SIM20765: Finally, Accurate Part Shrinkage Data from Moldflow?

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Schneider Electric — Over 180 years of history

19th Century	20th Century	21st Century
Steel Industry Established in 1836 by Eugene Schneider	Power & Control	Energy Management

- 160,000+ Employees Globally.
- Major Businesses: Buildings, Industry, Infrastructure, IT, etc.
- €26.6B (US$32B) Sales in 2015.
- About 5% of Revenues (US$1.5B) devoted to R&D

Introduction

- One of the burning issues that the injection molding industry has been struggling with for decades is to determine the correct Plastic Shrinkage to apply to the mold prior to cutting steel.

- For the last three years, Schneider Electric has been working extensively with Autodesk Moldflow to improve the accuracy of 3D Shrinkage Predictions for Thermoplastic Materials.

- In my presentation, I will give you the details of our work including Mold Steel Measurements, Molding Trials, Material Re-characterization and Part Shrinkage measurements.

What Shrinkage Value to Apply to a Tool (X, Y, Z Directions)?

Material: Polyamide 66

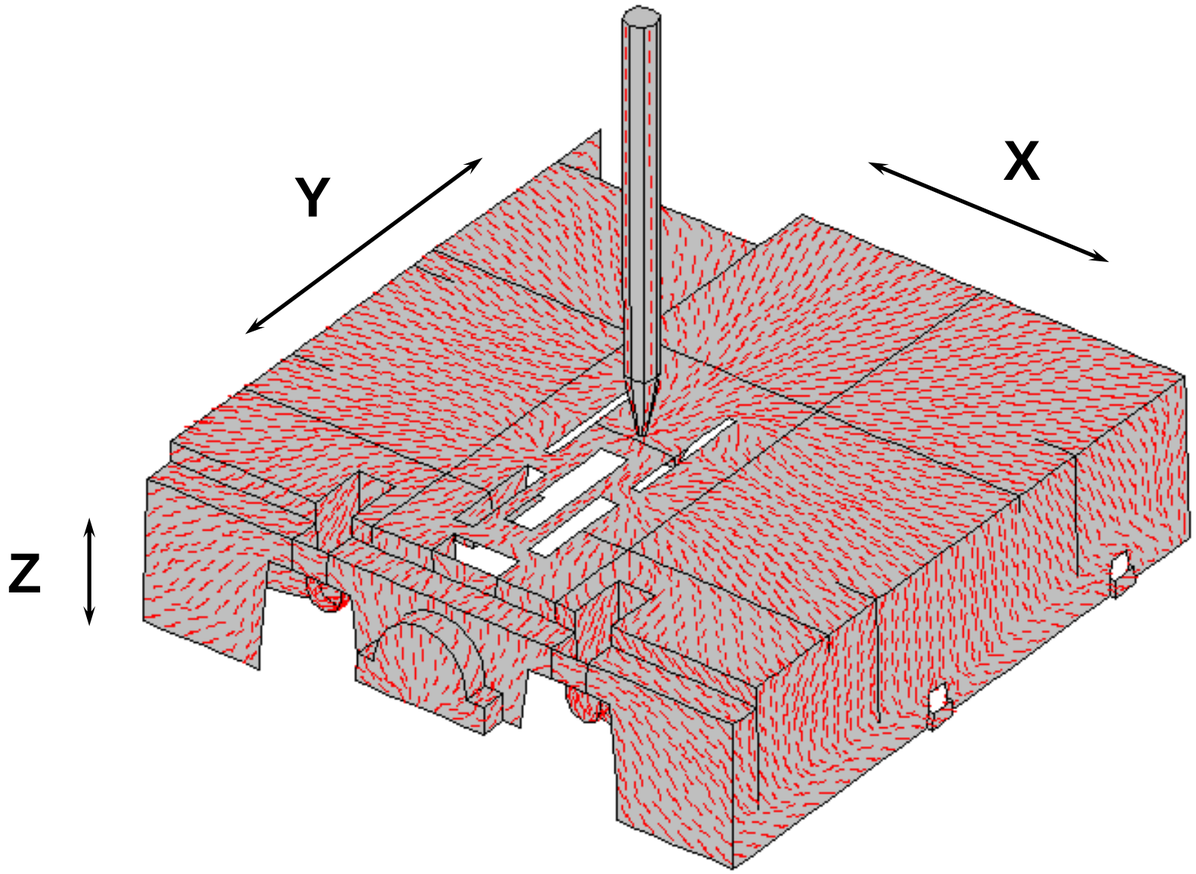
- **Zytel 70G13 (13% Glass Filled PA 6/6)***
  - Flow Direction 0.006 in/in
  - Transverse Direction: 0.013 in/in

  ≈ 2x
- **Zytel 71G33 (33% Glass Filled PA 6/6)***
  - Flow Direction 0.004 in/in
  - Transverse Direction: 0.012 in/in

  3x

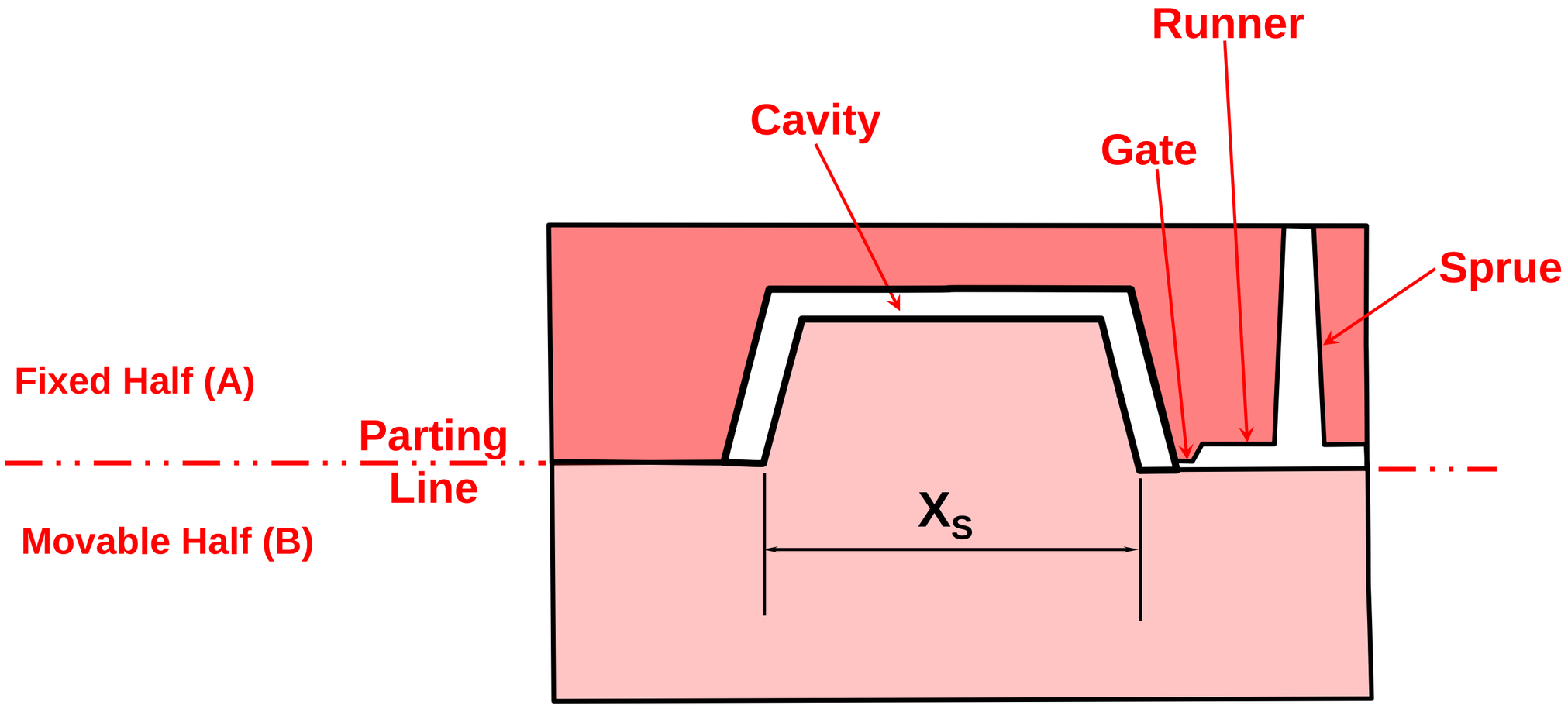
* End Gated Plaque: 6” x 3” x 1/8”, DuPont Zytel GRZ Molding Guide

Fiber Orientation Plot for a Central Gated Part

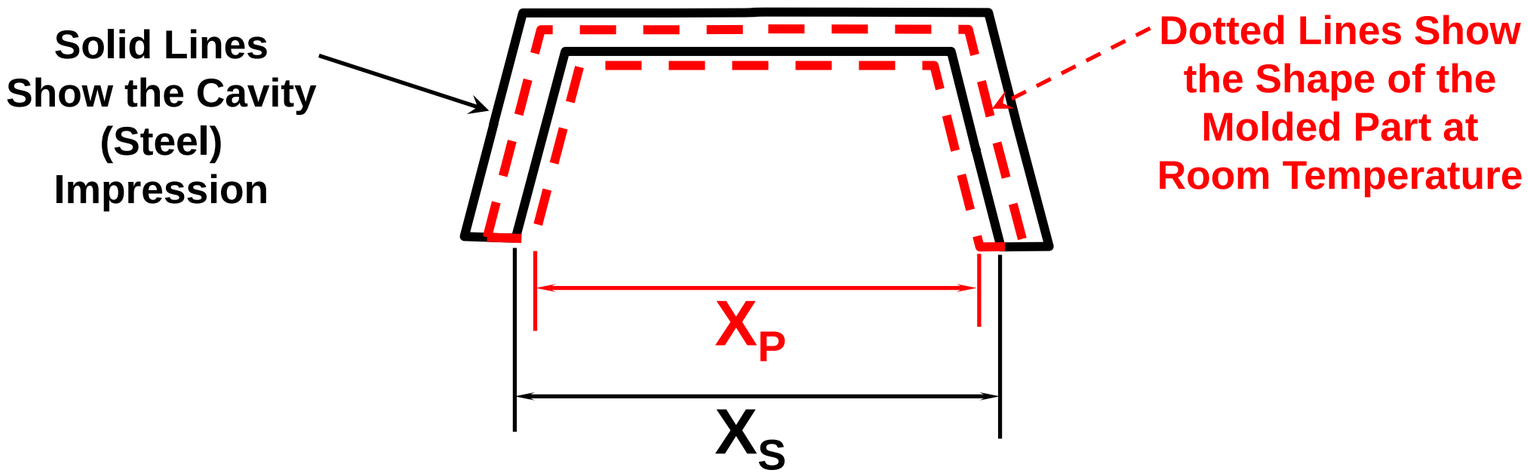


What are Flow and Transverse Directions ?

Components of a Typical Mold



Thermoplastic Shrinkage



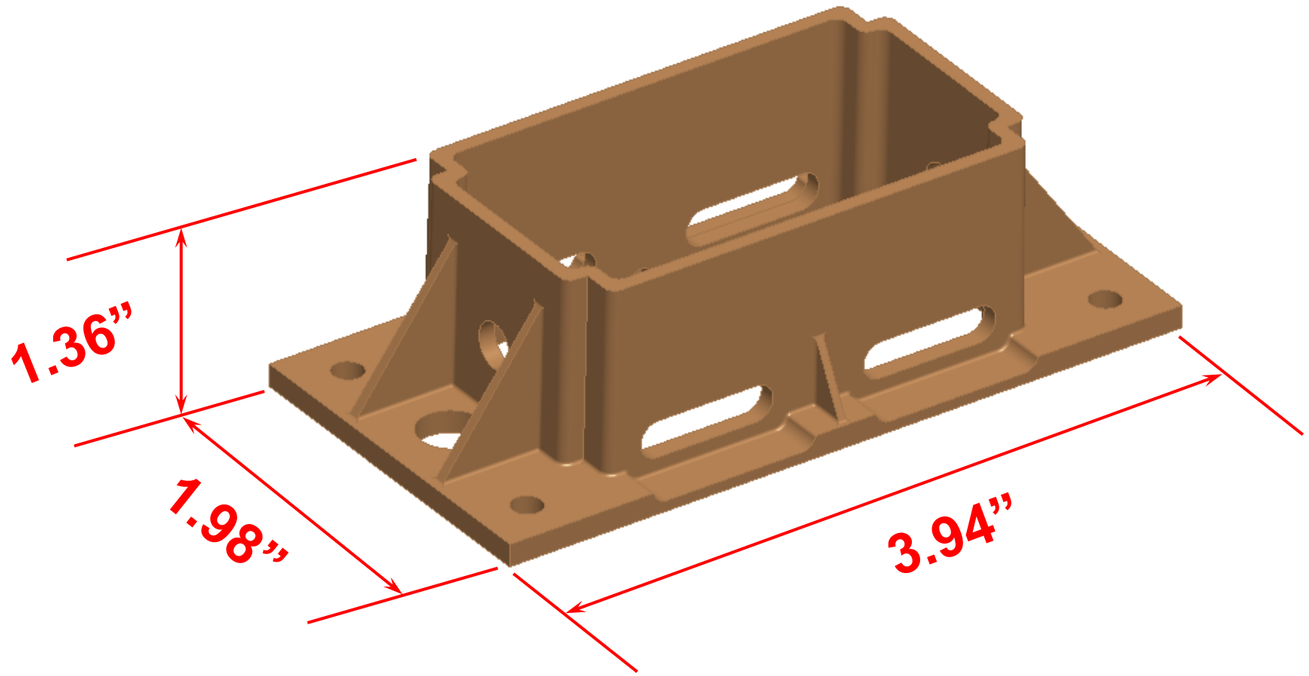
Generally, the Data Sheet obtained from the Material Supplier will give one Shrinkage value each for the flow and cross-flow directions. In most molded parts, the polymer flow is usually in a complex pattern and the shrinkage is a combination of flow and cross-flow shrinkages. Moldflow is the only tool that allows us to compute the polymer velocity vectors, element by element, and combine all the Individual Shrinkages into an overall shrinkage value in the X, Y and Z directions.

Material Shrinkage Calculation

$$\boldsymbol{Material\ Shrinkage}\ (\%) = \frac{\boldsymbol{X_S - X_P}}{\boldsymbol{X_S}} \times 100$$

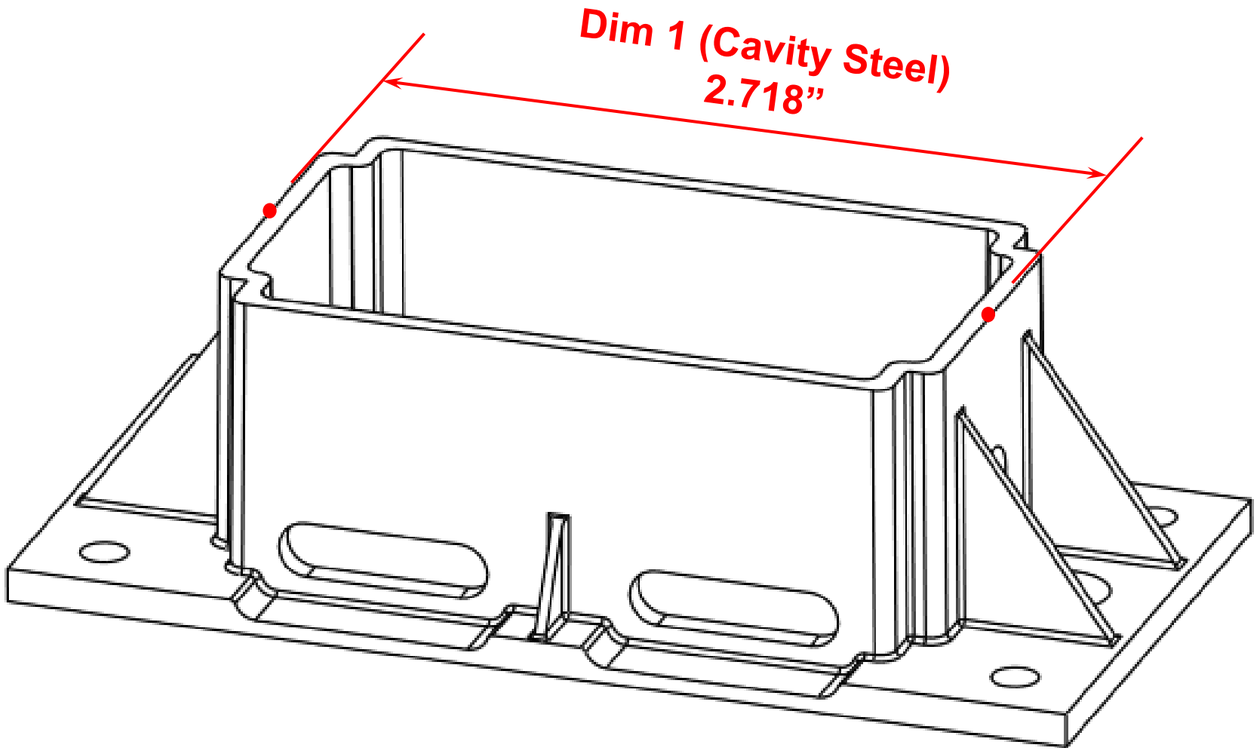
Where,
X_S = Steel Dimension &
X_P = Molded Part Dimension

Schneider Part



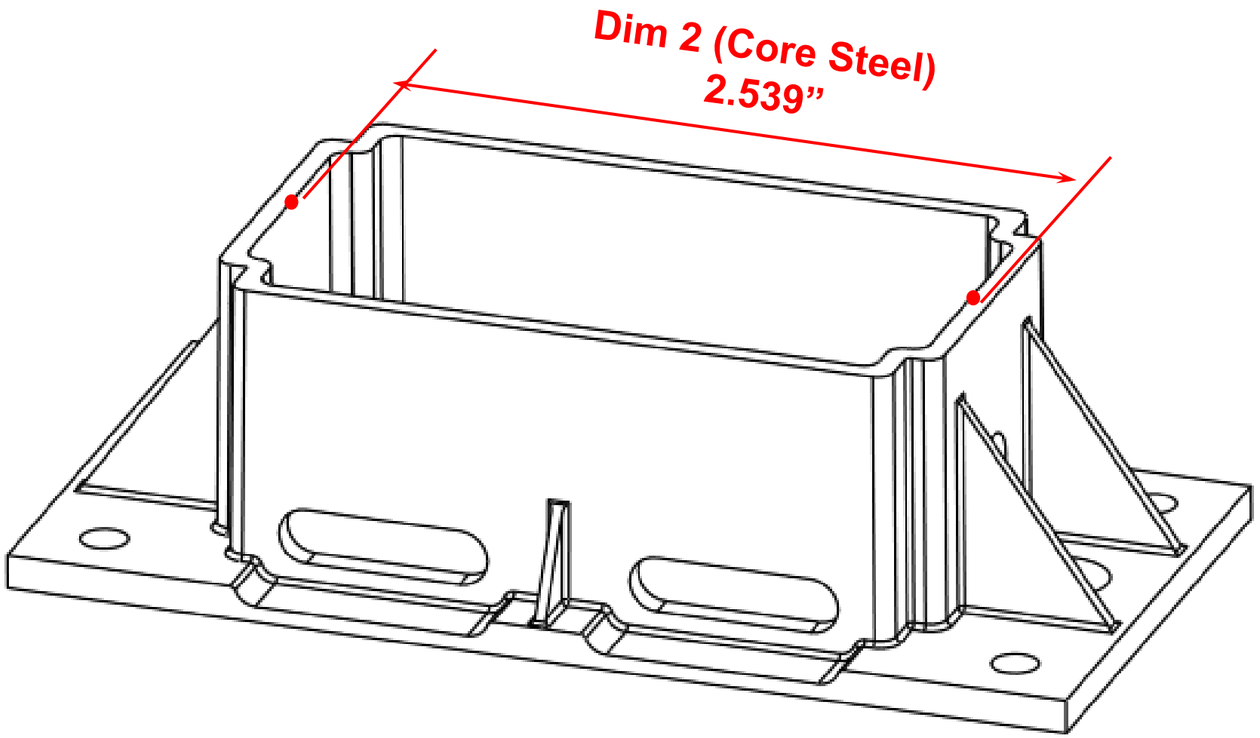
- A Schneider part molded out of SABIC Lexan 500R, a 10% Glass Filled Polycarbonate.
- We first selected key dimensions on this part that would be used for Shrinkage measurements.
- We then measured corresponding Steel Dimensions from the tool.
- CMM (Hexagon Metrology) was to measure the selected Steel Dimensions on the Core and Cavity (courtesy Versatile Mold & Design, GA).

Steel Measurements



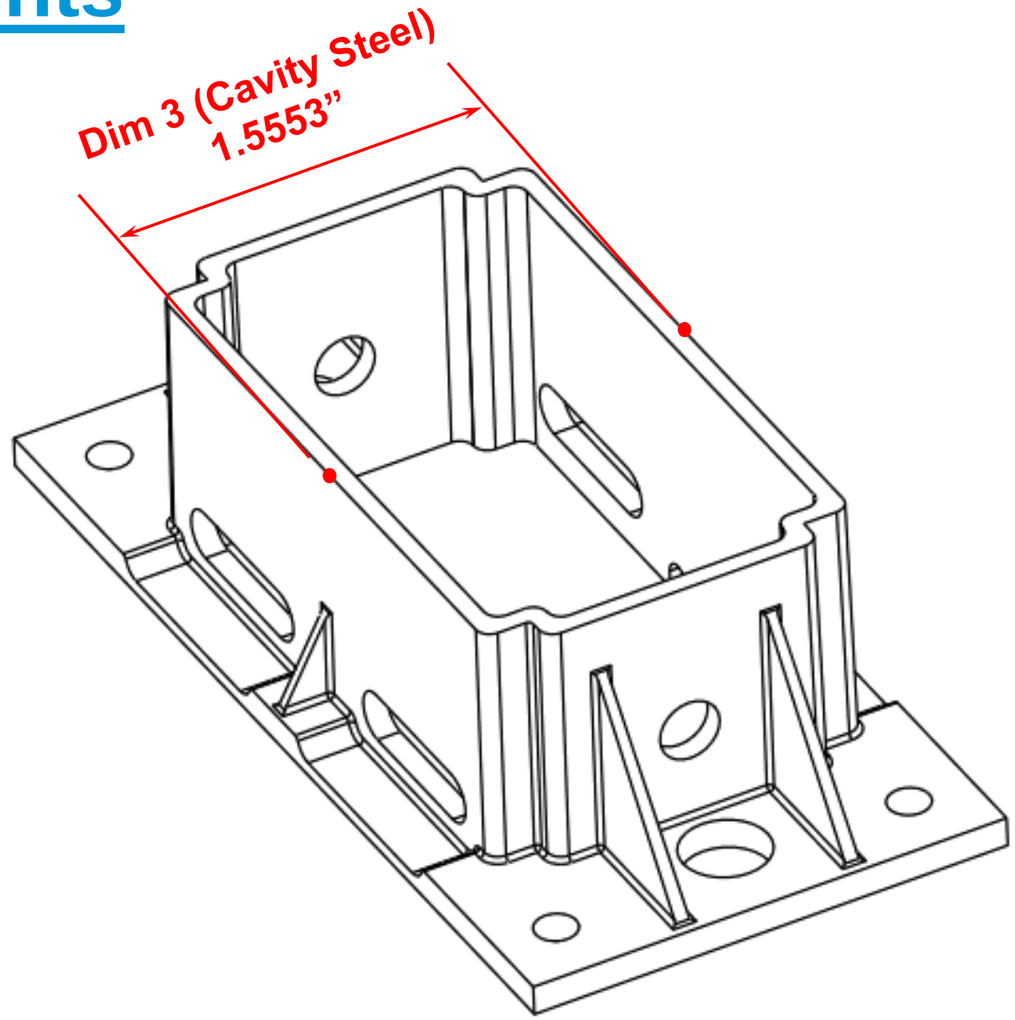
1 (Cavity Steel) = Length, Cavity Dimension at the Top (Outside)

Steel Measurements



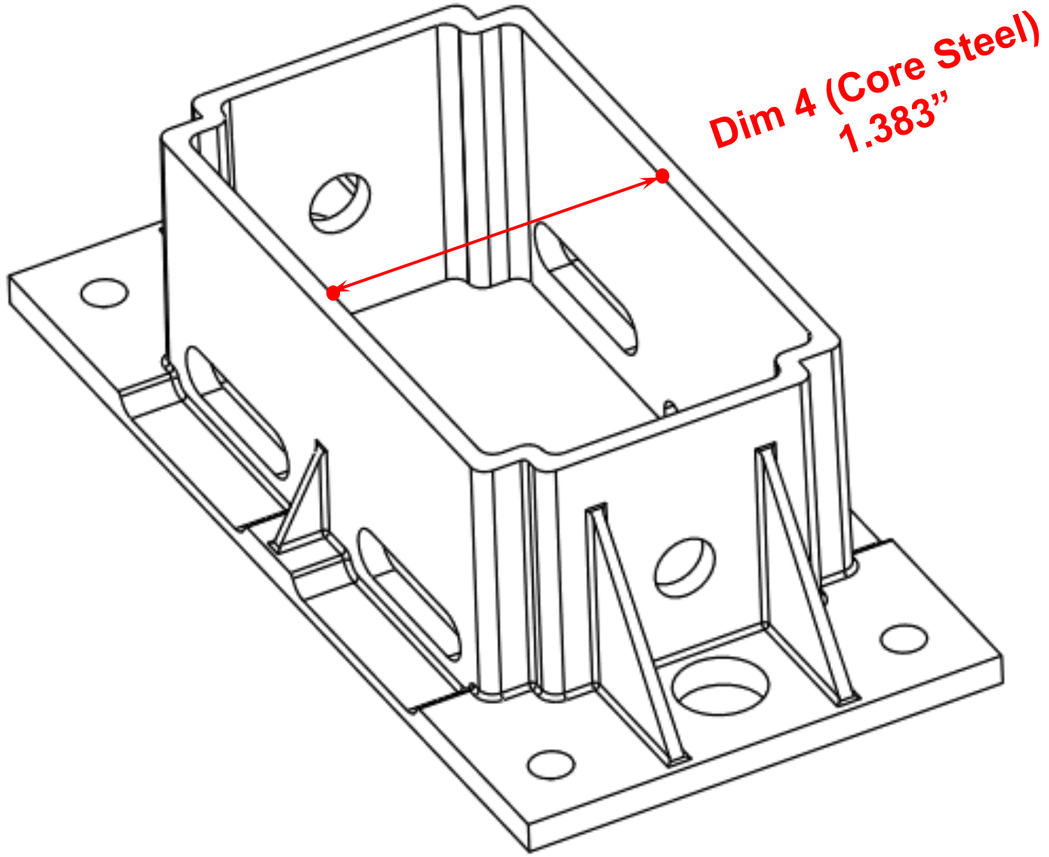
2 (Core Steel) = Length, Core Dimension at the Top (Inside)

Steel Measurements



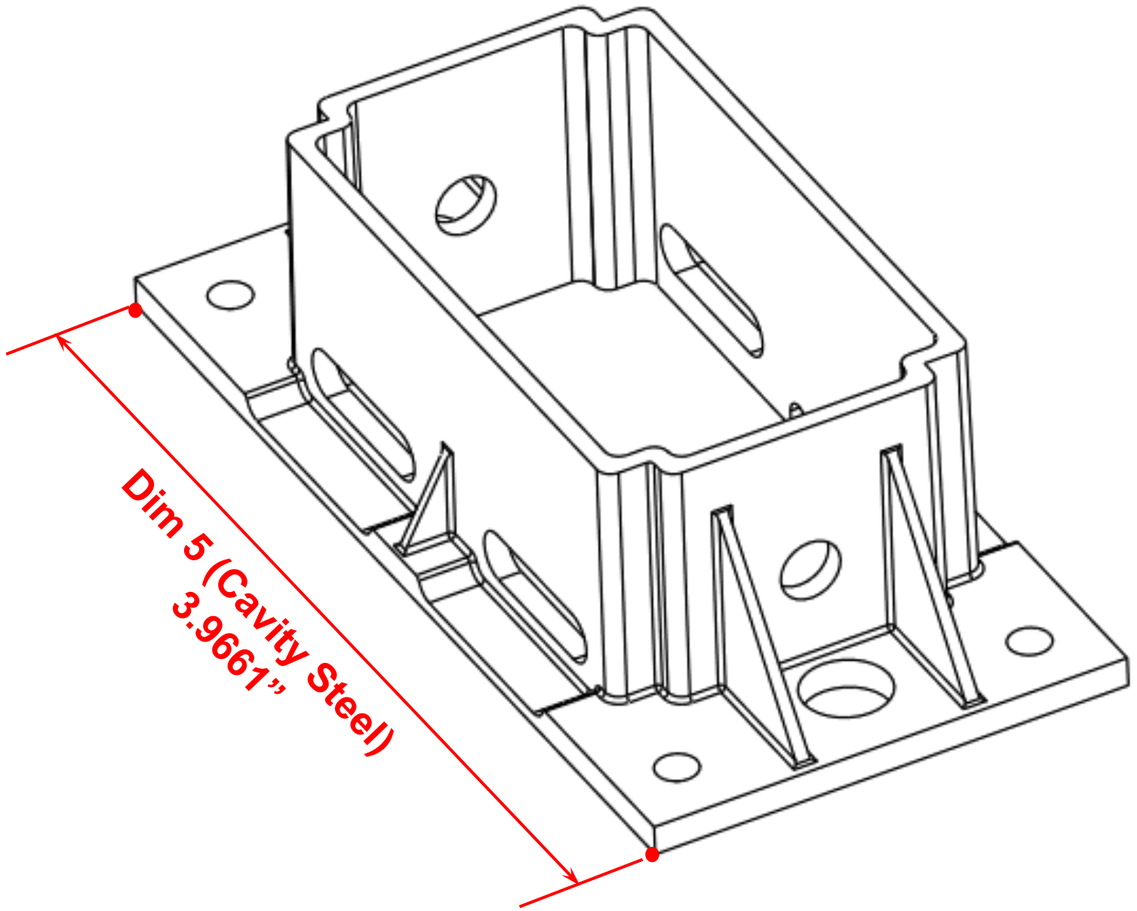
3 (Cavity Steel) = Width, Cavity Dimension at the Top (Outside)

Steel Measurements



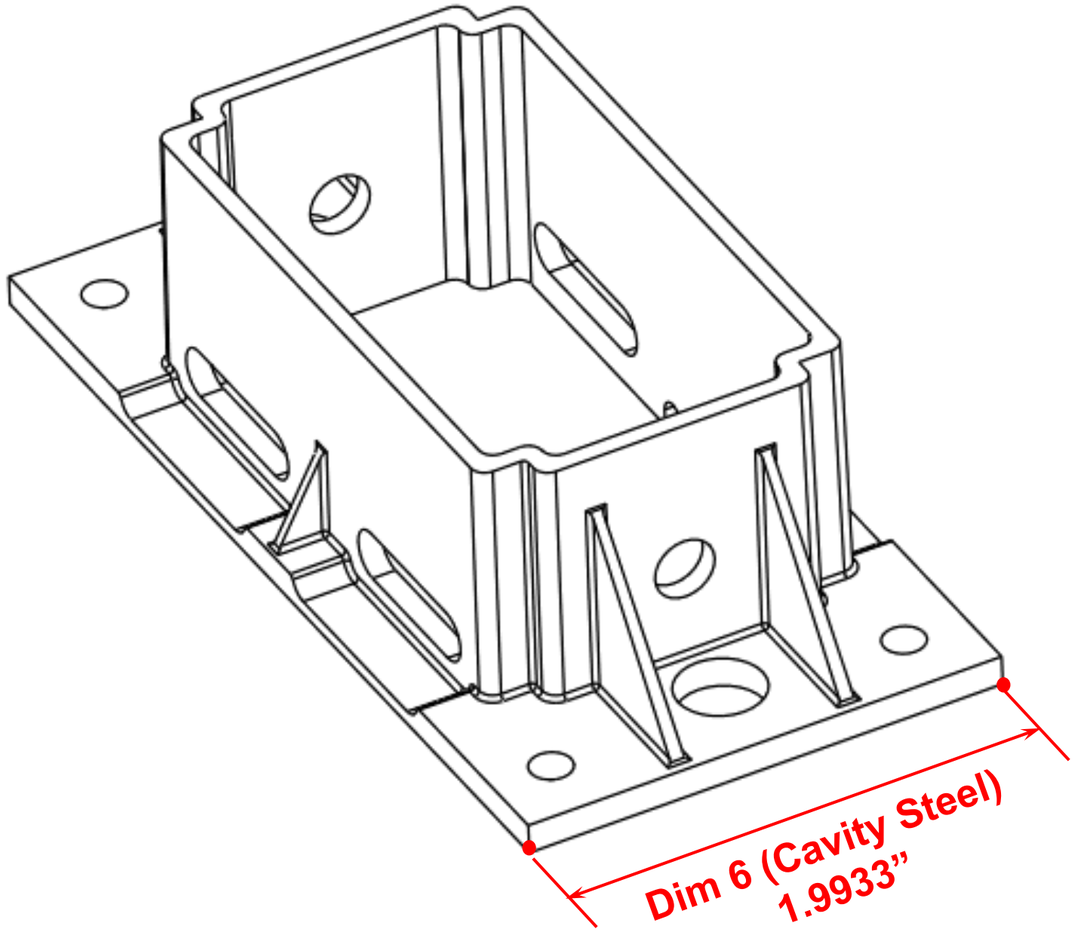
4 (Core Steel) = Width, Core Dimension at the Top (Inside)

Steel Measurements



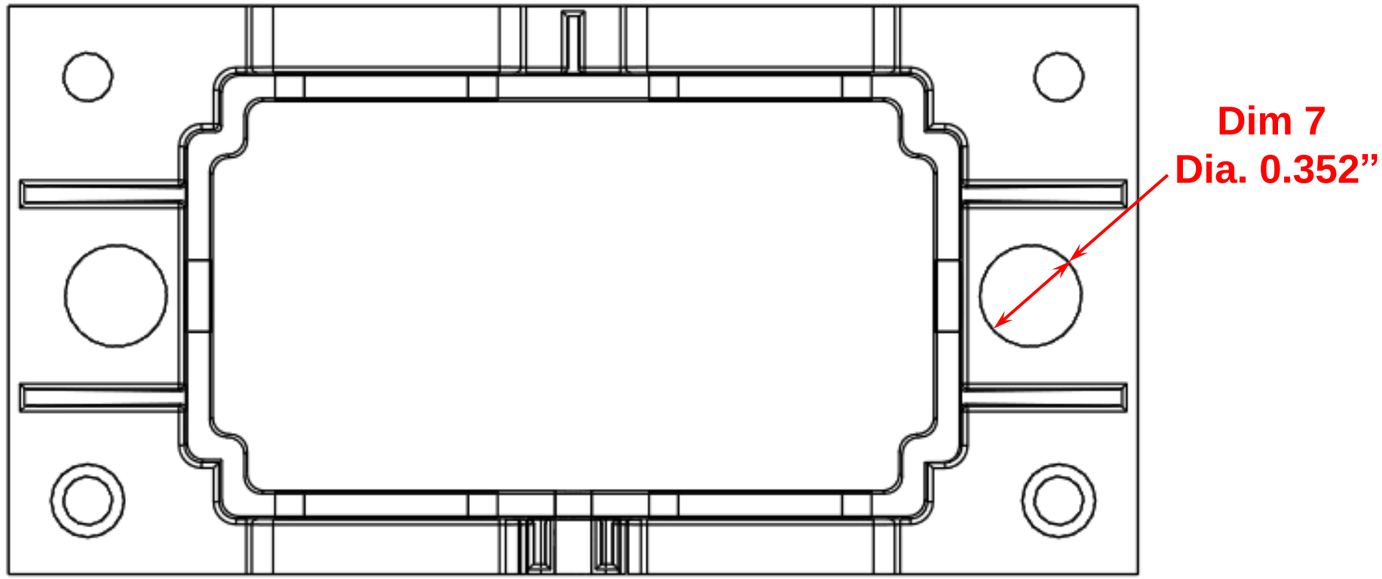
5 (Cavity Steel) = Length, Overall Cavity Dimension

Steel Measurements



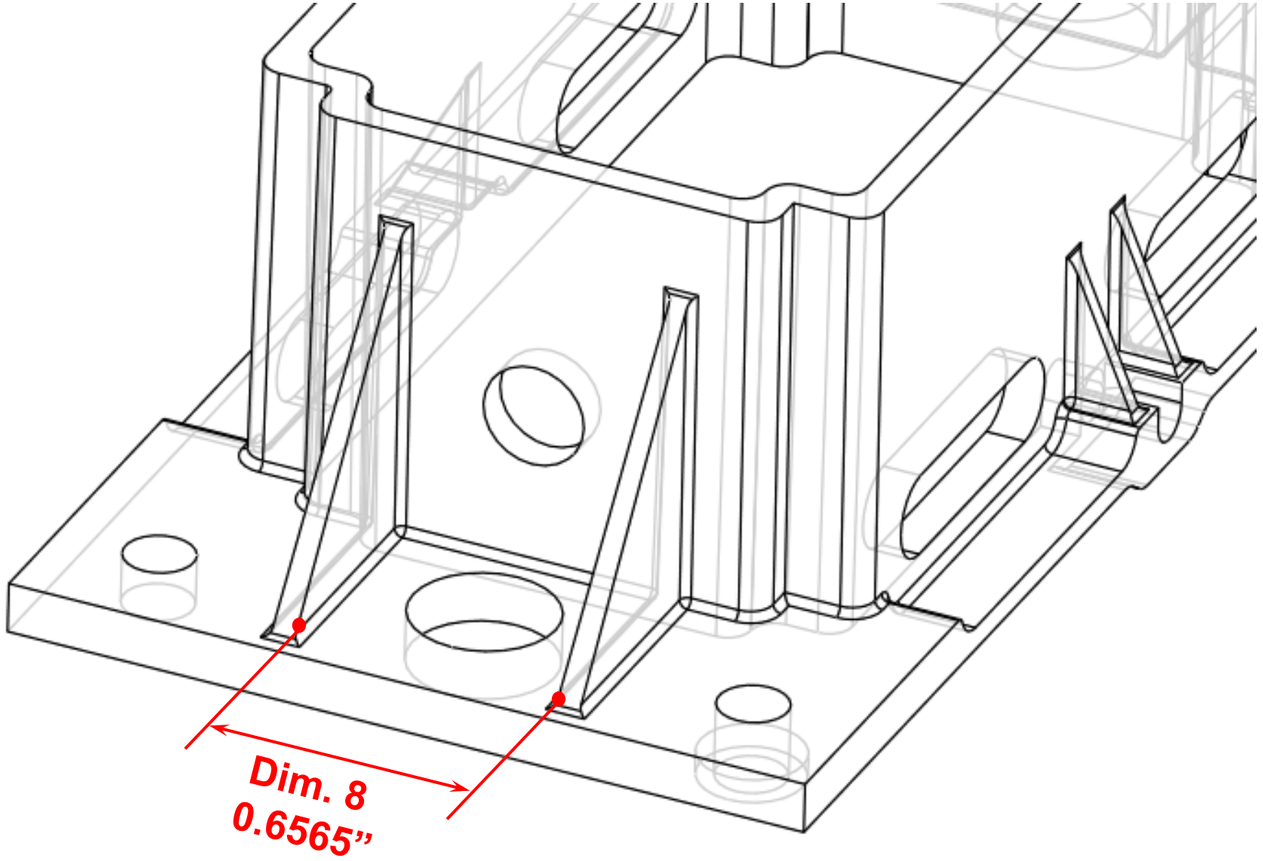
6 (Cavity Steel) = Width, Overall Cavity Dimension

Steel Measurements



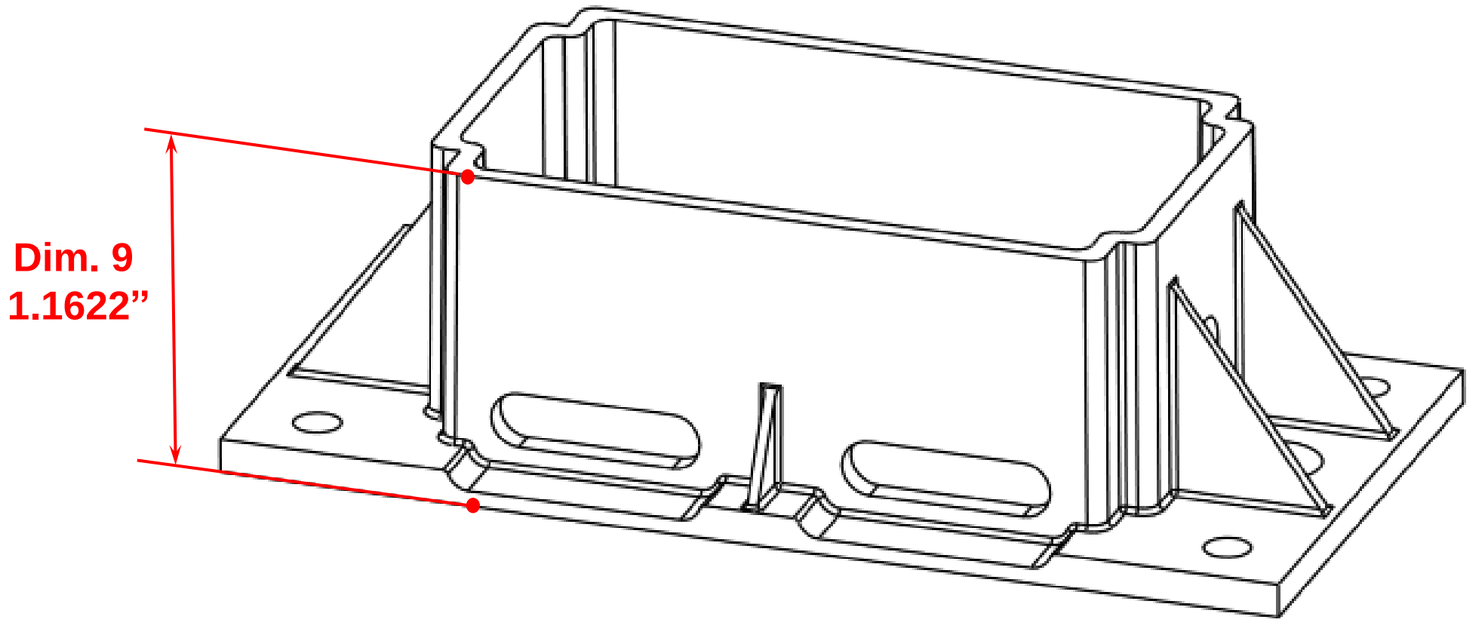
7 (Cavity Steel) = Diameter

Steel Measurements



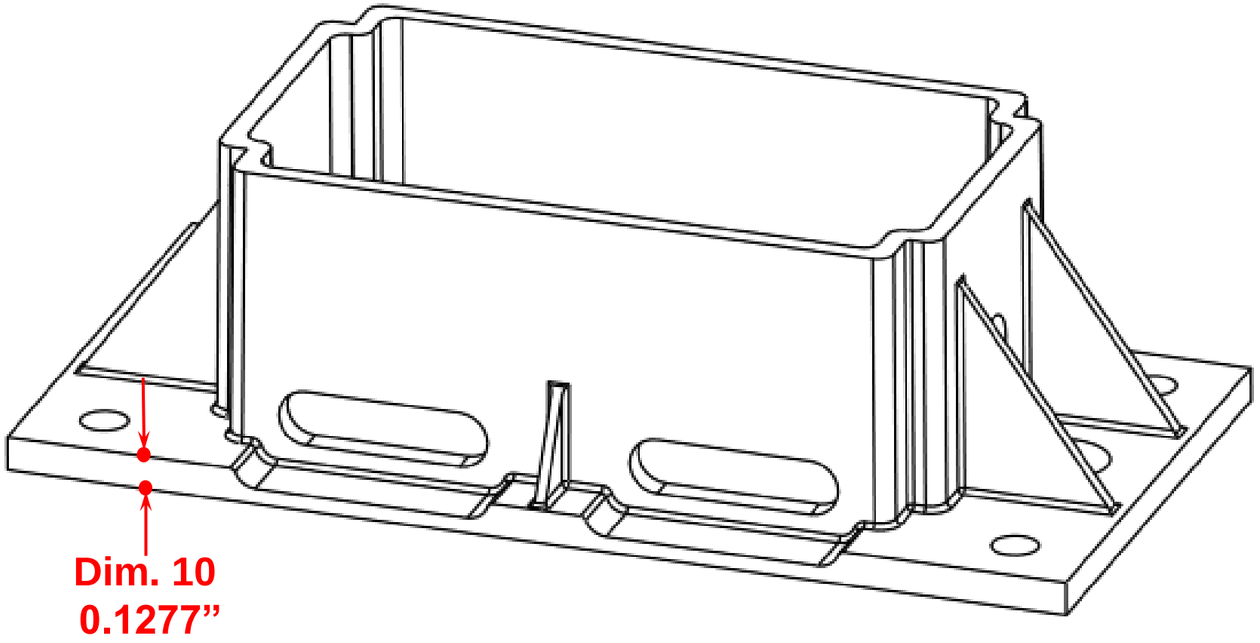
8 (Core Steel) = Distance between the inside edges at the bottom (exclude the fillets)

Steel Measurements



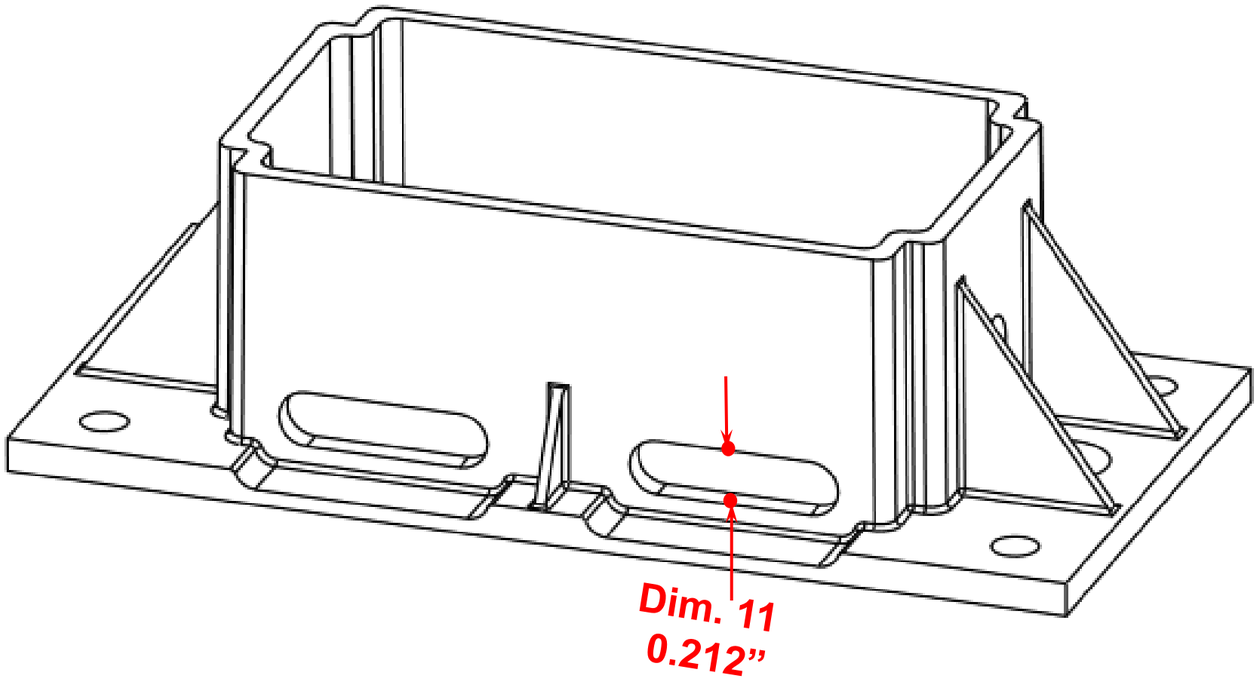
9 (Core Steel) = Height, Overall Core

Steel Measurements



10 (Cavity Steel) = Thickness

Steel Measurements

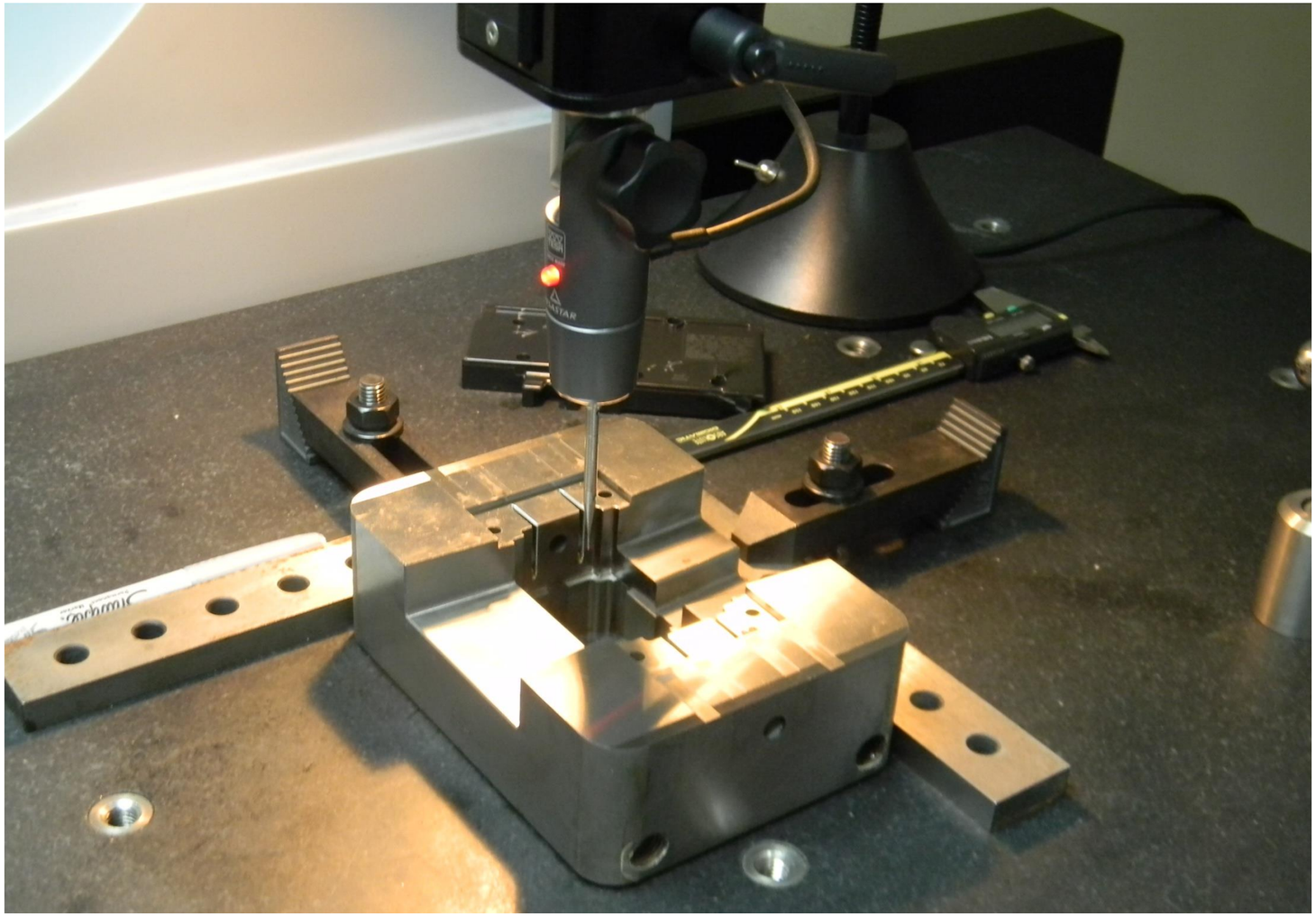


11 (Slide Steel) = Width of the Oval Hole

CMM by Hexagon Metrology

Courtesy of Versatile Mold & Design Inc., Rutledge, GA

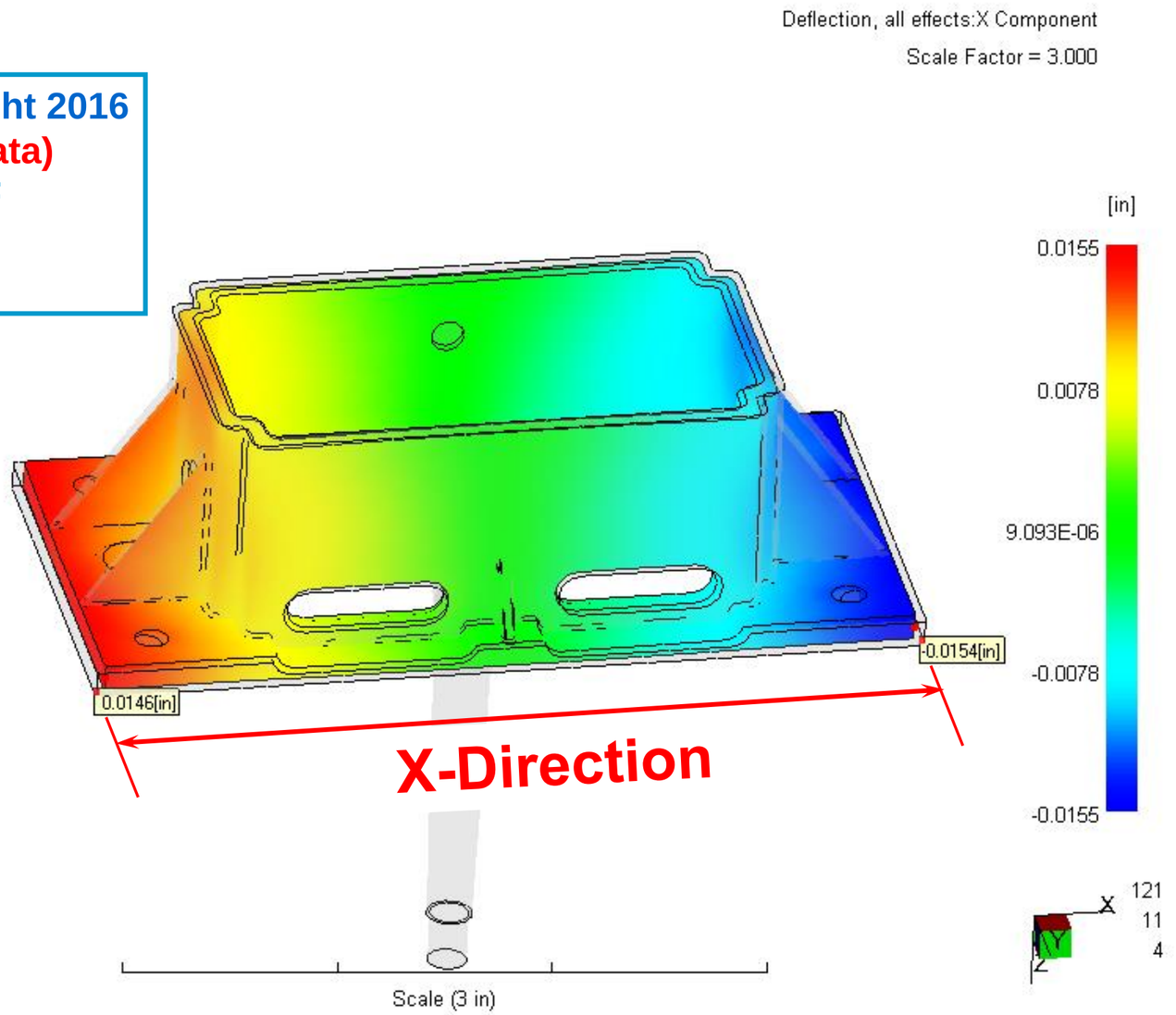
CMM by Hexagon Metrology



Courtesy of Versatile Mold & Design Inc., Rutledge, GA

Moldflow Analysis showing X-Displacement

Autodesk Moldflow Insight 2016
Lexan 500R (2007 Data)
Mold Temp: 210 F
Melt Temp: 610 F
Fill Time: 1.5 sec



Moldflow Analysis: Deflection Measurements & Shrinkage

Coordinates & Deflection

Node 1

Node 2

Distance Between Nodes 1 & 2.

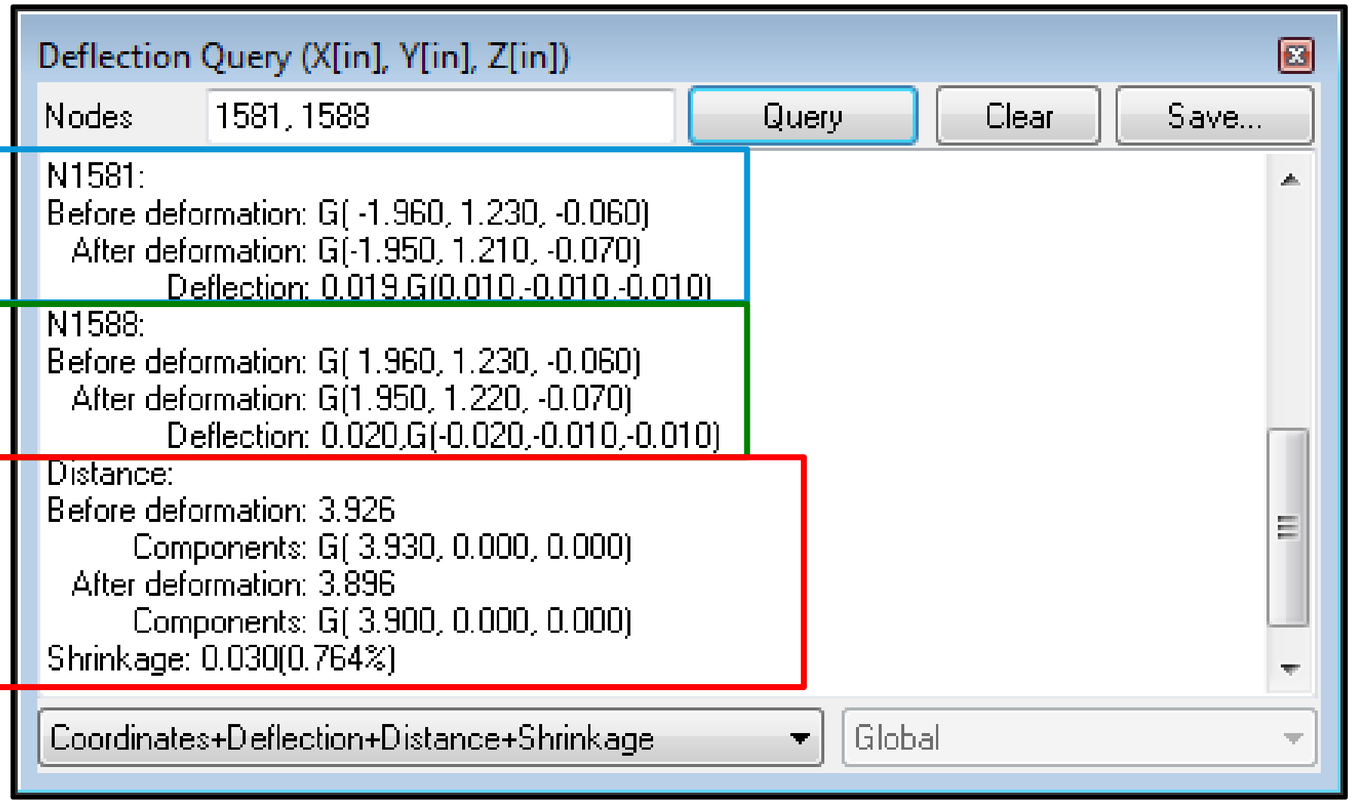


Table I: Dimensions from Mold Steel, Molded Part & Moldflow Results

Dimension	Measurements *			
	Steel **	Molded Part	Moldflow Prediction*** (before deformation)	Moldflow Prediction*** (after deformation)
1	2.718	2.695	2.696	2.673
2	2.539	2.520	2.533	2.512
3	1.555	1.540	1.540	1.521
4	1.383	1.369	1.375	1.357
5	3.966	3.946	3.940	3.910
6	1.993	1.981	1.980	1.960
7	0.352	0.348	0.354	0.351
8	0.657	0.643	0.670	0.663
9	1.162	1.153	1.168	1.153
10	0.127	0.125	0.125	0.124
11	0.212	0.209	0.210	0.209

* All Dimensions in Inches (Tables I & II)

** 8% Shrinkage was initially applied to the mold in the X, Y, and Z directions,

*** Autodesk Simulation Moldflow Insight 2016, Service Pack 1, Synergy Build: 13221-Bin376-Ins360, Insight Build: 13095-Bin-Ins285, Analysis Type: 3D Part and Runner, 1D Cooling Channels, Surface Mesh for Mold

Table II: Moldflow Predicted Vs. Actual Shrinkage using Lexan 500R (2007 Data)

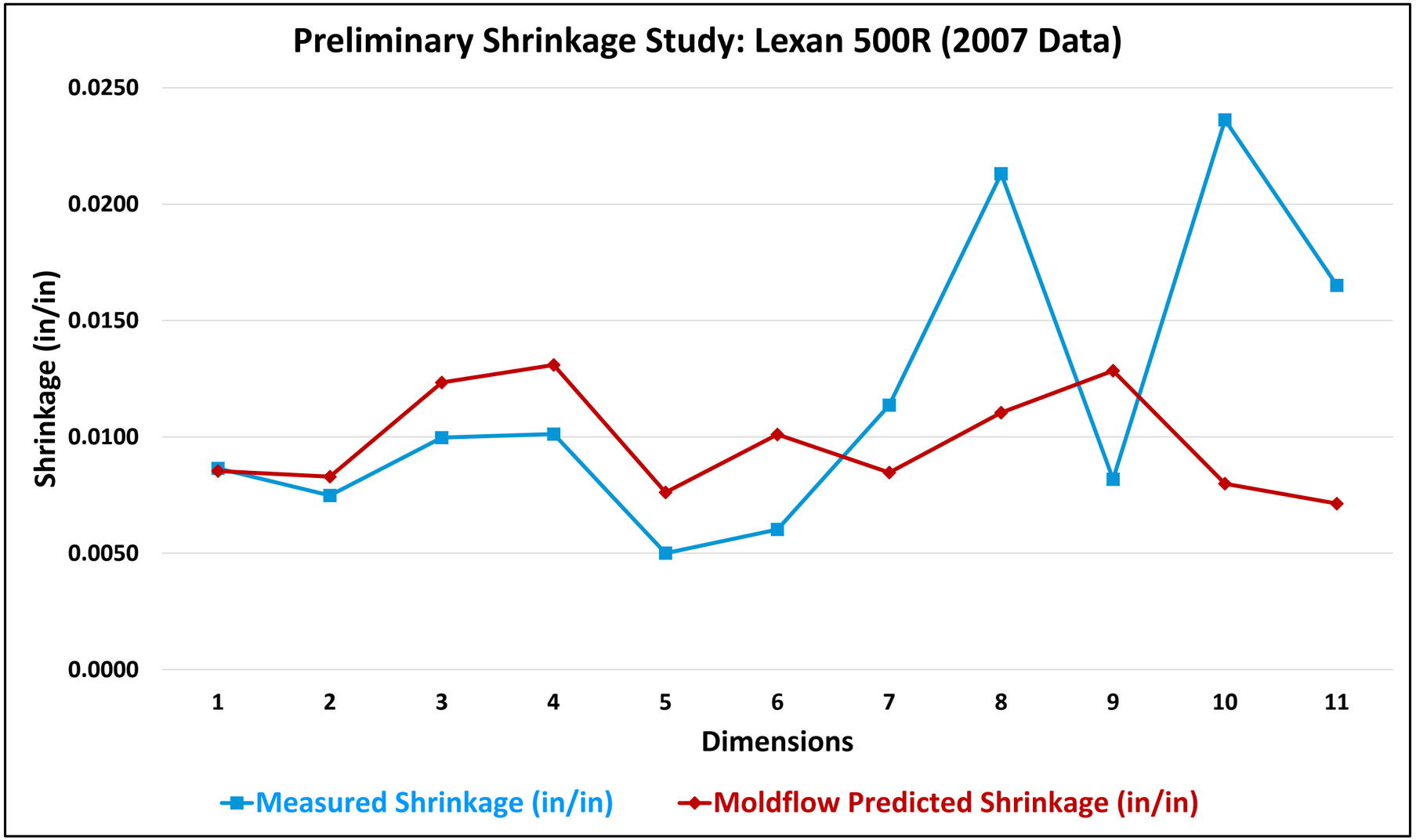
Dimension	Actual Measurements		Moldflow Predictions		Difference in Shrinkage (in/in)	% Change in Shrinkage ***
	Steel - Molded Part (in)	Shrinkage (in/in) *	Before – After (in)	Shrinkage (in/in) **		
1	0.0235	0.0086	0.0230	0.0085	-0.0001	-1
2	0.0190	0.0075	0.0210	0.0083	0.0008	11
3	0.0155	0.0100	0.0190	0.0123	0.0024	24
4	0.0140	0.0101	0.0180	0.0131	0.0030	29
5	0.0200	0.0050	0.0300	0.0076	0.0026	51
6	0.0120	0.0060	0.0200	0.0101	0.0041	68
7	0.0040	0.0114	0.0030	0.0085	-0.0029	-25
8	0.0140	0.0213	0.0074	0.0110	-0.0103	-48
9	0.0095	0.0082	0.0150	0.0128	0.0047	57
10	0.0030	0.0236	0.0010	0.0080	-0.0156	-66
11	0.0035	0.0165	0.0015	0.0071	-0.0094	-57

* $$Shrinkage = \frac{Steel\ Dim - Molded\ Part\ Dim}{Steel\ Dim}$$

** $$Moldflow\ Shrinkage = \frac{Before - After}{Before}$$

*** $$\%\ Change = \left\{\frac{Moldflow - Actual}{Actual}\right\} * 100$$

Comparison of Measured Shrinkage vs Predicted



Moldflow Involvement

- Observed up to 68% variation between the Actual and Predicted Shrinkages.
- Requested Moldflow to take a look and verify our results.
- Provided Moldflow with the following data:
  - Study File (Schneider Part),
  - Steel Measurements, and
  - Moldflow predicted Shrinkage with the 2007 Material Data.
- Additionally, Moldflow requested molded parts for the measurements using 3D Laser Scan Technology.

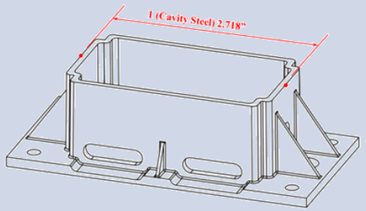
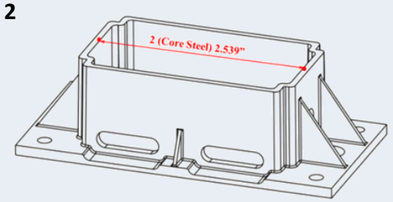
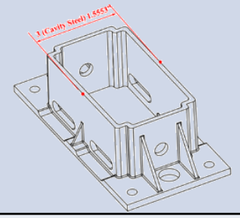
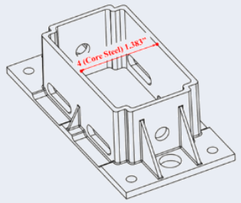
Molding Trial with Lexan 500R & 3D Scans

- Molding Trial was conducted at Dickten Masch Plastics, Monterrey, Mexico March 18, 2016.
- Machine: 85 Ton, Van Dorn 85HT5-0889, 35 mm Screw Diameter.
- Processing Conditions:
  - Drying Temperature: 250 F (3 hours)
  - Fill Time: 1.35 sec
  - Melt Temperature, Actual: ≈ 610 F
  - Thermolator Setting: 200 F (both halves)
  - Mold Temperature, Actual: A-Half: 203 F, B-Half: 196 F
- Mold Trials conducted for several different Pack Times (2, 4, 6, 8, 10, 12 & 14s) and Cooling Times (7, 12 & 17s).
- Collected 5 samples for each trial and sent them to Moldflow Lab, Australia for 3D Laser Scan.
  - Most Part Dimensions were measured using Romer Absolute Arm 7525SI (≈ 50 Micron / 0.002” Accuracy).
  - Dimensions 7, 10 and 11 were measured using Optical Gauge Products Measurement System (≈ 5 Micron / 0.0002” Accuracy).

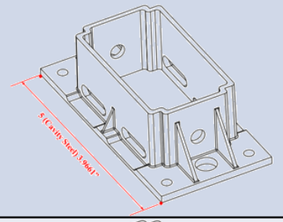
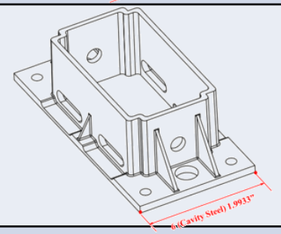
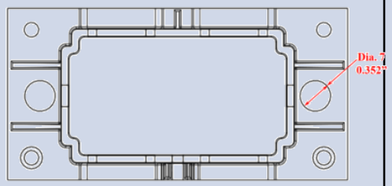
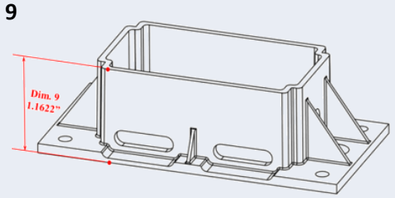
Moldflow Simulations & Observations

- **Moldflow observed that sink mark depths increased at lower Pack Times.**
  - **Moldflow decided to use the parts with 14 sec Pack Time for the measurements.**
- **Simulations were run using:**
  - **ASMI 2016, 3D Mesh for the part and the feed system,**
  - **2007 Material Data (File: mat52245) and**
  - **Dickten Masch Processing Conditions.**
- **Moldflow also decided to re-characterize Lexan 500R:**
  - **The 2007 Material Data was old and at a Bronze Level for Fill / Pack / Warp,**
  - **It only contained Supplemental Data from the manufacturer.**

Lexan 500 R: Measurements for 14 sec Pack Time

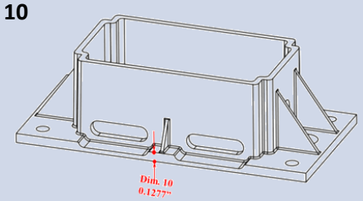
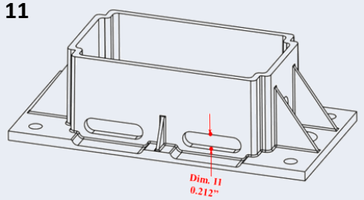
Dimension	Measurements of 5 parts (inch)	Average (inch)	Quoted Steel Distance (inch)	Average Shrinkage (%)	Shrinkage Std. Dev. (%)
1 	2.6947 2.7009 2.6983 2.6964 2.6981	2.6977	2.718	0.747	0.076
2 	2.5250 2.5233 2.5240 2.5229 2.5235	2.5237	2.539	0.603	0.028
3 	1.5336 1.5310 1.5313 1.5313 1.5311	1.5317	1.5553	1.517	0.063
4 	1.3710 1.3706 1.3669 1.3691 1.3696	1.3694	1.383	0.983	0.104

Lexan 500 R: Measurements for 14 sec Pack Time

Dimension	Measurements of 5 parts (inch)	Average (inch)	Quoted Steel Distance (inch)	Average Shrinkage (%)	Shrinkage Std. Dev. (%)
5 	3.9420 3.9436 3.9440 3.9443 3.9432	3.9434	3.9661	0.572	0.02
6 	1.9806 1.9791 1.9798 1.9785 1.9789	1.9794	1.9933	0.697	0.037
7 	0.3515 0.3515 0.3519 0.3518 0.3520	0.3517	0.352	0.085	0.059
9 	1.1535 1.1533 1.1555 1.1524 1.1523	1.1534	1.1622	1.293	0.099

Note: Dimension 8 is on the tapered section and the exact measurement location was unknown, so couldn't be accurately compared to steel dimension.

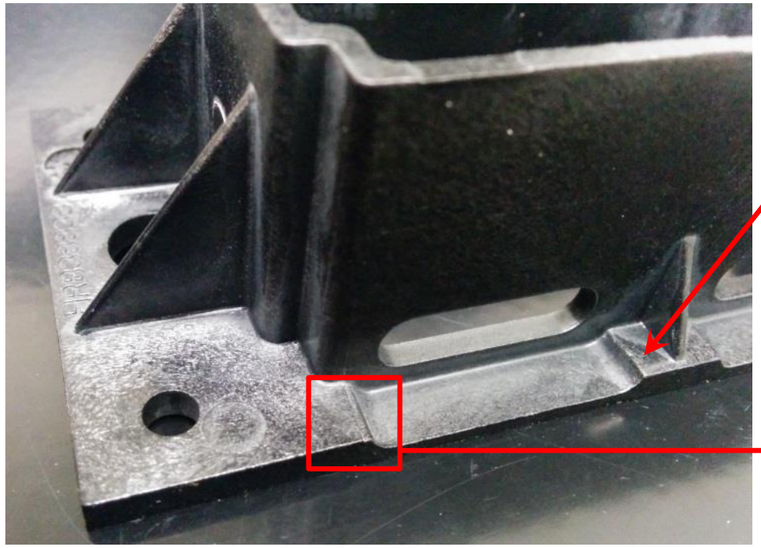
Lexan 500 R: Measurements for 14 sec Pack Time

Dimension	Measurements of 5 parts (inch)	Average (inch)	Quoted Steel Distance (inch)	Average Shrinkage (%)	Shrinkage Std. Dev. (%)
10 	0.1210 0.1215 0.1215 0.1214 0.1217	0.1214	0.1277	4.933*	0.181
11 	0.2115 0.2108 0.2107 0.2100 0.2115	0.2109	0.212	0.519	0.265

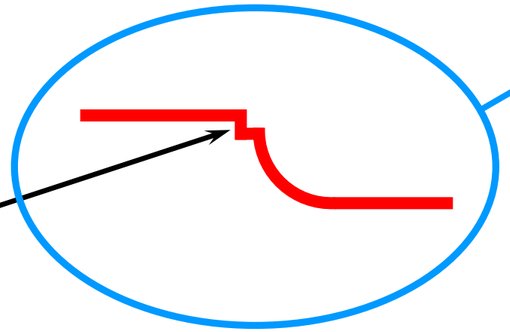
*** Dimension 10 Observation:**

- **3D Scan Measurements for Dimension 10 were much higher than the rest of the measurements.**
- **Moldflow requested verifying the mold steel measurements for Dimension 10.**

Review of Dimension 10



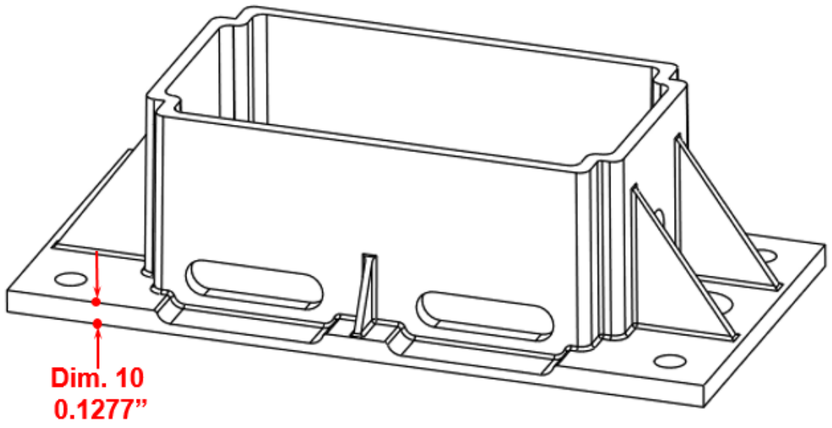
Parts were measured here for Dimension 10



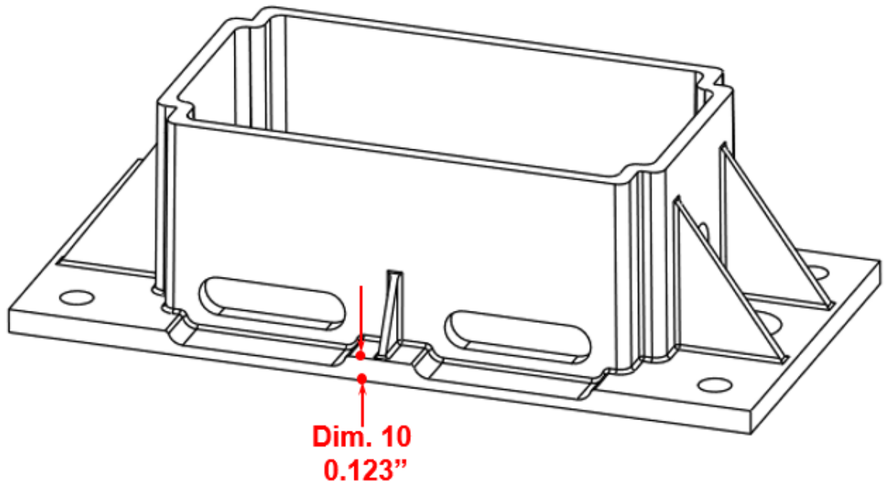
Step down due to the Slide

Review of Dimension 10

Original Steel Measurement



Verified Steel Measurement



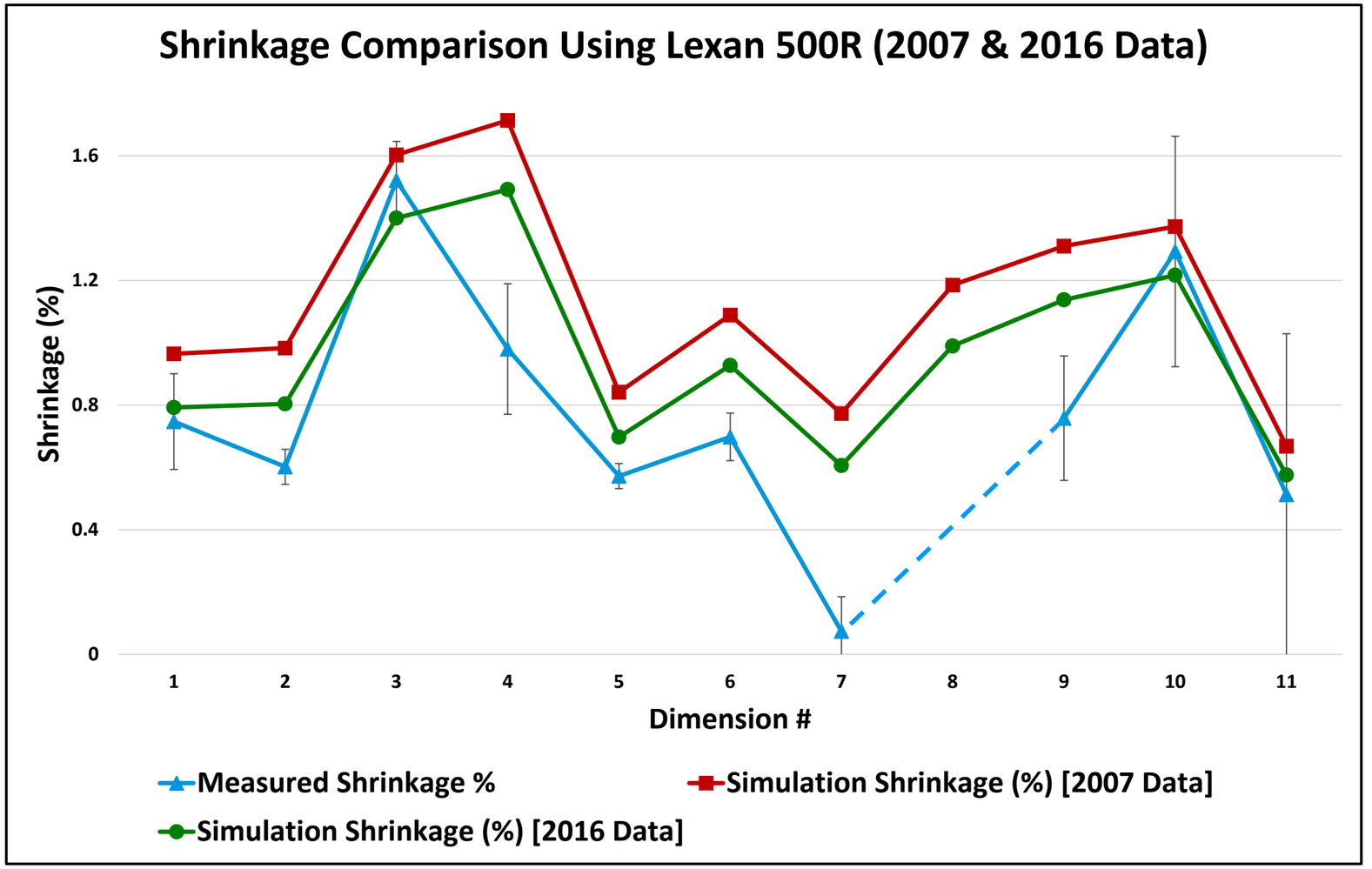
- **The Original measurement was at a different location than the location used for 3D Scan measurements.**
- **Steel re-measurement confirmed the difference between the two locations shown above, due to a Slide.**
- **With the Steel re-measurement, Dimension 10 was adjusted from 0.1277” to 0.123”, resulting in Measured Shrinkage from 4.93% to 1.29%.**

Table II: Measured Vs. Predicted Shrinkage using Lexan 500R

Dim	Measured Shrinkage (%)	Predicted Shrinkage 2007 Data (%)	% Error in Shrinkage (Measured vs 2007 Data)	Predicted Shrinkage 2016 Data (%)	% Error in Shrinkage (Measured vs 2016 Data)	Improvement in Shrinkage Prediction (2016 vs 2007 Data)
1	0.747	0.965	29	0.792	6	23%
2	0.602	0.983	63	0.804	34	30%
3	1.521	1.603	5	1.400	-8	13%
4	0.98	1.714	75	1.492	52	23%
5	0.572	0.841	47	0.697	22	25%
6	0.698	1.089	56	0.927	33	23%
7	0.074	0.773	945	0.606	719	226%
8 *		1.185		0.990		
9	0.758	1.310	73	1.138	50	23%
10	1.293	1.373	6	1.217	-6	12%
11	0.513	0.668	30	0.576	12	18%

*** Dimension 8 was omitted from 3D Scan, because it was on the tapered section and exact measurement location was unknown, so couldn't be accurately compared to steel dimension.**

Comparison of Shrinkages: Measured vs. Predicted



Lexan 500 R: Moldflow Simulations & Findings

- Initially, results showed an average over-prediction of about 42% in shrinkage with the 2007 Data compared to that with the Measured Shrinkage. Though simulation was based on a Bronze level material data (2007 Data).
- Exception: Dimension 7 showed little Measure Shrinkage, presumably due to the internal constraint (cylindrical steel insert) that forms the inside of the hole.
- Simulation predictions improved with the 2016 Data, as the gap narrowed between the Predicted Shrinkage and the Measured Shrinkage.
- With the 2016 Data, the improvement in Predicted Shrinkage was between 12% and 30%. The average over-prediction dropped to a half compared to that with the 2007 Data (42% to 21%).

Conclusions:

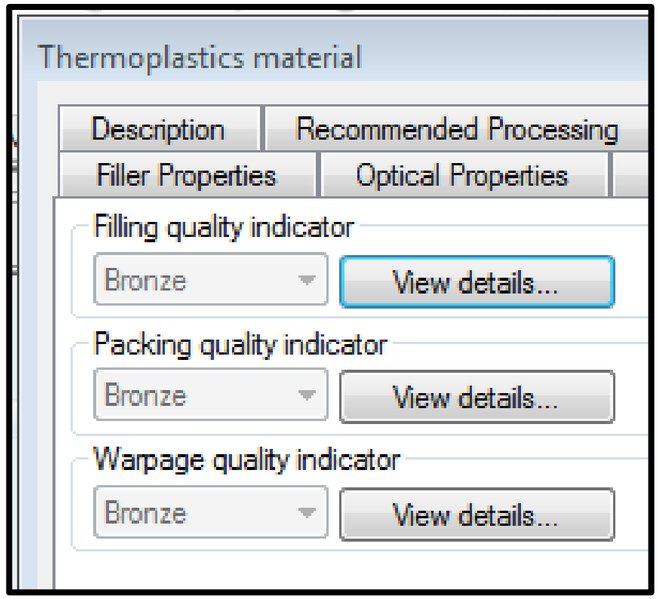
- **Re-characterized material showed improvement in the quality of the material data.**
- **Significant improvement in Specific Heat and Thermal Conductivity data may have contributed predicting more realistic Shrinkage.**
- **With the re-characterized data, the predictions may have improved, however, not sufficiently accurate to cut steel by.**
- **Our project is just a beginning and needs more work to get to where we want to be.**
- **We have also been working with Moldflow to study semi-crystalline materials including a Polyamide and a PBT.**

What Changed for Lexan 500R

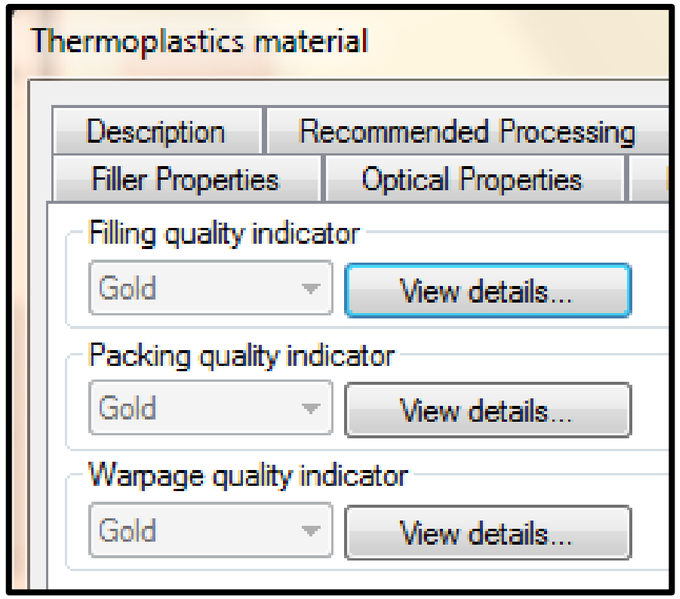
2016 measured data shows the following in comparison to the 2007 values:

- Looking through the old UDB data file, it only contained a limited amount of manufacturer supplied data from 2007 and earlier, with supplemental data for pvT and mechanical. So in terms of our material quality index it was at the bronze level.
- 2016 measured data shows:
  - Higher shear viscosities in high shear region.
  - Average of CTE values is lower, so should result in lower 3D shrinkages which better matched the part shrinkages.
  - Multi-Point Thermal Conductivity and Specific Heat data rather than a Single Point.
  - PvT curves showed a steeper decline in Specific Volume with a drop in Temperatures (molten region).
  - Additional Data for Mold Shrinkage that was absent from 2007 data (Slide 46)

Lexan 500R: Data Quality Indicator

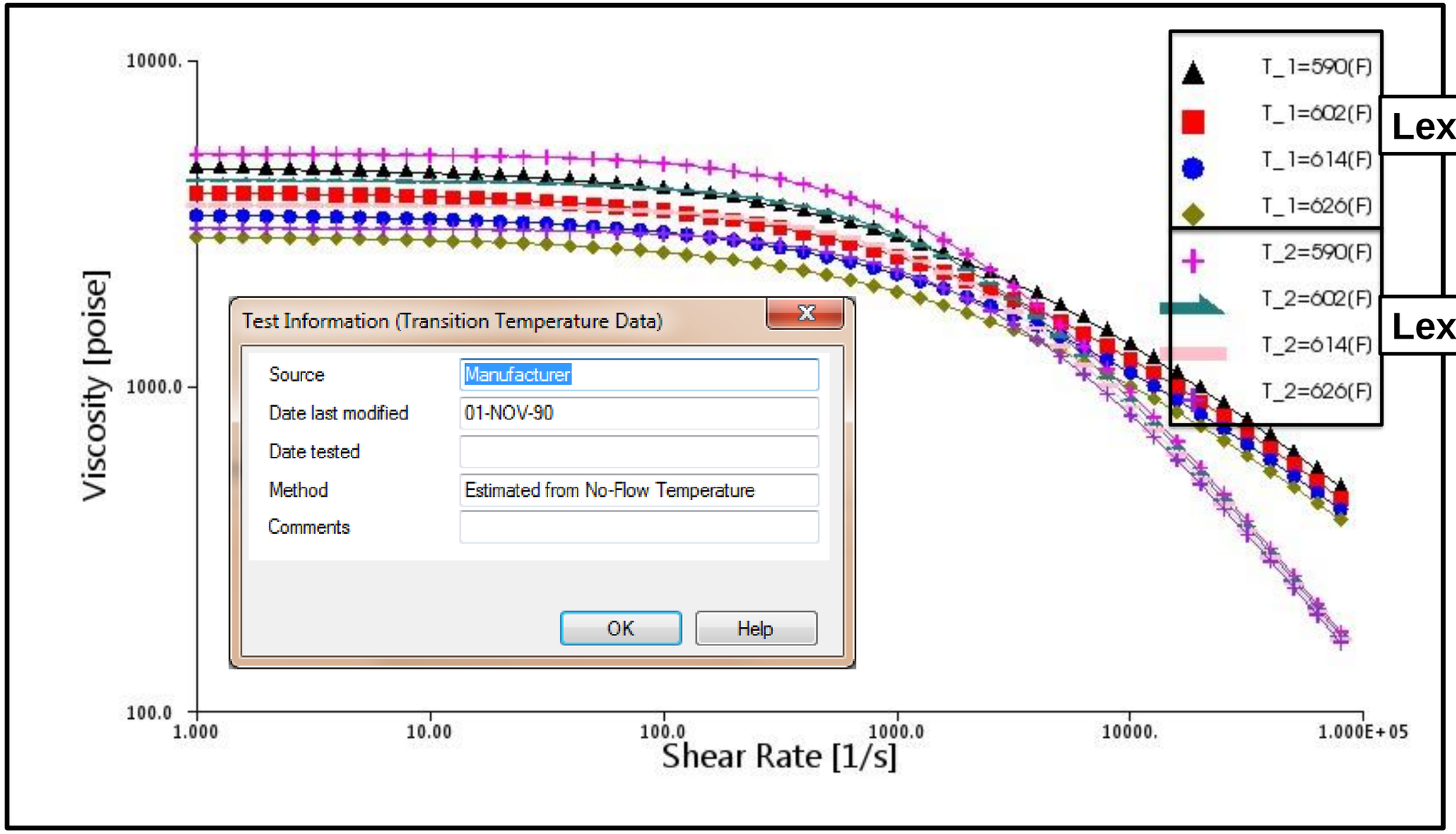


2007 Data: Bronze



2016 Data: Gold

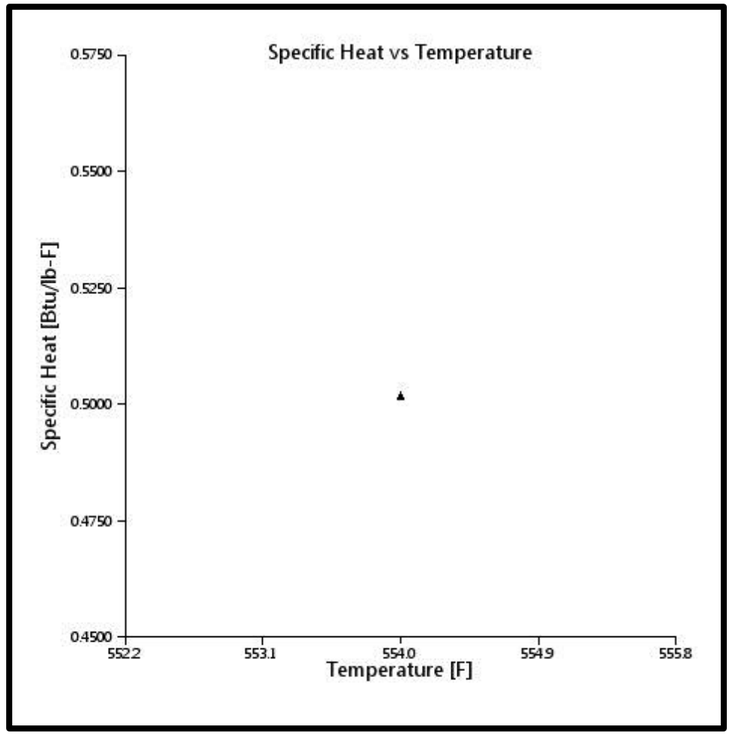
Shear Rater vs. Viscosity Comparison



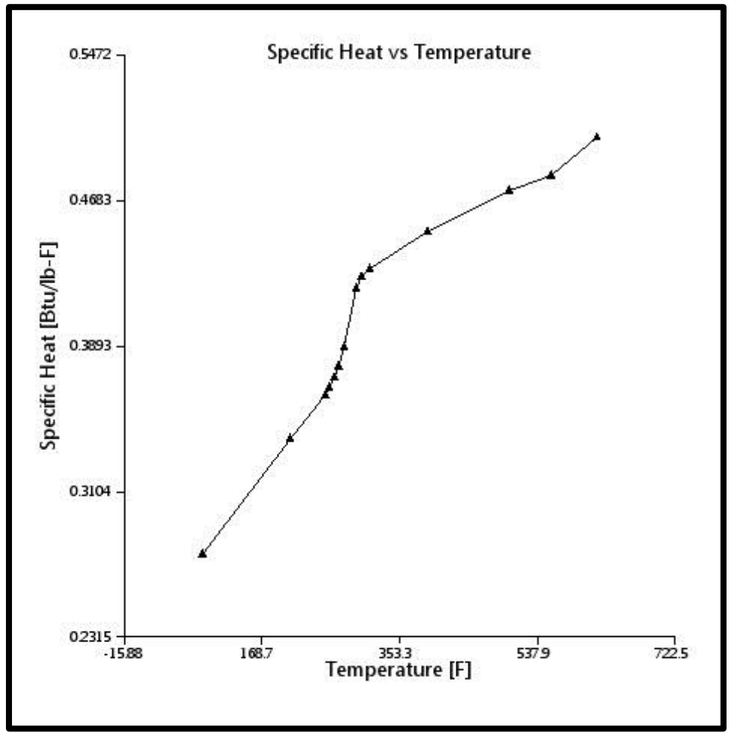
Lexan 500R 2016 Data

Lexan 500R 2007 Data

Specific Heat vs. Temperature Comparison

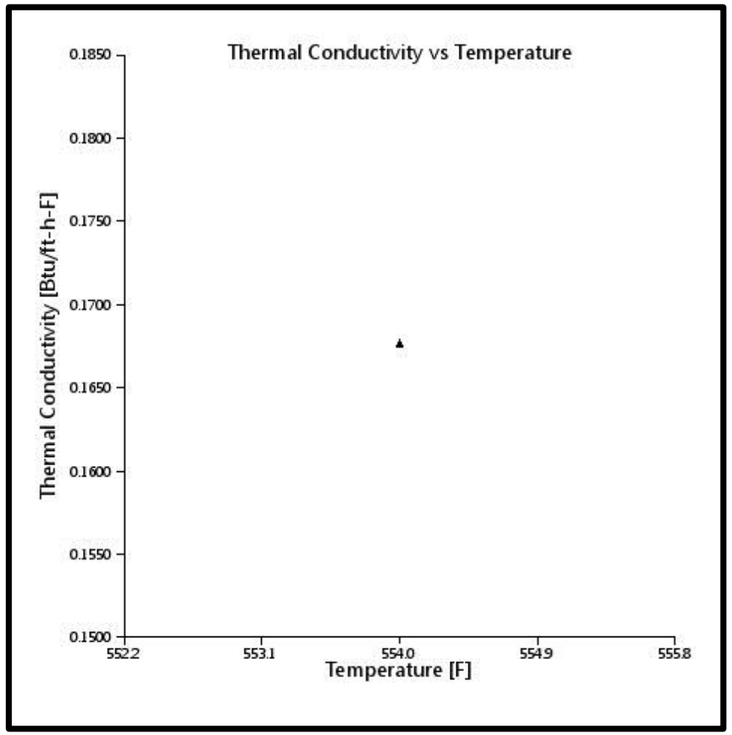


2007 Data

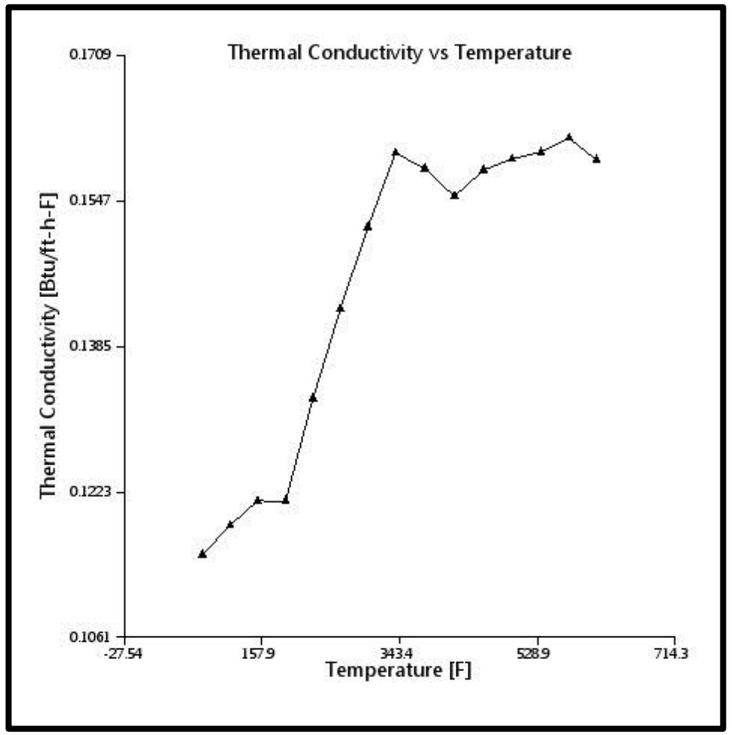


2016 Data

Thermal Conductivity vs Temperature Comparison

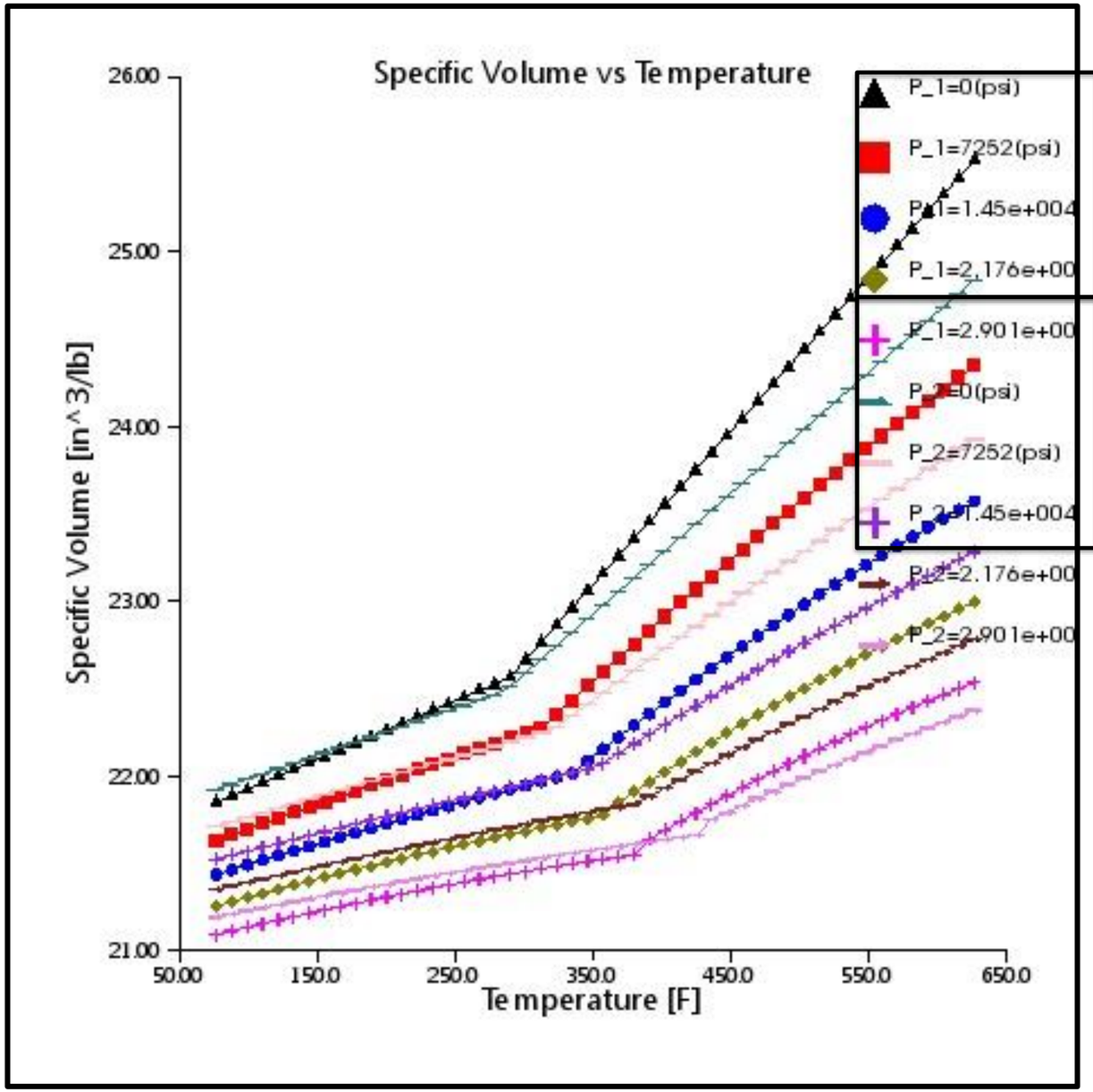


2007 Data



2016 Data

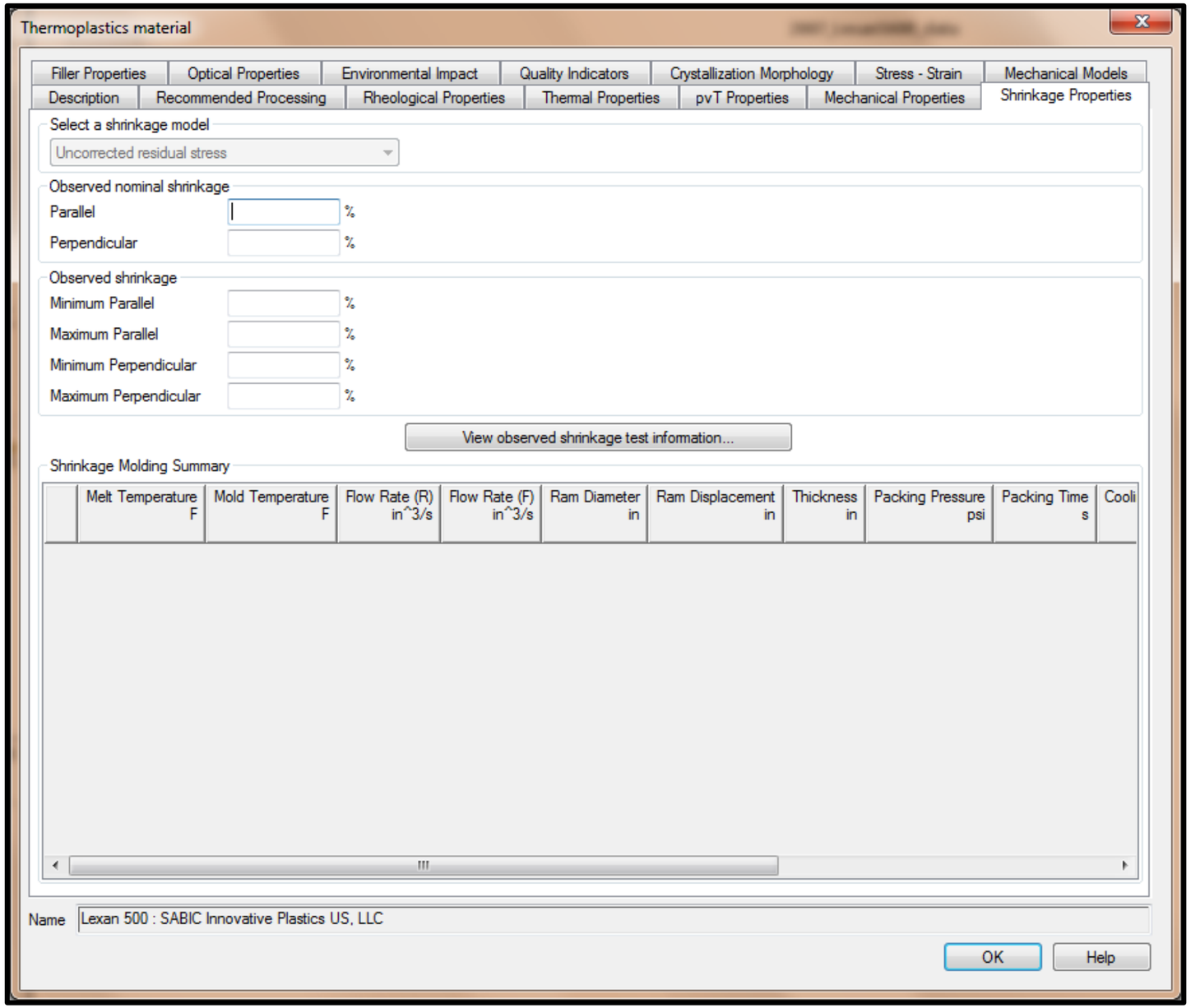
Specific Volume vs Temperature Comparison



Lexan 500R 2016 Data

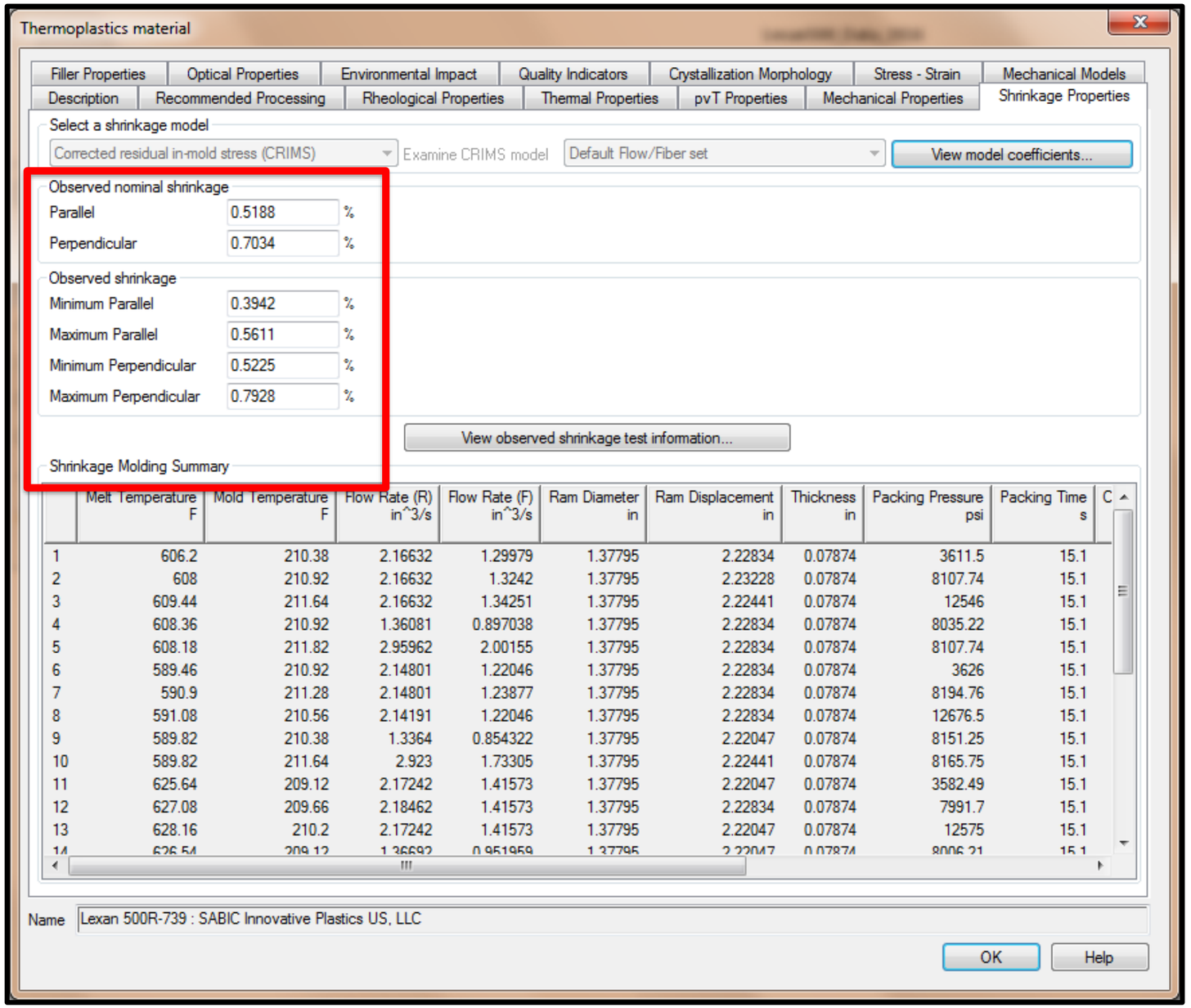
Lexan 500R 2007 Data

Lexan 500R: Shrinkage Properties for 2007 Data



Lexan 500R: Shrinkage Properties for 2016 Data

The latest tests have better captured the Shrinkage Properties Data that was absent with the 2007 Data.



	Melt Temperature F	Mold Temperature F	Flow Rate (R) in^3/s	Flow Rate (F) in^3/s	Ram Diameter in	Ram Displacement in	Thickness in	Packing Pressure psi	Packing Time s
1	606.2	210.38	2.16632	1.29979	1.37795	2.22834	0.07874	3611.5	15.1
2	608	210.92	2.16632	1.3242	1.37795	2.23228	0.07874	8107.74	15.1
3	609.44	211.64	2.16632	1.34251	1.37795	2.22441	0.07874	12546	15.1
4	608.36	210.92	1.36081	0.897038	1.37795	2.22834	0.07874	8035.22	15.1
5	608.18	211.82	2.95962	2.00155	1.37795	2.22834	0.07874	8107.74	15.1
6	589.46	210.92	2.14801	1.22046	1.37795	2.22834	0.07874	3626	15.1
7	590.9	211.28	2.14801	1.23877	1.37795	2.22834	0.07874	8194.76	15.1
8	591.08	210.56	2.14191	1.22046	1.37795	2.22834	0.07874	12676.5	15.1
9	589.82	210.38	1.3364	0.854322	1.37795	2.22047	0.07874	8151.25	15.1
10	589.82	211.64	2.923	1.73305	1.37795	2.22441	0.07874	8165.75	15.1
11	625.64	209.12	2.17242	1.41573	1.37795	2.22047	0.07874	3582.49	15.1
12	627.08	209.66	2.18462	1.41573	1.37795	2.22834	0.07874	7991.7	15.1
13	628.16	210.2	2.17242	1.41573	1.37795	2.22047	0.07874	12575	15.1
14	626.54	209.12	1.36692	0.951959	1.37795	2.22047	0.07874	8006.21	15.1

Thank you.

Questions ???