"Simulation of Injection-Compression and Compression Molding"
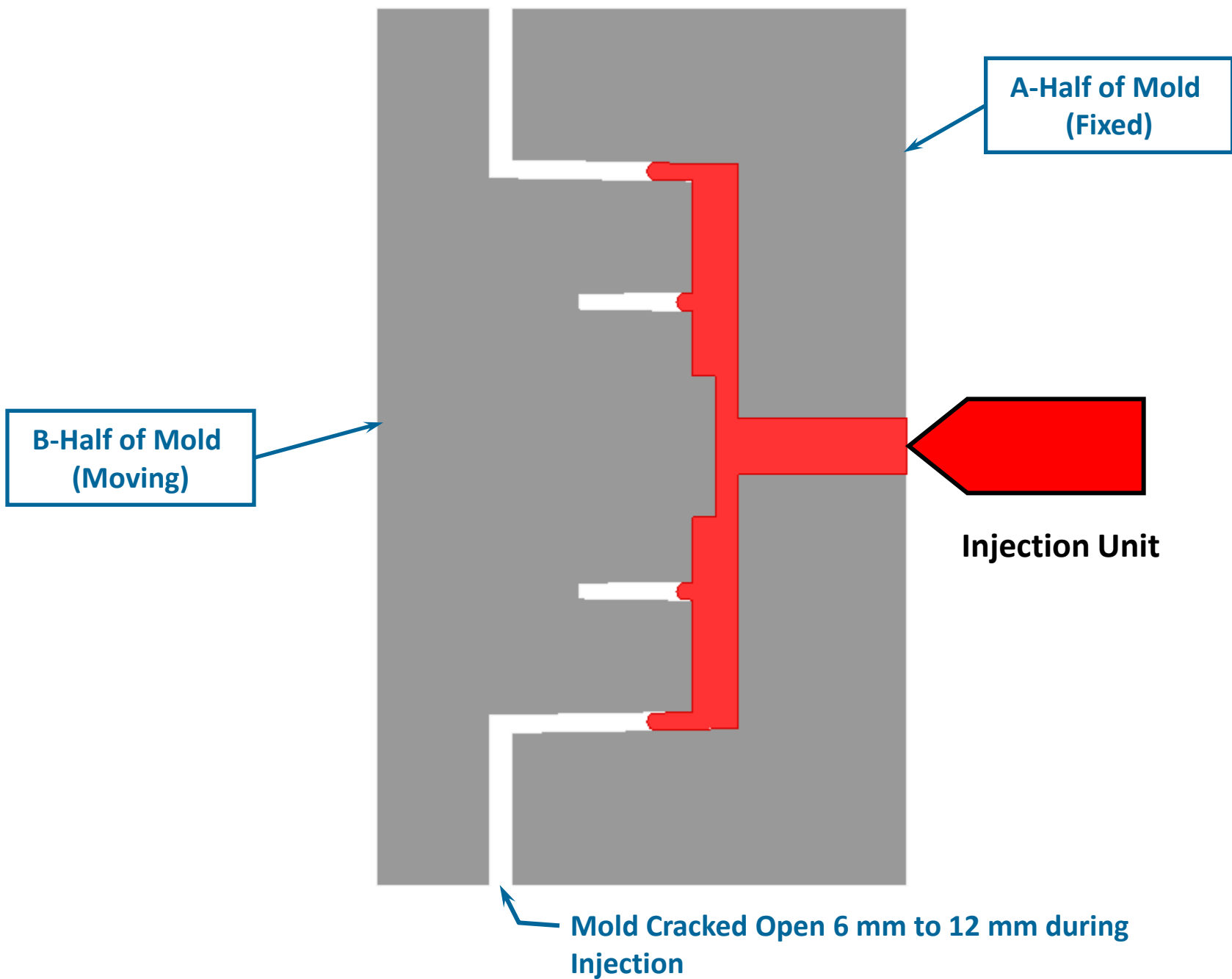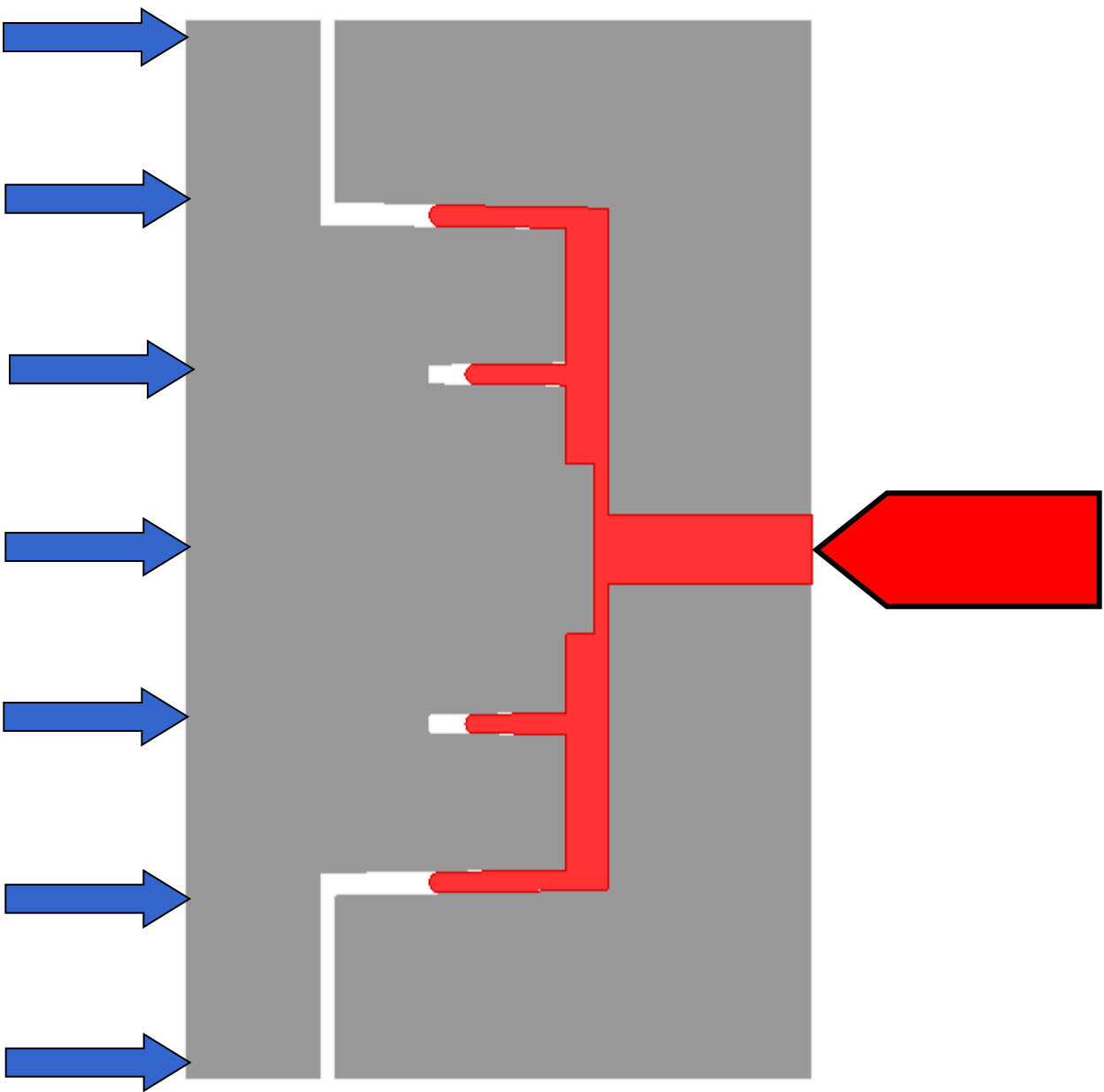
Autodesk University
December 4th, 2013

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Schneider Electric
Core Technology Group
Raleigh, North Carolina

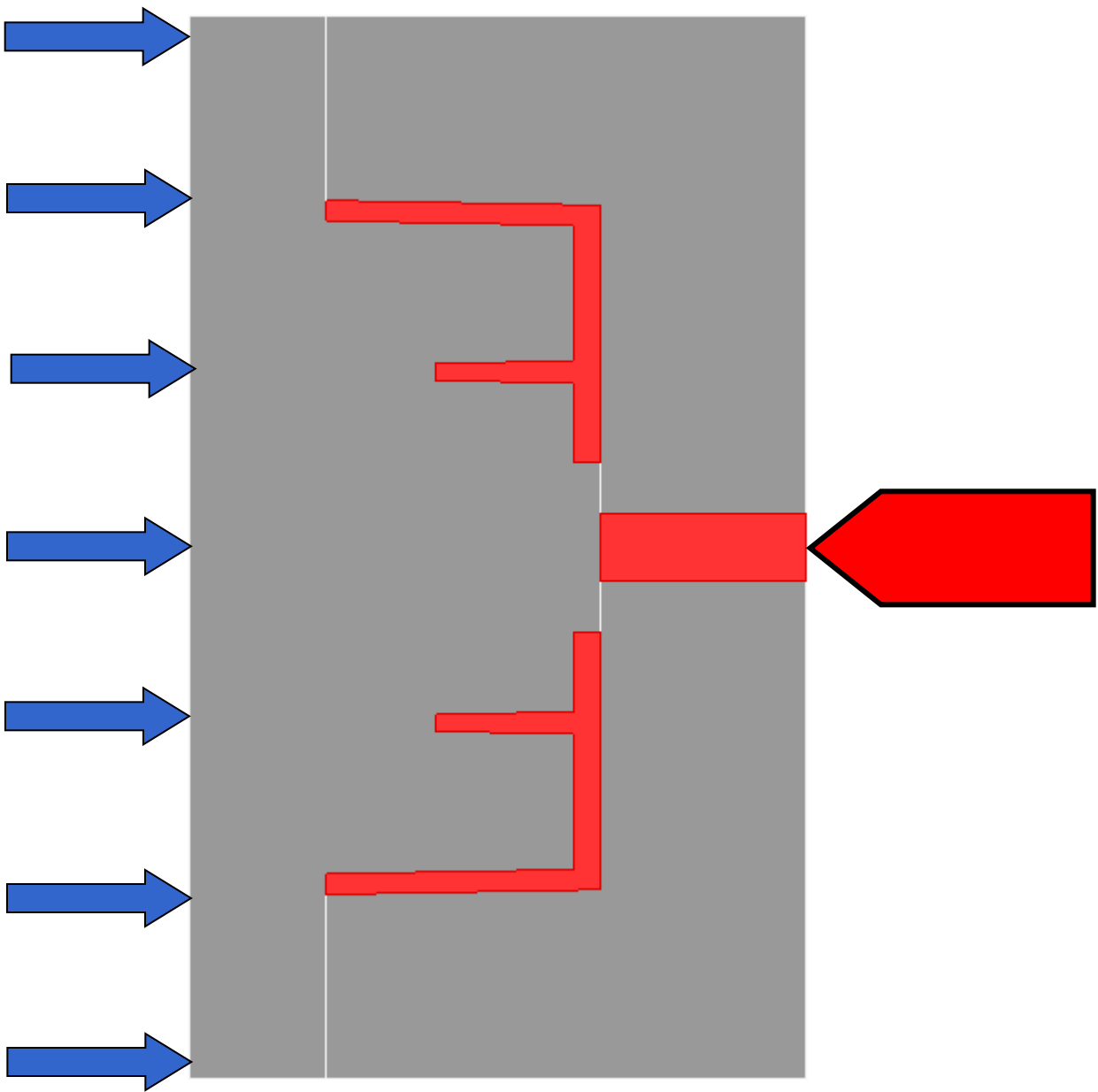# Introduction

- 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.
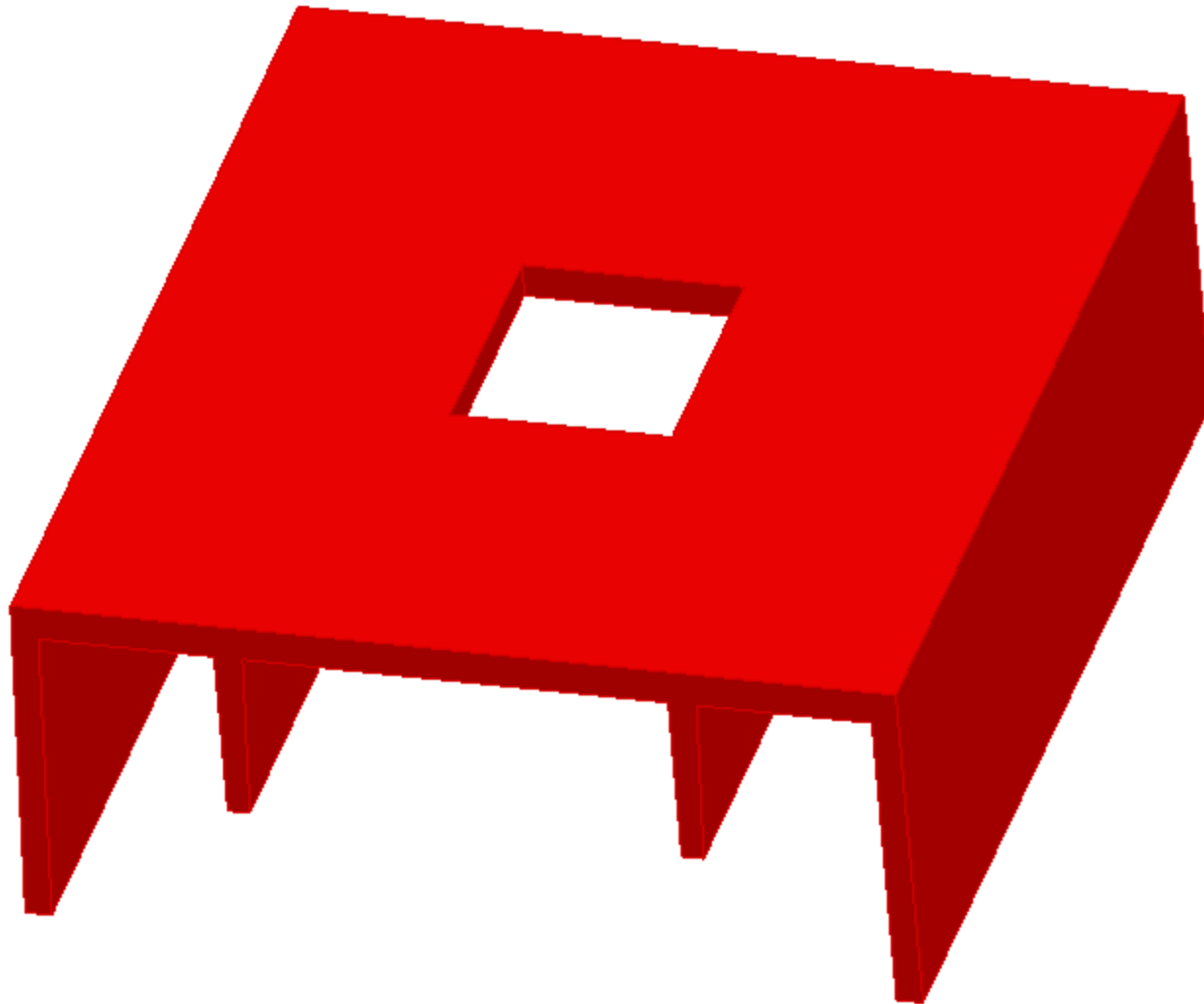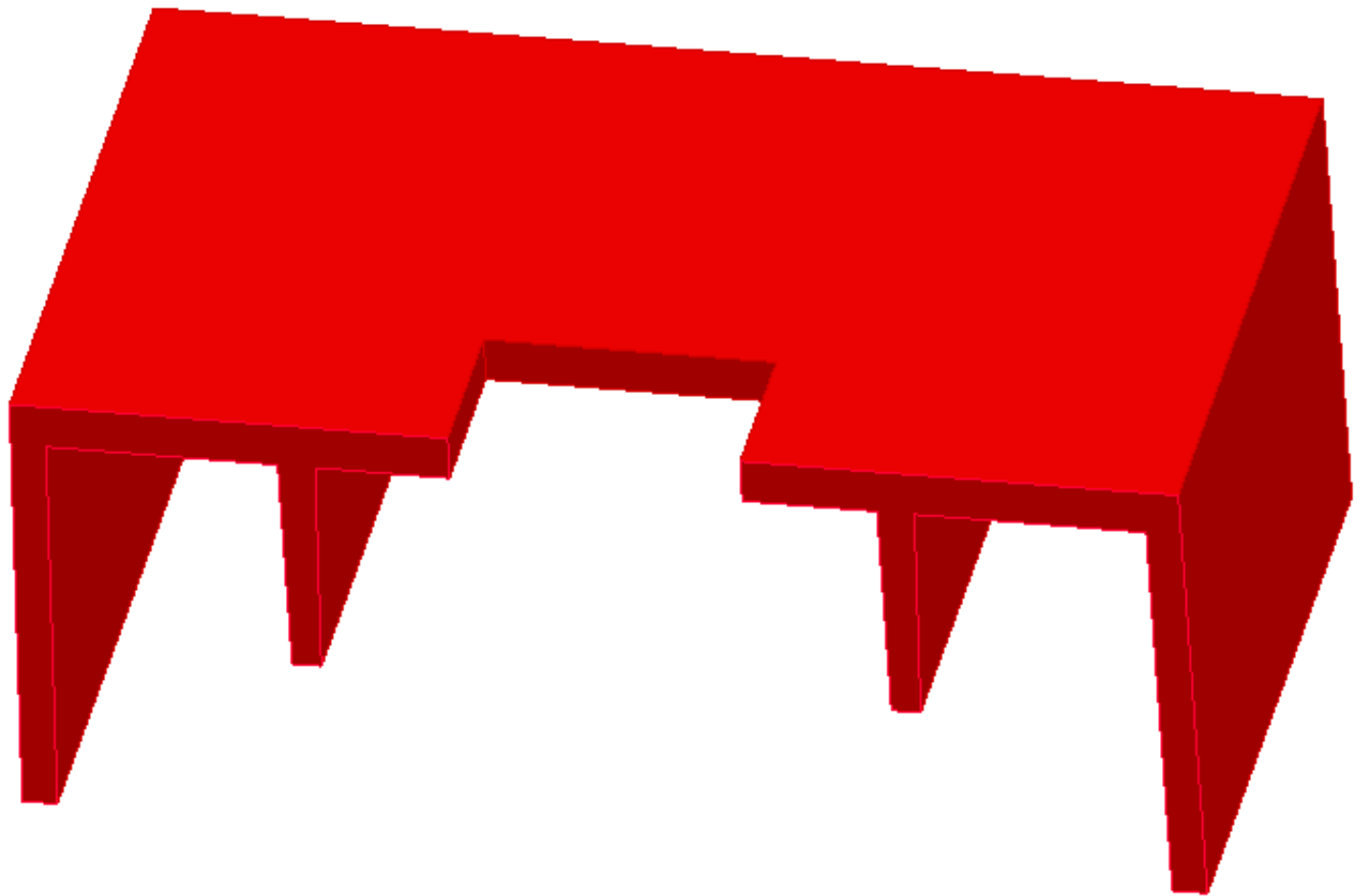
Thermoset Injection-Compression (Test Case)

A-Half of Mold (Fixed)

B-Half of Mold (Moving)

Injection Unit

Mold Cracked Open 6 mm to 12 mm during Injection
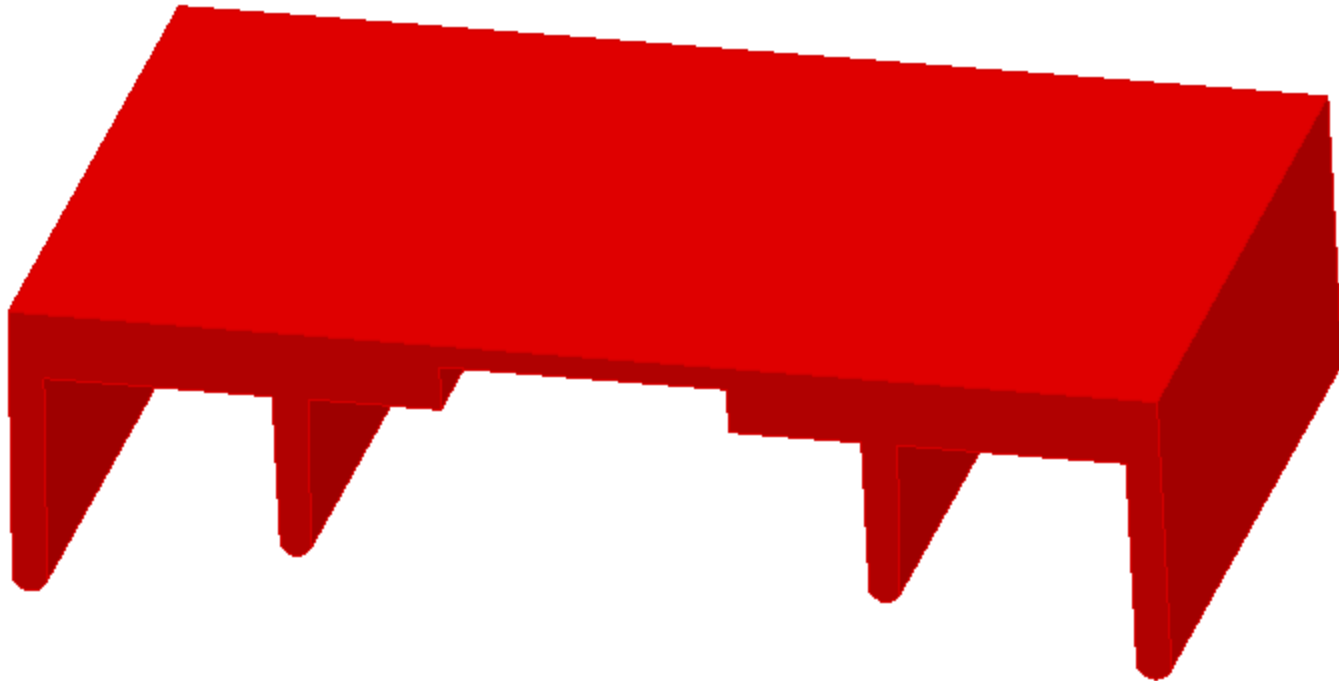
Finished Part

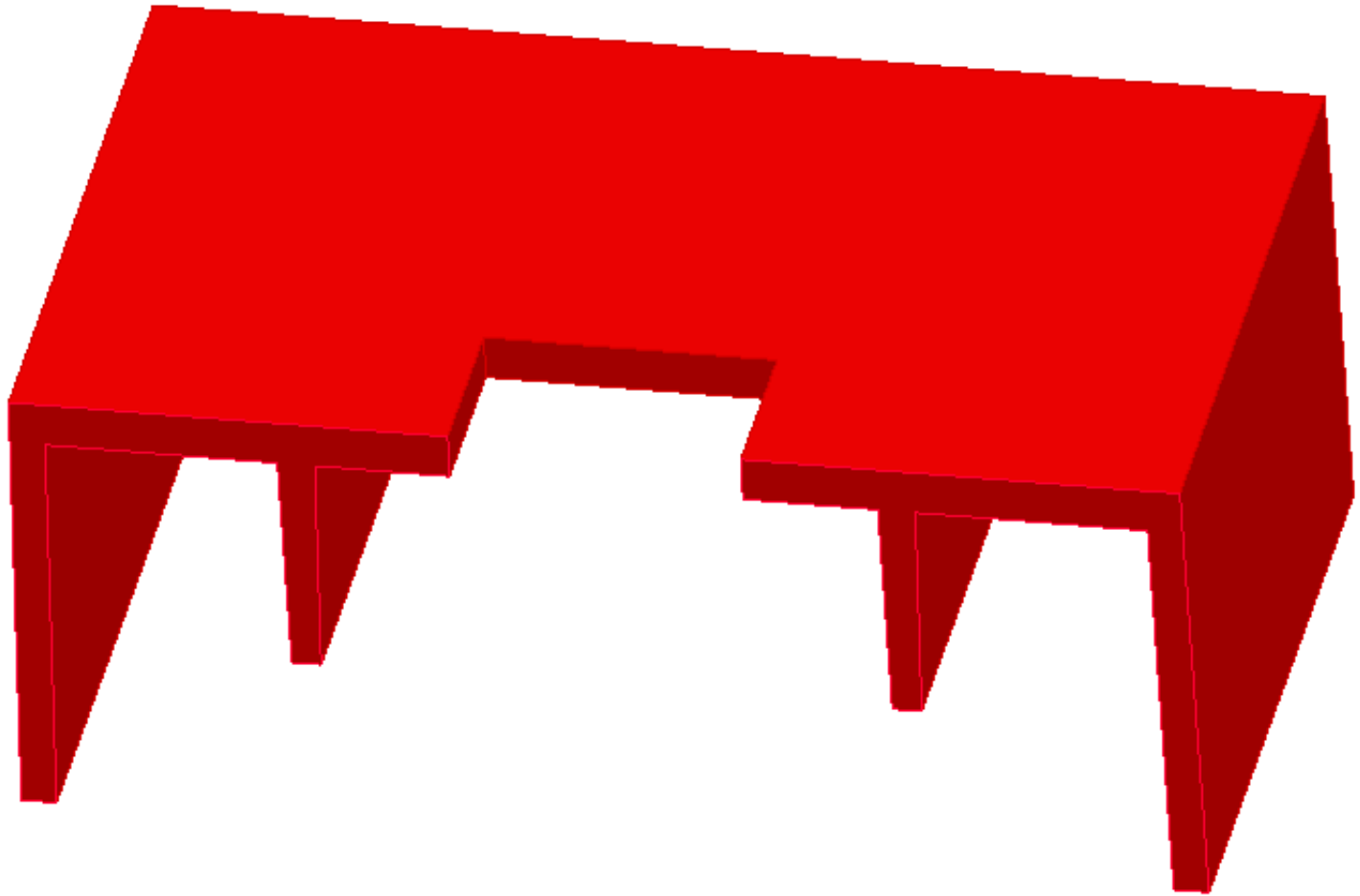**Finished Part
(cut in half)**

Two Steps prior to Mold Shutting Off
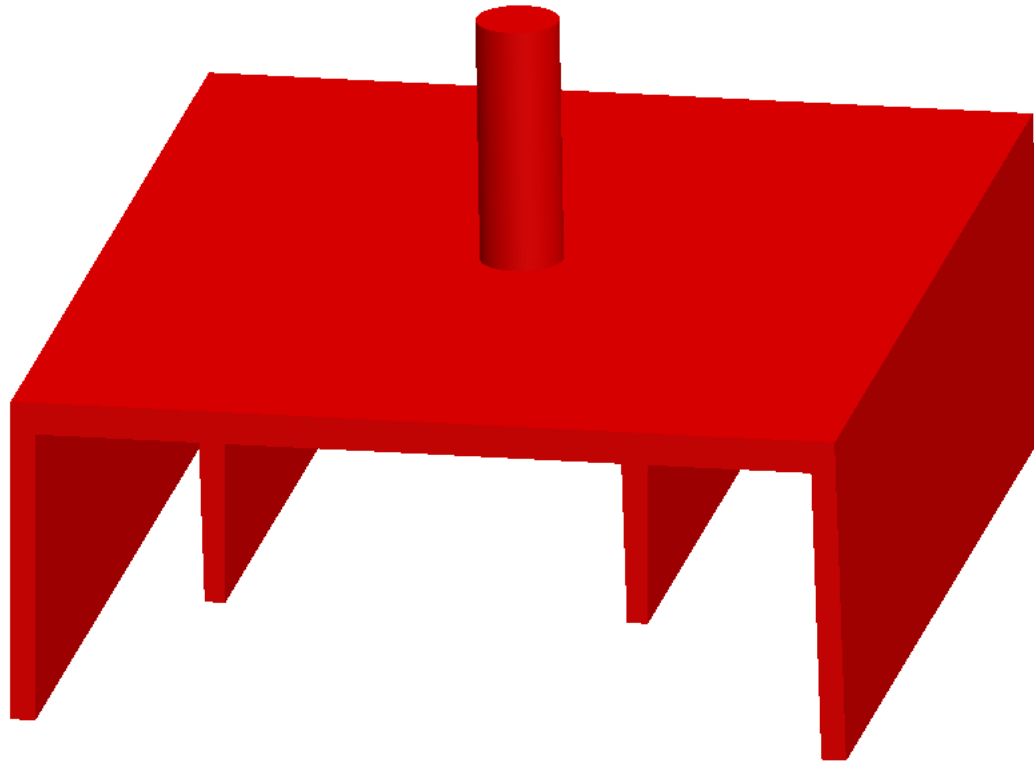
One Step prior to Mold Shutting Off

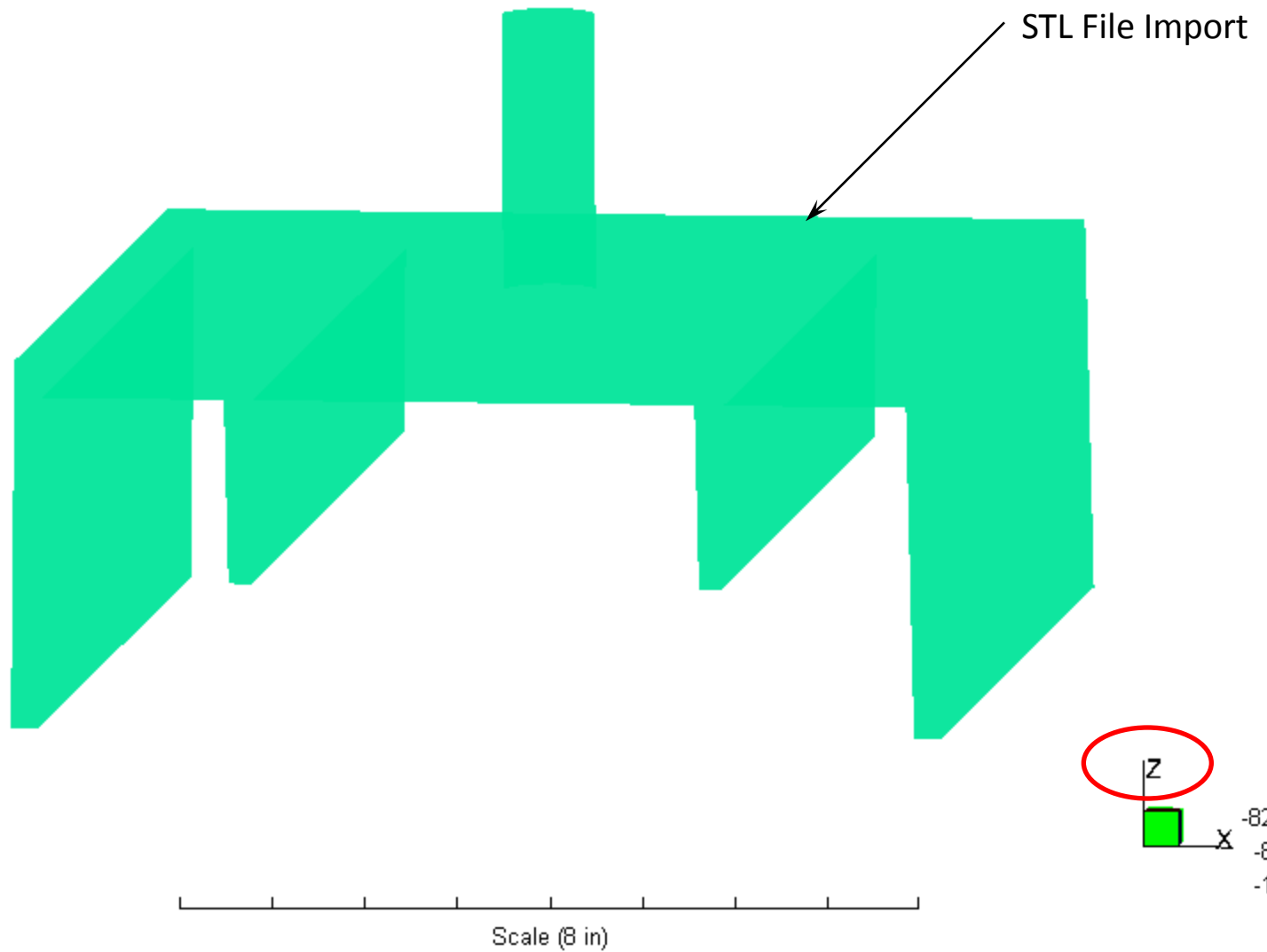**Window forms only when Mold shuts off completely**

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

Injection - Compression Molding Analysis - Moldflow Synergy Scandium 2014
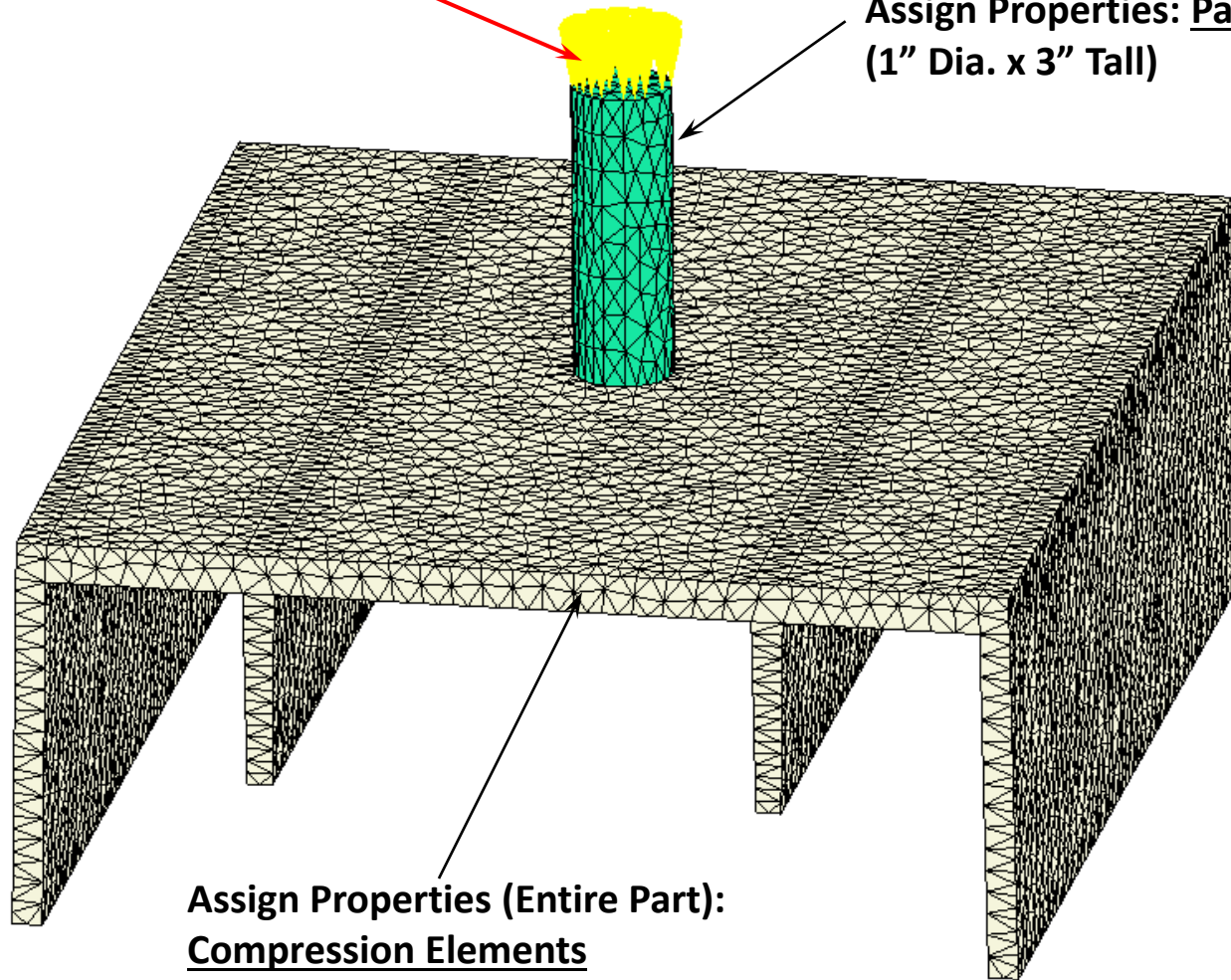

STL File Import

Scale (8 in)

Z
X
-82
-8
-1

Autodesk
SIMULATION MOLDFLOW
INSIGHT

Assign Injection Nodes

Assign Properties: <u>Part 3D</u> (1" Dia. x 3" Tall)

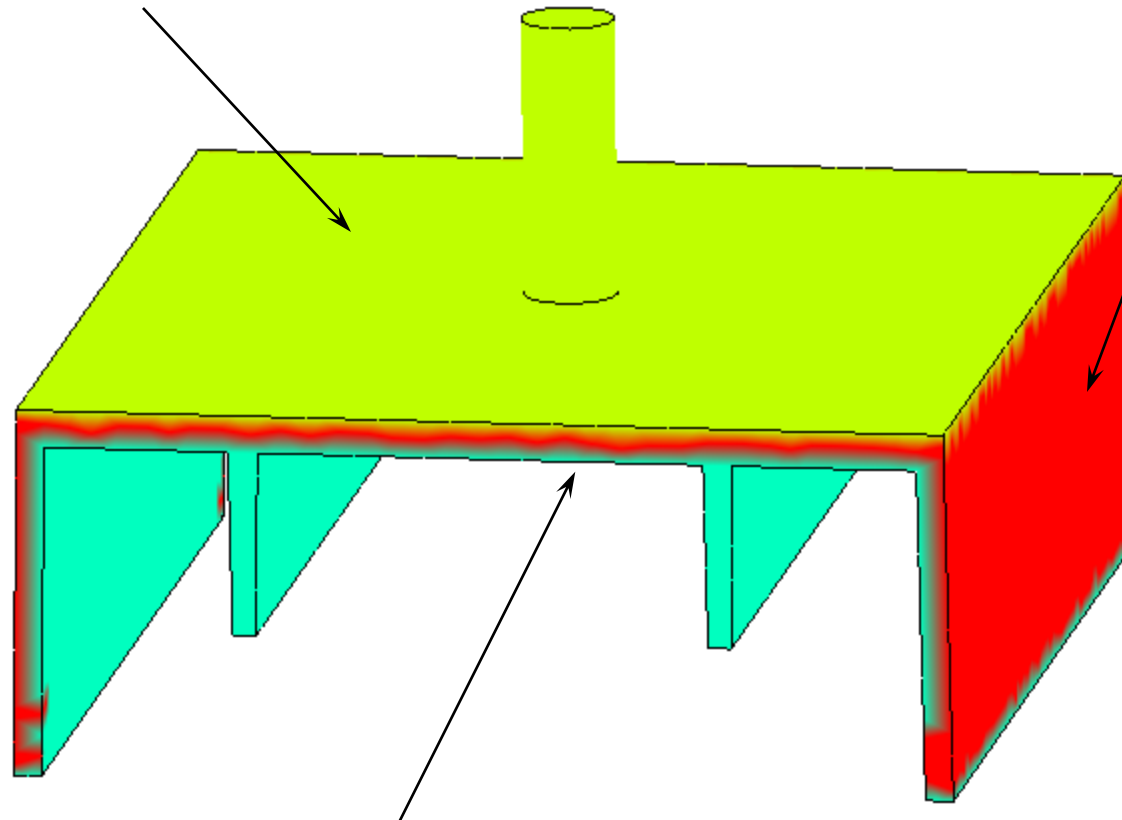**Assign Properties (Entire Part): <u>Compression Elements</u>**

Injection-Compression, Test Case, Scandium 2014

sample-part-2_Inj-Comp_100pct

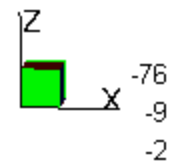Compression surface property
= 3.000

Fixed Surface

Side Surface

Compression Surface

3.000
2.250
1.500
0.7500
0.0000

Scale (9 in)

Autodesk
SIMULATION MOLDFLOW INSIGHT

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

Polymer fill region
Time = 0.1492[s]

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
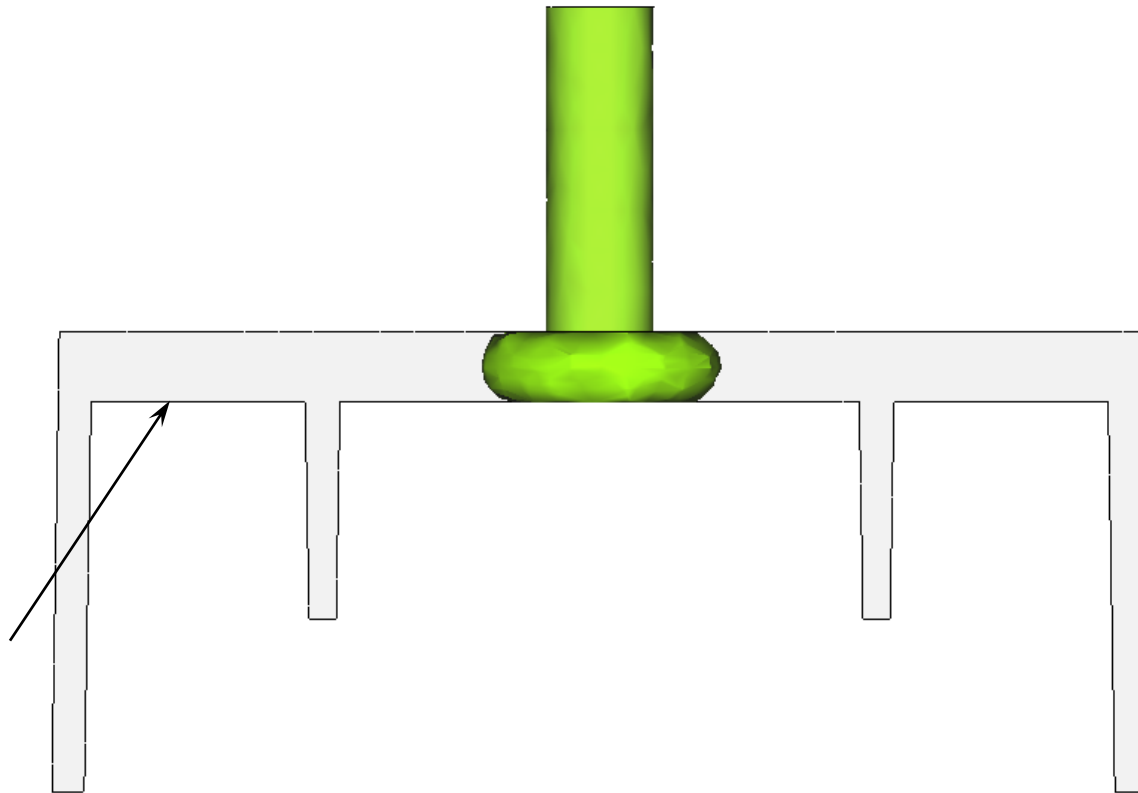
sample_part_2_inj_comp_100pct.gif

Scale (8 in)

Z
-90
X 0
0

AUTODESK
SIMULATION MOLDFLOW
INSIGHT

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").
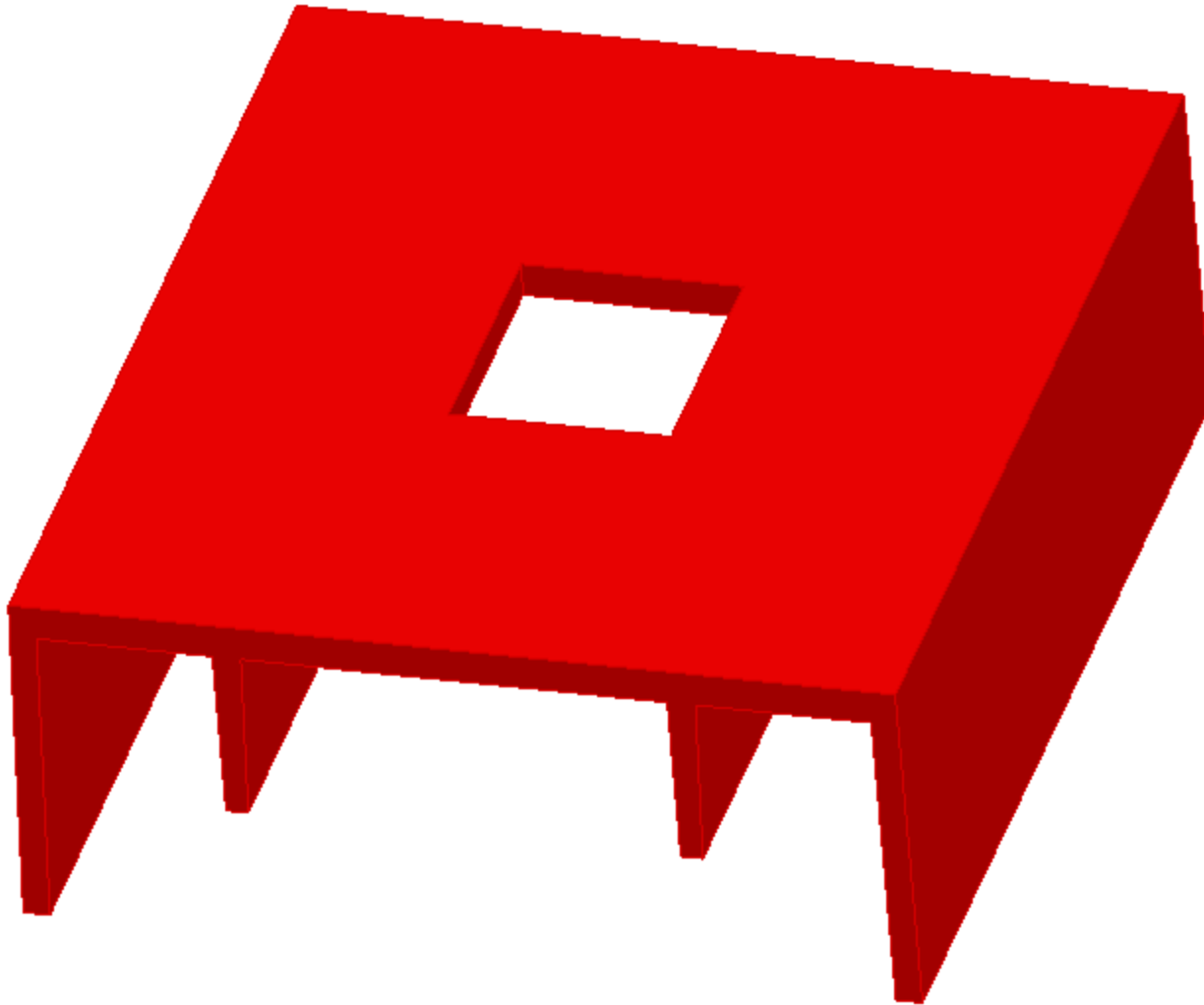
Polymer fill region
Time = 0.4832[s]

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

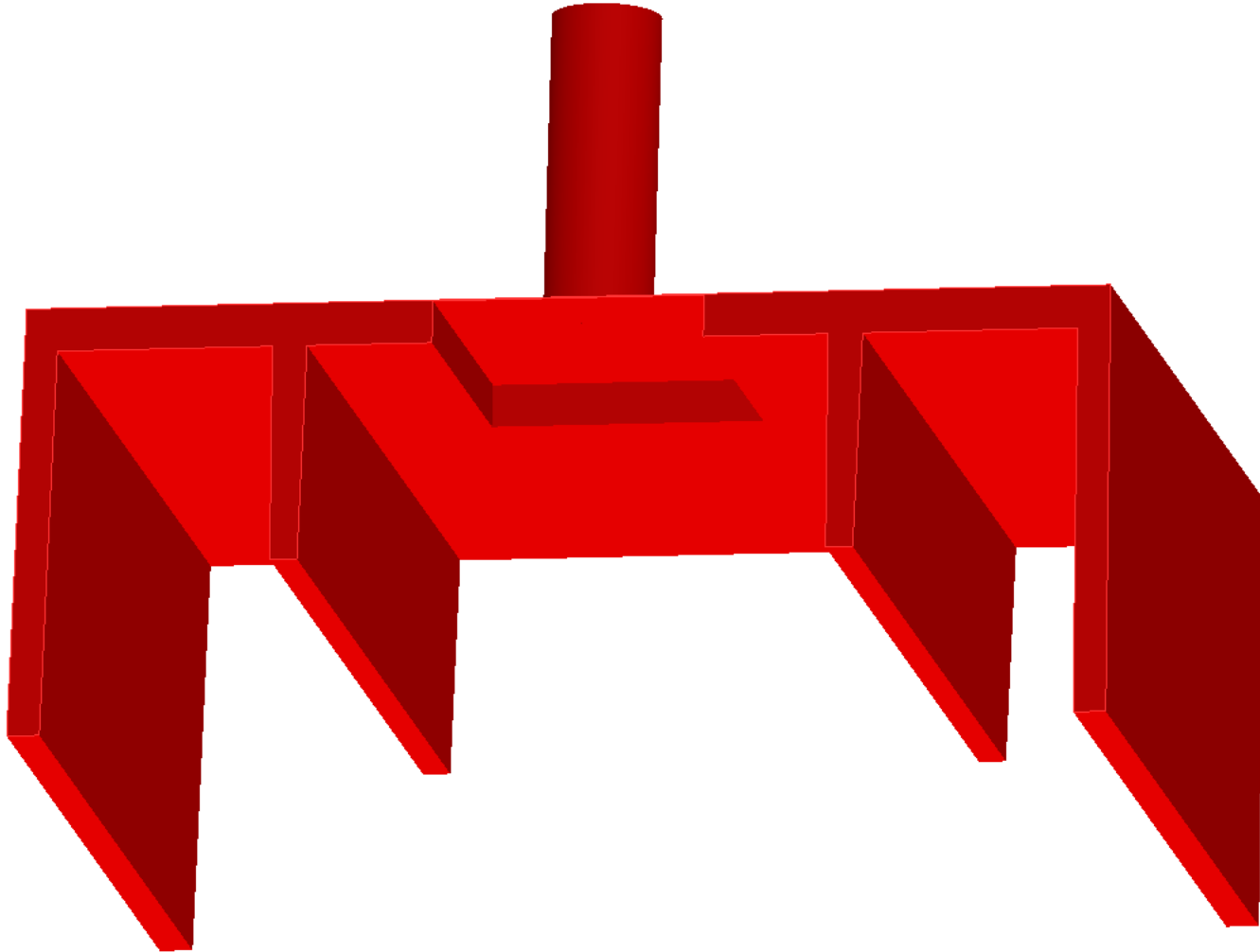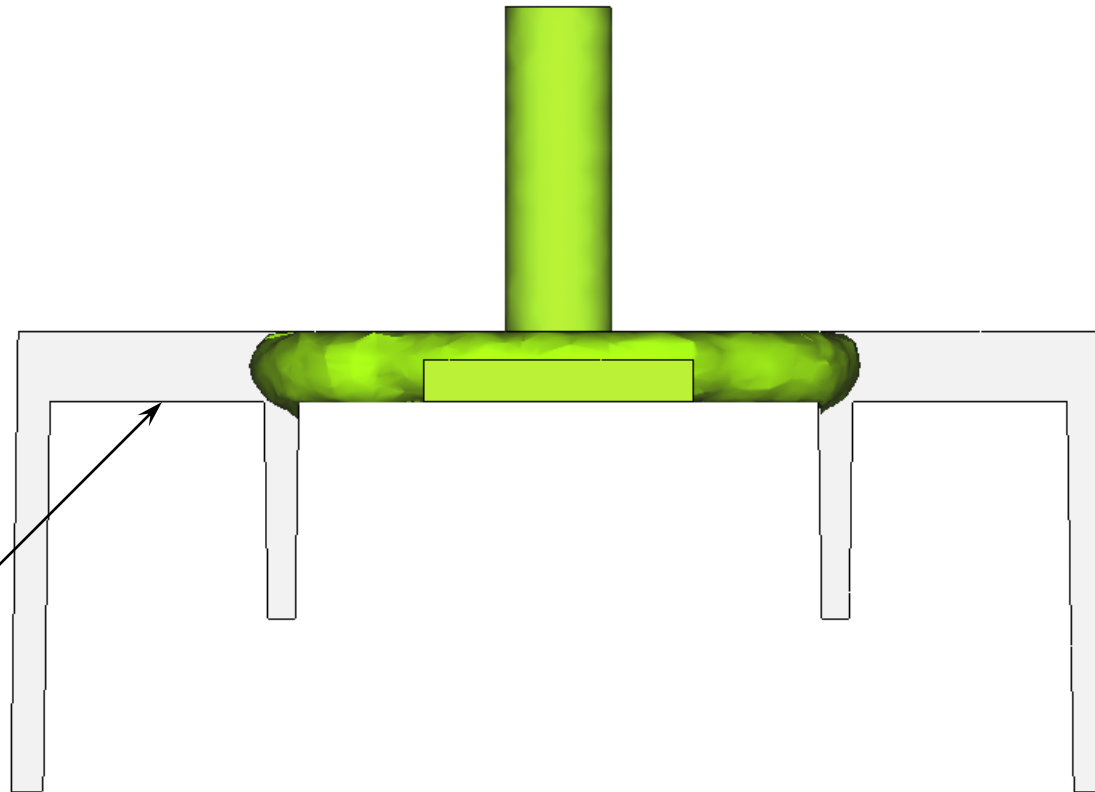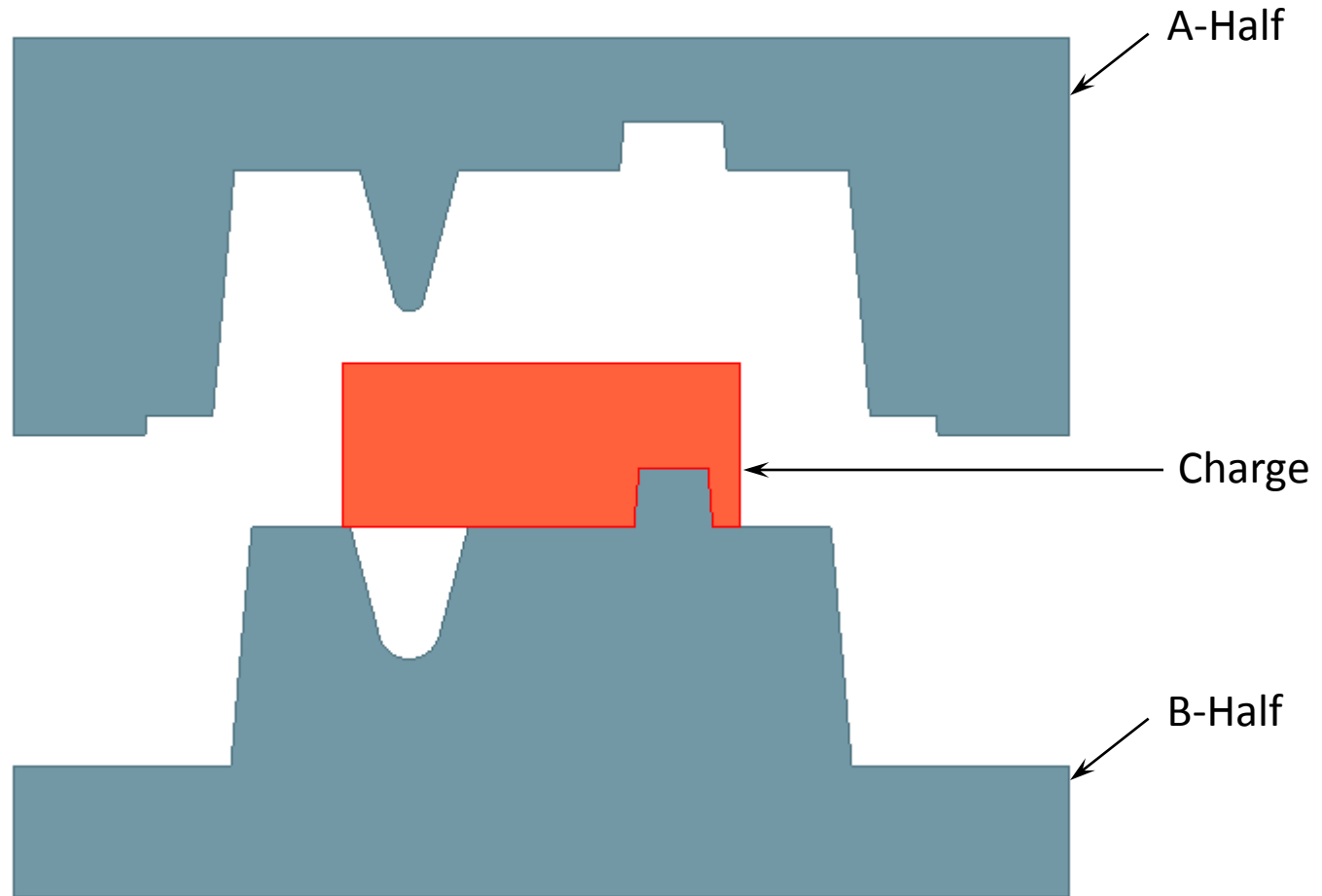sample-prt-w-p010-web_inj-comp_100p.gif

Scale (8 in)

Thermoset Compression Molding Validation – Test Case

Thermoset Compression Molding Representation – Test Part

A-Half

Charge

B-Half

We first show a graphical depiction of an actual compression molding process where a Thermoset BMC charge is compressed between two die halves.
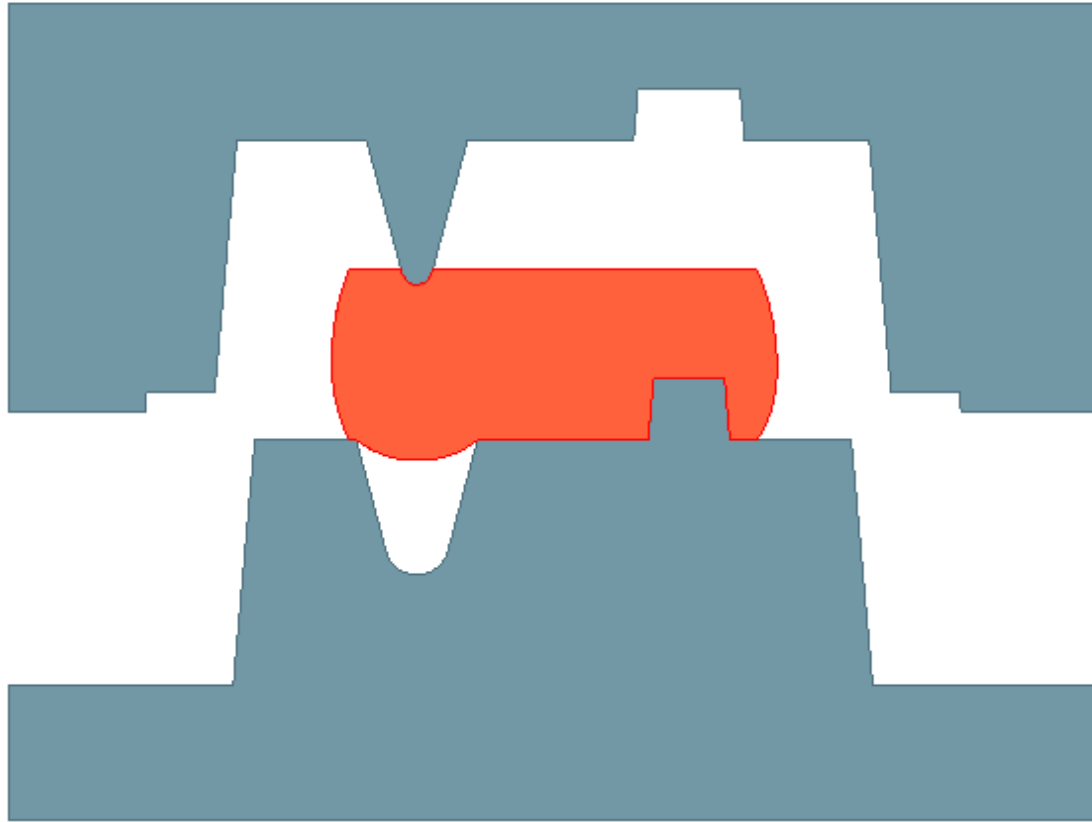
As the A-half starts to move down the upper surface of the charge is penetrated by any protrusion that may exist on the upper die. This displaces some of the volume and the charge starts to deform.
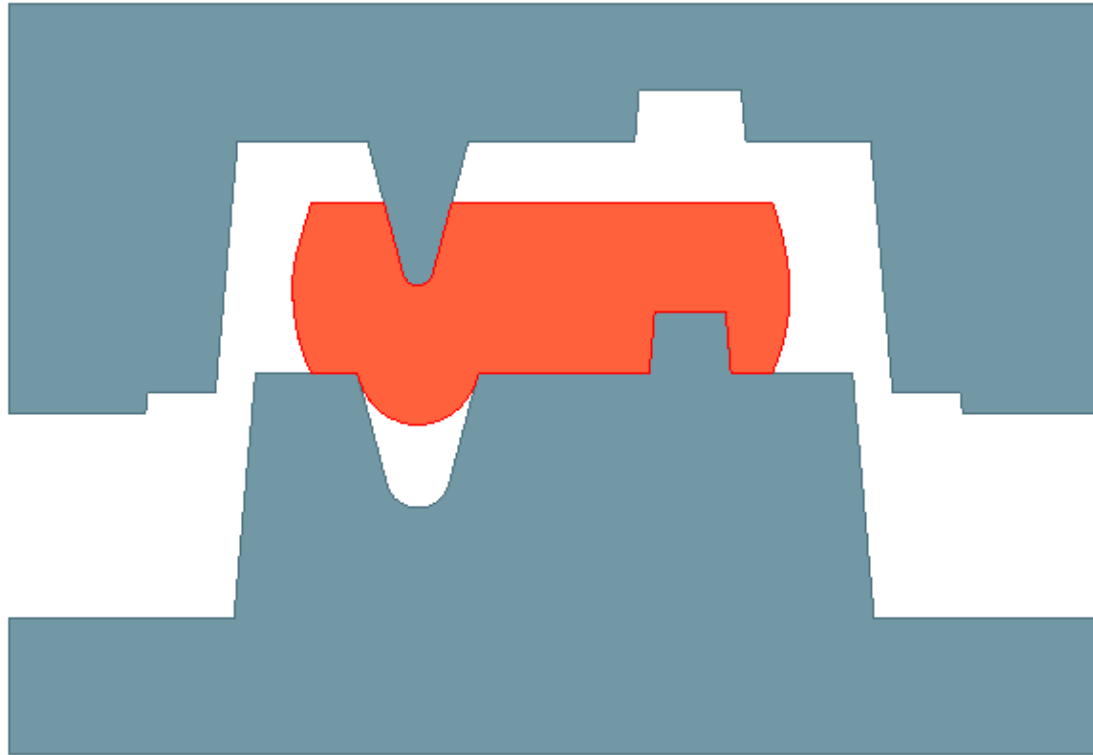
As the A-half moves down, the charge is further deformed. Notice that other than the protrusion on the upper die, the rest of the tool has not made contact with the charge.
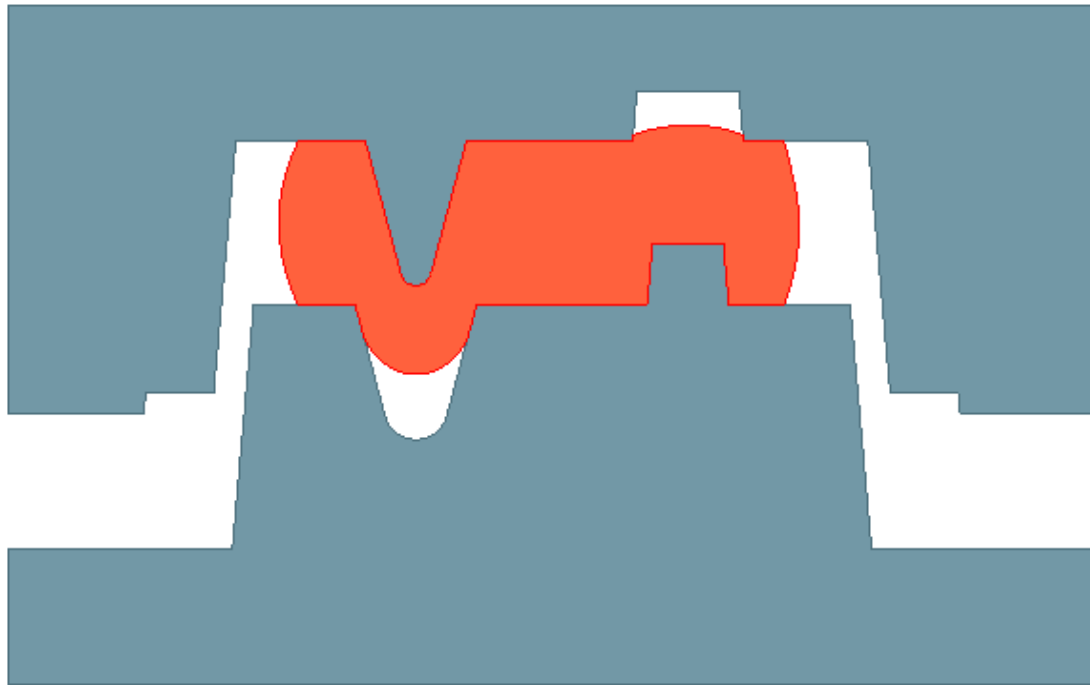
At this stage of movement of the A-half, notice that the entire upper surface of the charge comes into contact with the die. Material starts to bulge into the cut-out in the upper surface of the cavity.
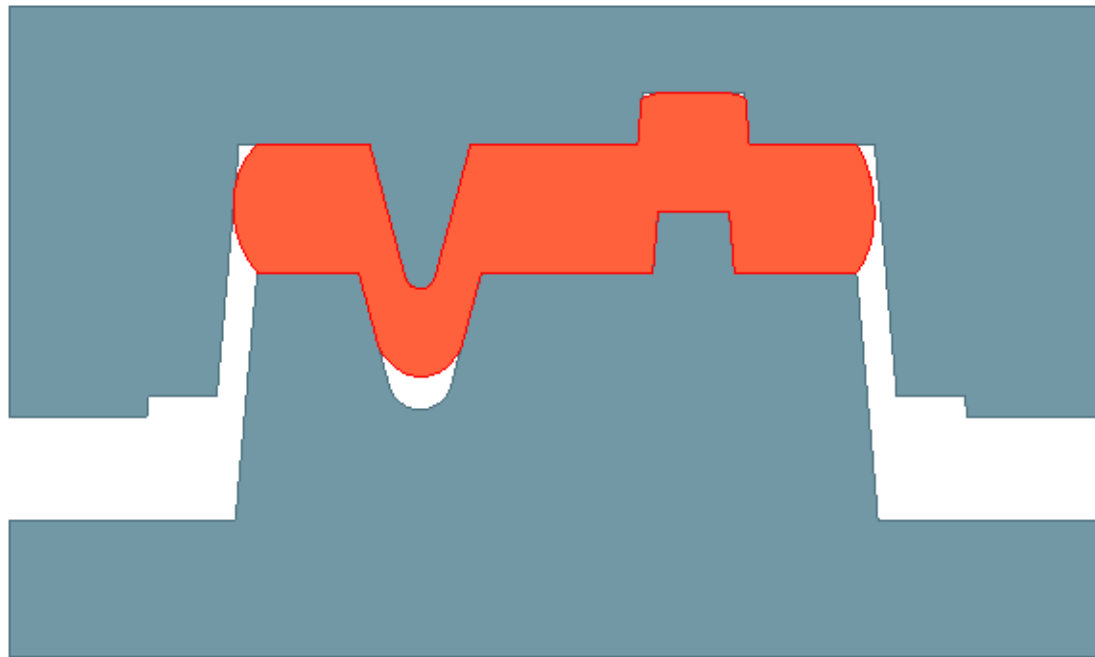
At this stage of compression, notice that the charge has come into contact with most of the upper surface of the cavity.   However, it has not completely filled the U-shaped cut-out on the B-half.
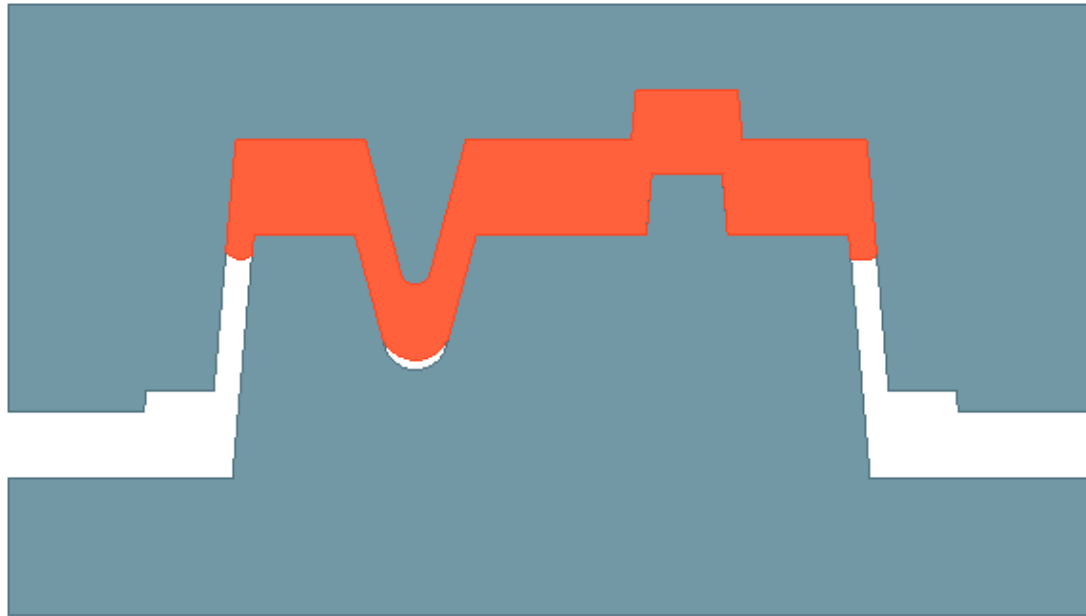
As the A-half moves down further, the upper surface of the charge has completely contacted the upper die. The U-shaped cut-out on the lower die is almost filled, while the polymer has started to move down the edges of the B-half to form the side walls.
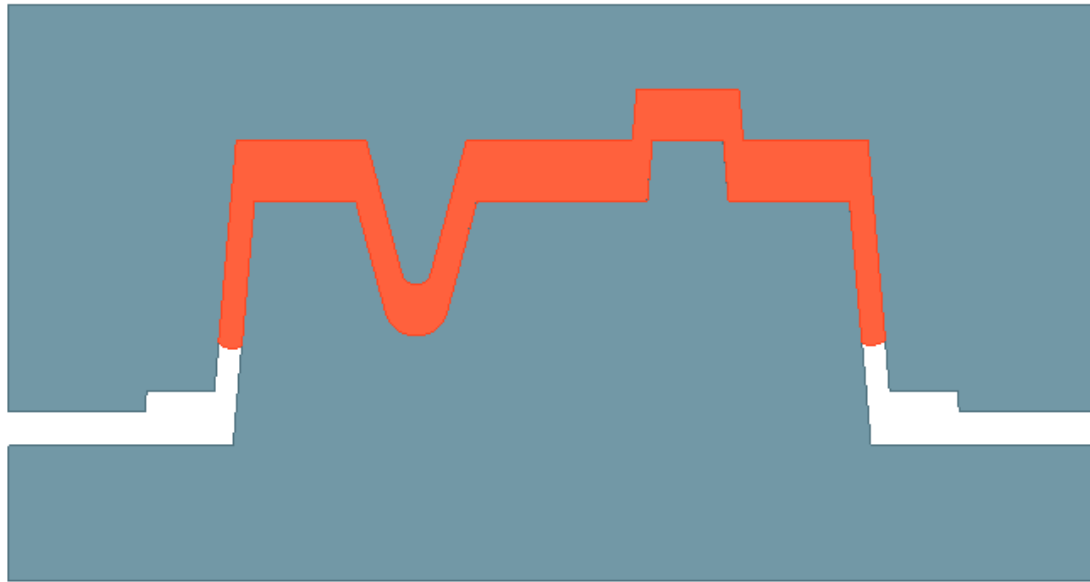
At this stage of compression, the lower surface of the A-half and the upper surface of the B-half are completely in contact with the charge and the polymer has moved down significantly to form the side walls. Notice the thickness of the side walls are larger than the final part side wall thickness.
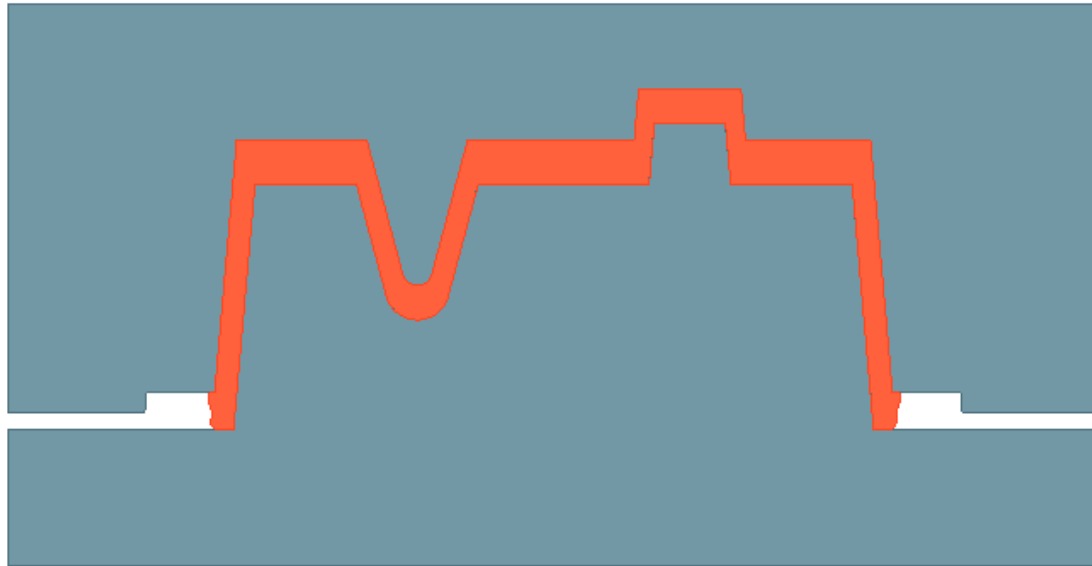
The polymer has now been squeezed all the way to the parting line. The only portion of the cavity yet unfilled are the flanges on the bottom.
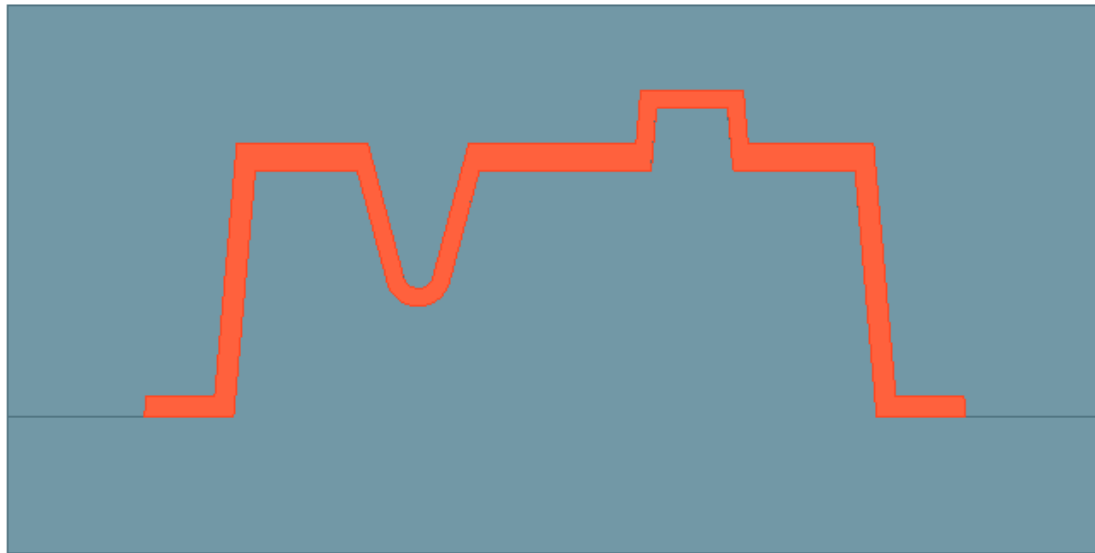
End of compression. A-half shuts off on B-half at the Parting Line. Notice that only at this stage, the wall thicknesses have the dimensions of the final part.

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.
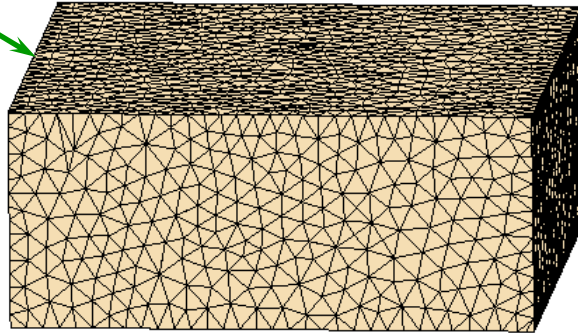
Compression Elements: Volume = 71.7256 cu. in.

Scale (9 in)

Z

X

-78

-6

-0

Compression, Test Case, Scandium 2014

External Initial Charge

Compression Elements

3"
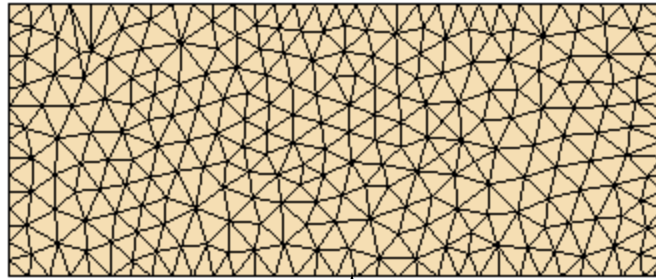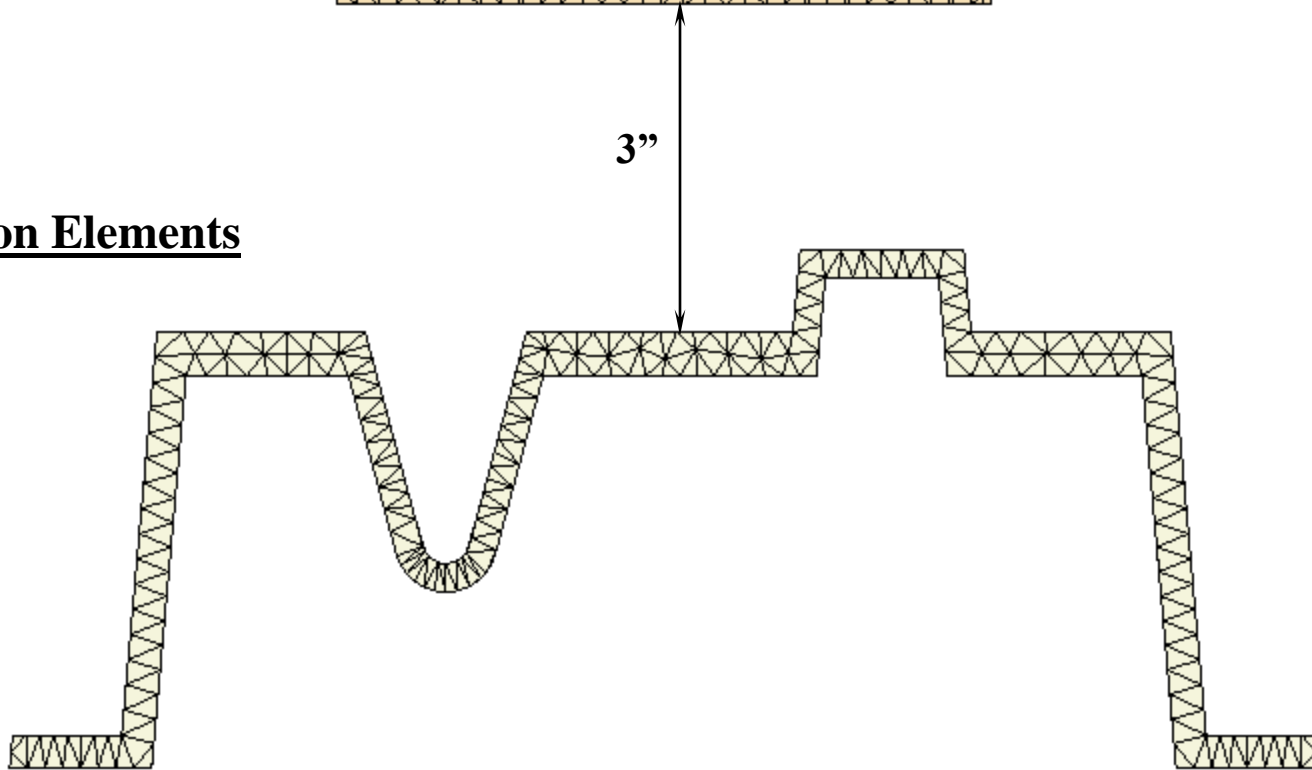
Polymer fill region
Time = 0.3514[s]
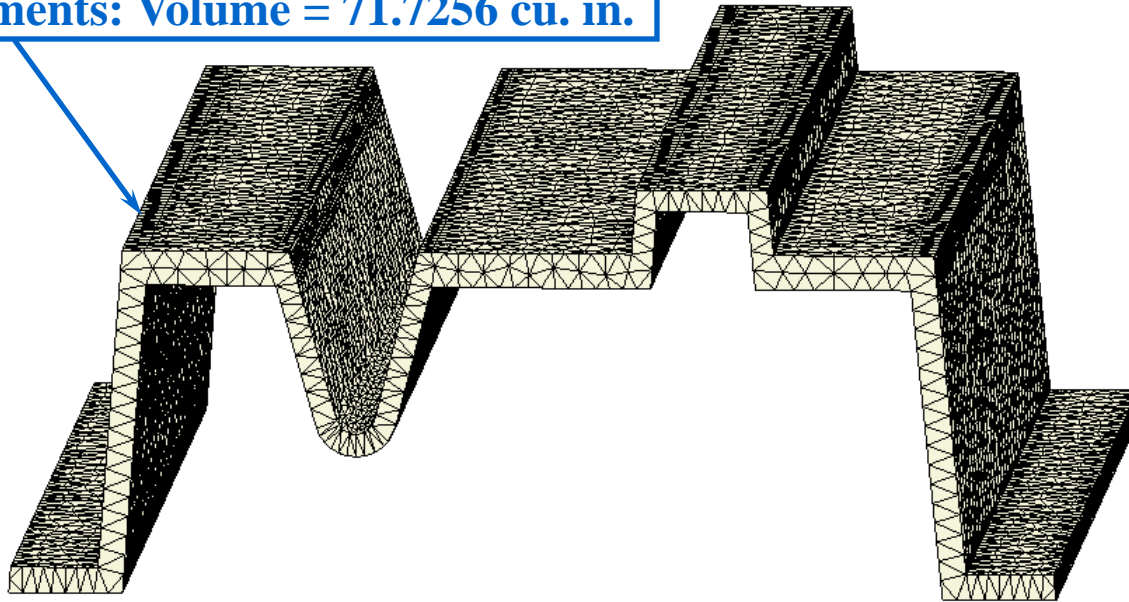
Notice that the upper Surface of the part is stretched in the Z direction to represent the upper die

Notice that the charge does not touch this surface at the start of compression?
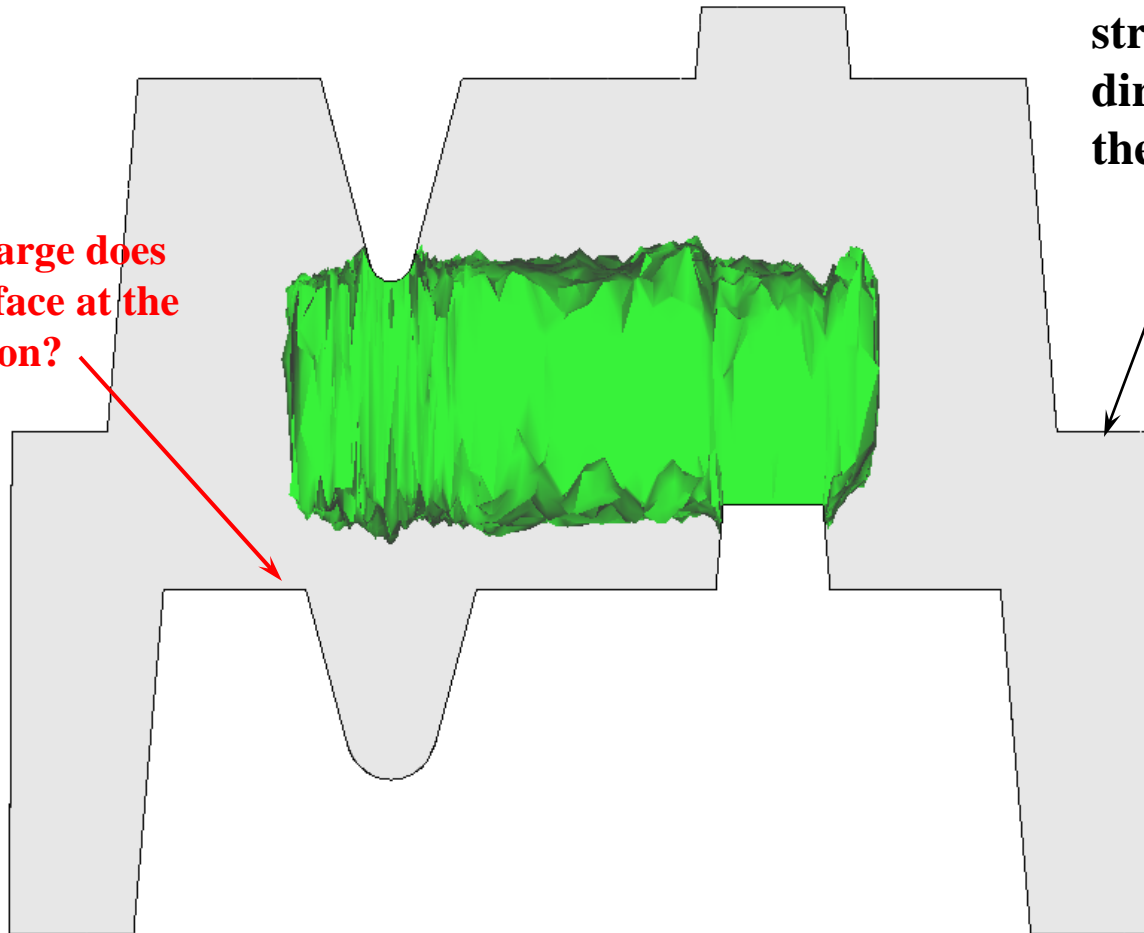
comp-model2_w_6x6x2_in_box.gif

Scale (9 in)
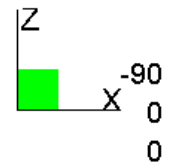
Compression, Test Case with Shaped Charge, Scandium 2014

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

Polymer fill region
Time = 0.3514[s]

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?
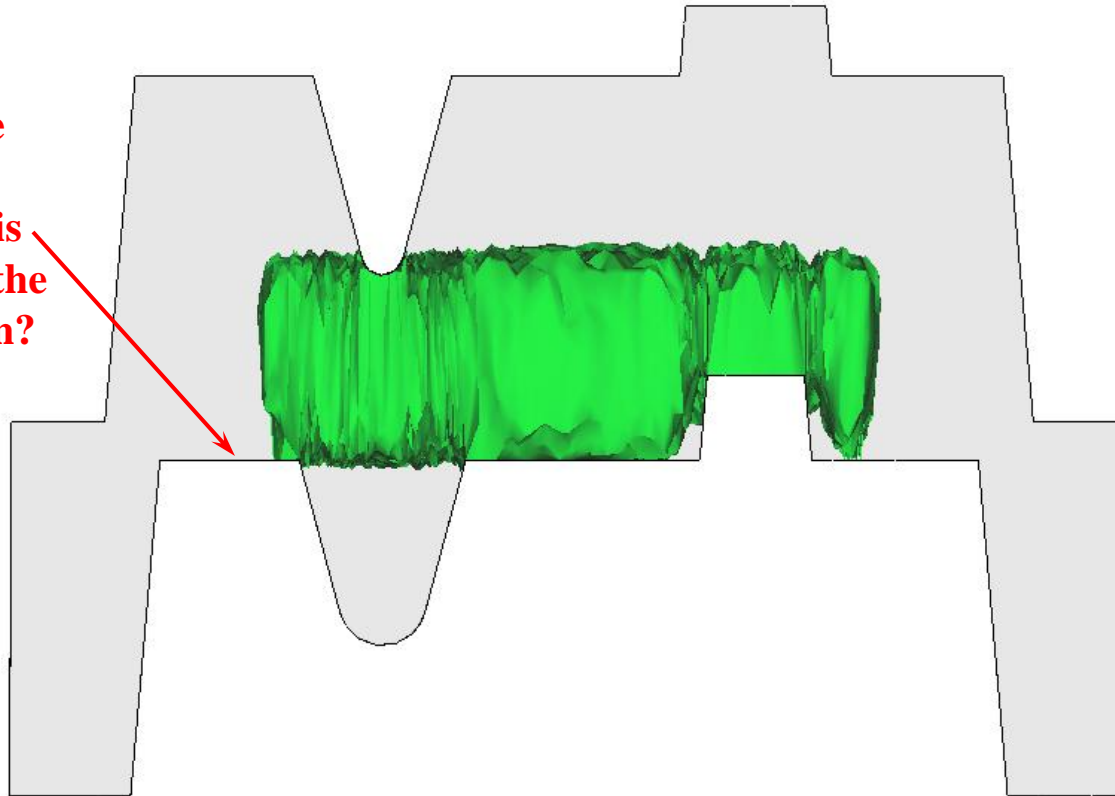
comp-model_w-shaped-charge.gif

Scale (9 in)

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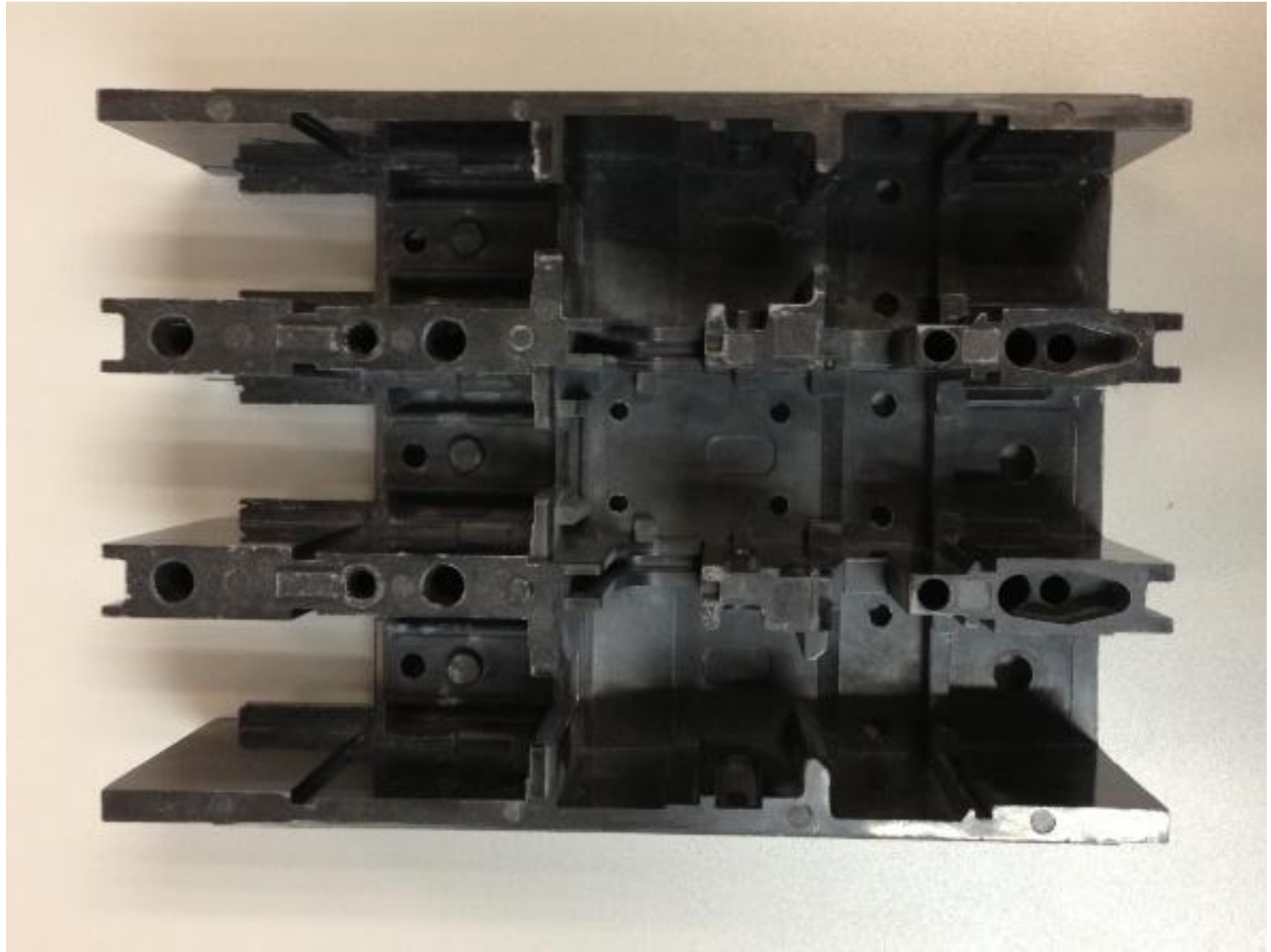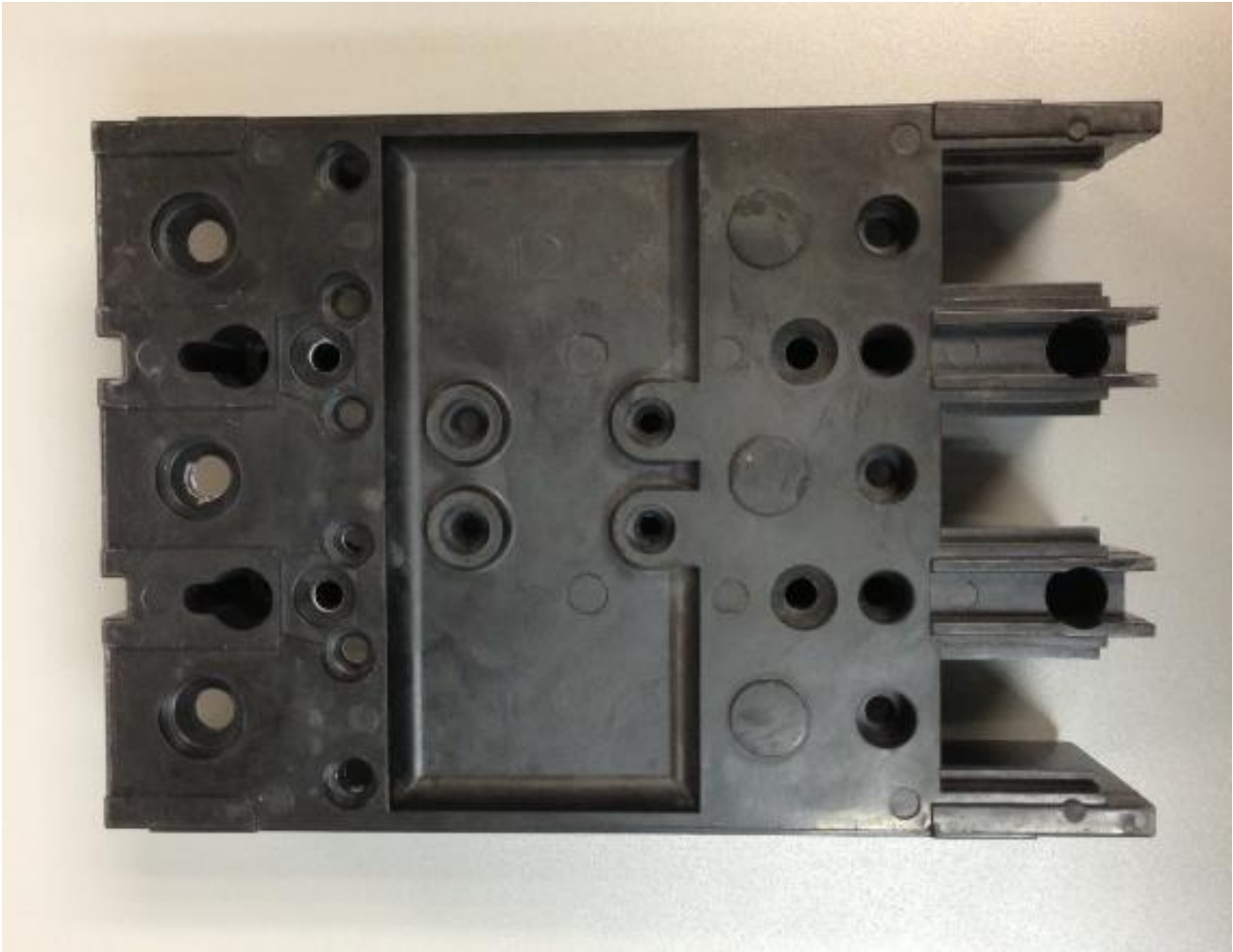
**Q2R, 3Pole Base, Compression Molding
Model/Mesh: Part & Charge Placement**

**External Initial
Charge:**

Volume: 20.6 cu. in.

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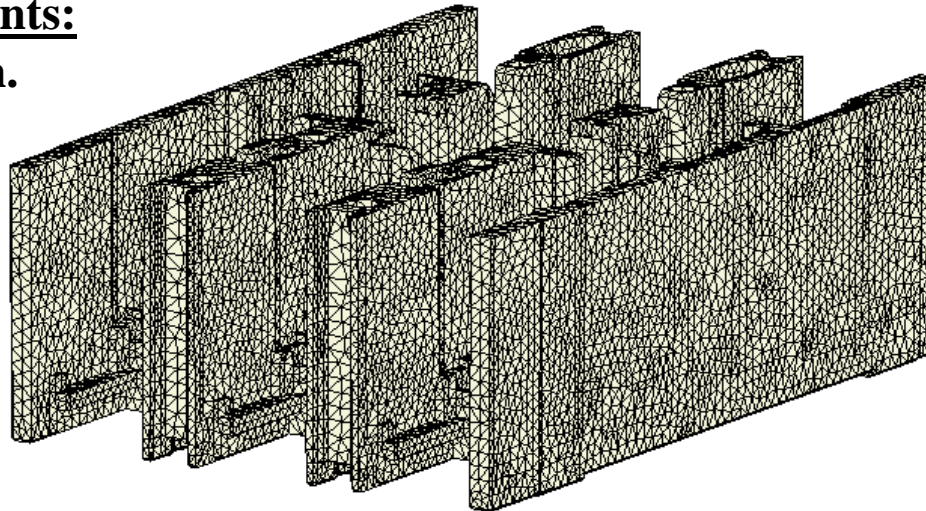
Q2R, 3Pole Base, Model/Mesh: Part & Charge Placement

q2r_3p_base_3_comptime180_slow

4.331"

2.756"

1.732"

3.937"

This distance does not matter

2.19"

6.47"

4.485"
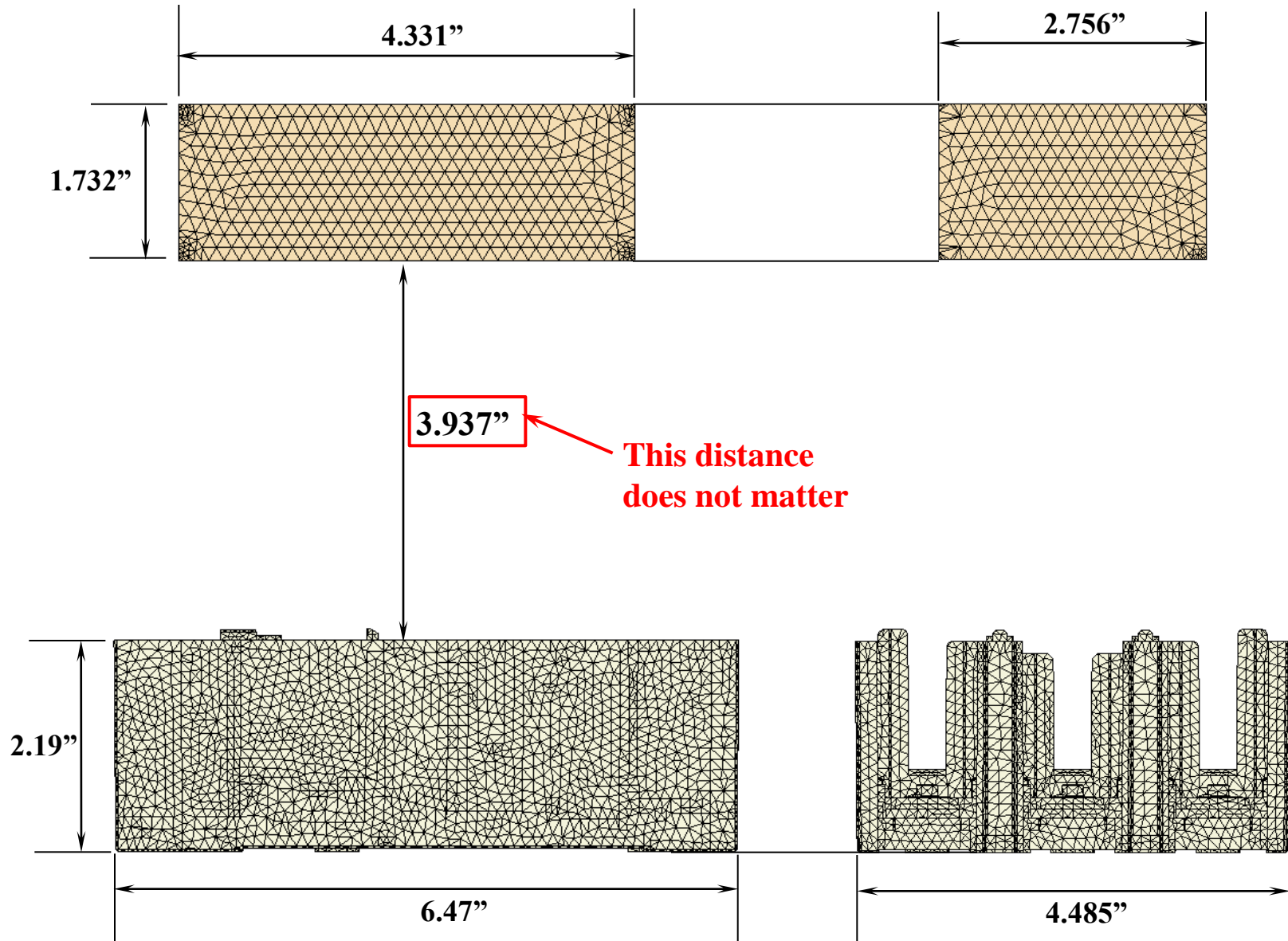
Q2R, 3Pole Base, Model/Mesh: Part & Charge Placement

In the X & Y direction, the charge placement location does matter

Scale (5 in)

180
Z Y 180
90
X
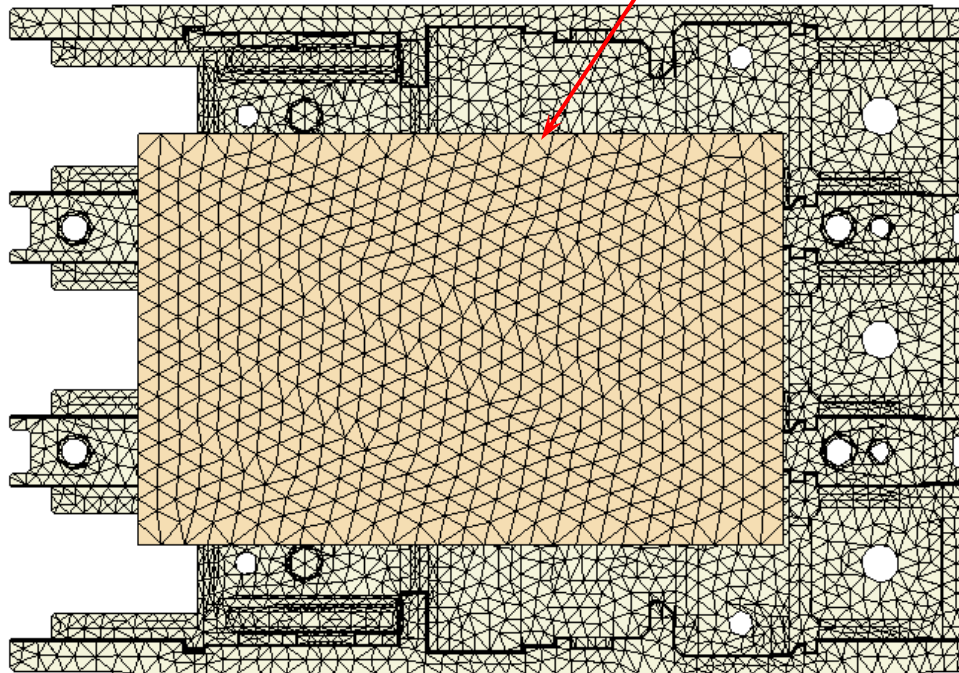
Clips from Video showing how material is loaded into the cavity half (lower stationary side).
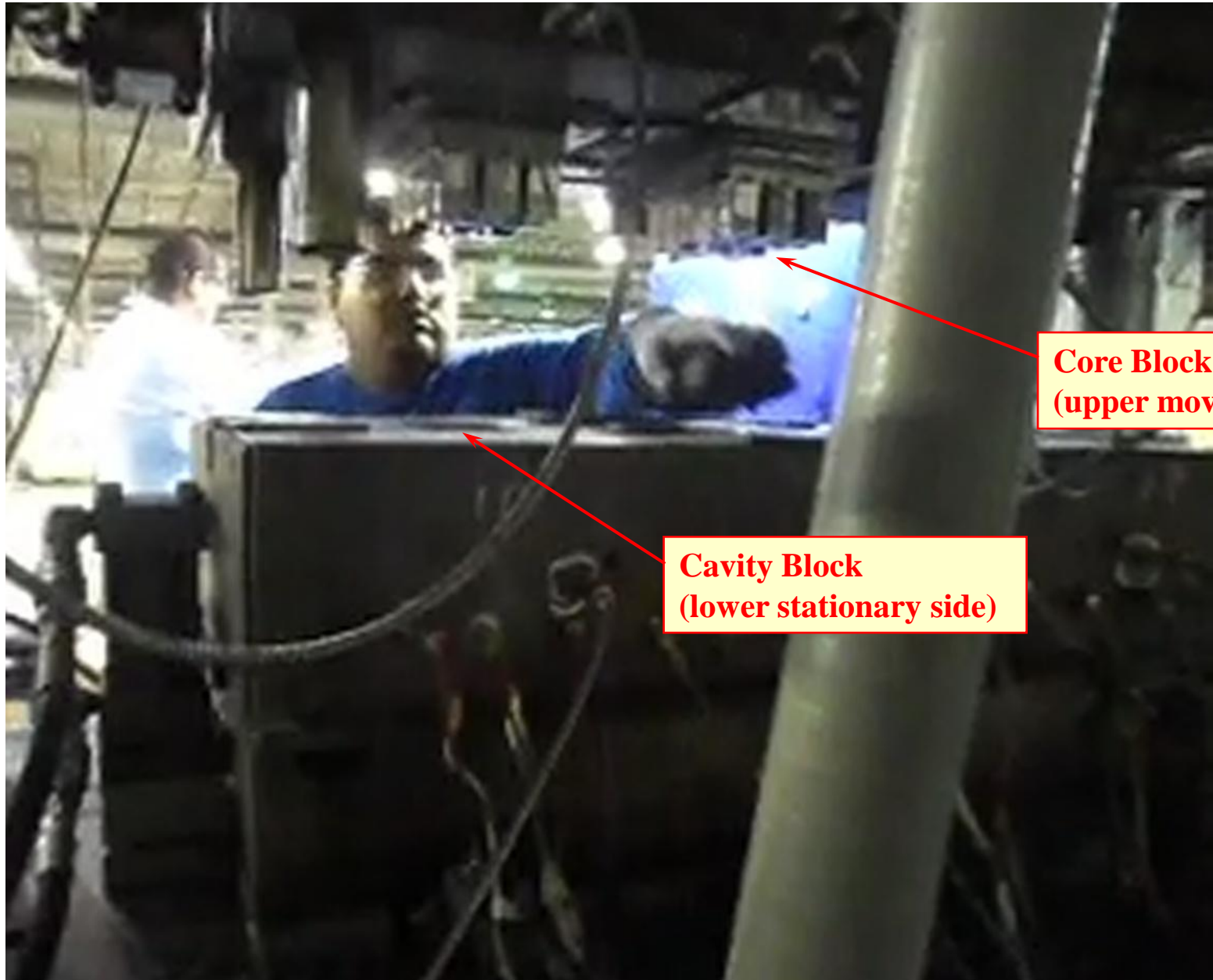
Core Block
(upper moving side)

Cavity Block
(lower stationary side)

Loading
Charge

Loading Charge
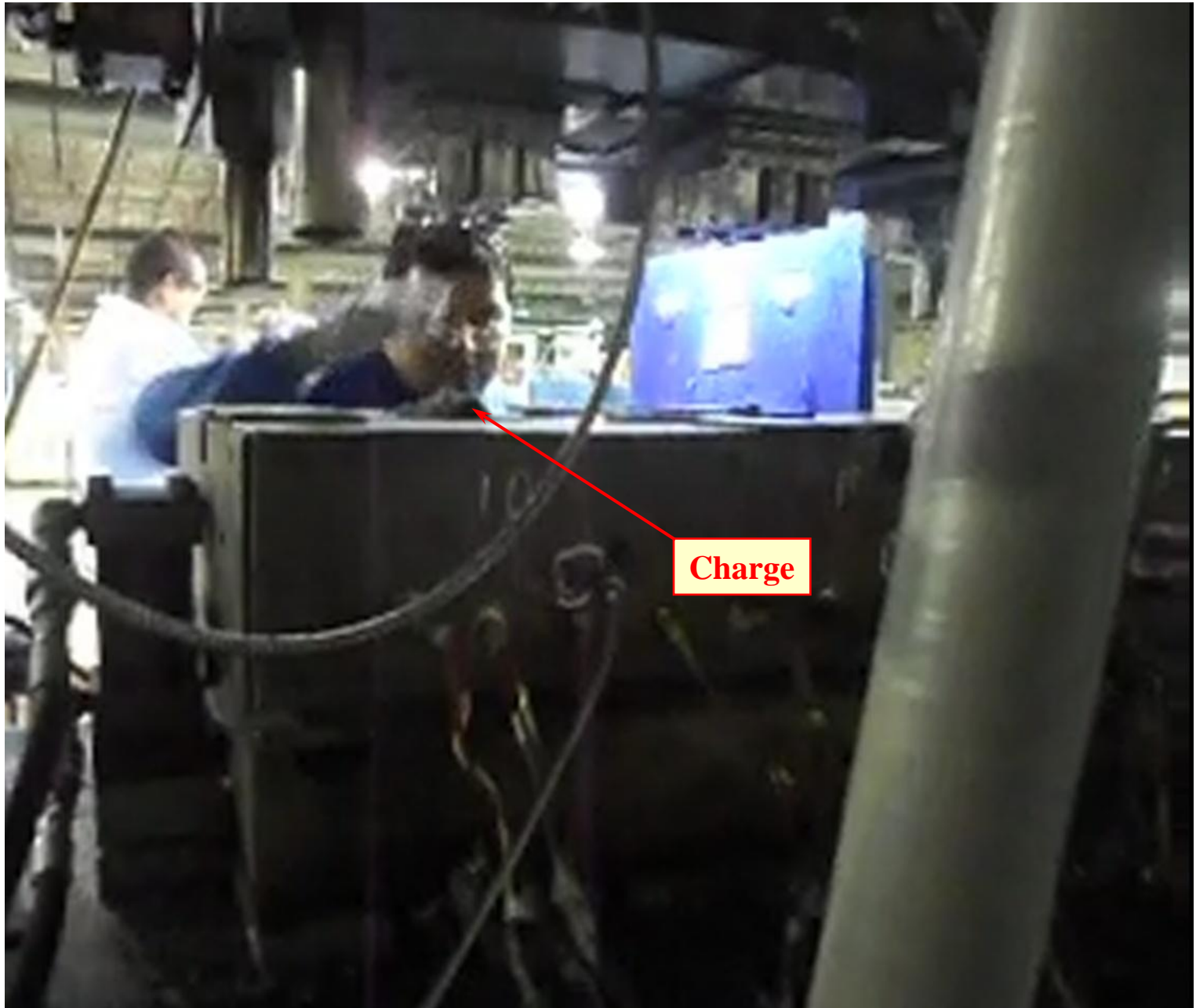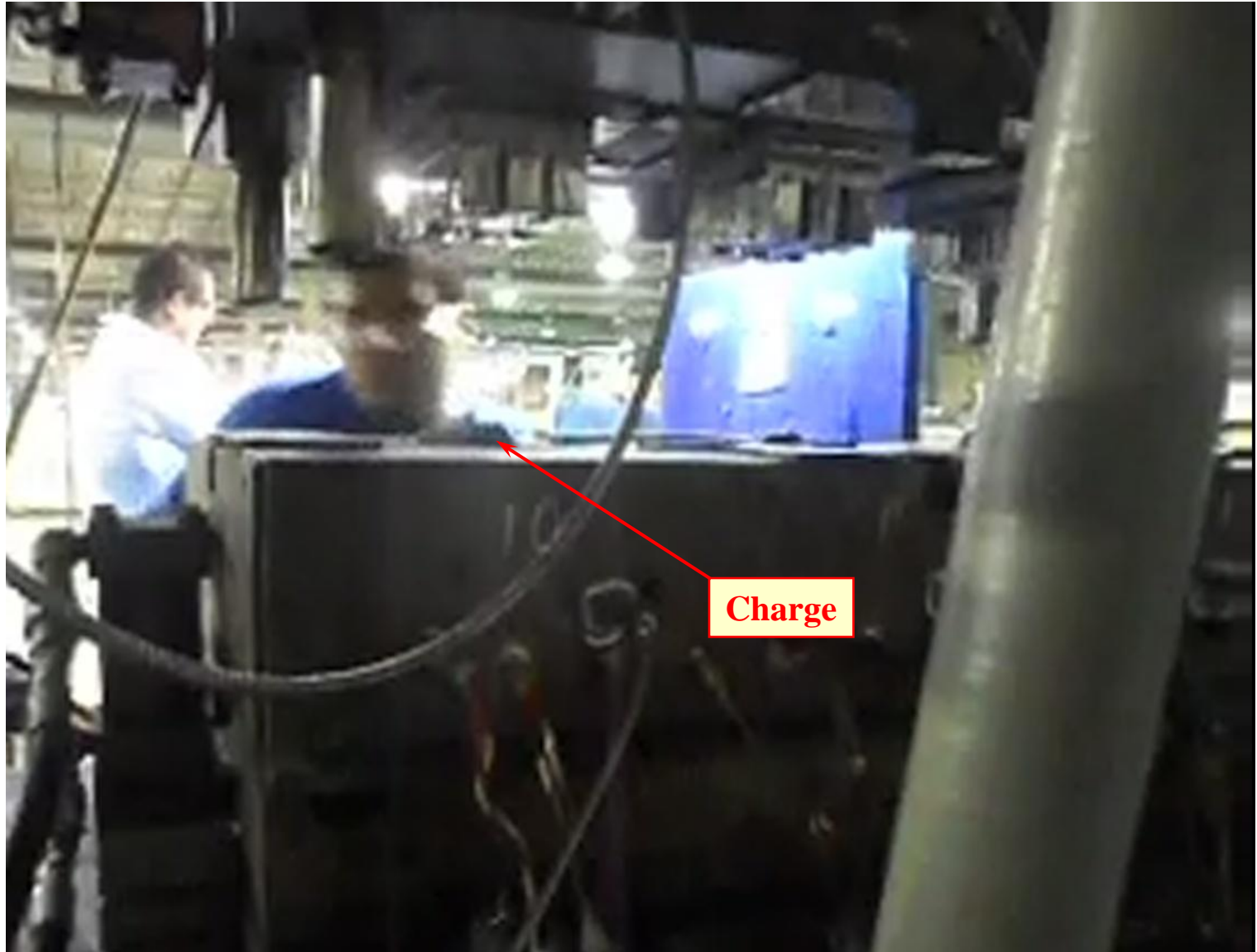
Charge

Charge

**Upper Die (A-half)
Moving**

**Lower Die (B-half)
Stationary**
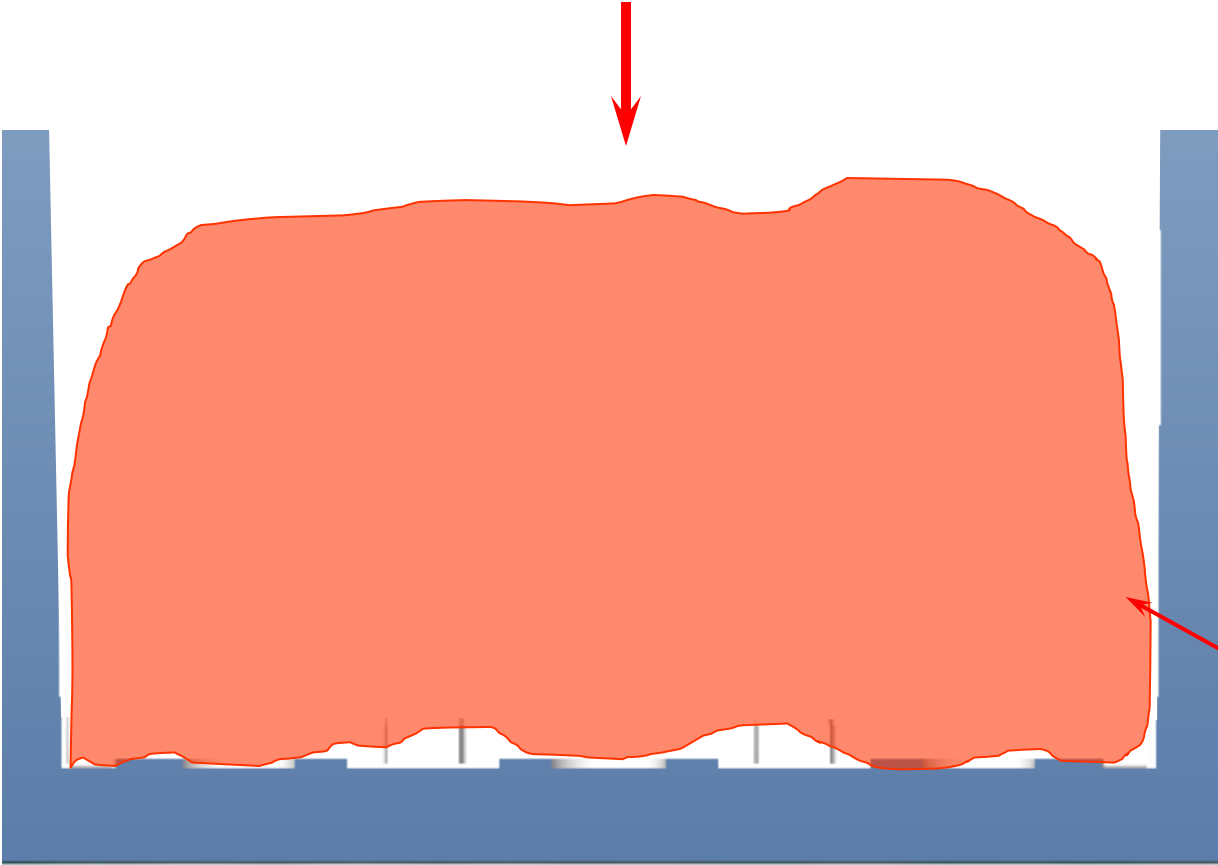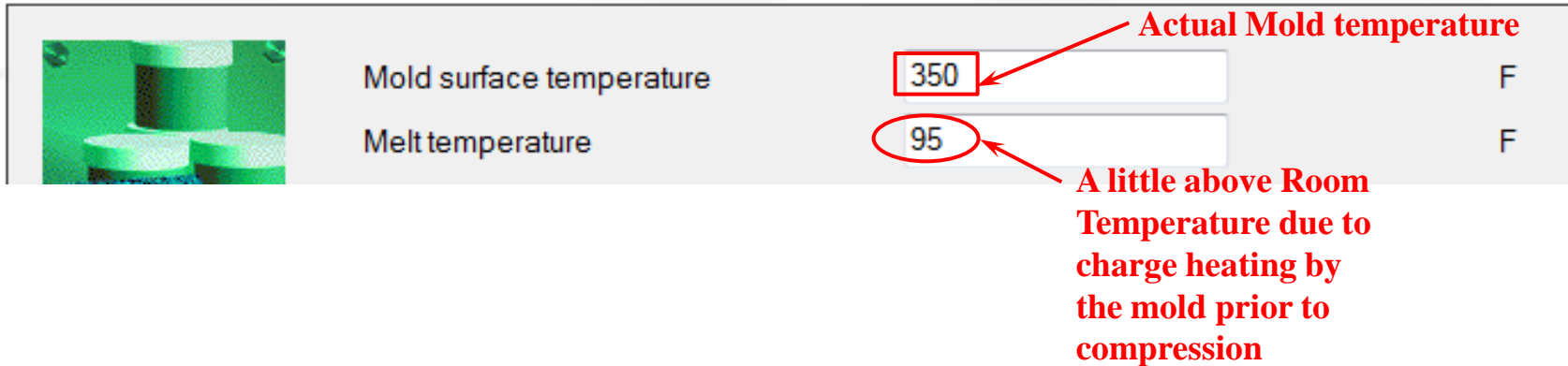
Charge is placed at the bottom of the B-half

Scandium 2014 – Compression Molding Study – Q2R 3Pole Base

Parkway, Mexico, Processing Conditions
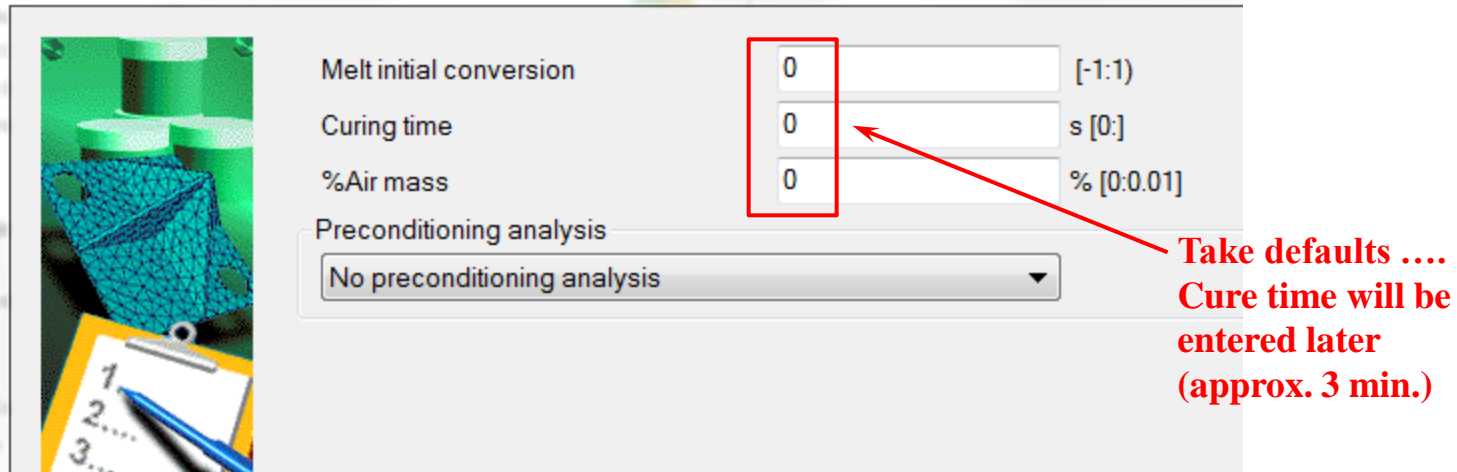
Process Settings Wizard - RIM Settings - Page 1 of 4

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

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.)
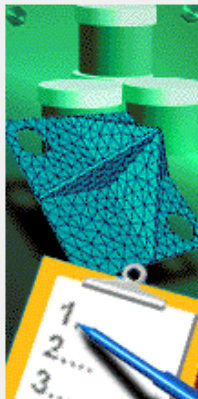
Compression direction   [-Z ▼]

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]

rall

III

Parkway, Mexico, Processing Conditions

Injection Compression Advanced Options

Molding material
BMC BMC 605 : BMC Inc   **Thermoset Material: BMC 605**   Edit...   Select...

Process controller
Process controller for reactive injection-compression   Edit...   Select...

Compression press controller
Compression press controller defaults   Edit...   Select...
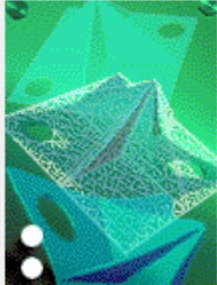
Injection molding machine
Default injection molding machine   Edit...   Select...

Mold material
Tool Steel H-13   **Mold material**   Edit...   Select...

Solver parameters
Reactive molding solver parameters defaults (3D)   Edit...   Select...

OK   Cancel   Help

Process Settings Wizard - Warp Settings - Page 4 of 4

☐ Consider mold thermal expansion

☐ Include tetrahedral cold runners

☑ Use mesh aggregation and 2nd-order tetrahedral elements

Number of threads for parallelization

Maximum

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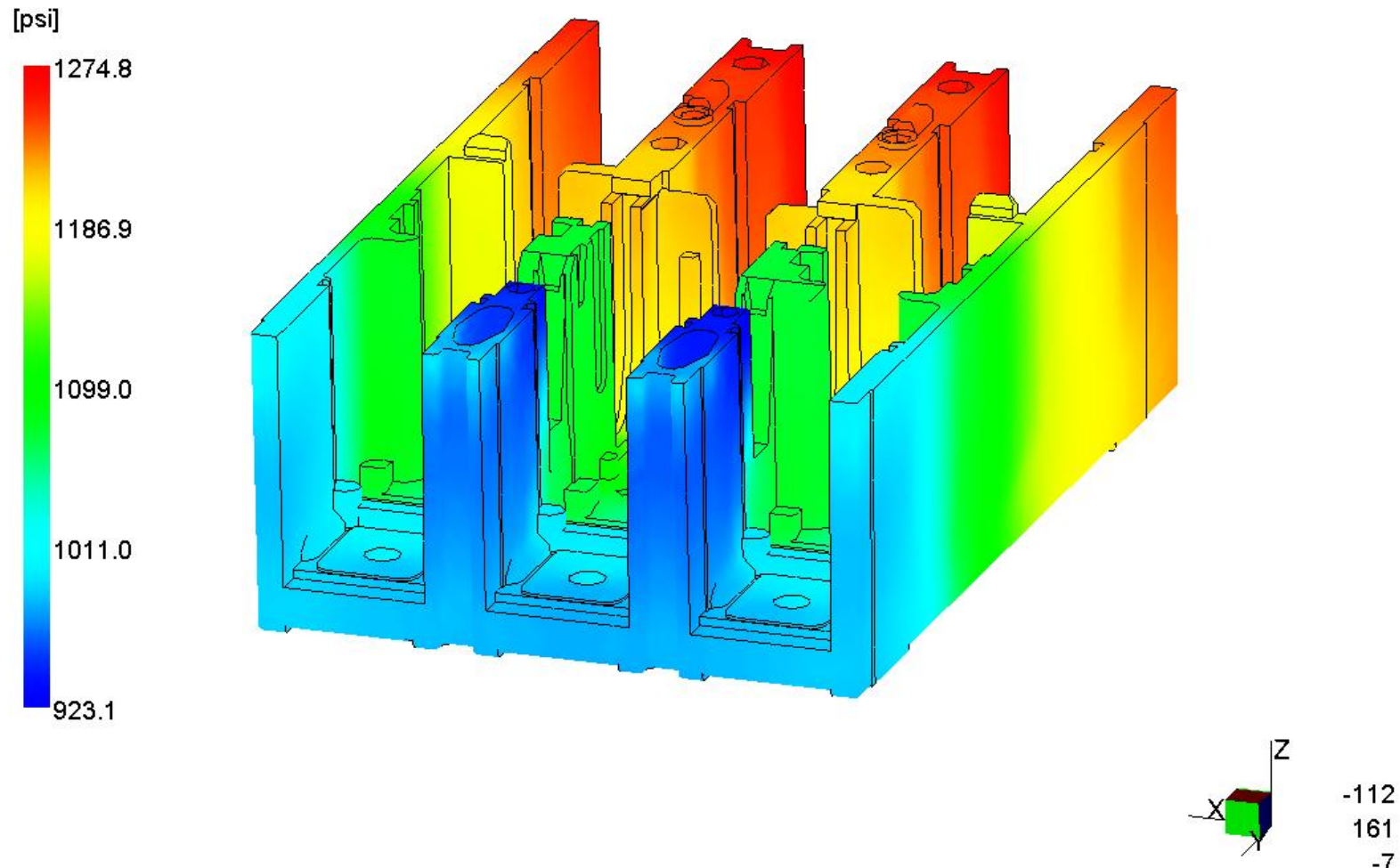
With BMC 605, results of our analysis showed that the Compression Pressure required to fill the part would be 1,275 psi. Shown on the next Slide is the actual hydraulic pressure measured off a dial gauge at the press.

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.

Polymer fill region

Time = 0.1521[s]

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

Scale (4 in)

Z

Y X -57

27

18

AUTODESK
SIMULATION MOLDFLOW
INSIGHT

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")**

Y

Z ___ X

0
0
0

AUTODESK
SIMULATION M
INSIGHT

Polymer fill region
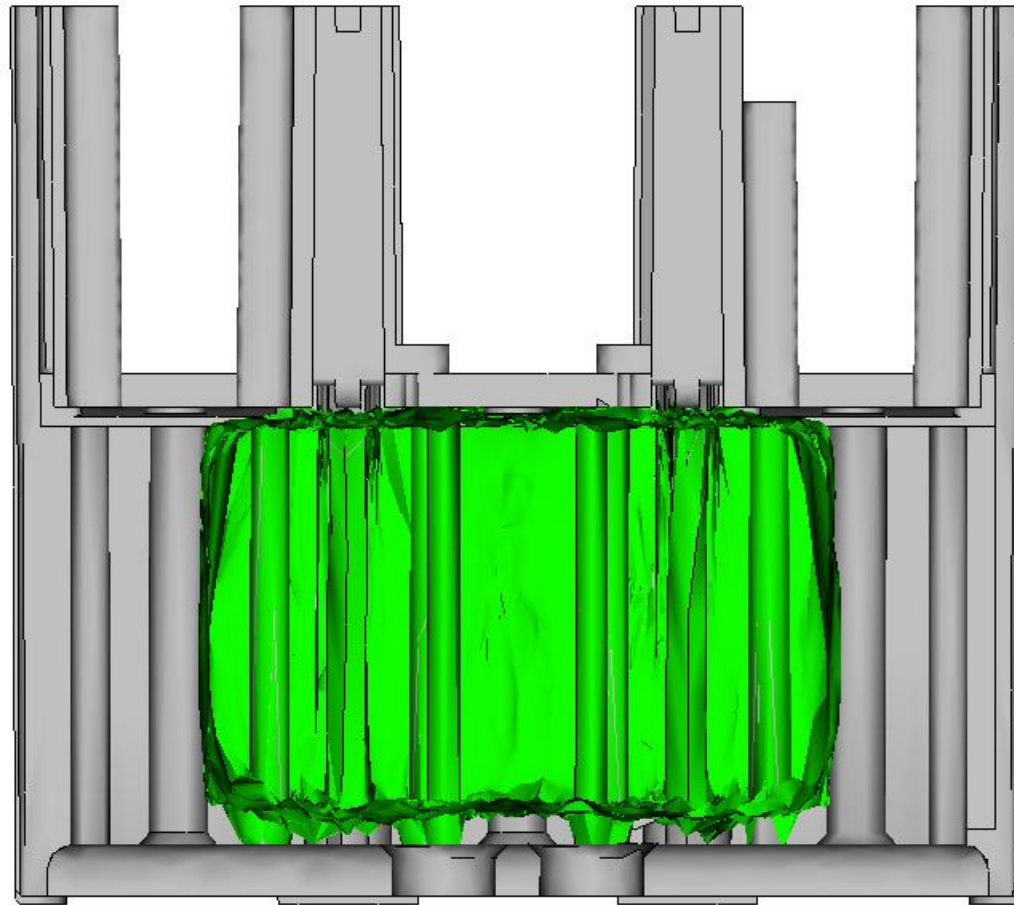
Time = 0.1521[s]

q2r-chrg3_comptime180_slow_sideassgn3_Scandium-NewBMC.gif
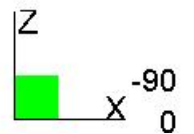
Polymer fill region
Time = 0.1521[s]
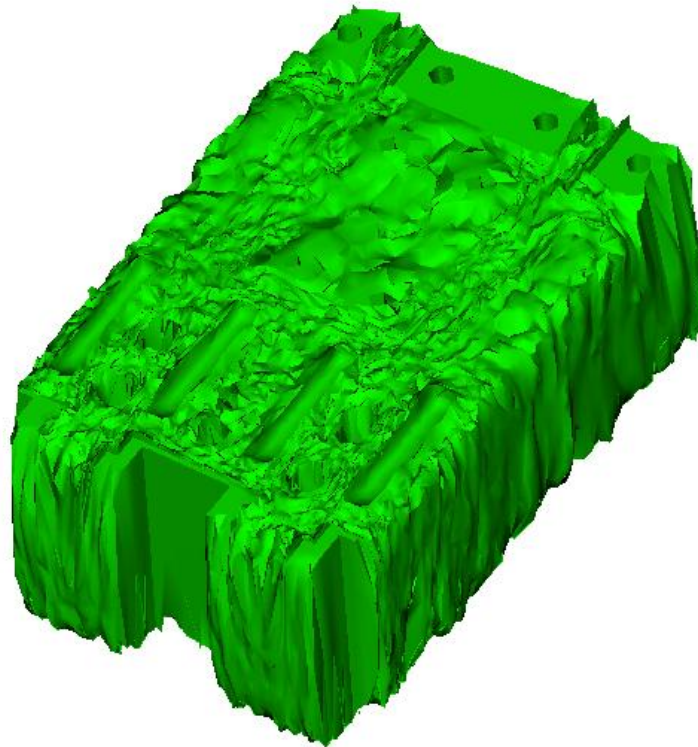
q2r-charge3_comptime180_slow_sideassign3_Scandium-NewBMC_ISO.gif

Scale (5 in)

-36
-23
-24
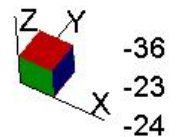
Short-Shots from Mold Trials of Q2R 3Pole Base conducted at Parkway, Mexico
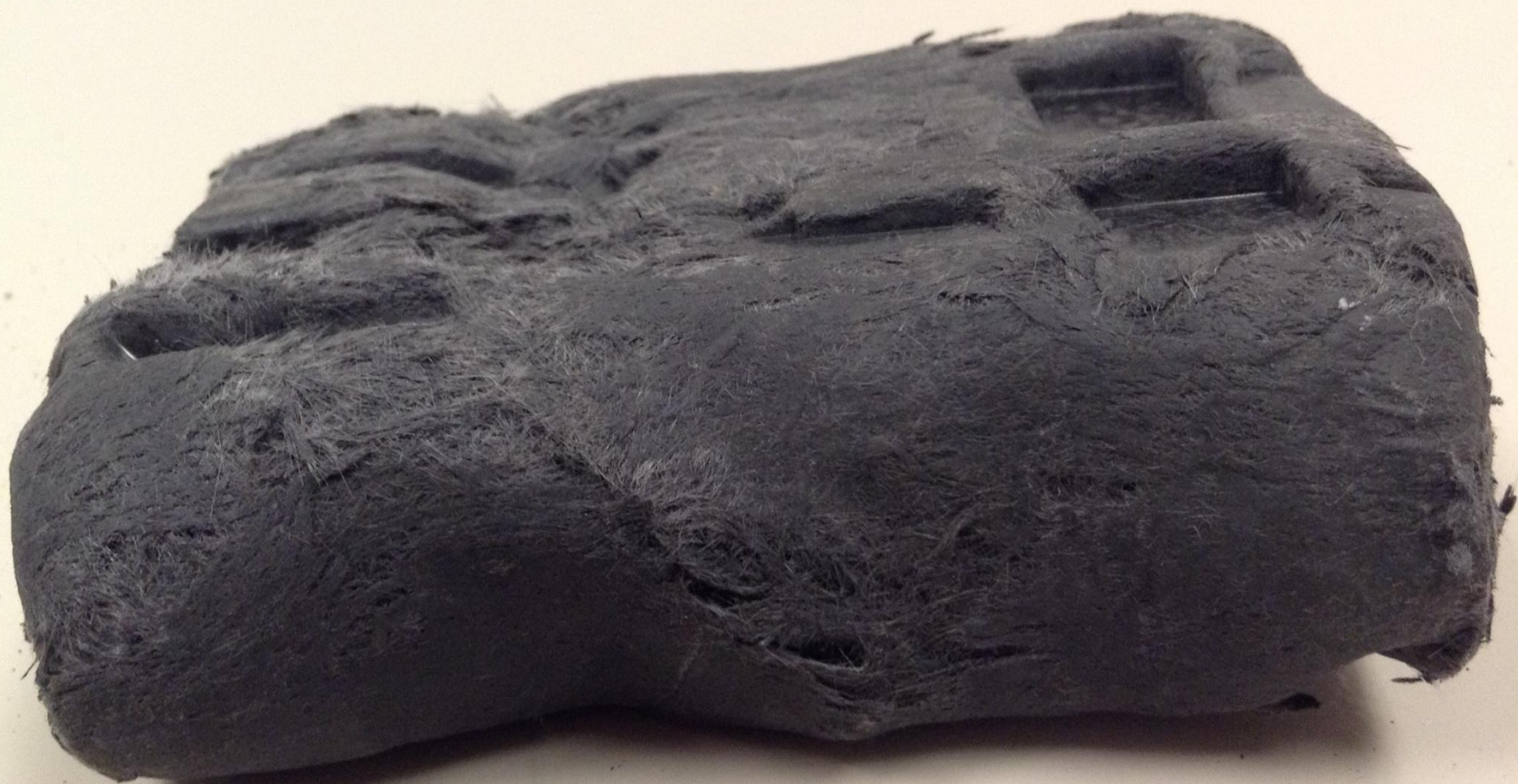
Features on bottom of cavity block form first.

Ribs starting to fill.

Short Shot 100% Cav.3
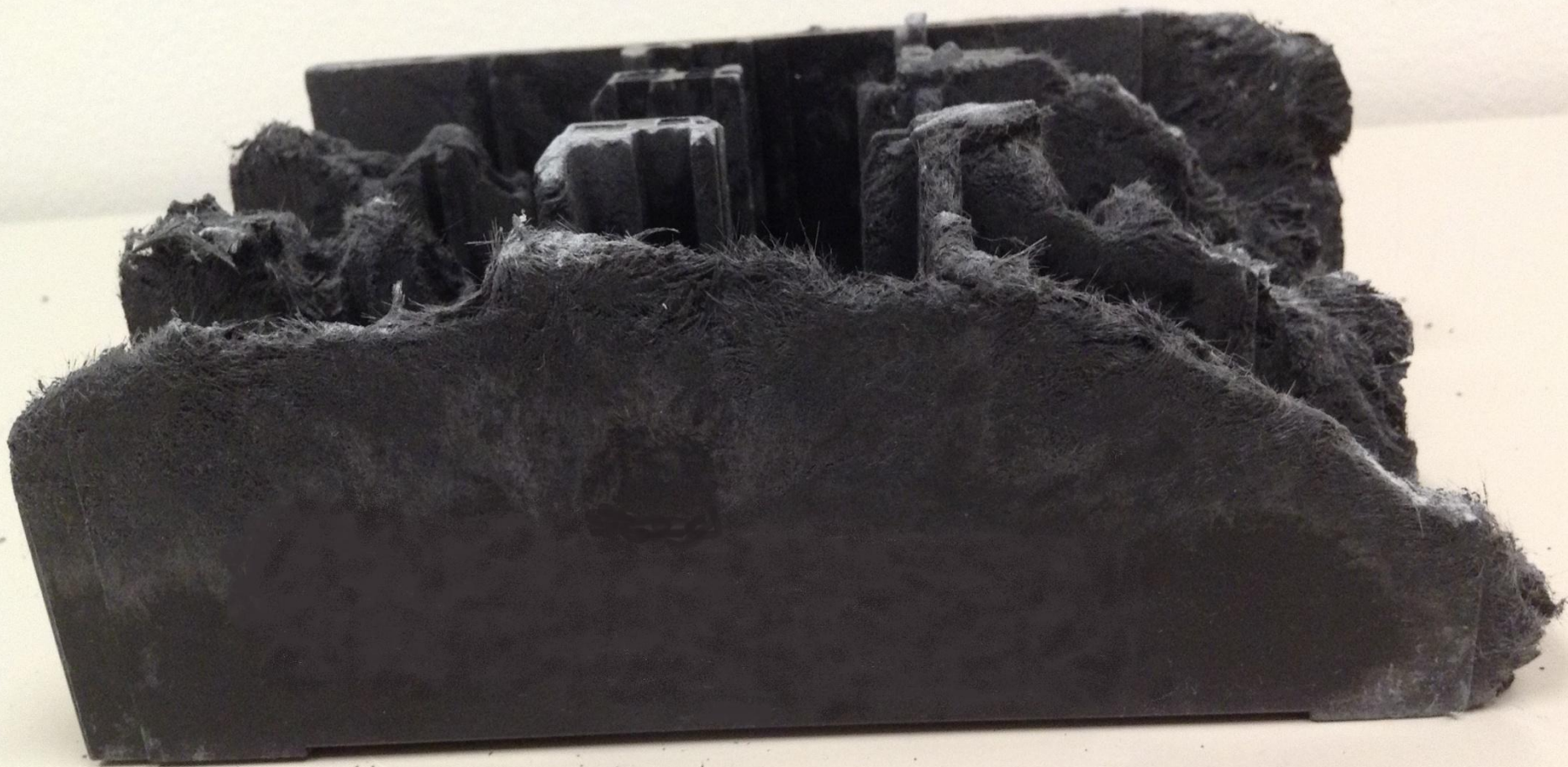
Design of Experiment (DOE)

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 →

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	

Distances Measured

Distances (Top & Bottom)

AB
CD
EF
AE
GH

Top

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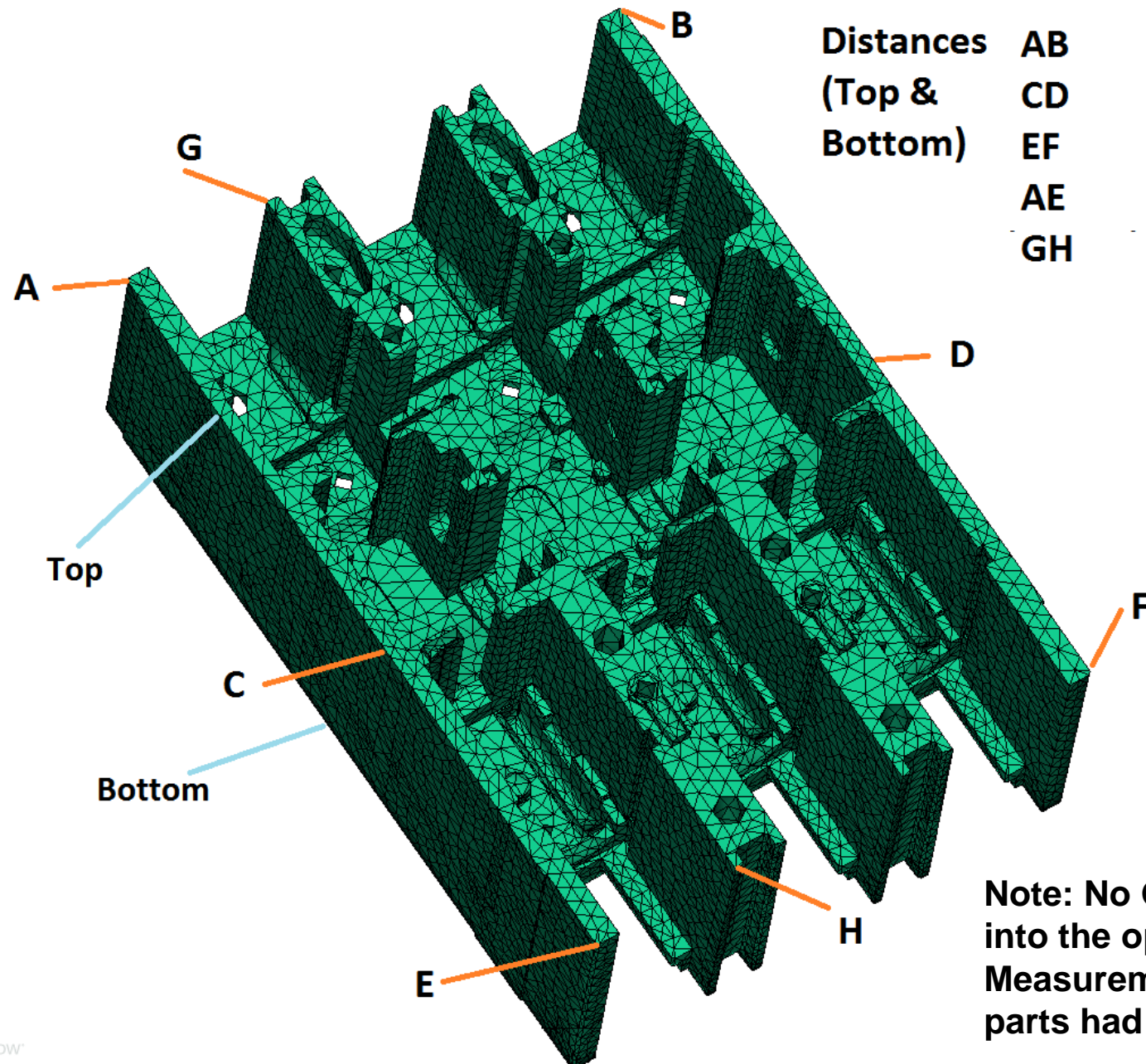
Note: No Gauges were inserted into the open end while cooling. Measurements were taken after parts had cooled down.

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

AB - Top
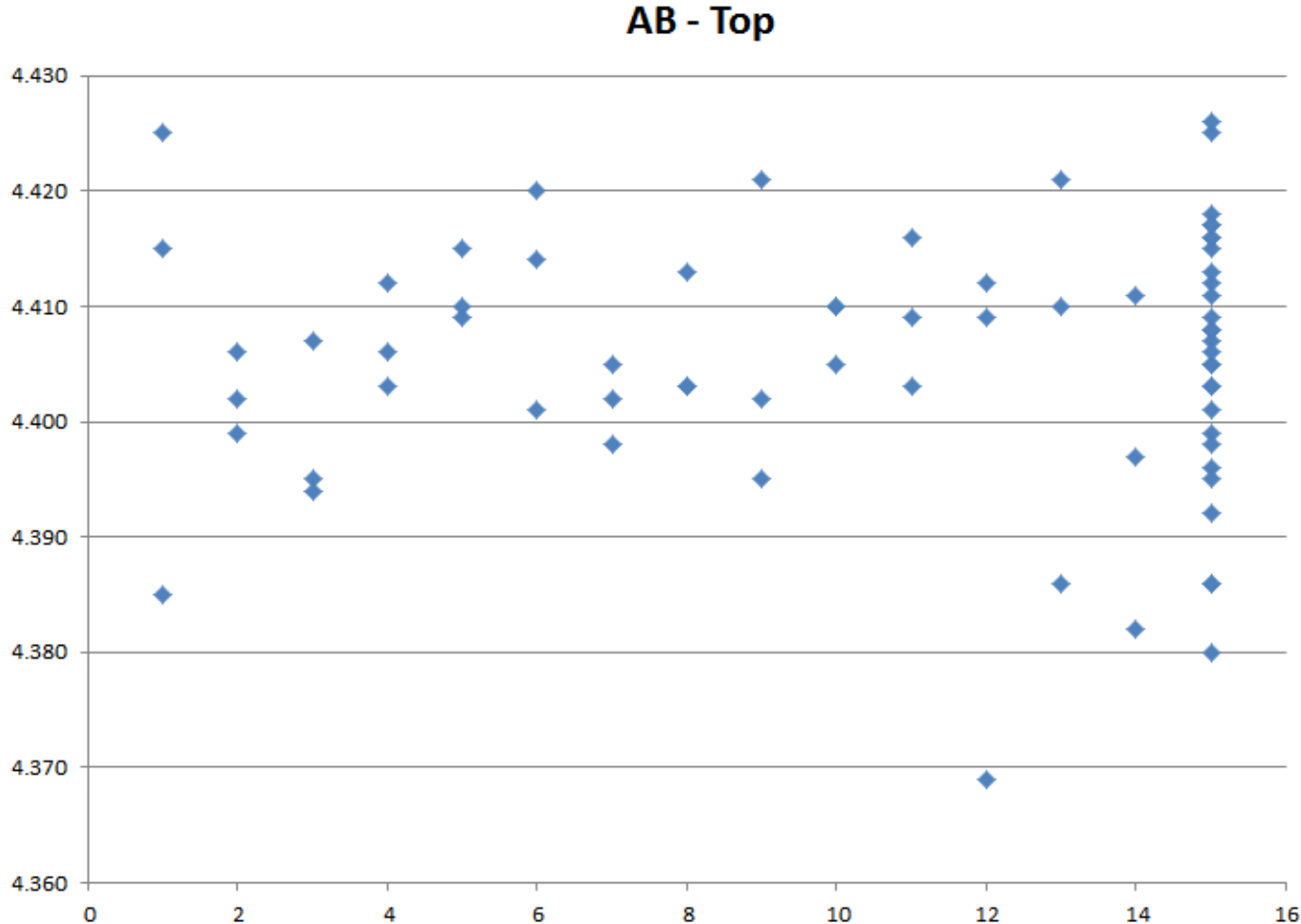
Notice that the Distance AB, measured at the Top of the part, varies from 4.369" to 4.426" (a range of 0.057").   The steel dimension is 4.454". This implies that the shrink factor ranges from 0.006 – 0.019 in/in . The shrink factor applied in the tool was 0.002 in/in for BMC 605. The measured shrinkage 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 (15 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 <u>same cavity</u> at the <u>same processing conditions</u>, 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. <u>Note</u>: Gauges were <u>NOT</u> inserted into the open end while the part was cooling.

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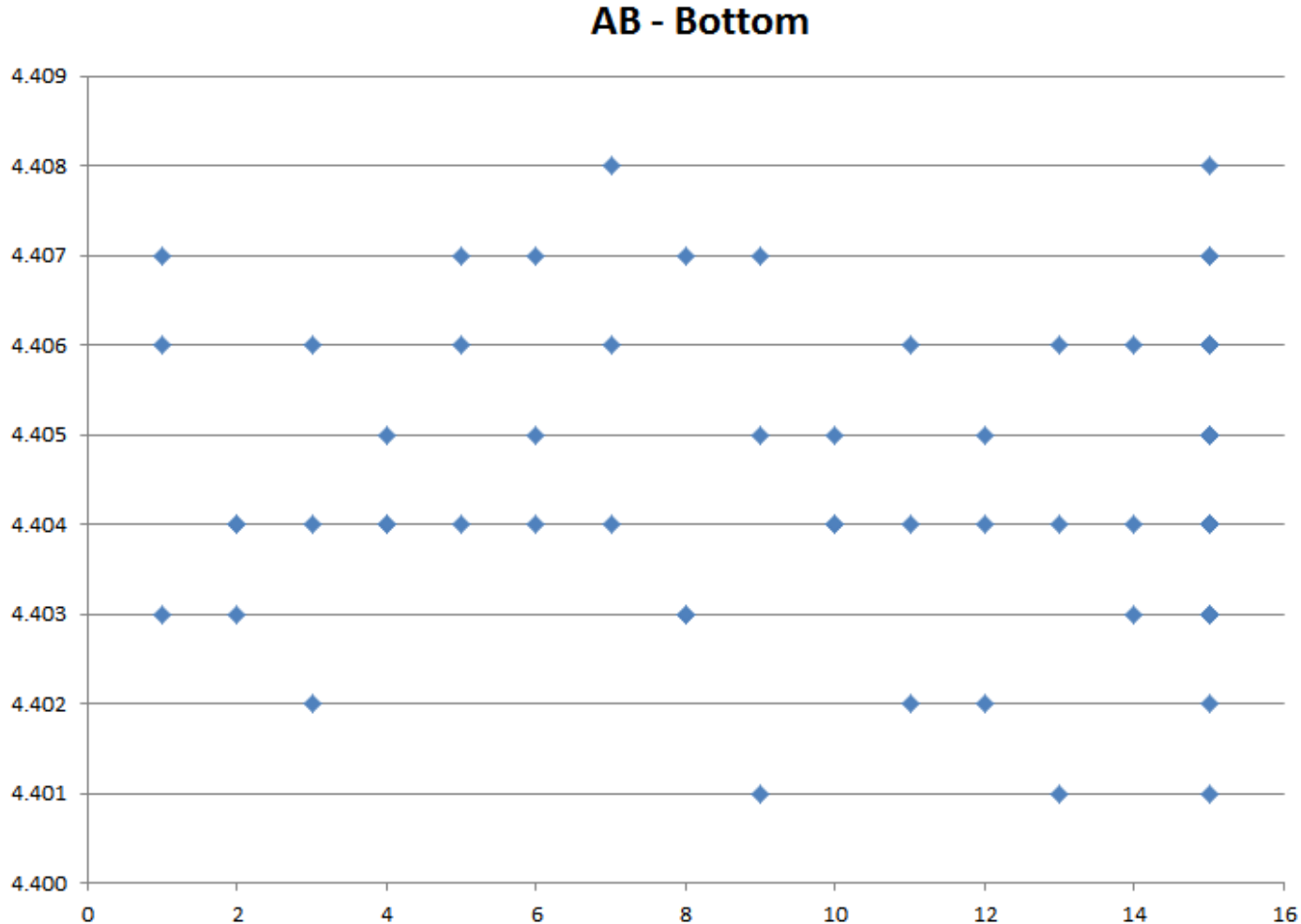
AB - Bottom

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)
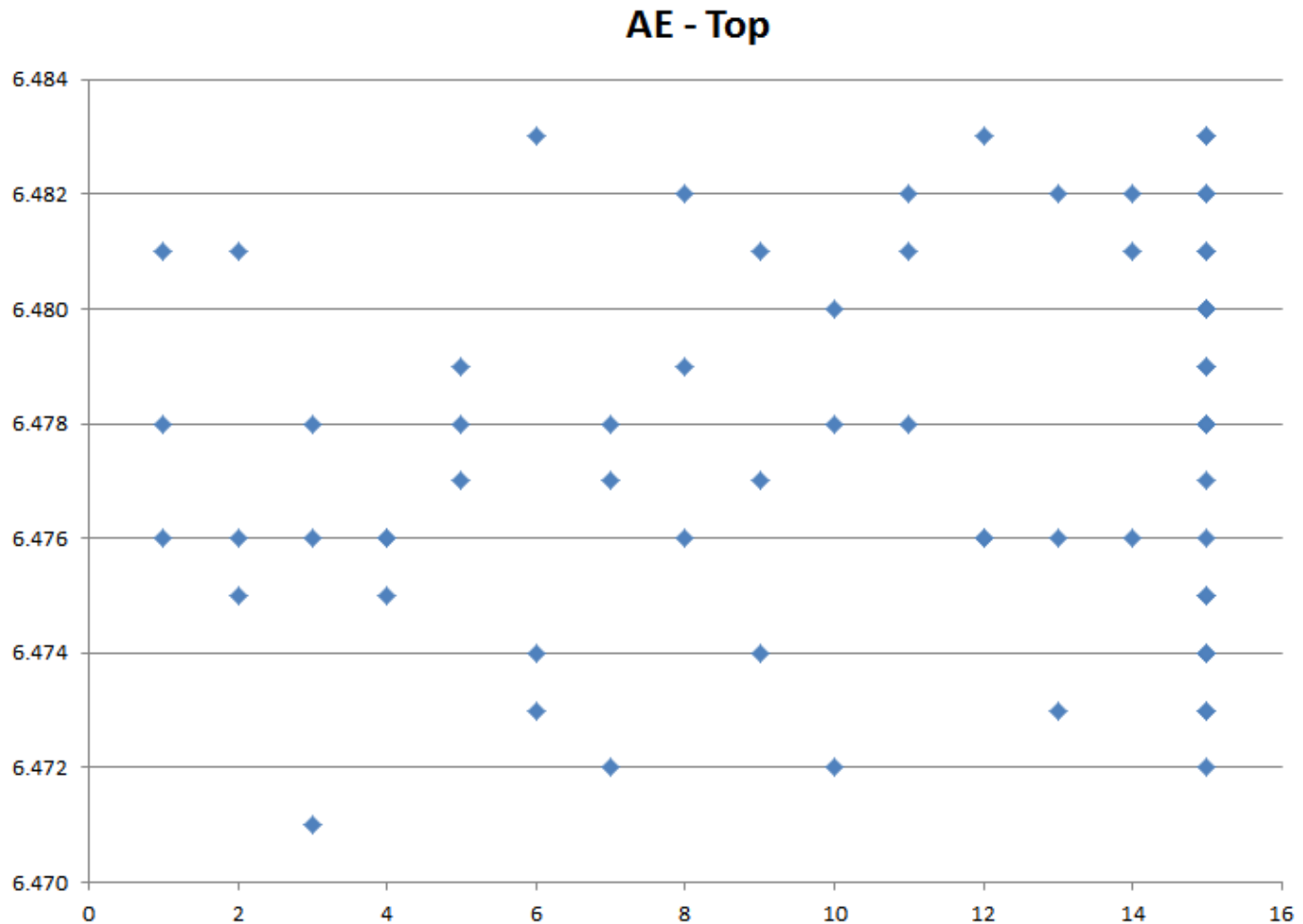
Notice that the Distance AE, measured at the Top of the part, varies from 6.471" to 6.483" (a range of 0.012"). This range is fairly tight for the longest dimension measured in the part (along the length, at the top of the side wall). The steel dimension is 6.483". This implies that the shrink factor 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.
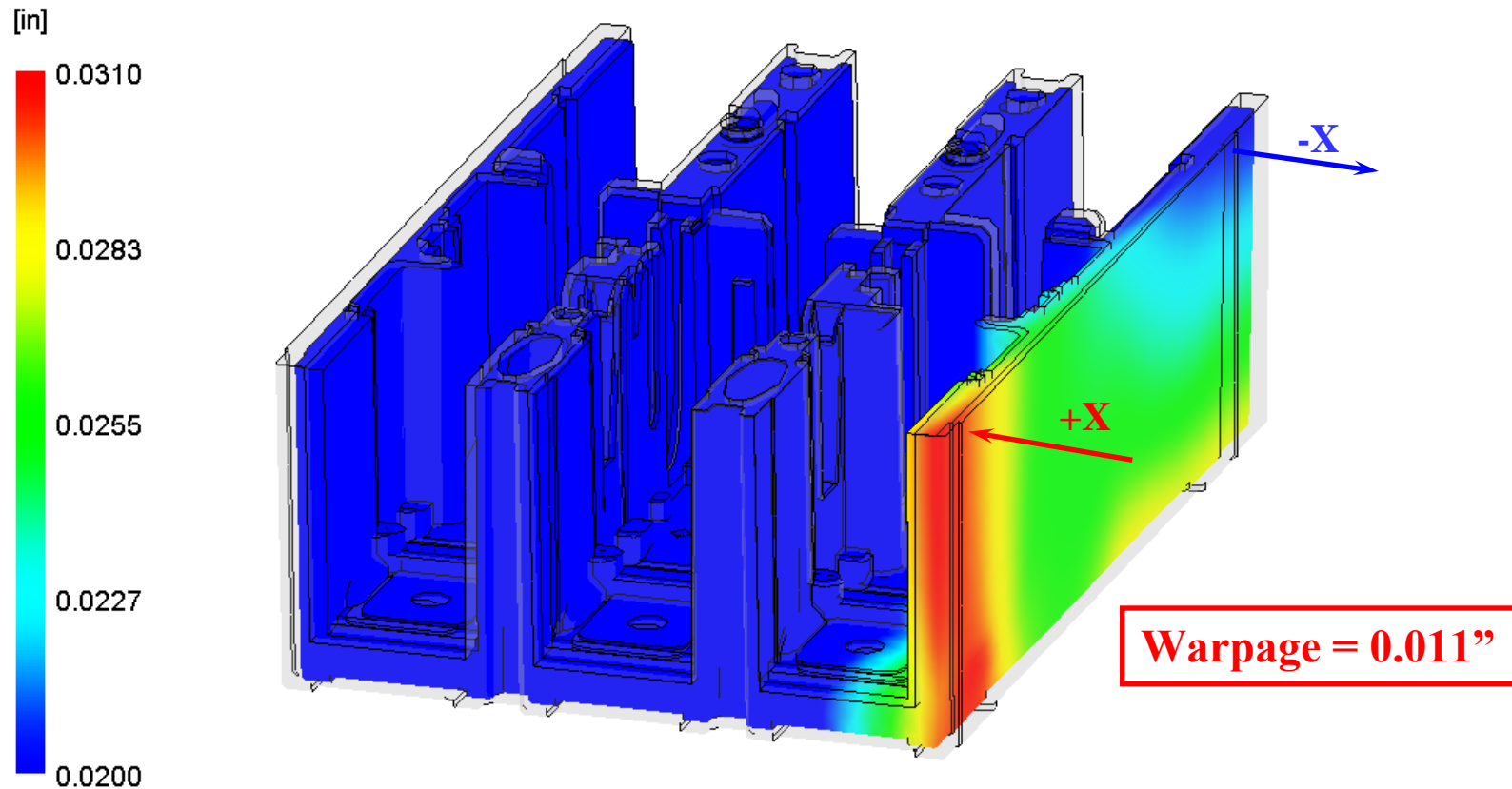
Warpage predicted was roughly 0.011" in the X-direction at the top of one of the side walls. Actual warpage measured in the molded parts was roughly 0.017". Therefore, the predicted warpage is roughly 35% lower than the measured warpage. These predictions are on the same order of magnitude of what was measured and is quite good considering all the variables that influence shrinkage and warpage.
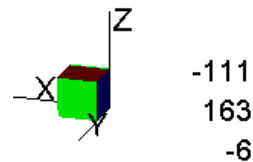
Conclusions

- **The filling pattern predicted by Moldflow Scandium 2014 for both the Injection-Compression and Compression Molding Test Cases seemed to reasonably 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. <u>Note</u>: 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.**