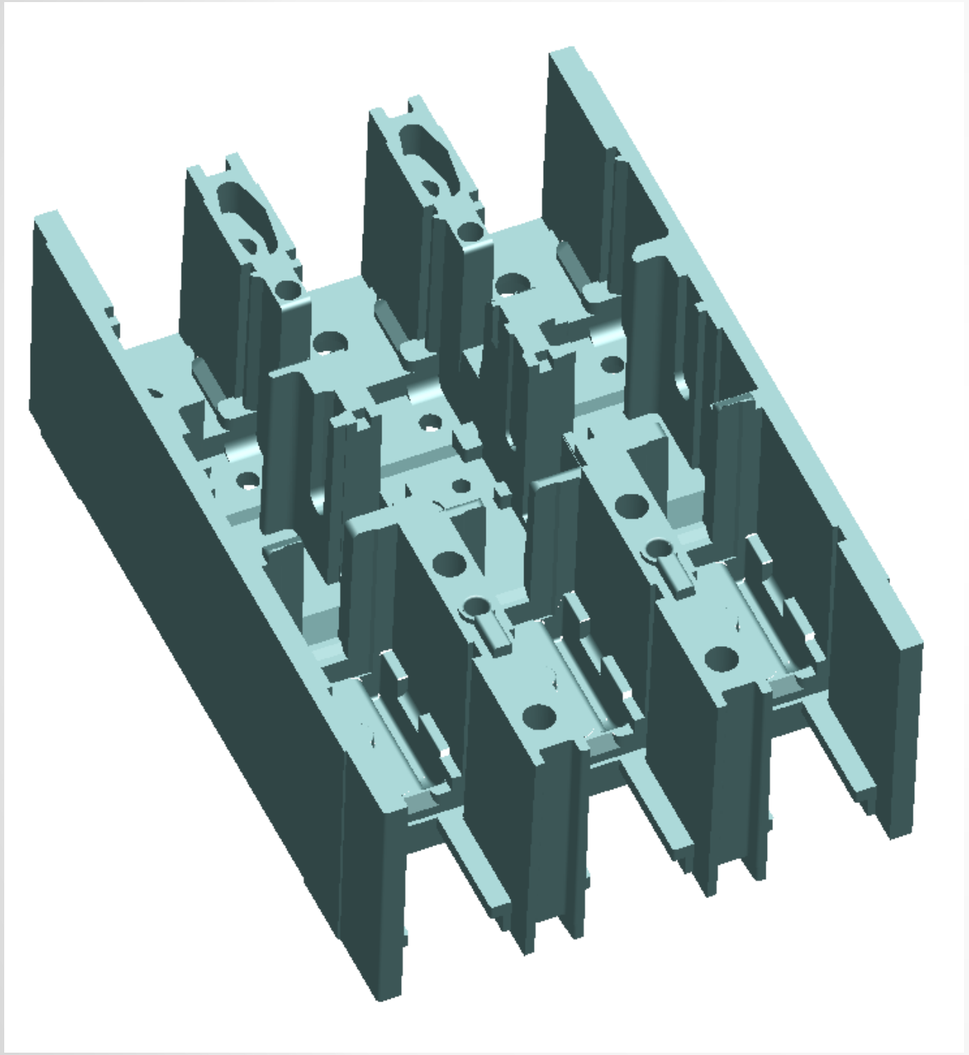


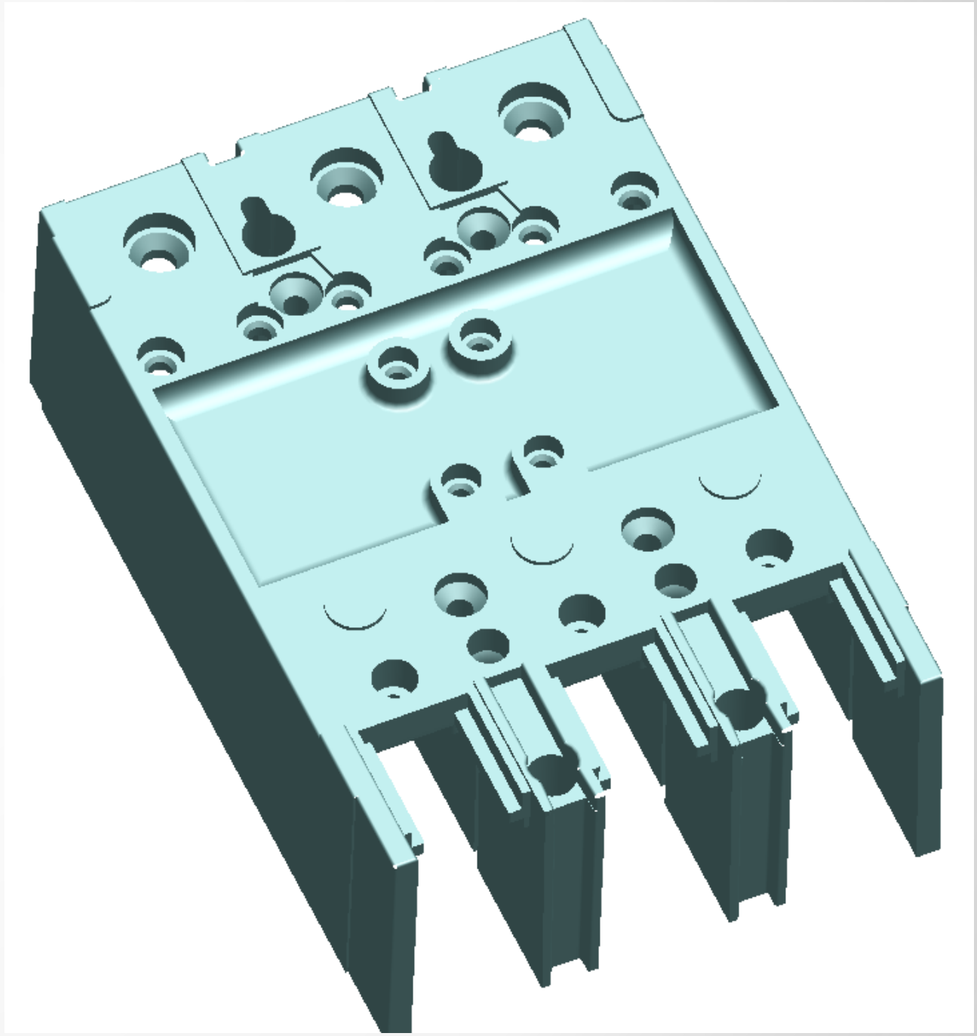
With BMC 605, results of our analysis showed that the Compression Pressure required to fill the part would be 1,275 psi. Shown on the next Slide is the actual hydraulic pressure measured off a dial gauge at the press.

q2r_charge3_comptime180_slow_sideassign3_Scandium_NewBMC

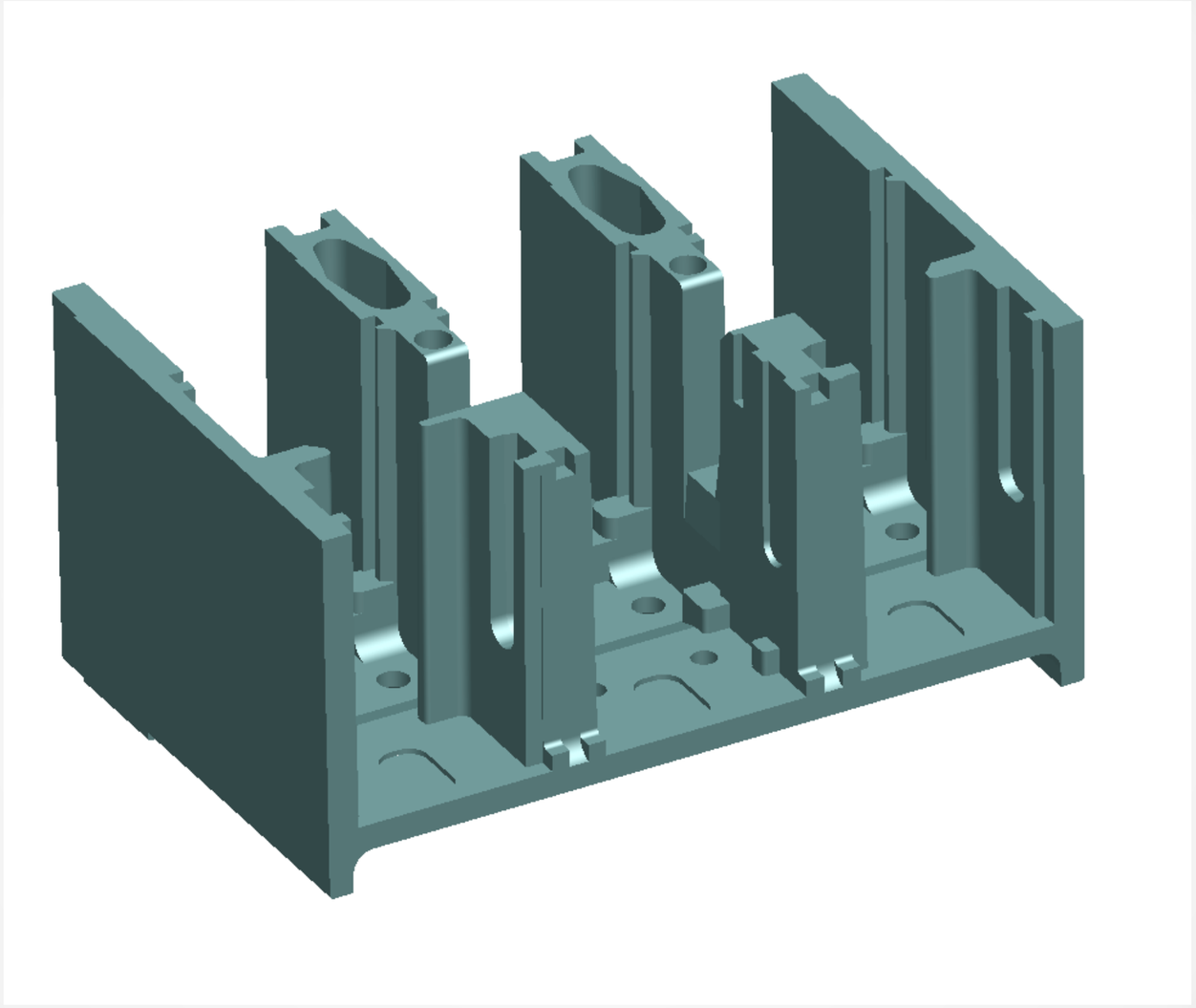
Pressure Gauge on the machine showed roughly 1,700 psi Hydraulic Pressure during the cure cycle. However, we do not have sufficient information from the molder as to how this pressure translates to Compression Force on the platen of the mold.

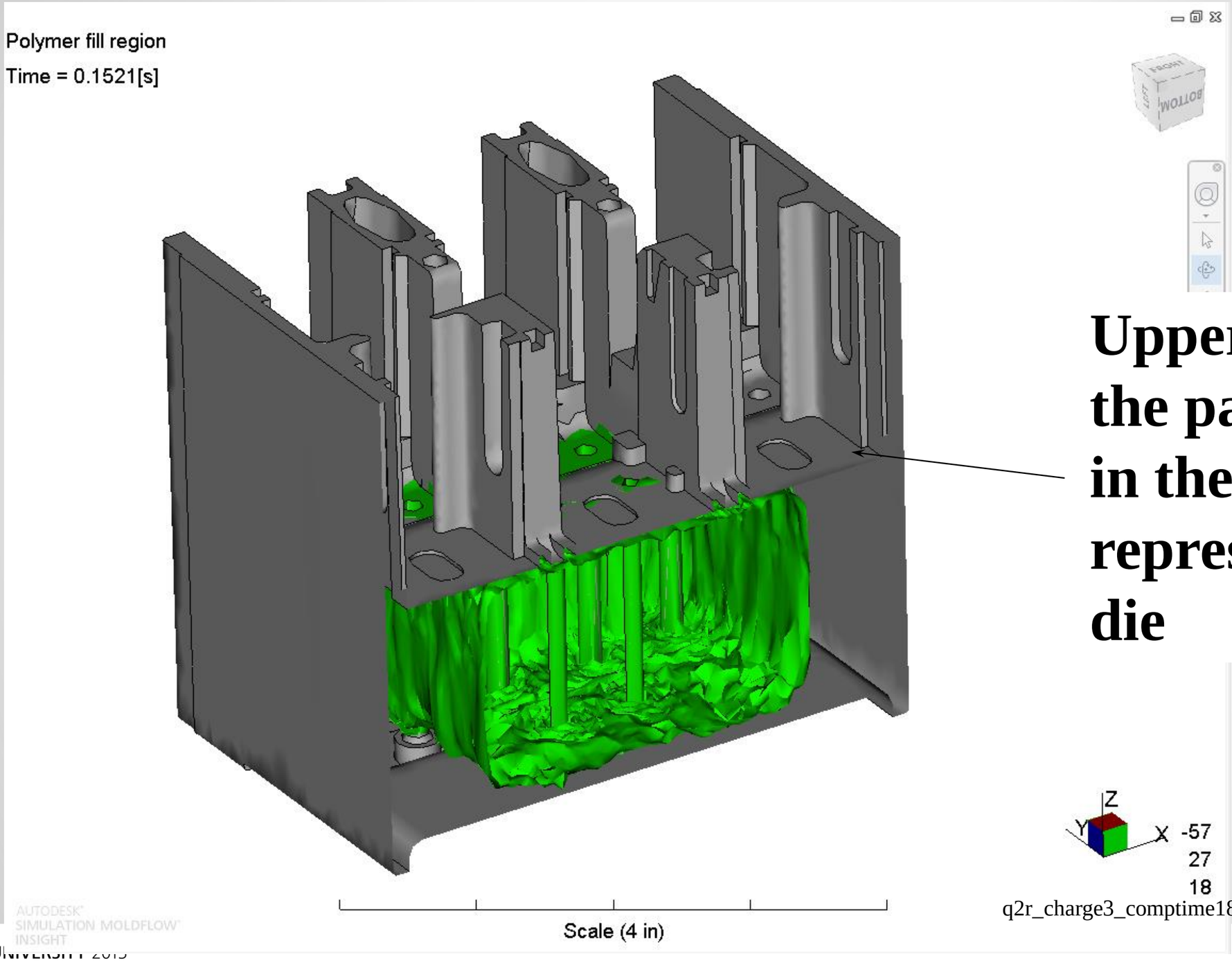
Q2R 3 Pole Base, Compression Molding





Scandium 2014 - Q2R 3 Pole Base, Sectioned Part



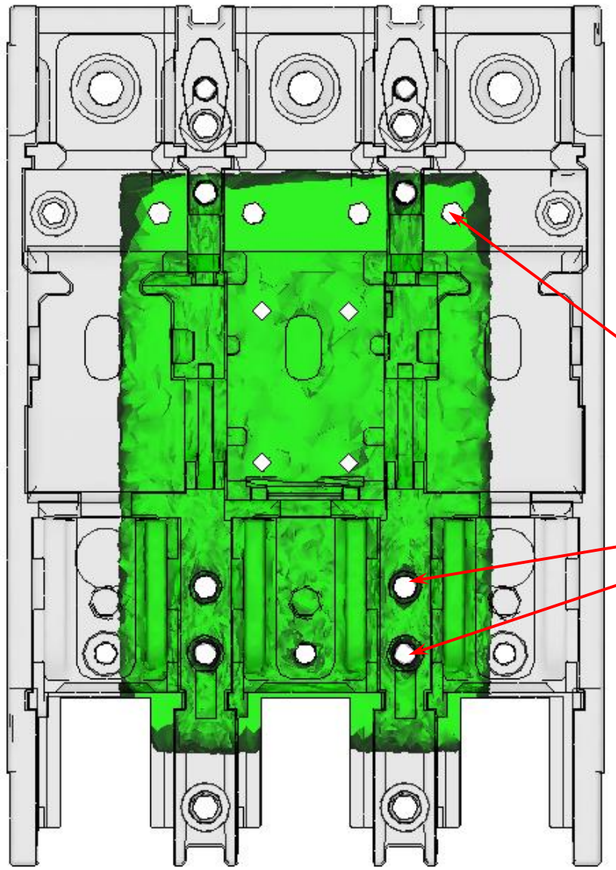


Upper Surface of the part is stretched in the Z direction to represent the upper die

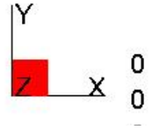
q2r_charge3_comptime180_slow_sideassign3_Scandium_NewBMC

Polymer fill region

Time = 0.1521[s]

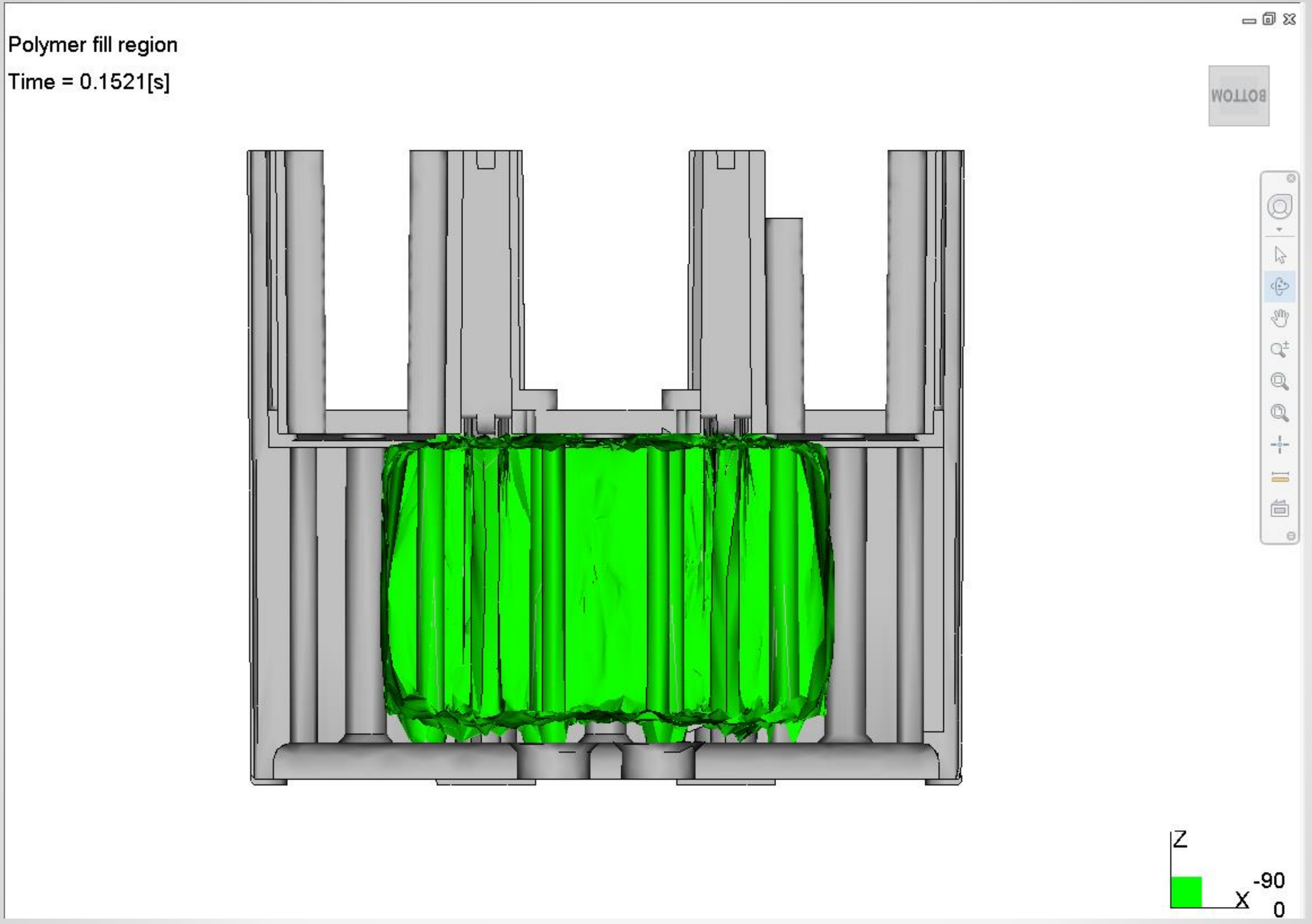


These holes do not exist at this stage of compression.



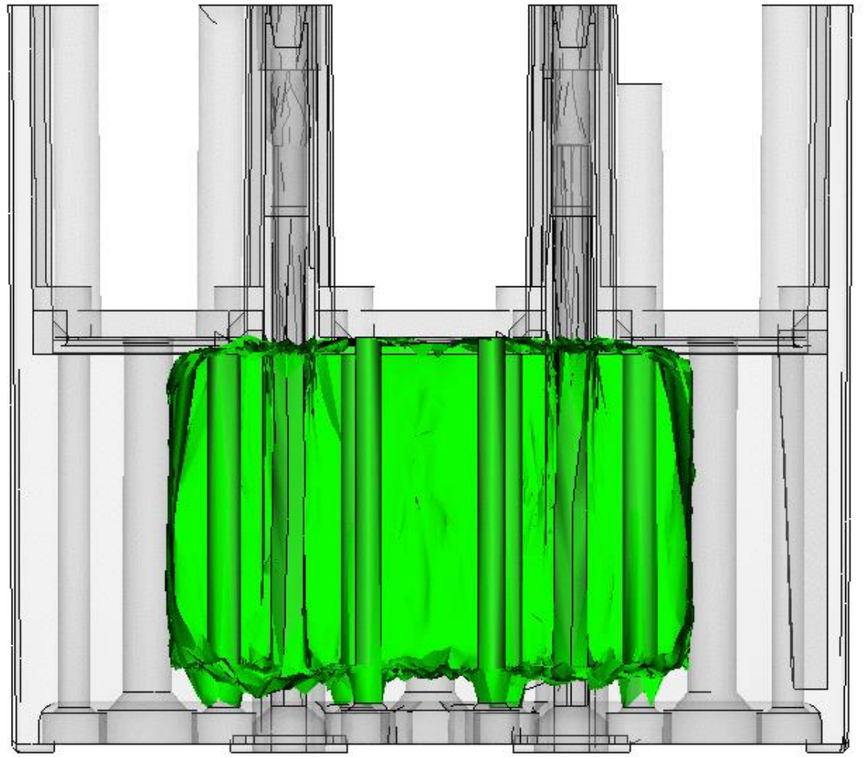
To avoid the holes at the start of compression, a thin web needs to modeled over each of the holes (thickness: 0.010” – 0.020”)

q2r_charge3_comptime180_slow_sideassign3_Scandium_NewBMC


Polymer fill region
Time = 0.1521[s]
BOTTOM
Z
X
-90
0

Polymer fill region

Time = 0.1521[s]



Z

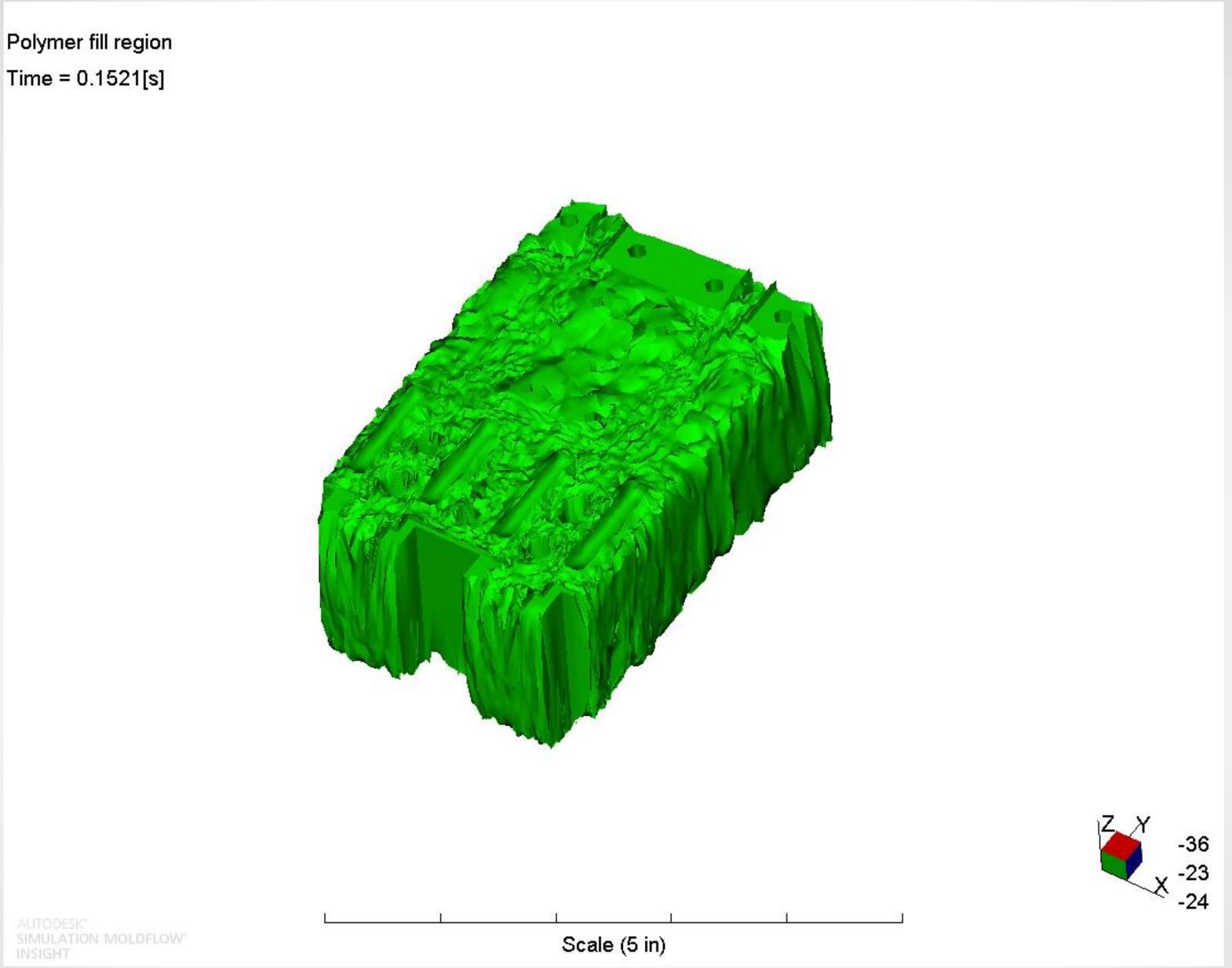
X -90

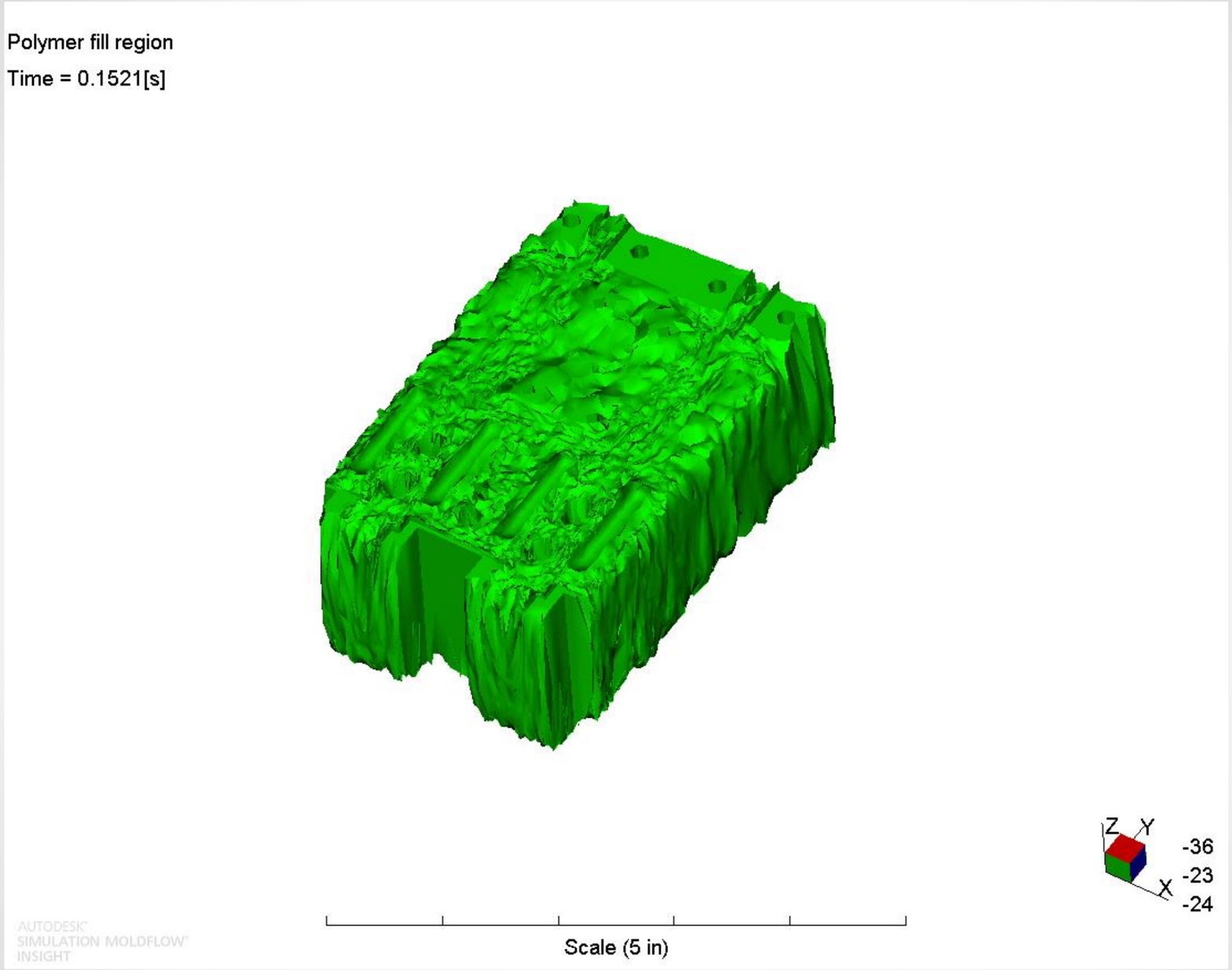
0

0

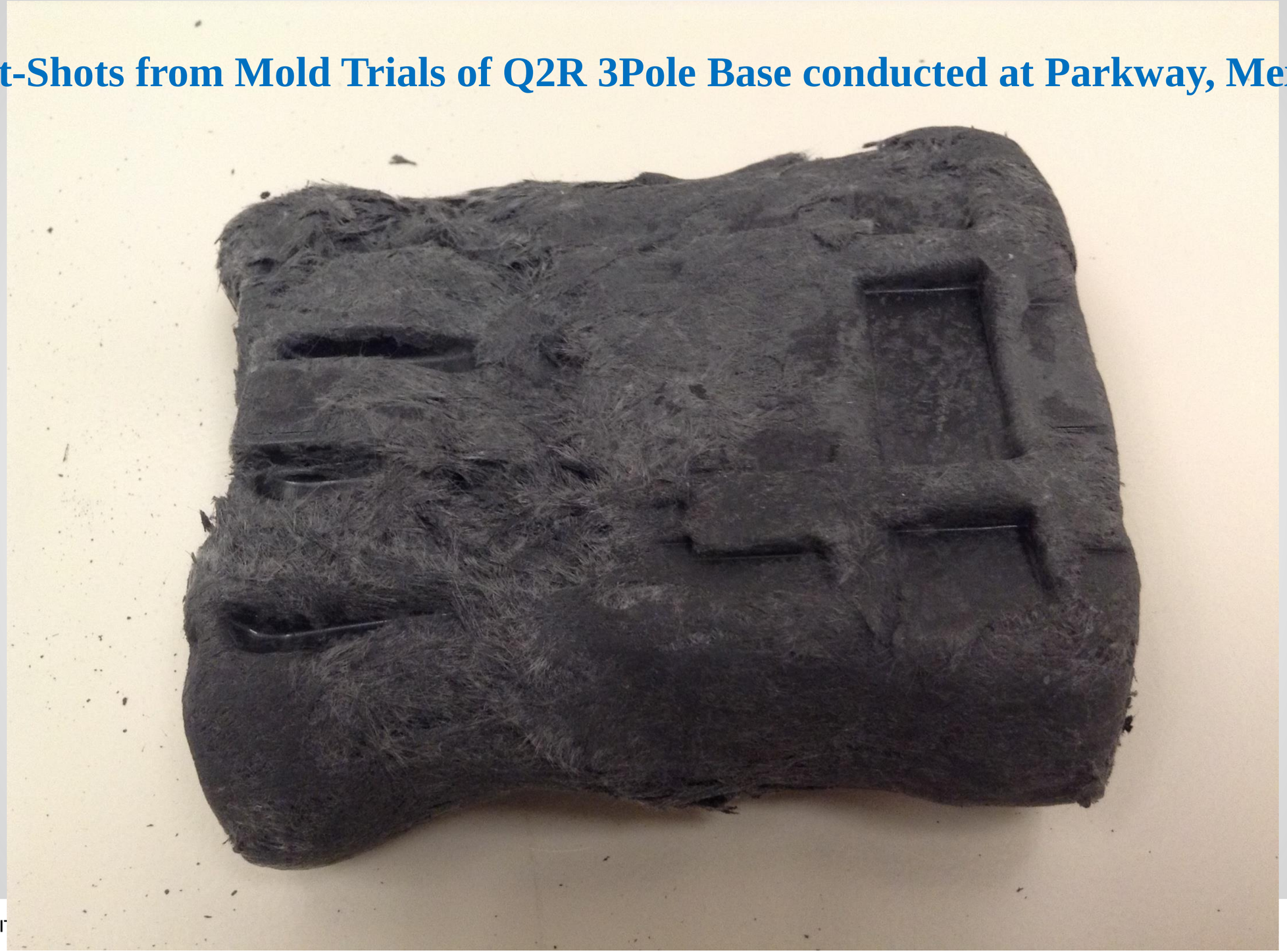
Scale (4 in)

AUTODESK
SIMULATION MOLDFLOW
INSIGHT


Polymer fill region
Time = 0.1521[s]
Z
Y
X
-36
-23
-24
Scale (5 in)
AUTODESK
SIMULATION MOLDFLOW
INSIGHT

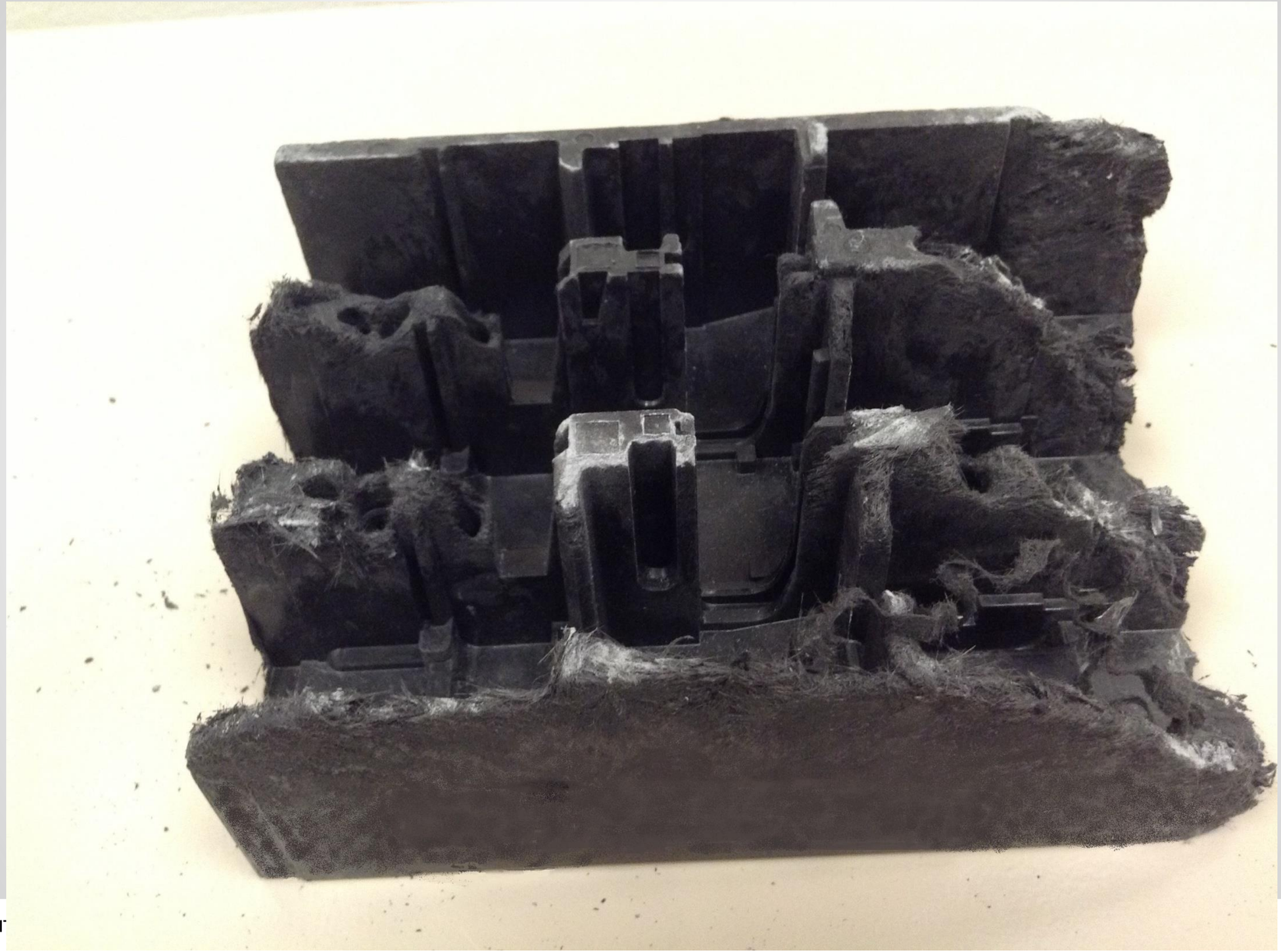

Polymer fill region
Time = 0.1521[s]
Z
Y
X
-36
-23
-24
AUTODESK
SIMULATION MOLDFLOW
INSIGHT
Scale (5 in)

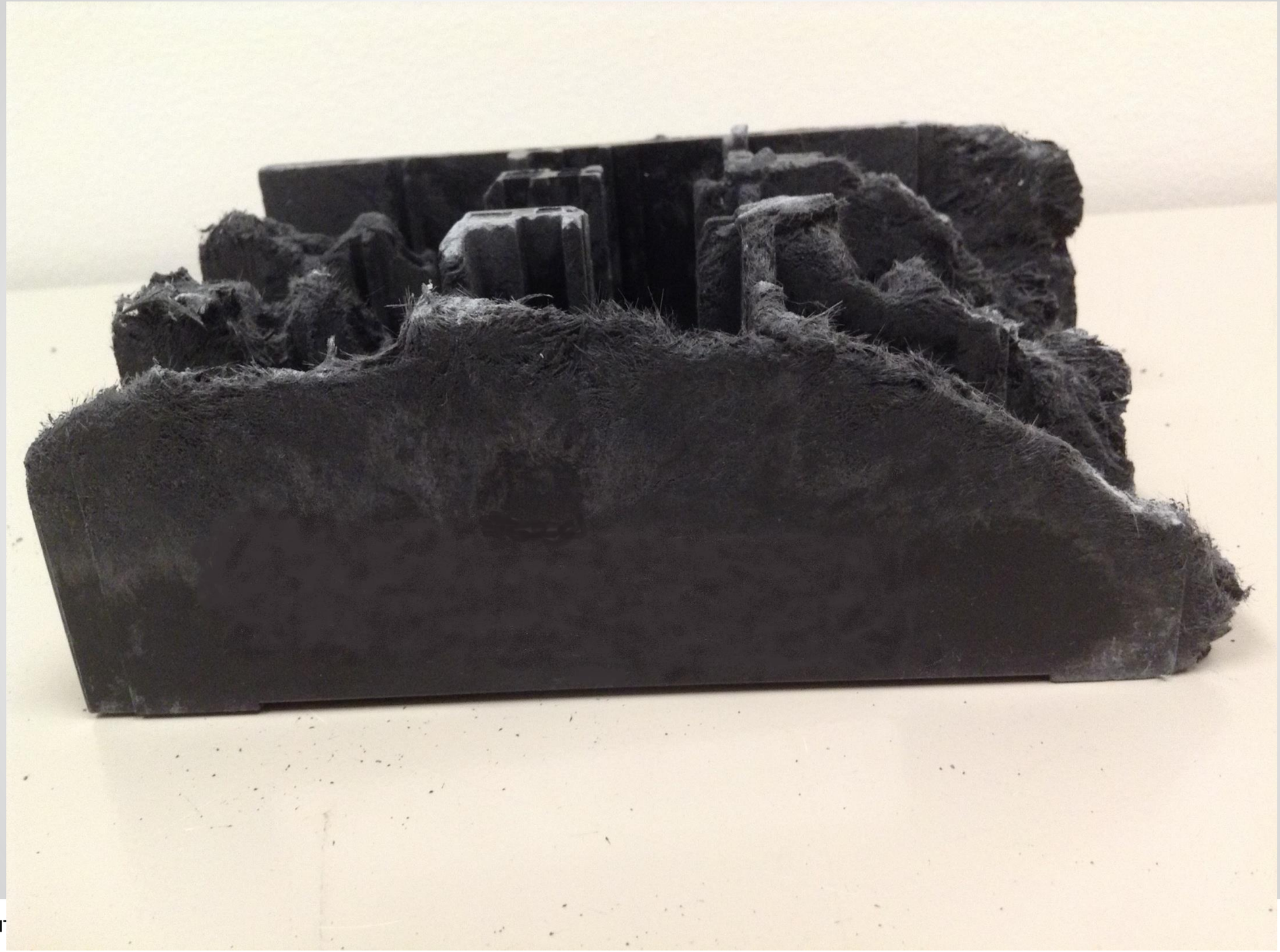
Short-Shots from Mold Trials of Q2R 3Pole Base conducted at Parkway, Mexico




Short Shoot 50% Cav2
Features on bottom of cavity block form first.


Ribs starting to fill.






Short Shot 100% Cav.3

Design of Experiment (DOE)

Method for the DOE

"Central Composite Design (Face-centered)".

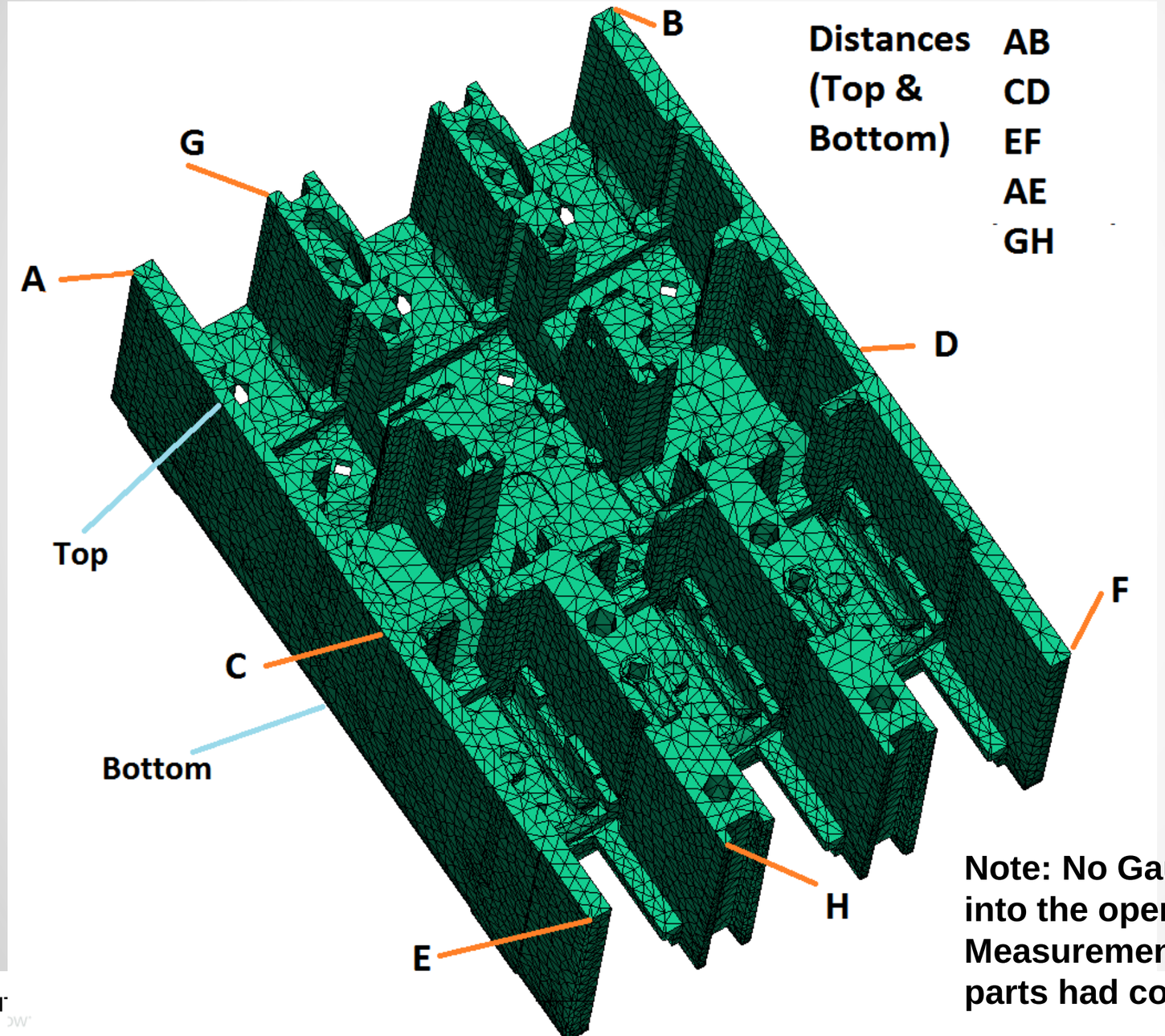
Parameters not chosen for this experiment.

Compression force,
Cure time
Charge weight

Molding Run	Compression speed (inch/sec)	Delay time (s)	Mold temperature (F)	
1	1.28	16	330	
2	0.645	16	330	
3	1.28	26	330	
4	0.645	26	330	
5	1.28	16	370	
6	0.645	16	370	
7	1.28	26	370	
8	0.645	26	370	
9	1.28	21	350	
10	0.645	21	350	
11	0.917	16	350	
12	0.917	26	350	
13	0.917	21	330	
14	0.917	21	370	
15 – 16*	0.917	21	350	

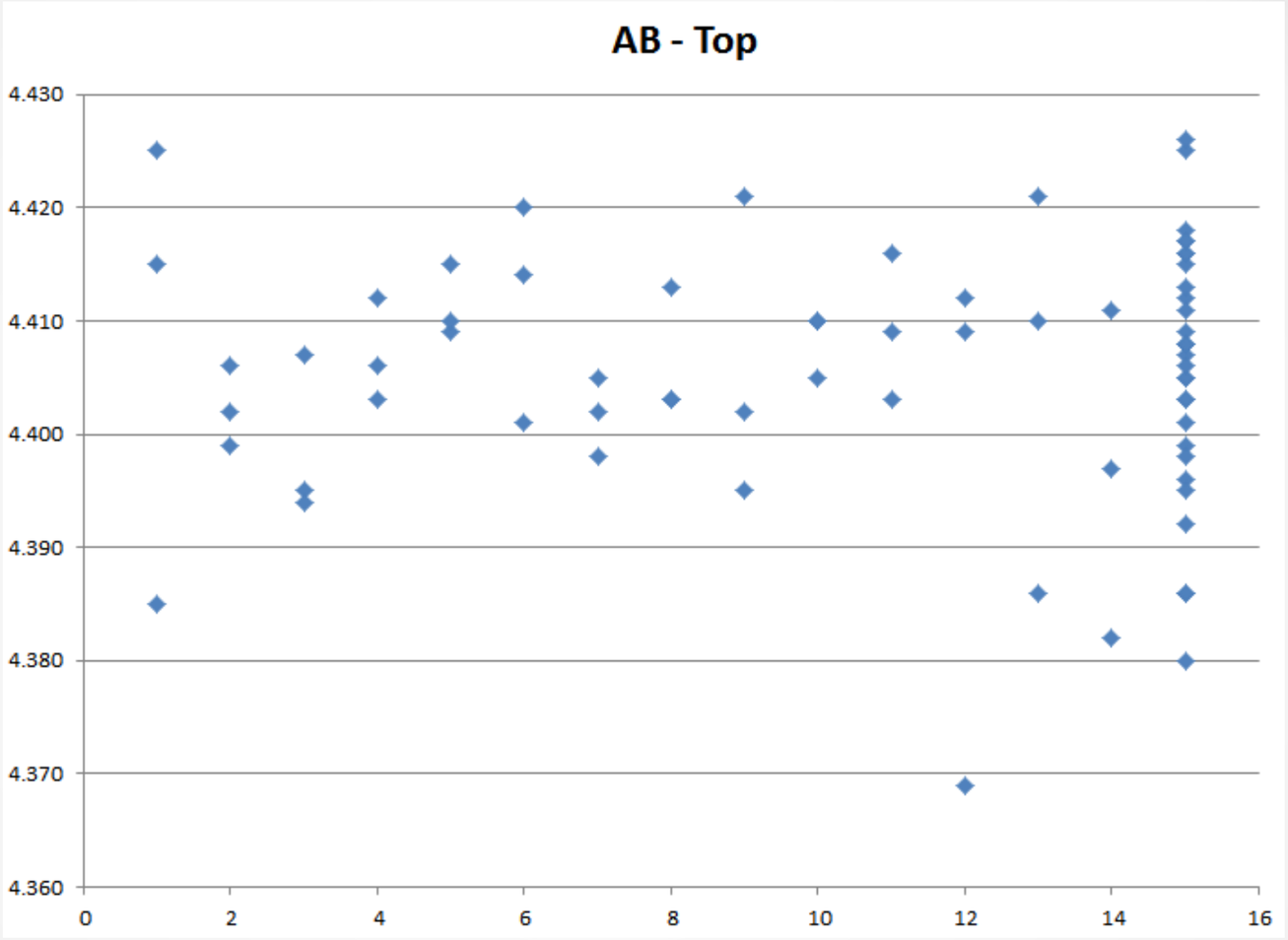
* Run 15 – 16 are at the same condition (nominal process); 5 parts for each run

Distances Measured



Note: No Gauges were inserted into the open end while cooling. Measurements were taken after parts had cooled down.

Measured Dimensions: Distance AB – Top for all Runs (DOE)



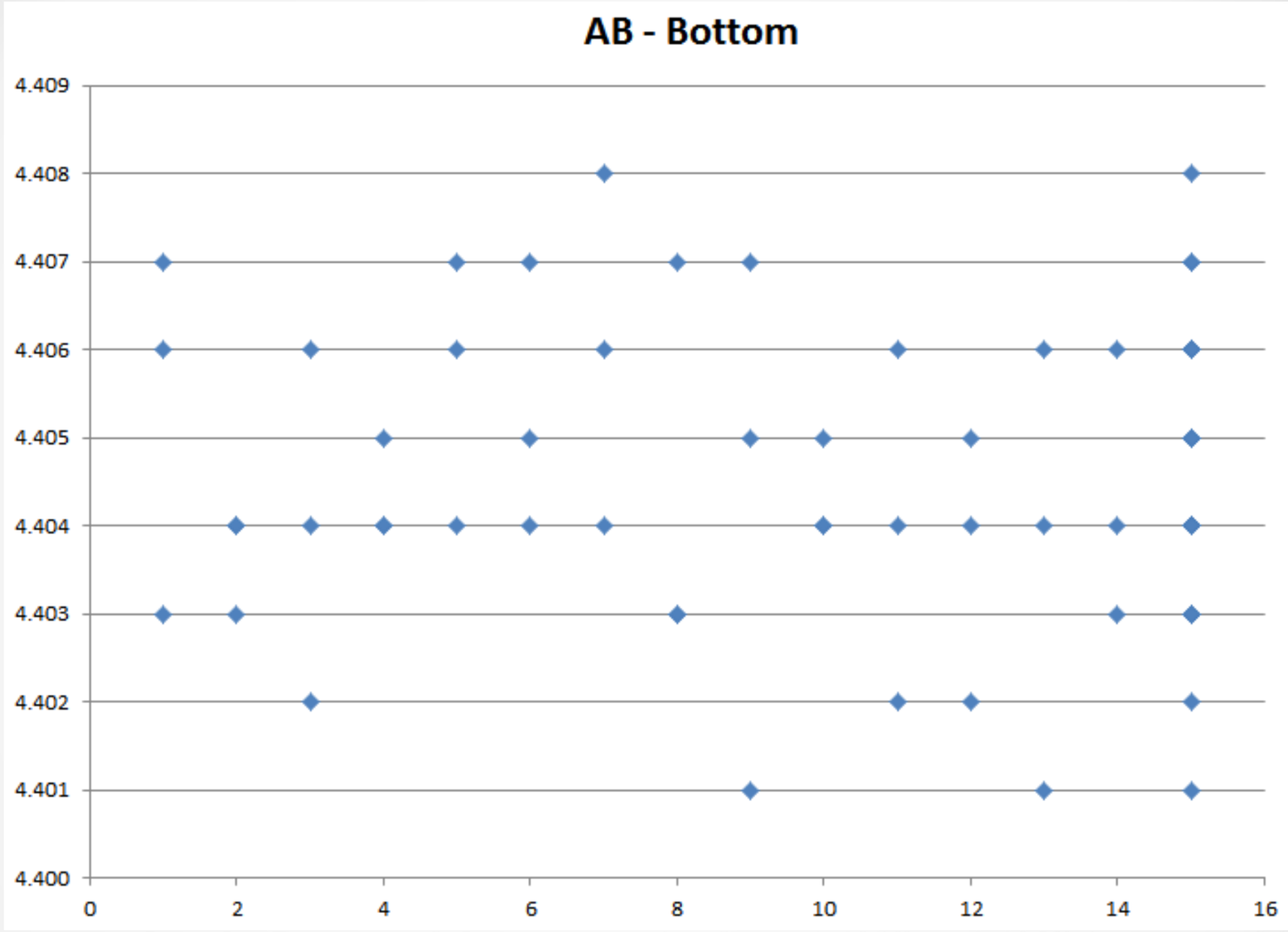
Notice that the Distance AB, measured at the Top of the part, varies from 4.369” to 4.426” (a range of 0.057”). The steel dimension is 4.454”. This implies that the shrink factor ranges from 0.006 – 0.019 in/in . The shrink factor applied in the tool was 0.002 in/in for BMC 605. The measured shrinkage 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.

Measured Dimensions: Distance AB - Top for Run 16 (DOE)

	Compression speed (x Normal speed)	Delay time (s)	Mold Temperature (°F)	A-B
16 - SHOT 1	0.917 in/s	21s	350	4.386
				4.408
				4.425
16 - SHOT 2	0.917 in/s	21s	350	4.405
				4.411
				4.398
16 - SHOT 3	0.917 in/s	21s	350	4.403
				4.416
				4.426
16 - SHOT 4	0.917 in/s	21s	350	4.392
				4.417
				4.417
16 - SHOT 5	0.917 in/s	21s	350	4.405
				4.413
				4.406
Run 15 – 16 are at the same condition; 5 shots (10 pieces)				Diff: 0.019

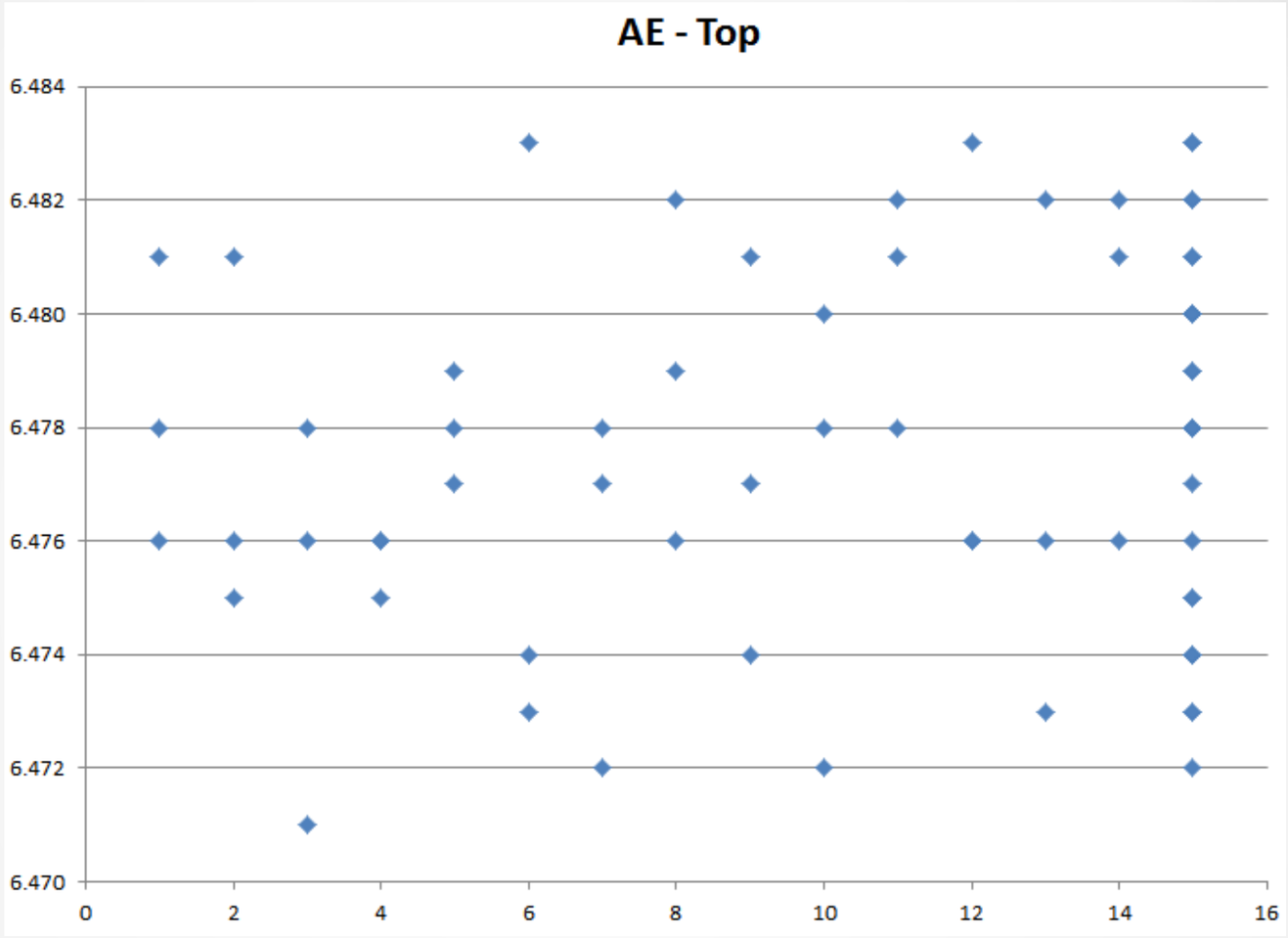
Notice that, even for Run 16, performed at Nominal Processing Conditions (Compression Speed: 0.917 in/sec, Delay Time: 21 sec, Mold Temp: 350 F), the variation in the distance measured for AB in Cavity 1 was 0.019". Since all measurements were from the same cavity at the same processing conditions, one 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.

Measured Dimension: Distance AB -Bottom for all Runs (DOE)

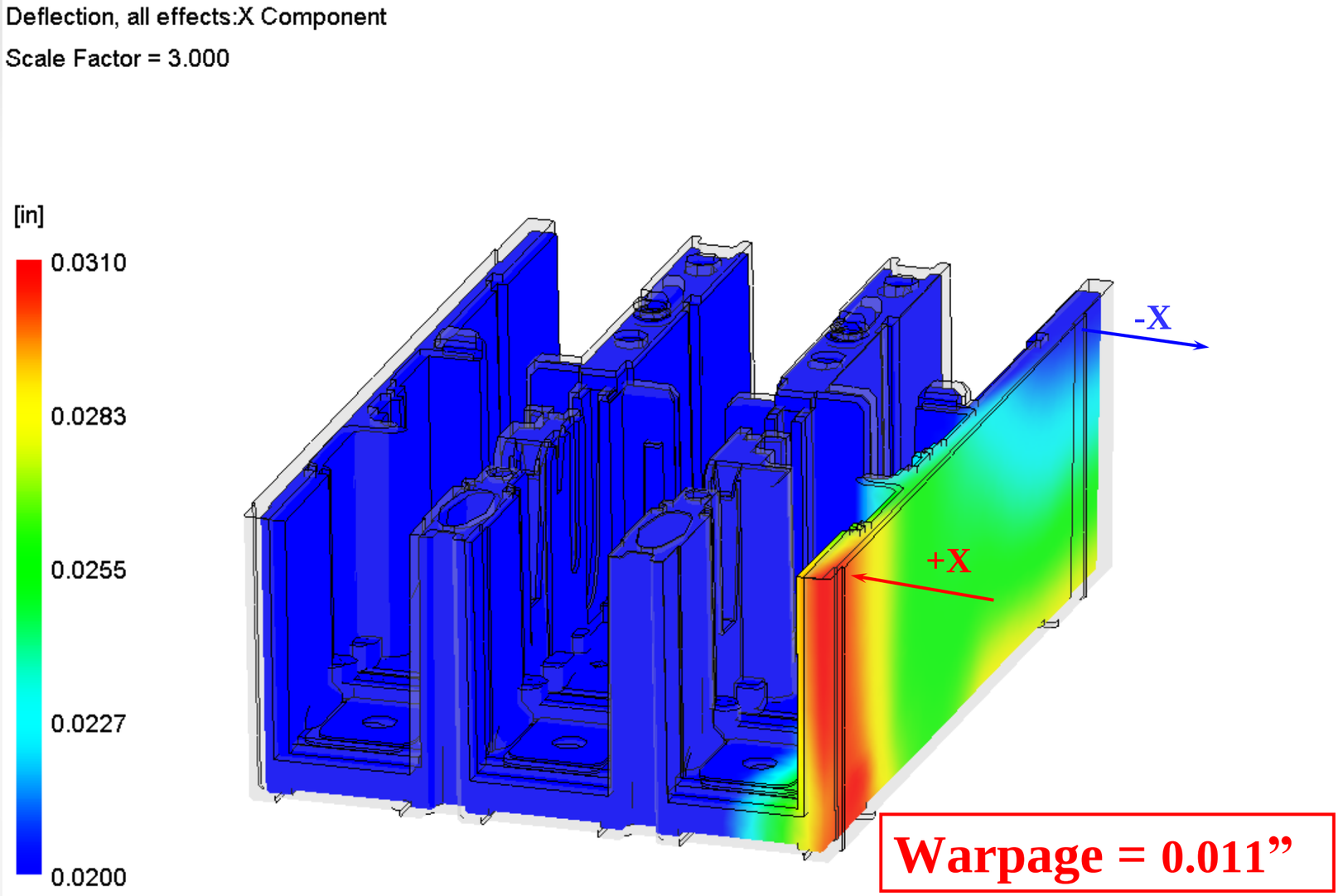


Notice that the Distance AB, measured at the Bottom of the part, varies from 4.401” to 4.408” (a range of 0.007”). This range of variation at the closed end is much tighter than at the open end. The steel dimension is 4.416”. This implies that the shrink factor ranges from 0.002 – 0.003 in/in . The shrink 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.

Measured Dimensions: Distance AE - Top for all Runs (DOE)



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.**

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