Material Characterization

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Lab Manager

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AIM Institute
Autodesk® Moldflow® Instructor

Introductions

- Eric Bowersox
  - Lab Manager, Beaumont Advanced Processing
  - B.S. Degree – Plastics Engineering Technology - Penn State Behrend
  - 14 Years in the Plastics Industry
    - 3 Years Mold Designer
    - 11 Years Process Engineer/Trainer
- Jennifer Schmidt
  - Moldflow® Instructor, American Injection Molding (AIM) Institute
  - Design Engineer, Beaumont Technologies
  - B.S. Degree – Plastics Engineering Technology - Penn State Behrend
  - 19 Years in the Plastics Industry
    - 11 Years performing Moldflow Analyses
    - Autodesk Moldflow Expert Certified

Learning Objectives

- Why Beaumont?
  - The history behind the acquisition
- How is material characterized?
  - What tests are performed
- Where is it used in the software?
  - How the quality of material data affects accuracy

Quick Questions

- What makes Autodesk Moldflow valuable?
  - The accuracy of the simulation
- What makes Autodesk Moldflow accurate?
  - The user
  - The software
  - Material characterization
- What makes material characterization accurate?

Beaumont History

Beaumont Advanced Processing

Beaumont Technologies

1999

American Injection Molding Institute

2014

Beaumont Development

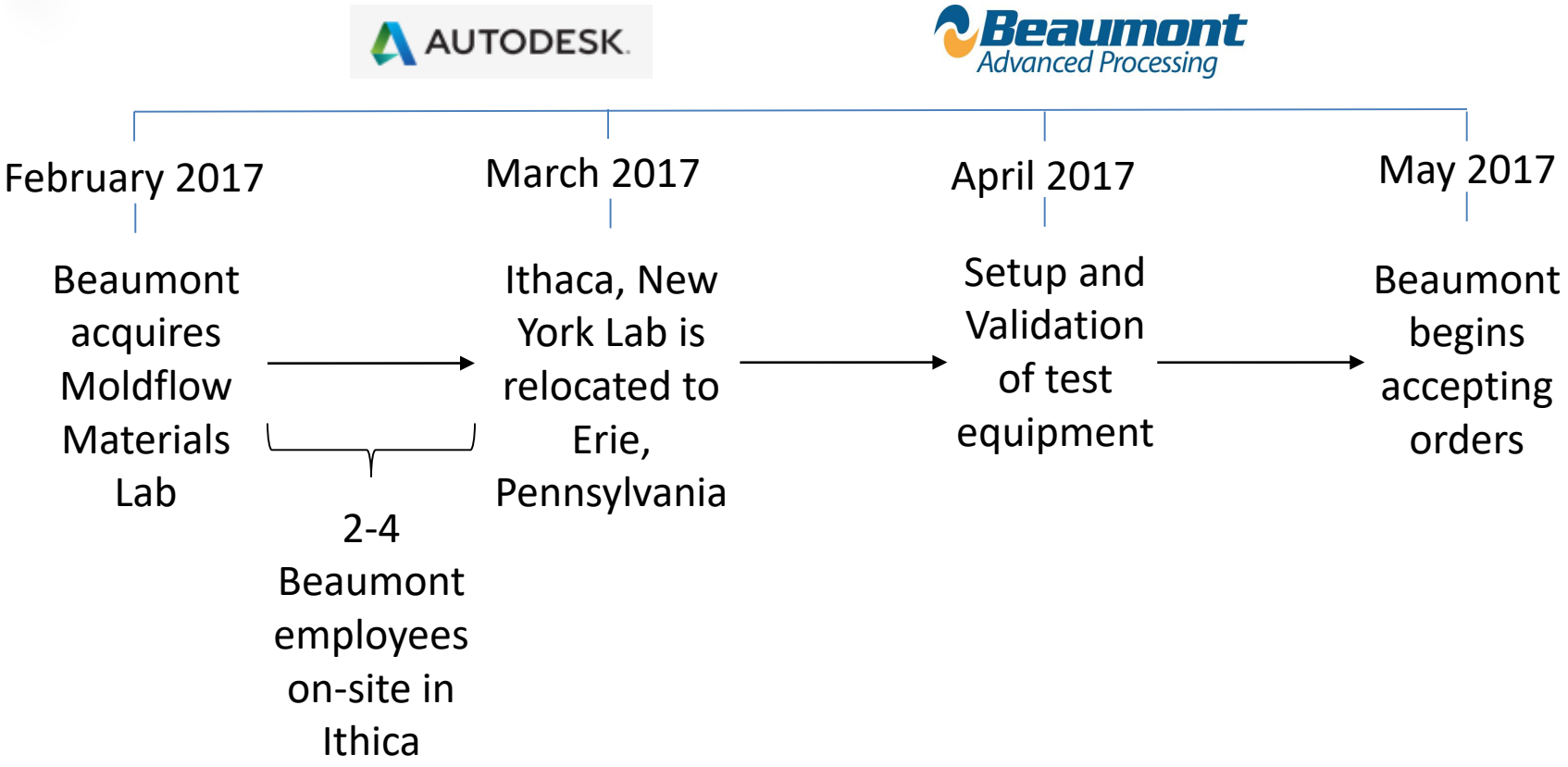
2005

AUTODESK.

Beaumont Advanced Processing

2012

Acquisition Timeline



Beaumont Advanced Processing Lab

- What makes material characterization accurate?
  - Testing equipment
  - Testing procedures
  - Trained technicians
- 80% of all testing utilizes molded specimens
  - Moisture content when molding
  - Residence time
  - Actual melt temperature
  - Combined effects on material degradation
- Without properly manufactured test specimens

Beaumont Advanced Processing Lab

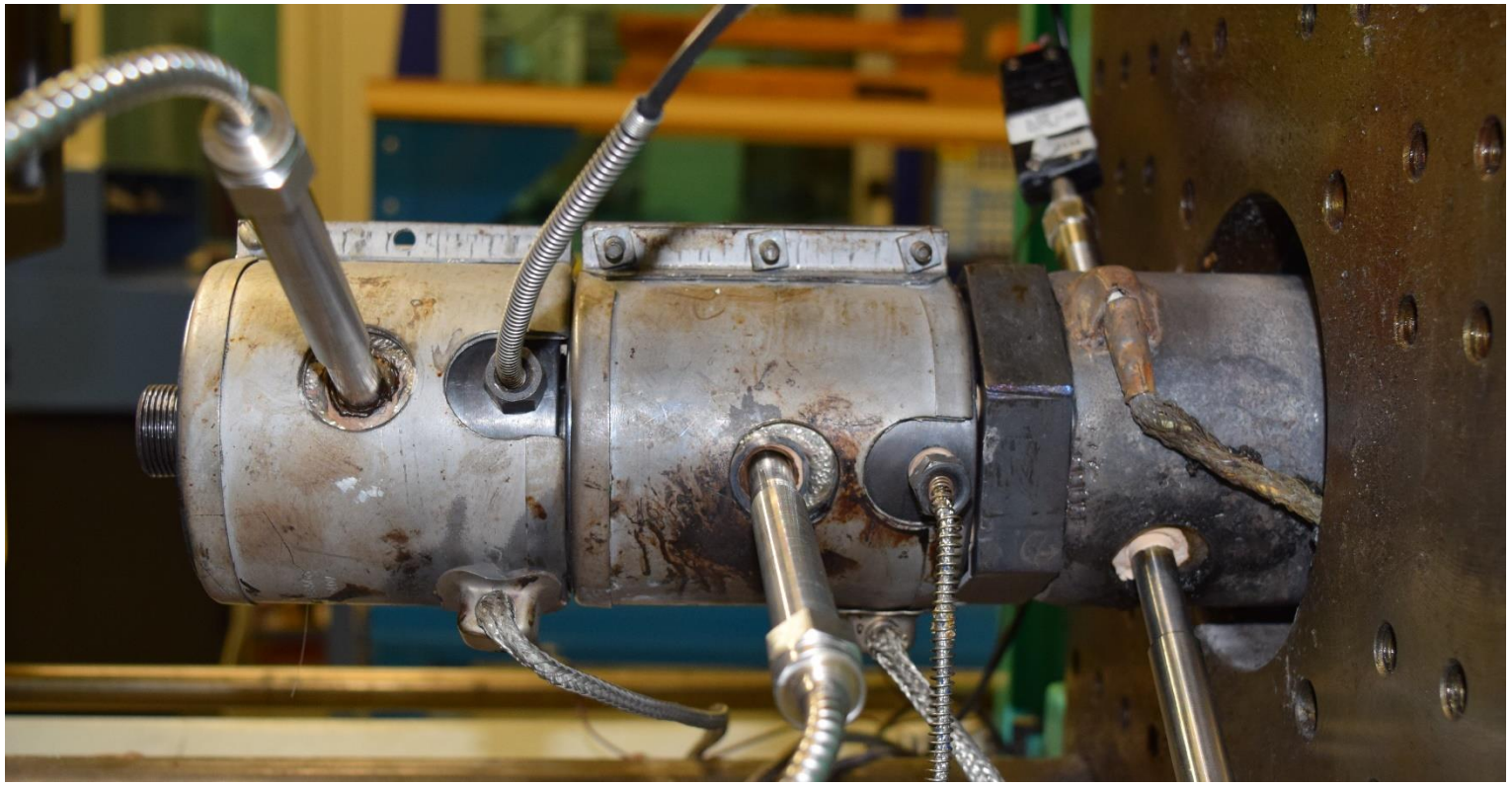
- Current testing offered:
  - Thermal Expansion (CTE): Longitudinal and Transverse
  - Specific Heat (Cp): Transition and Ejection temperatures
  - Shrinkage Correlation (Corrected residual in mold stress - CRIMS)
  - Mold Verification
  - PVT
  - Melt and Solid Density
  - Viscosity: IMR and Capillary
  - Pressure Dependent Viscosity
  - Mechanicals: Tensile Modulus and Poisson's Ratio

Viscosity- IMR

Equipment- Arburg Allrounder 270s

Viscosity- IMR

- Additional values captured during IMR testing
  - Juncture Loss
  - Extensional Viscosity



Viscosity- Capillary Rheometer

Equipment- CEAST Smart RHEO
Test Standard- ASTM D3835 Standard Test Method for Determination of Properties of Polymeric Materials by Means of a Capillary Rheometer

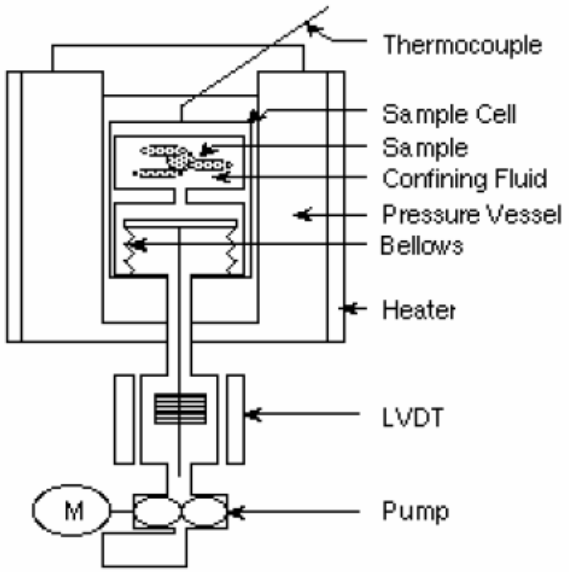
Capillary Vs. IMR Viscosity Testing

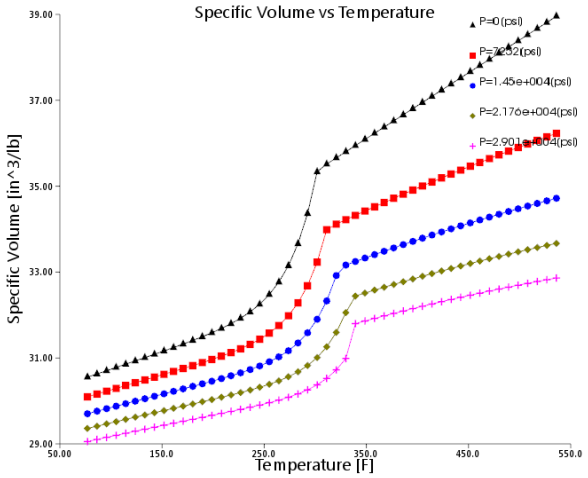
- Capillary rheology
- Pros:
  - Most widely available
  - Good reproducibility on most polymers
  - Standardized (ASTM D-3835)
- Cons:
  - No shear or pressure during plastication
  - Long dwell times (5-6 minutes) prior to testing
  - Long test times (1 - 4 minutes)
  - May not represent in-mold polymer behavior
  - Does not test long fibers accurately

- IM rheology
- Pros:
  - Plastication similar or identical to injection molding process
  - Plastication quickly through shear and pressure, also better mixing
  - Higher shear rates 60,000 reciprocal sec
  - Short dwell (residence) times (0.5 - 2 min.)
  - Short test times (<< 1 minute)
- Cons:
  - Temperature transient prior to test start
  - Requires more material
  - Long fiber breakage due to screw

Melt & Solid Density

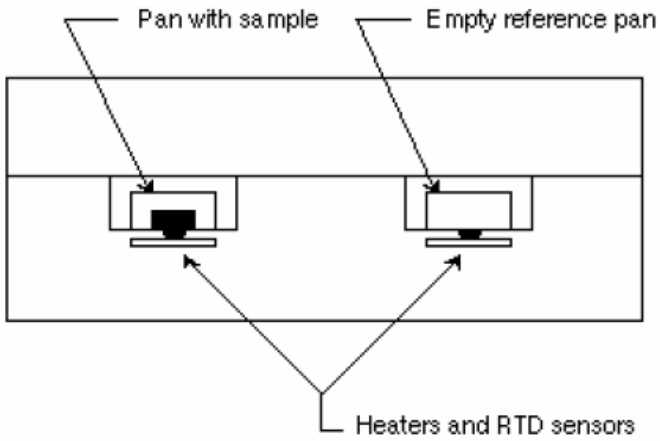
- **Equipment-** Gnomix PVT Apparatus

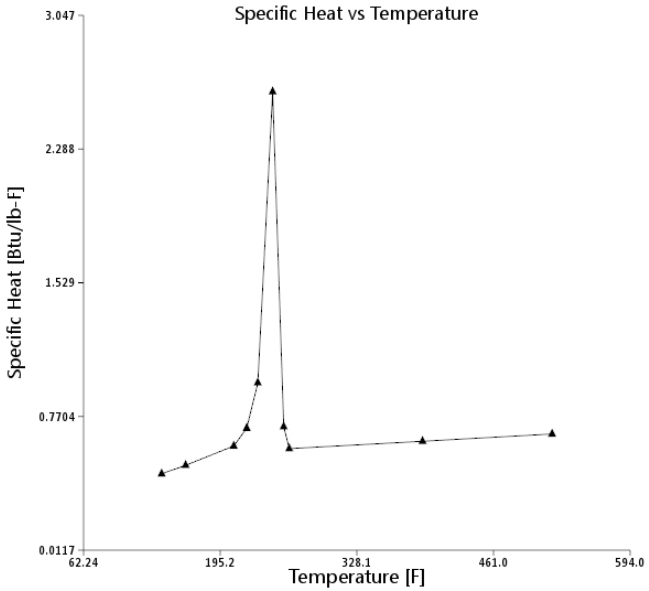




Specific Heat

- **Equipment-** Diamond DSC
- **Test Standards-**
  - ASTM E1269 Determination of Specific Heat Capacity by DSC



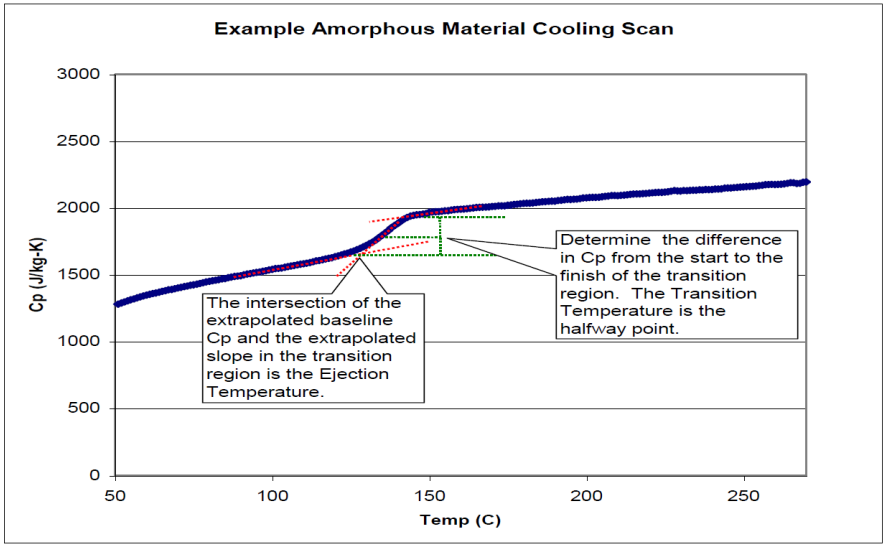


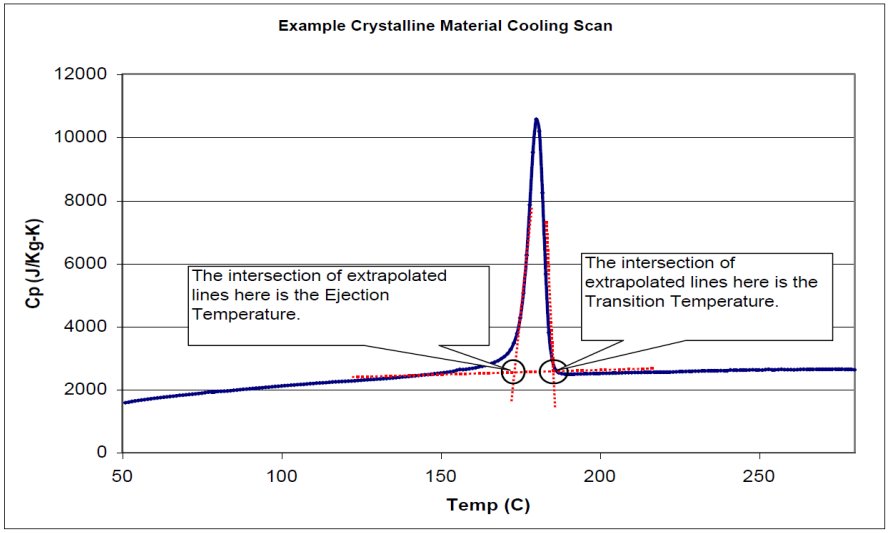
Transition and Ejection Temperatures

Equipment- Diamond DSC

Test Standards-

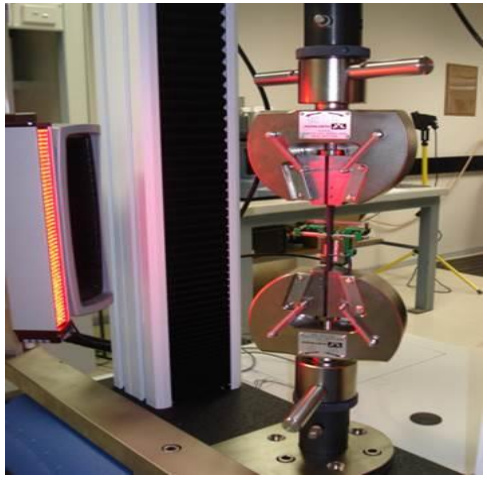
ASTM D3418 Transition Temperatures of Polymers by Differential Scanning Calorimetry





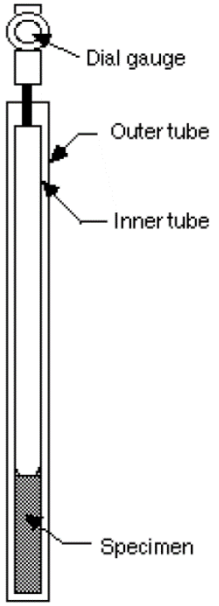
Tensile Modulus and Poisson's Ratio

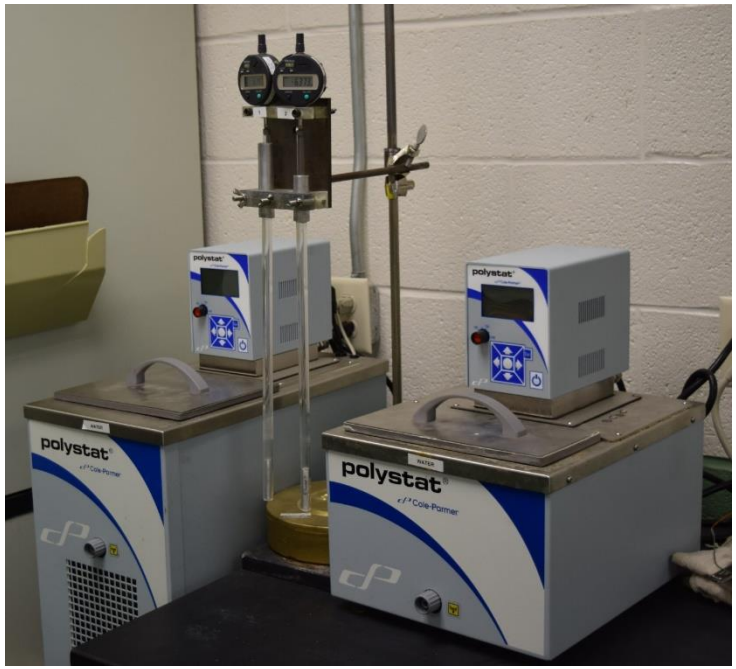
- **Equipment-** MTS Sintech 5/G
- **Test Standards-**
  - ASTM D638 Standard Test Method for Tensile Properties of Plastics
  - ASTM E132 Standard Test Method for Poisson's Ratio at Room Temperature



Coefficient of Linear Thermal Expansion

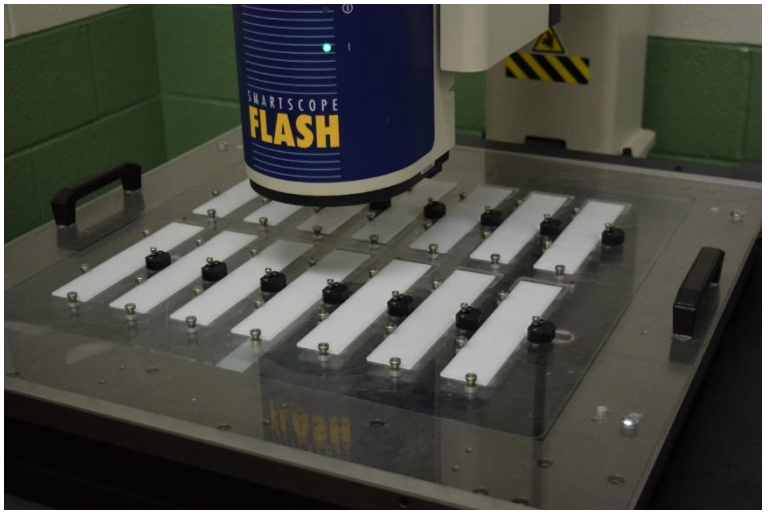
- **Test Standards-**
  - ASTM D696 Coefficient of Linear Thermal Expansion of Plastics
  - ISO-11359 Measurement of Conductive Liquid Flow in Closed Conduits

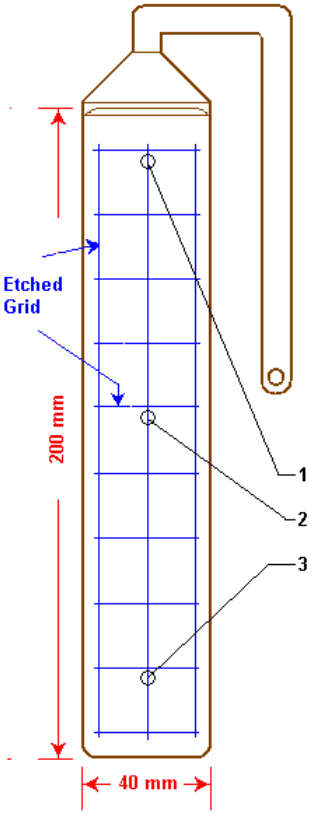




Shrinkage

- **Equipment-** Krauss Maffei KM 160-1000CX; OGP Flash 400





Mold Verification

Equipment- Krauss Maffei KM 160-1000CX

Pressure Dependent Viscosity

- D3 term in Moldflow

Factors that Affects Accuracy

- Solver Technology

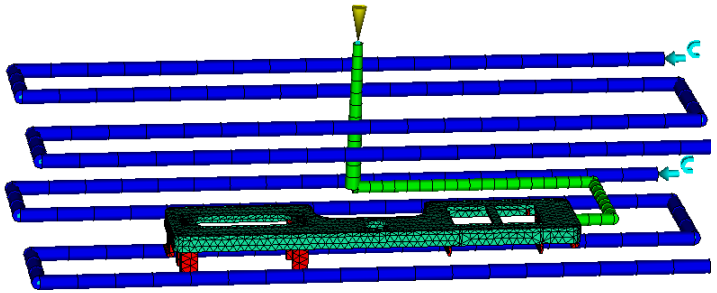
$$u_{t+\Delta t} = u_t + \dot{u}_t \Delta t + \left[\left(\frac{1}{2} - \alpha\right)\ddot{u}_t + \alpha\ddot{u}_{t+\Delta t}\right]\Delta t^2$$

$$\Leftrightarrow u_{t+\Delta t} - u_t + \dot{u}_t \Delta t - \left(\frac{1}{2} - \alpha\right)\ddot{u}_t \Delta t^2 = \alpha\ddot{u}_{t+\Delta t}\Delta t^2$$

$$\Leftrightarrow \ddot{u}_{t+\Delta t} = \frac{u_{t+\Delta t} - u_t}{\alpha\Delta t^2} - \frac{\dot{u}_t}{\alpha\Delta t} - \left(\frac{1/2 - \alpha}{\alpha}\right)\ddot{u}_t$$

$$\text{mit } a_0 = \frac{1}{\alpha\Delta t^2};\quad a_2 = \frac{1}{\alpha\Delta t};\quad a_3 = \frac{1}{2\alpha} - 1$$

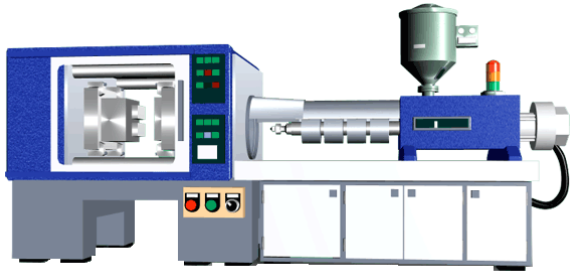
$$\ddot{u}_{t+\Delta t} = a_0\left(u_{t+\Delta t} - u_t\right) - a_2\dot{u}_t - a_3\ddot{u}_t$$



- Component Modeling

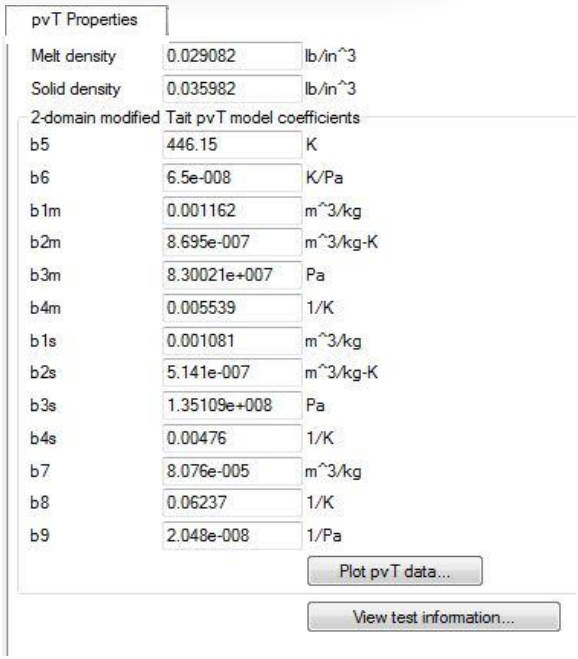
- Material Data

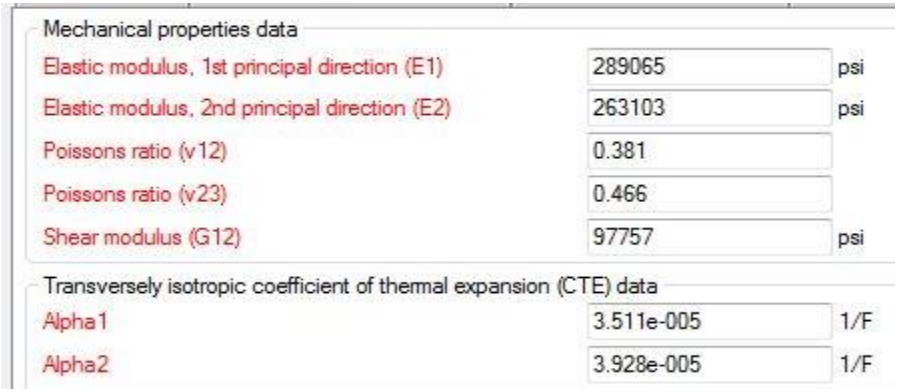
- Process Conditions



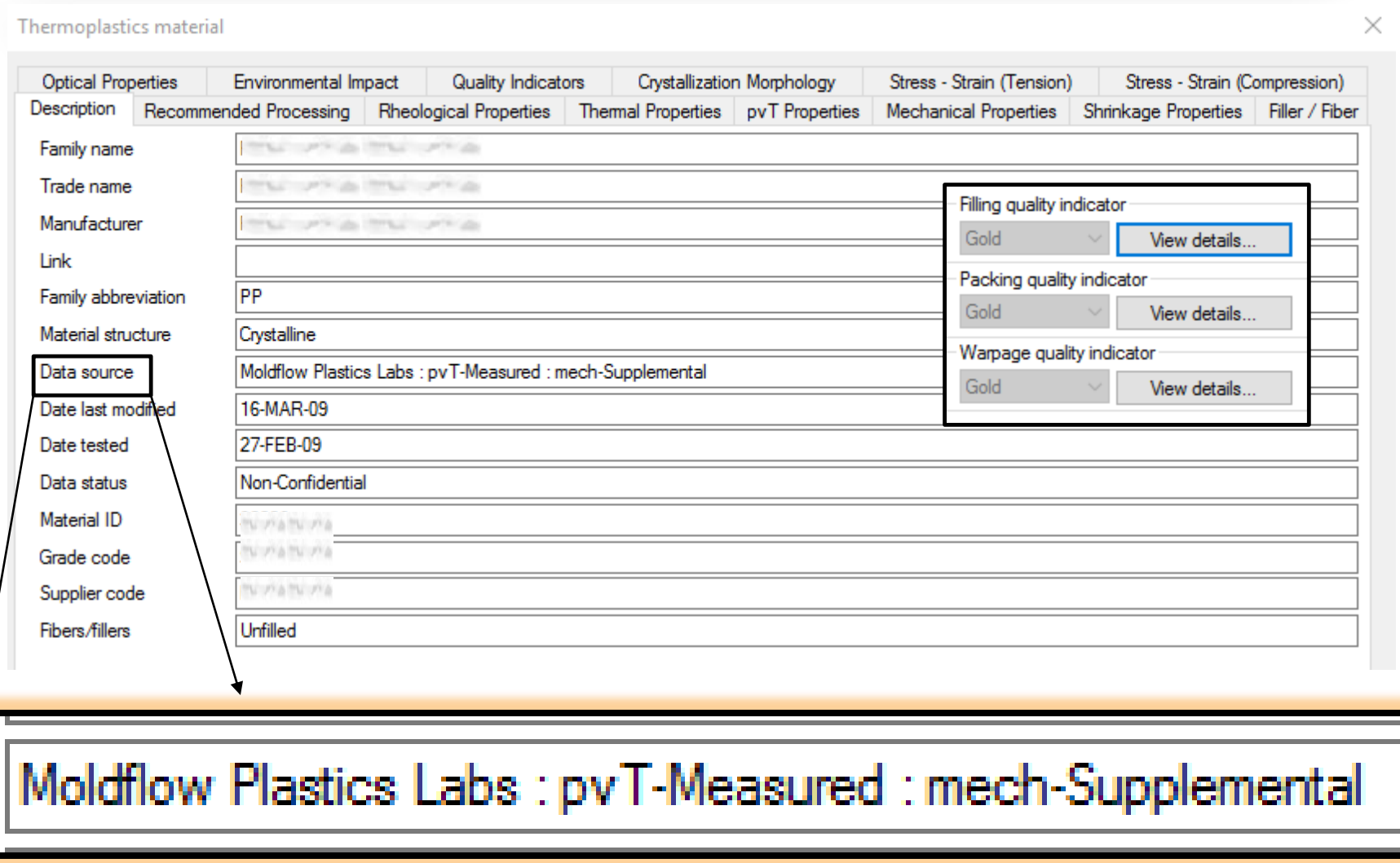
Material Properties

- Material Characterization
  - When was it tested?
    - Material formulations may have changed
  - What data is available?
    - Bronze, silver, gold (Autodesk Moldflow)
      - Indicates level of characterization
  - Data (Moldflow .udb file)
    - PVT
    - Melt density
    - Thermal conductivity
    - Specific heat
    - Transition temperatures
    - Etc…

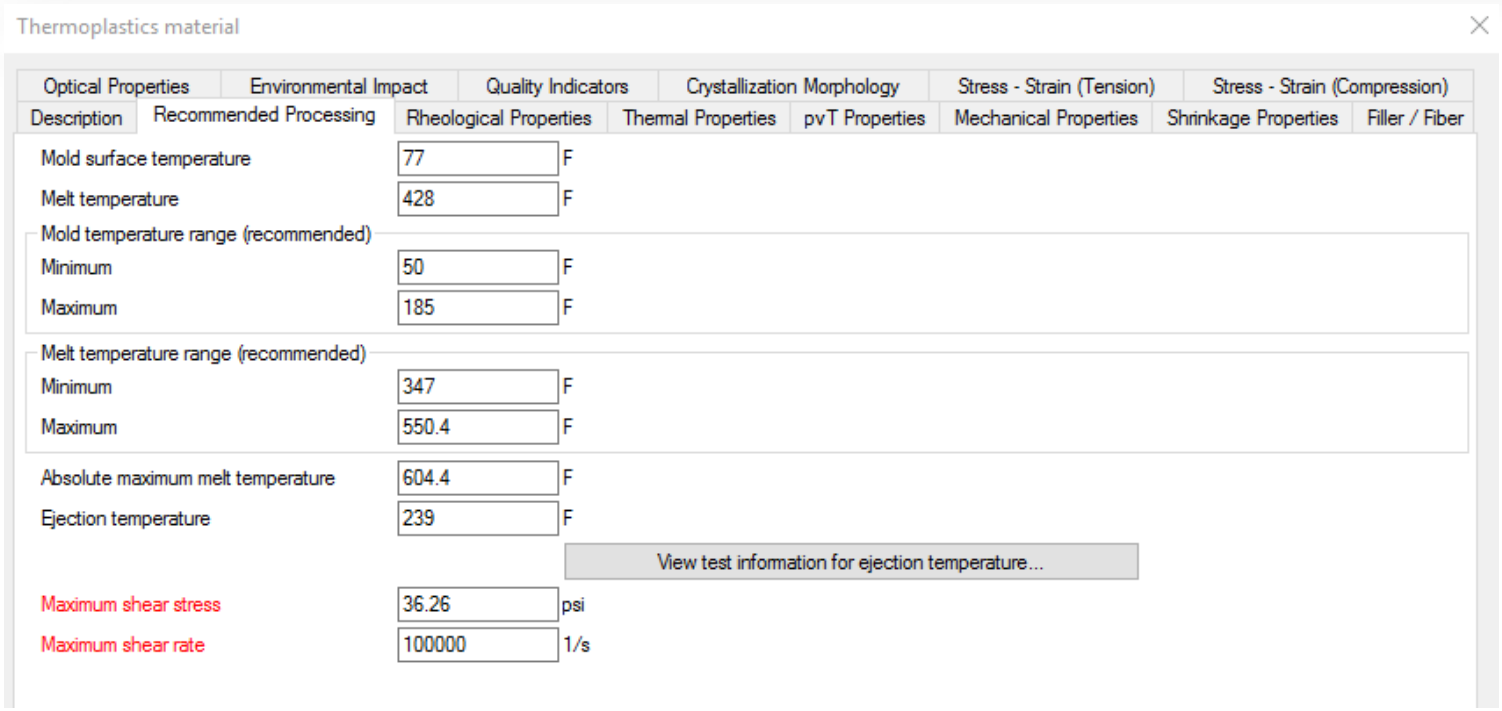




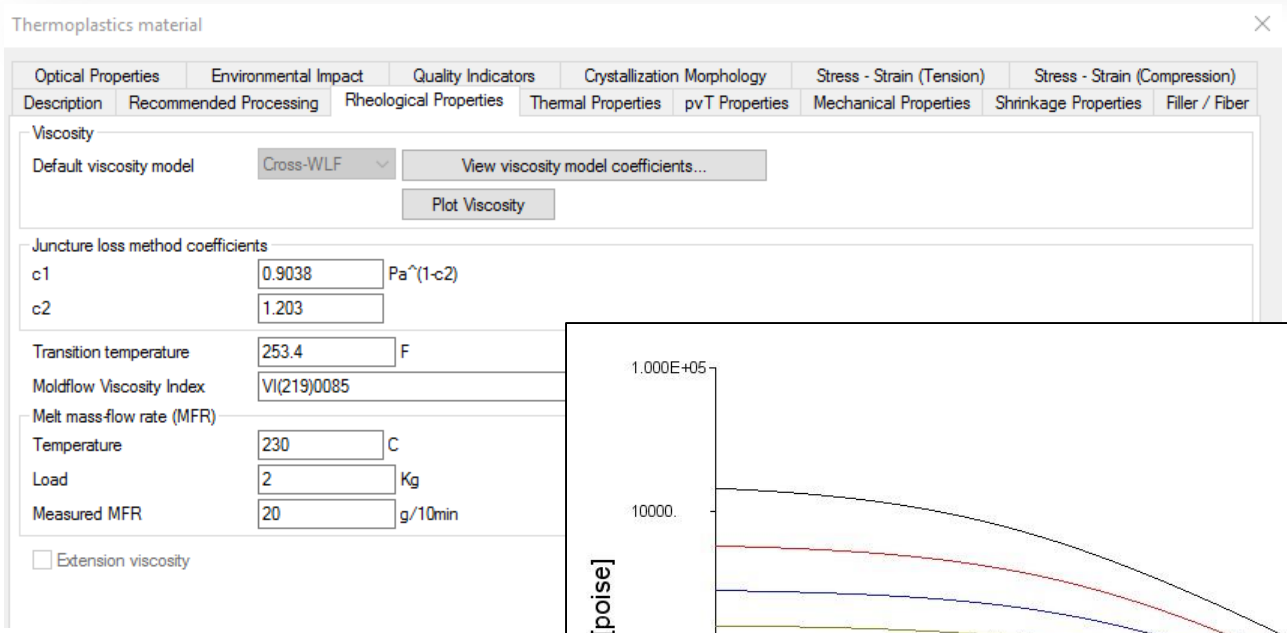
Description

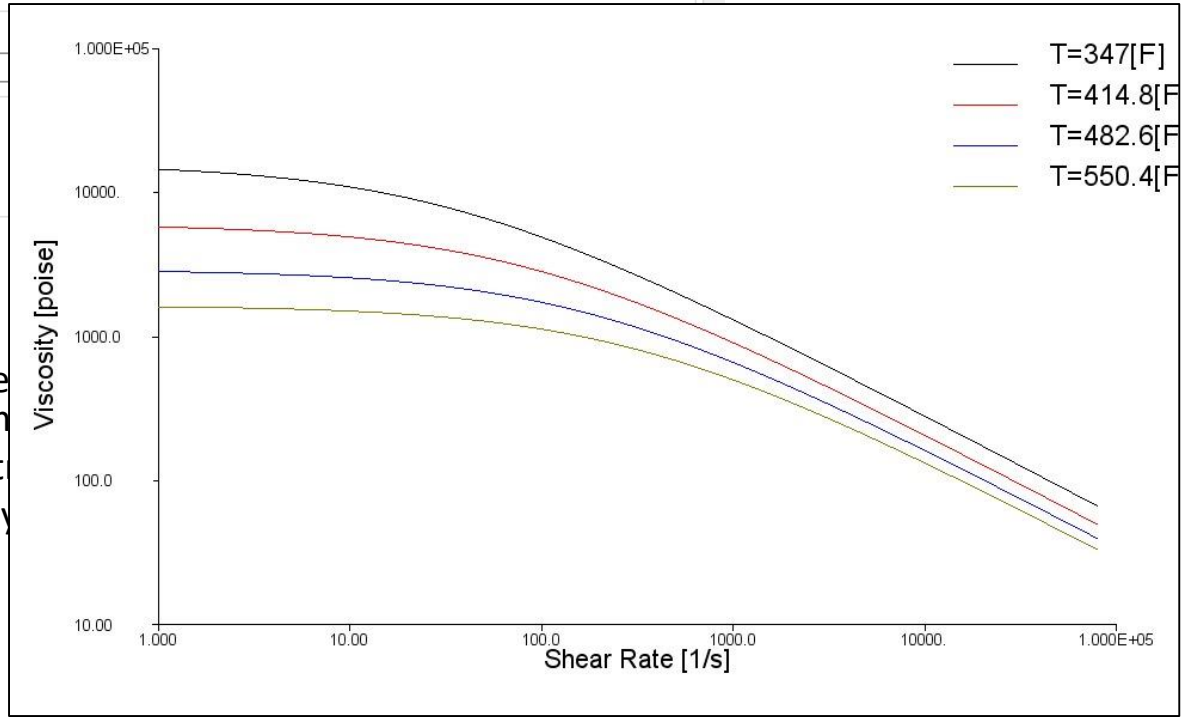


Processing


Thermoplastics material
Optical Properties
Environmental Impact
Quality Indicators
Crystallization Morphology
Stress - Strain (Tension)
Stress - Strain (Compression)
Description
Recommended Processing
Rheological Properties
Thermal Properties
pvT Properties
Mechanical Properties
Shrinkage Properties
Filler / Fiber
Mold surface temperature
77
F
Melt temperature
428
F
Mold temperature range (recommended)
Minimum
50
F
Maximum
185
F
Melt temperature range (recommended)
Minimum
347
F
Maximum
550.4
F
Absolute maximum melt temperature
604.4
F
Ejection temperature
239
F
View test information for ejection temperature...
Maximum shear stress
36.26
psi
Maximum shear rate
100000
1/s

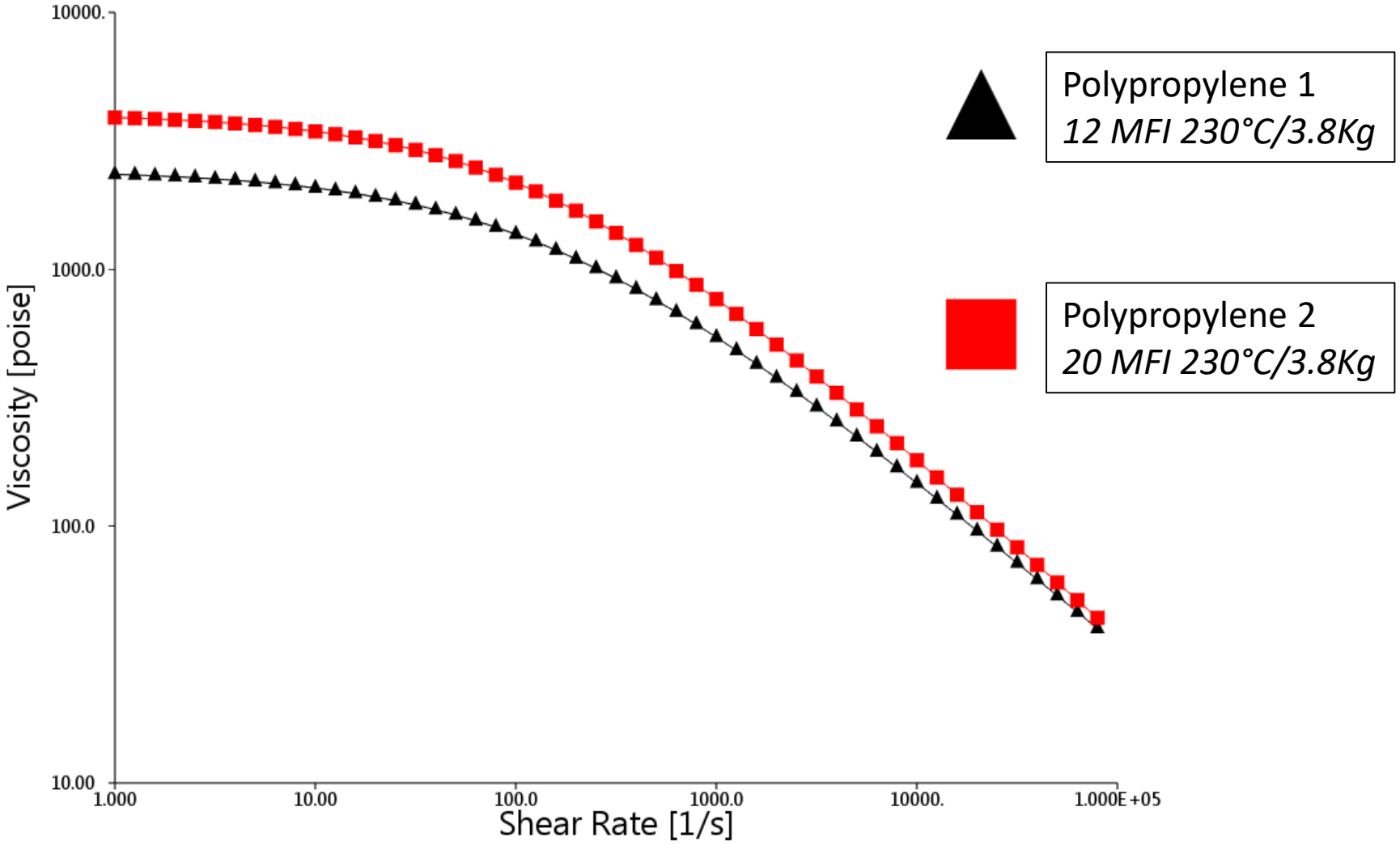
Rheological





- Transition temperature is the
  polymer transitions from a m
  - Amorphous: (Tg) glass-t
  - Semi-Crystalline: (Tc) cry

Comparing Viscosity



Juncture Loss

- The pressure drop observed when the melt passes through contractions in the feed system
- Used in beam feed systems for MP, DD or 3D
- Helps improve pressure prediction

- If JLC are not available on your selected material
  - run the analysis with and w/o JLC using typical values
- If the analysis results show that juncture loss is significant
  - Get the material characterized for JLC

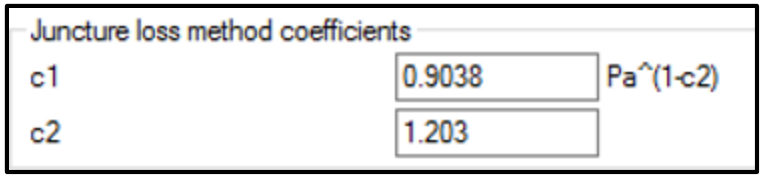


Table C-1. Bagley Constants for Juncture-Loss Calculations

Generic Class	C1	C2
POM	2.20e-05	2.055
PE-HD	6.79e-02	1.399
LCP	1.94e+01	1.000
PE-LD	3.37e-01	1.321
PA 66	2.15e+01	1.000
PBT	2.75e-02	1.577
PC	1.15e+01	1.000
PET	8.26e+00	1.099
PP	3.60e-05	2.098
PPS	3.31e+00	1.075
PS	3.30e-05	2.108
PC|ABS	5.26e+00	1.000
PBT|PET	1.31e+01	1.019

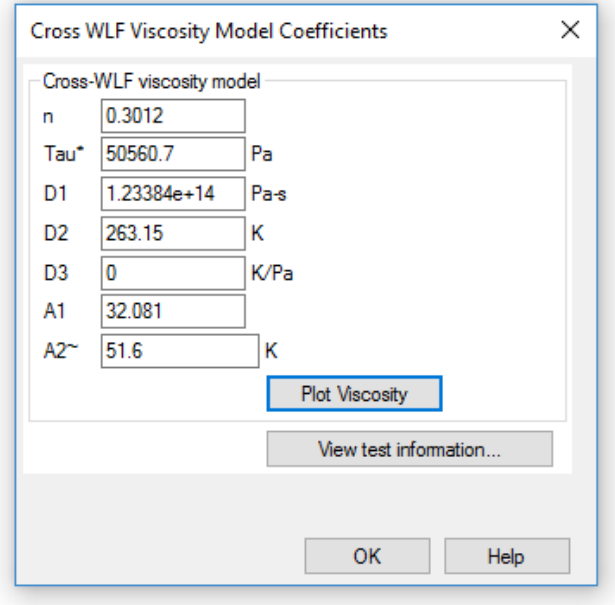
Extensional Viscosity

- A measure of the resistance of a polymer to stretching forces
  - When a polymer flows through a large cross section to a smaller one, it will be stretched longitudinally, which will result in a pressure drop.
- Pressure drop due to extensional effects often occurs when a material flows from a large runner into a very small gate.
- Only used in 3D elements
- Helps improve pressure prediction

- Use when the extension rate is higher than 200 1/s
  - as the EV may significantly increase the injection pressure required

Pressure Dependence

- Typically D3 for Cross-WLF = zero
- Increases pressure prediction
- Not in the standard testing
  - Must request specific characterization



- Important for:
  - Thin wall molding, less than 2mm
  - Flow length to thickness ratios are greater than 100
  - Injection pressures are greater than 100 MPa
  - Polymers that exhibit a tendency for pressure dependence

Source: Mahishi, M., Material Characterization for Thin Wall Molding Simulation, ANTEC 1998
Eric Foltz, Influence of Material Characterization & Modeling For Improved Pressure Prediction , AU 2014

pvT

Thermoplastics material

Optical Properties | Environmental Impact | Quality Indicators | Crystallization Morphology | Stress - Strain (Tension) | Stress - Strain (Compression)

Description | Recommended Processing | Rheological Properties | Thermal Properties | pvT Properties | Mechanical Properties | Shrinkage Properties | Filler / Fiber

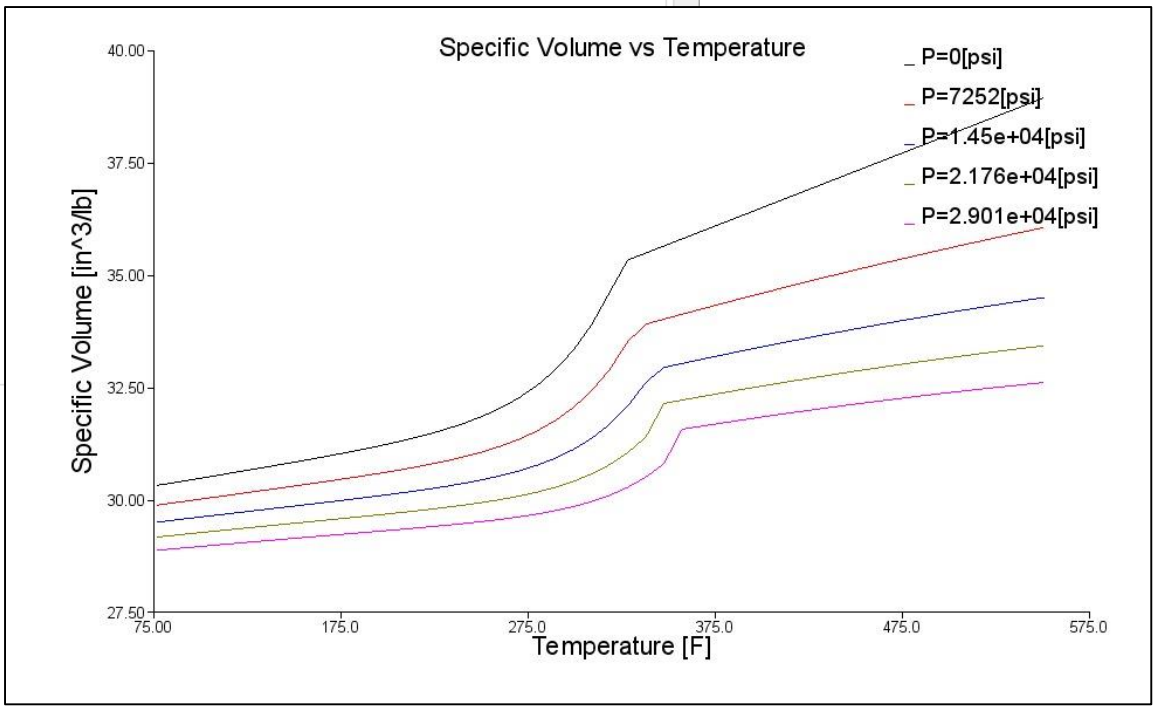
Melt density	0.027058	lb/in^3
Solid density	0.032974	lb/in^3

2-domain modified Tait pvT model coefficients

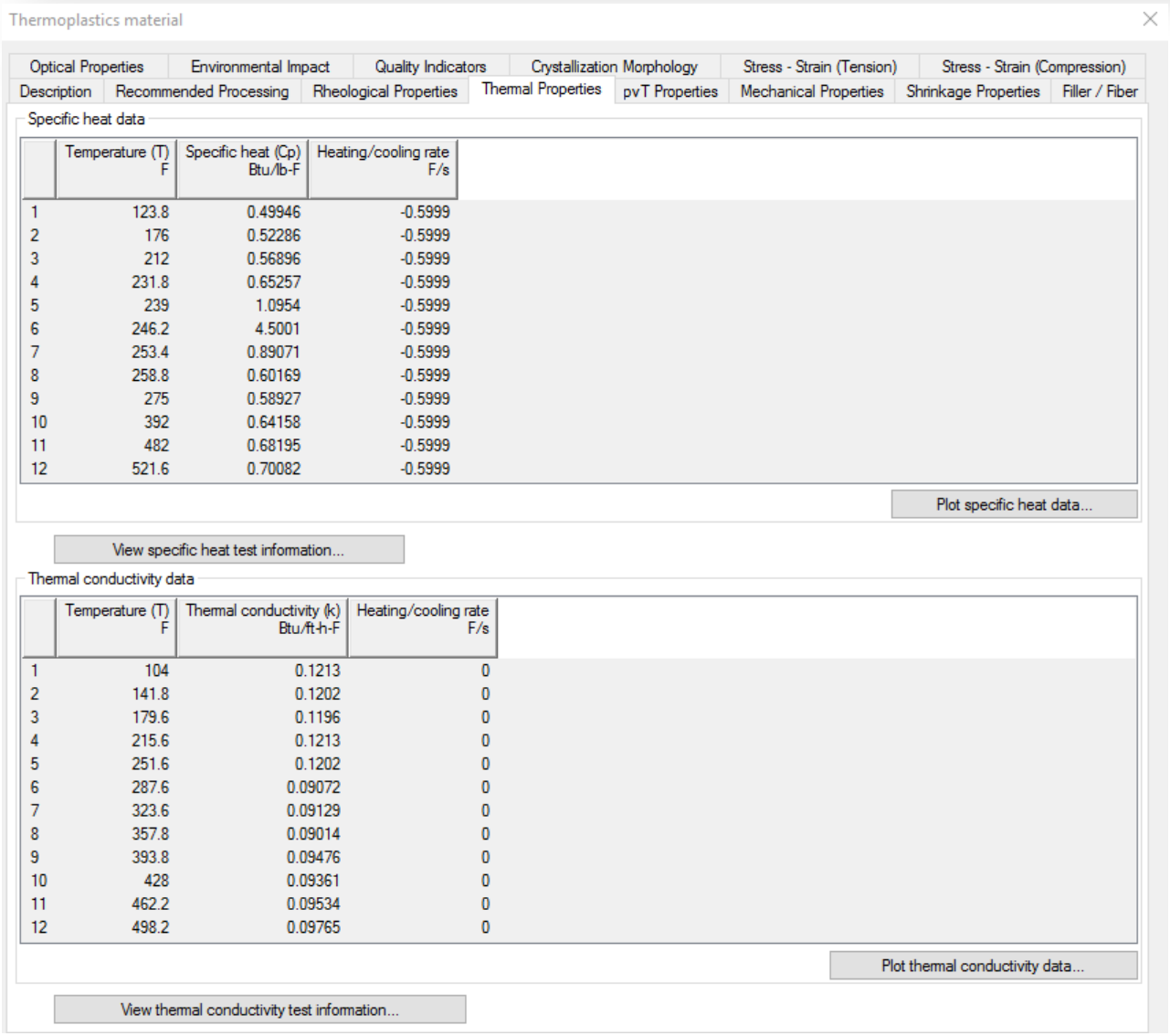
b5	436.15	K
b6	7.5e-08	K/Pa
b1m	0.001275	m^3/kg
b2m	1.056e-06	m^3/kg-K
b3m	8.06452e+07	Pa
b4m	0.005863	1/K
b1s	0.001157	m^3/kg
b2s	4.448e-07	m^3/kg-K
b3s	1.55891e+08	Pa
b4s	0.004364	1/K
b7	0.0001172	m^3/kg
b8	0.05352	1/K
b9	8.721e-09	1/Pa

Plot pvT data...

View test information...



Thermal Data



Specific heat data

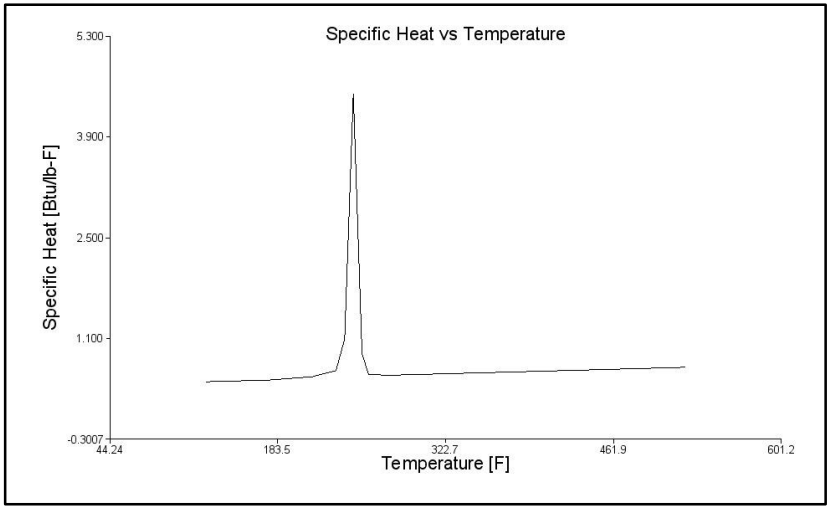
	Temperature (T) F	Specific heat (Cp) Btu/lb-F	Heating/cooling rate F/s
1	123.8	0.49946	-0.5999
2	176	0.52286	-0.5999
3	212	0.56896	-0.5999
4	231.8	0.65257	-0.5999
5	239	1.0954	-0.5999
6	246.2	4.5001	-0.5999
7	253.4	0.89071	-0.5999
8	258.8	0.60169	-0.5999
9	275	0.58927	-0.5999
10	392	0.64158	-0.5999
11	482	0.68195	-0.5999
12	521.6	0.70082	-0.5999

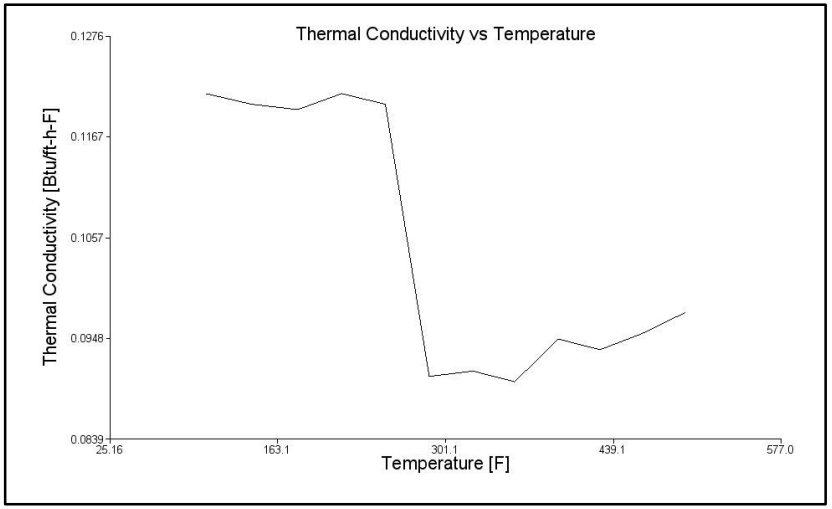
Thermal conductivity data

	Temperature (T) F	Thermal conductivity (k) Btu/ft-h-F	Heating/cooling rate F/s
1	104	0.1213	0
2	141.8	0.1202	0
3	179.6	0.1196	0
4	215.6	0.1213	0
5	251.6	0.1202	0
6	287.6	0.09072	0
7	323.6	0.09129	0
8	357.8	0.09014	0
9	393.8	0.09476	0
10	428	0.09361	0
11	462.2	0.09534	0
12	498.2	0.09765	0

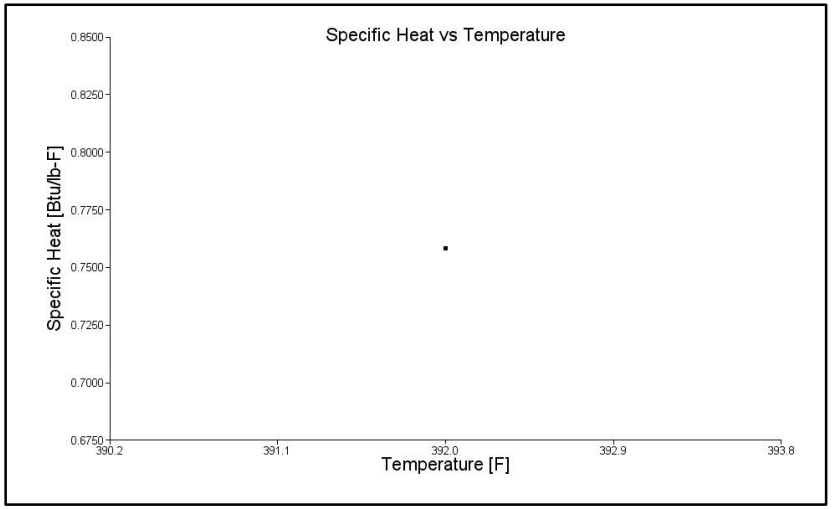
Thermal Data

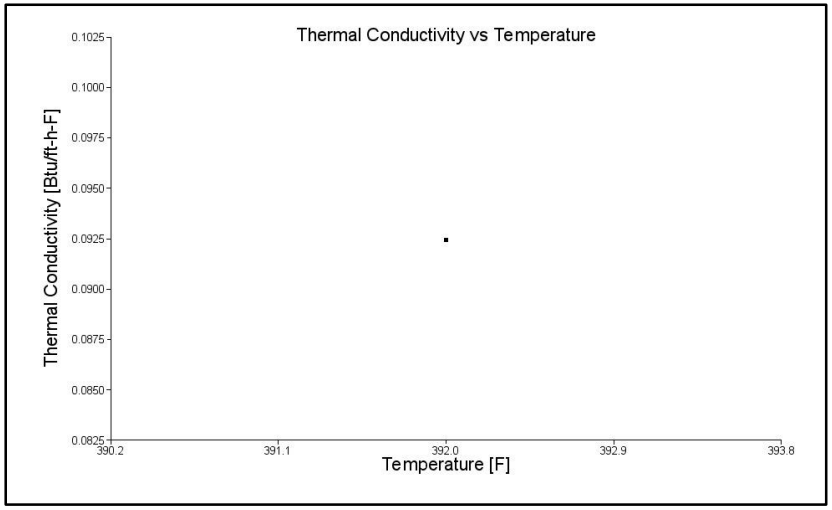
Multi point data





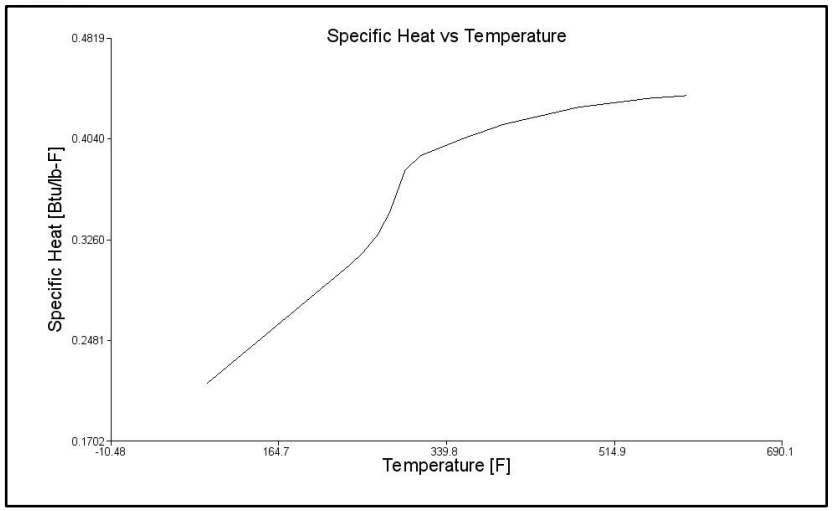
Single point data

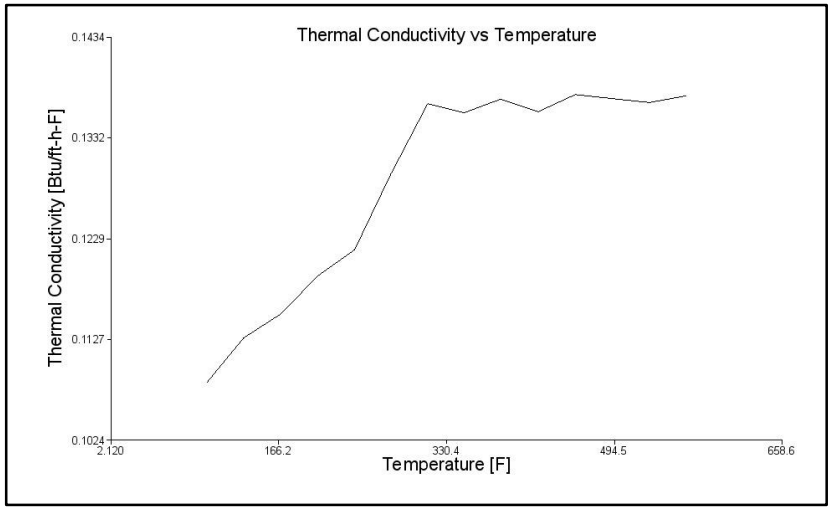




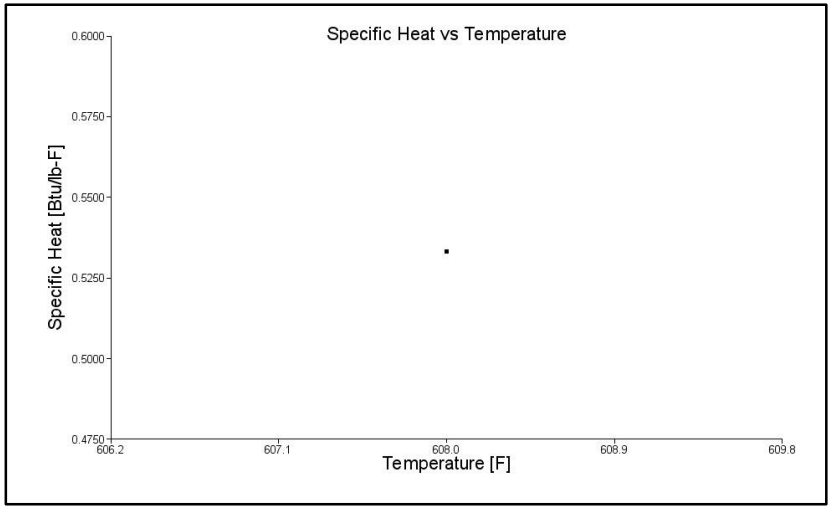
Thermal Data

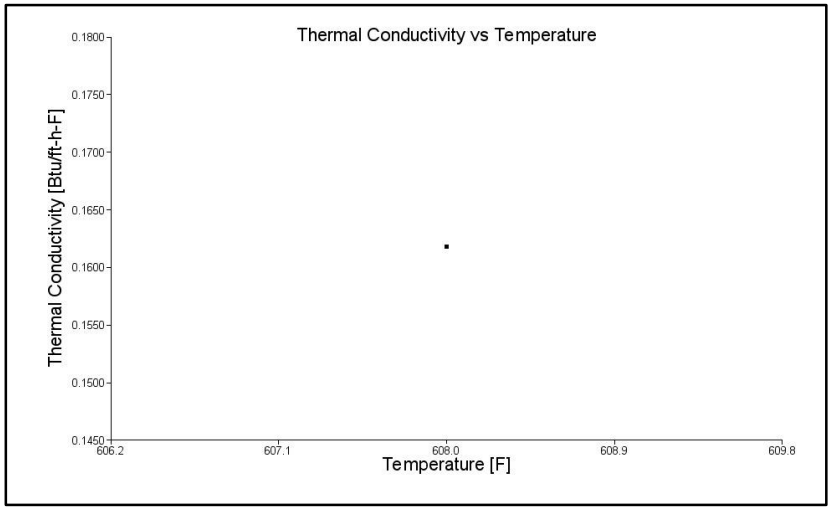
Multi point data





Single point data





Shrinkage

Thermoplastics material

Quality Indicators | Crystallization Morphology | Stress - Strain (Tension) | Stress - Strain (Compression)

Description | Recommended Processing | Rheological Properties | Thermal Properties | pvT Properties | Mechanical Properties | Shrinkage Properties | Filler / Fiber | Optical Properties | Environmental Impact

Select a shrinkage model (Midplane and Dual Domain)

Corrected residual in-mold stress (CRIMS) | Examine CRIMS model | Default Flow/Fiber set | View model coefficients...

Select a shrinkage model (3D)

Uncorrected residual stress

Observed nominal shrinkage

Parallel	1.393	%
Perpendicular	1.404	%

Observed shrinkage

Minimum Parallel	1.239	%
Maximum Parallel	1.604	%
Minimum Perpendicular	1.236	%
Maximum Perpendicular	1.58	%

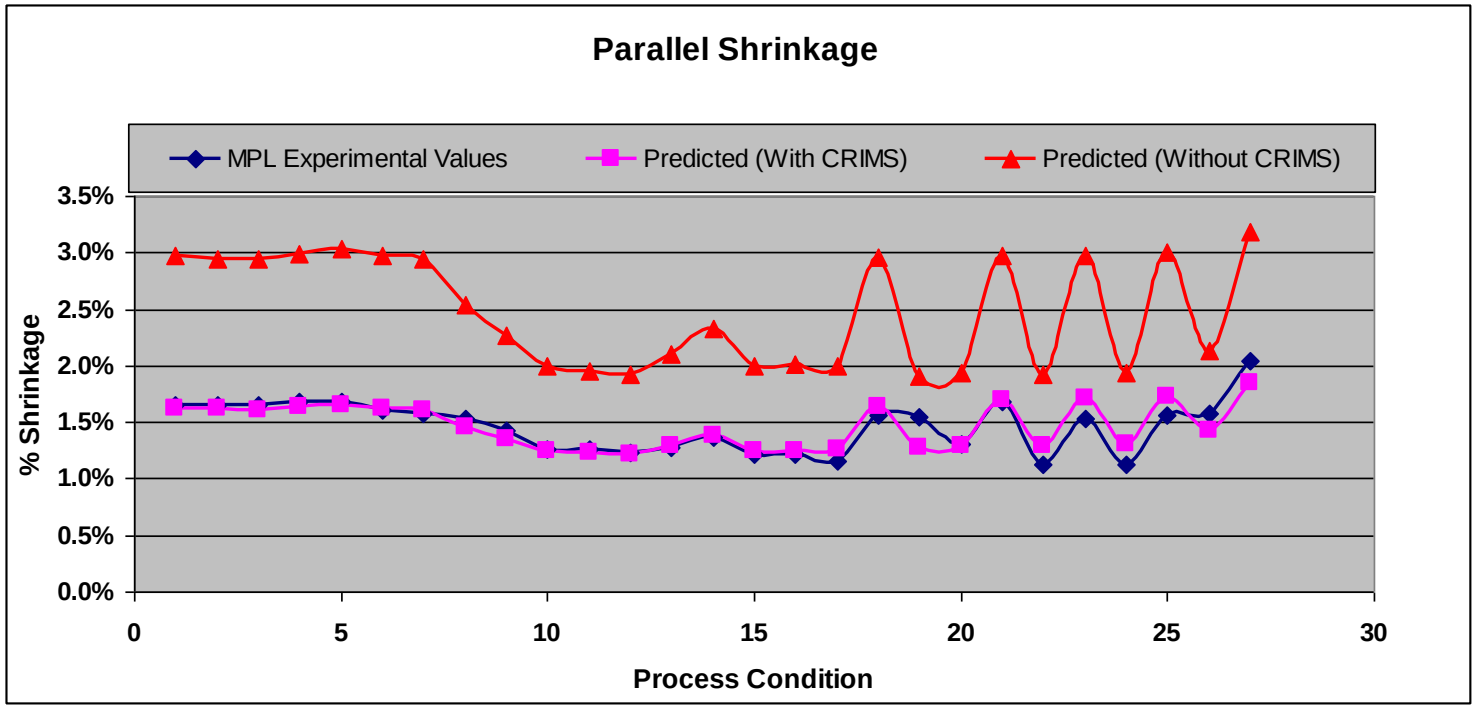
View observed shrinkage test information...

Shrinkage Molding Summary

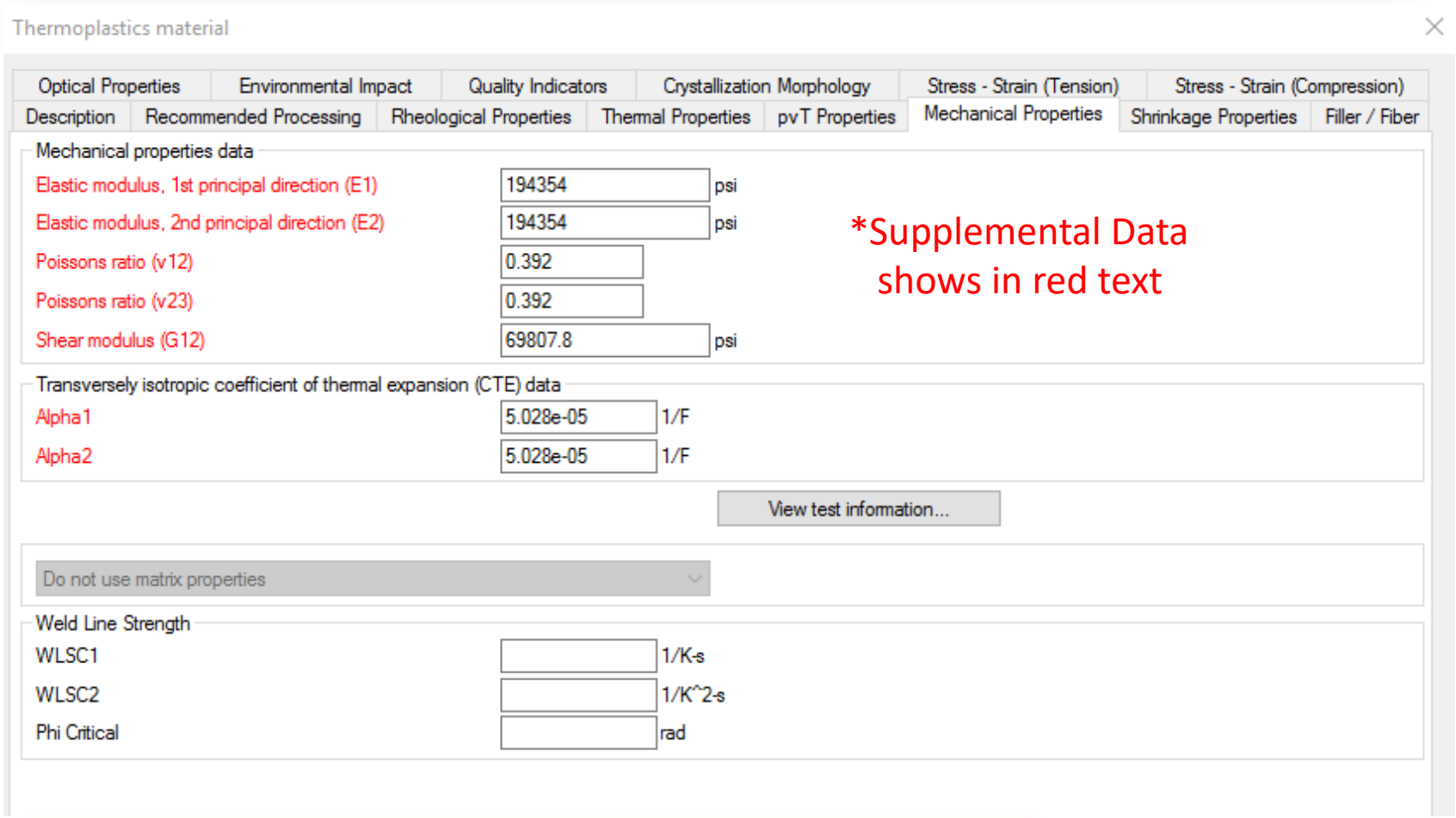
	Melt Temperature F	Mold Temperature F	Flow Rate (R) in^3/s	Flow Rate (F) in^3/s	Ram Diameter in	Ram Displacement in	Thickness in	Packing Pressure psi	Packing Time s	Cooling Time s	Parallel Shrinkage %	Perpendicular Shrinkage %	Volumetric Shrinkage %
1	442.22	91.58	1.52558	1.34861	0.98425	2.14566	0.07874	3118.36	10	20	1.33	1.42	3.2
2	440.42	92.3	1.52558	1.34861	0.98425	2.12598	0.07874	3103.86	10	20	1.31	1.41	3.21
3	440.42	95.72	1.51947	1.43404	0.98425	2.12204	0.07874	3553.48	9.9	20	1.44	1.41	3.09
4	440.42	92.48	1.51947	1.27538	0.98425	2.12598	0.07874	3205.38	10	20	1.34	1.42	3.17
5	440.42	92.84	1.51947	1.14723	0.98425	2.12598	0.07874	3263.4	10	20	1.3	1.4	3.15
6	440.42	97.52	2.30057	2.08699	0.98425	2.12598	0.07874	4090.13	9.9	20	1.38	1.33	2.92
7	440.42	93.56	1.52558	1.27538	0.98425	2.12204	0.07874	3248.9	9.9	20	1.45	1.41	3.18
8	440.42	91.04	0.76889	0.634639	0.98425	2.12598	0.07874	2987.82	9.9	20	1.44	1.47	3.2
9	440.42	102.38	1.52558	1.20215	0.98425	2.51968	0.11811	3045.84	15	20	1.54	1.54	5.43
10	440.42	100.04	1.52558	1.25097	0.98425	2.52362	0.11811	3074.85	15	20	1.51	1.55	5.4
11	440.42	101.3	1.53168	1.25097	0.98425	2.51968	0.11811	3118.36	14.9	20	1.48	1.54	5.39
12	440.42	103.1	1.52558	1.16554	0.98425	2.51968	0.11811	3147.37	14.9	20	1.6	1.58	5.28
13	440.42	101.66	1.52558	1.25097	0.98425	2.51968	0.11811	3118.36	15	20	1.49	1.5	5.39
14	440.42	104.36	2.30667	1.6049	0.98425	2.51968	0.11811	3422.94	15	20	1.47	1.54	5.29
15	440.42	99.86	1.52558	1.25097	0.98425	2.51968	0.11811	3132.86	14.9	20	1.44	1.5	5.38
16	440.42	102.02	0.762788	0.646844	0.98425	2.51968	0.11811	2987.82	14.9	20	1.48	1.61	5.03
17	441.14	82.76	1.53778	1.00078	0.98425	1.74015	0.03937	5105.41	4.9	20	1.31	1.26	2.81
18	440.24	84.56	1.51337	0.915345	0.98425	1.74015	0.03937	5090.9	5	20	1.29	1.3	2.82
19	440.96	86.72	1.55609	1.00078	0.98425	1.72047	0.03937	5047.39	5	20	1.36	1.28	2.77
20	440.42	85.28	1.51947	1.00078	0.98425	1.73622	0.03937	5119.91	5	20	1.33	1.29	2.76
21	440.96	83.12	1.51947	1.00078	0.98425	1.72441	0.03937	5018.38	5	20	1.24	1.27	2.84
22	440.96	86.36	2.27616	1.56829	0.98425	1.72441	0.03937	5293.96	5	20	1.25	1.24	2.74
23	440.42	87.44	1.51947	1.00078	0.98425	1.72441	0.03937	5090.9	4.9	20	1.26	1.27	2.76
24	440.42	83.3	0.756685	0.475979	0.98425	1.73622	0.03937	5105.41	5	20	1.38	1.3	2.65

Moldflow Shrinkage Testing

- Corrected Residual In-Mold Stress coefficients (CRIMS)
  - Dual Domain and Midplane only
  - Corrects for gap between lab vs. production environment



Mechanical

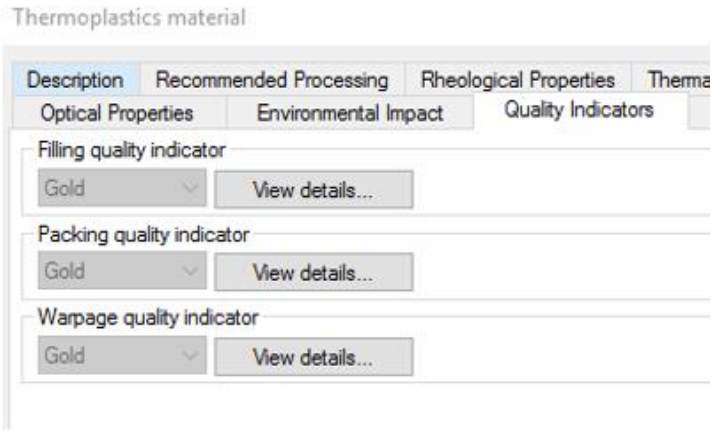


Moldflow Plastics Labs : pvT-Measured : mech-Supplemental

Material Quality Indicators

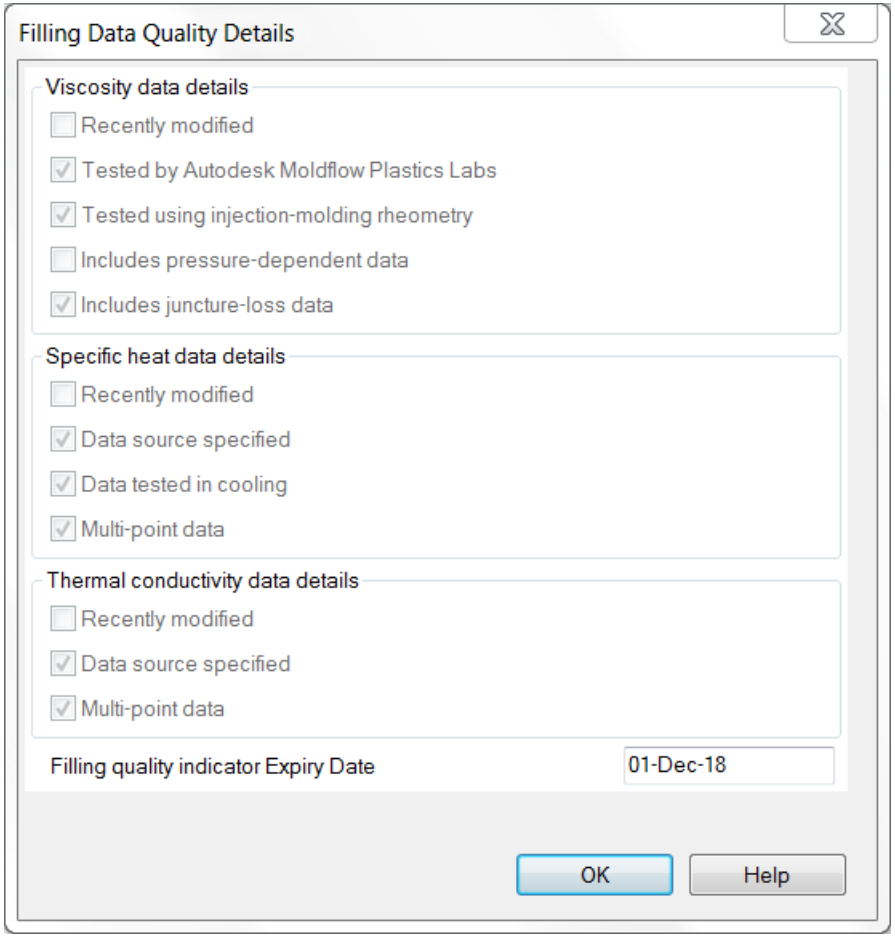
- MQI's are simple 3 tier descriptions of the quality of material properties (Gold, Silver, or Bronze)
- Thermoplastic materials only
- Weighted scale used

- Accurate Material Data = Accurate Simulation Results
- How data is measured matters
  - Test Methodology, Single/Multiple Point
- Source of data matters
  - Supplemental data, Tested in certified Lab
- MQI is not a static measure
  - Data quality reduces with time



Material Quality Indicators

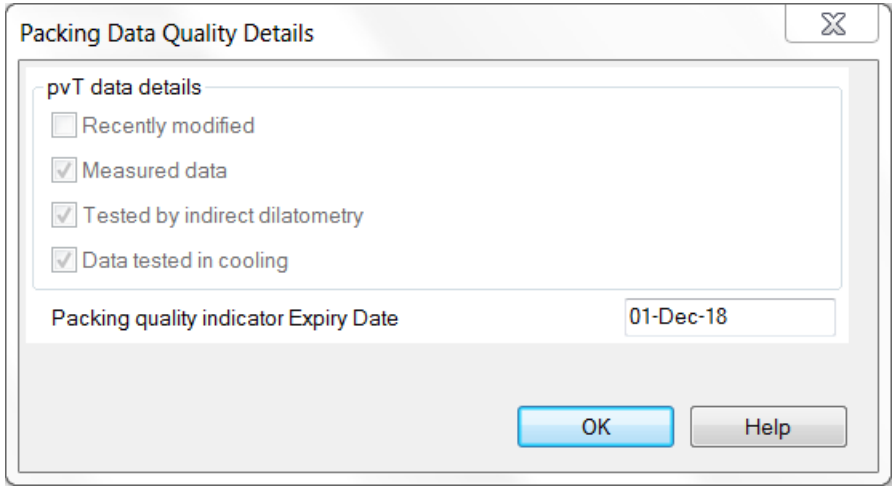
- Fill Quality Indicator – Investigates the quality of the Viscosity, Specific Heat Capacity and Thermal Conductivity data



Material Quality Indicators

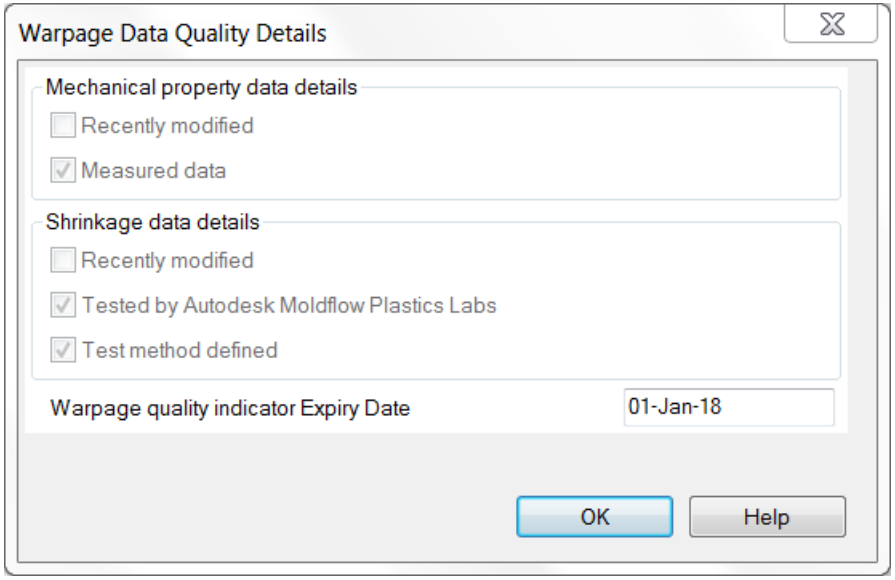
- Packing Quality Indicator – Incorporates the quality of the Fill Quality Indicator results and the pvT data

- The Packing and Warpage Quality Indicator cannot exceed the previous Quality Indicator



Material Quality Indicators

- Warpage Quality Indicator – Incorporates the suitability of the Packing Quality Indicator along with the Mechanical Property and Shrinkage data



- Warpage requires either:
  - Mechanical data or Shrinkage data

- This is a mesh type specific concern for analysis.
  - DD/Midplane mesh uses shrinkage data (like CRIMS)
  - 3D mesh uses mechanical properties

MQI Ratings

- A Gold rating indicates a high confidence in the quality of the material data for the analysis type. When accurate analysis results are critical, it is recommended that a material with a Gold rating should be used.

- A Silver rating can result from a combination of well tested, and supplemental material data. For example, a material might have a Gold Packing Quality rating but use supplemental Mechanical Properties data. This could result in a Silver Warpage Quality Indicator rating.

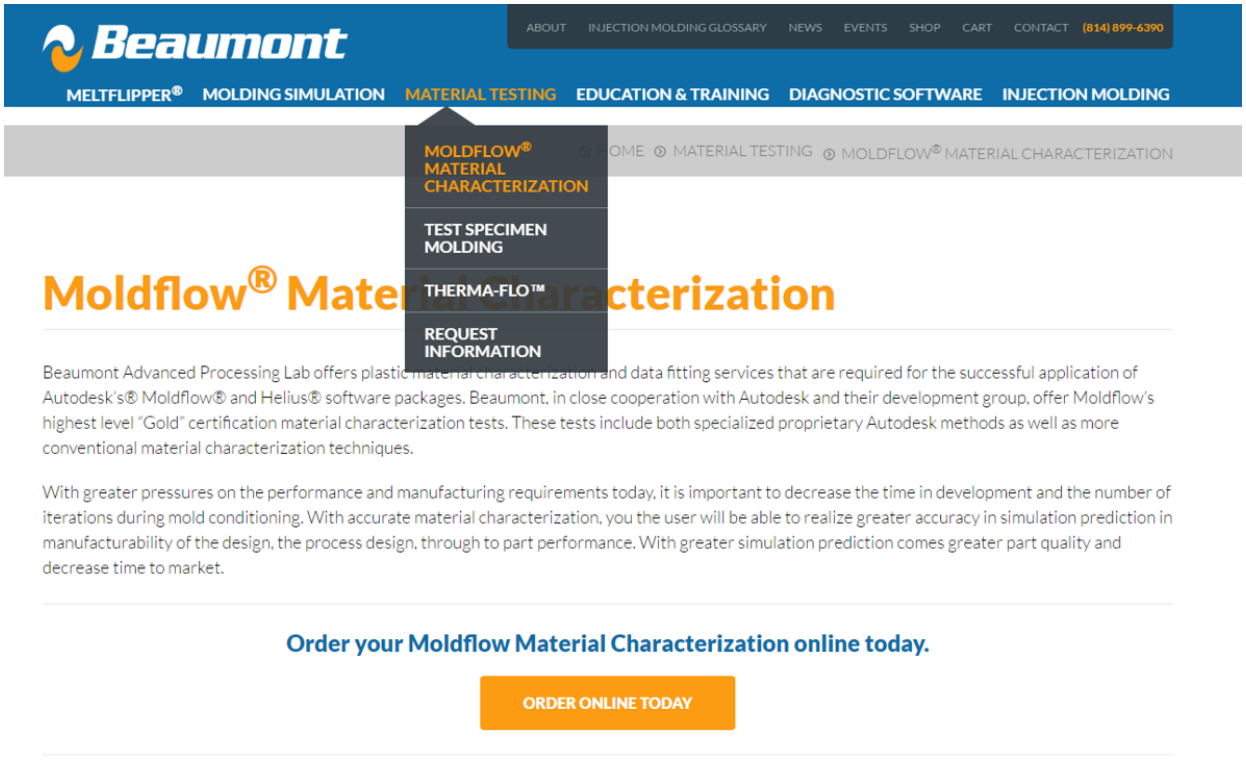
- Bronze ratings can reflect problems such as incomplete data sets, the extensive use of supplemental data and untested material properties. The use of Bronze-rated materials can still generate good results, but these results should not be relied upon to determine critical requirements such as precise warpage or shrinkage allowances used for the cutting of molds.

The Future

- Duplicate
- Low hanging fruit
  - Ease of ordering

How do I order material characterization?

- Online ordering @ www.beaumontinc.com



How do I order material characterization?

Moldflow® Material Characterization Order Form

OPTION 1: Autodesk Moldflow Package

OPTION 2: Autodesk Moldflow Package - 5 Packs

OPTION 3: Order Individual Tests

Fill In Your Material

Data Status: (•) Not Confidential ( ) Confidential ($845 surcharge applies)

Family Abbreviation *Required

Trade Name *Required

Lot Number *Required

Manufacturer *Required

Filler 1 Status (% and type)

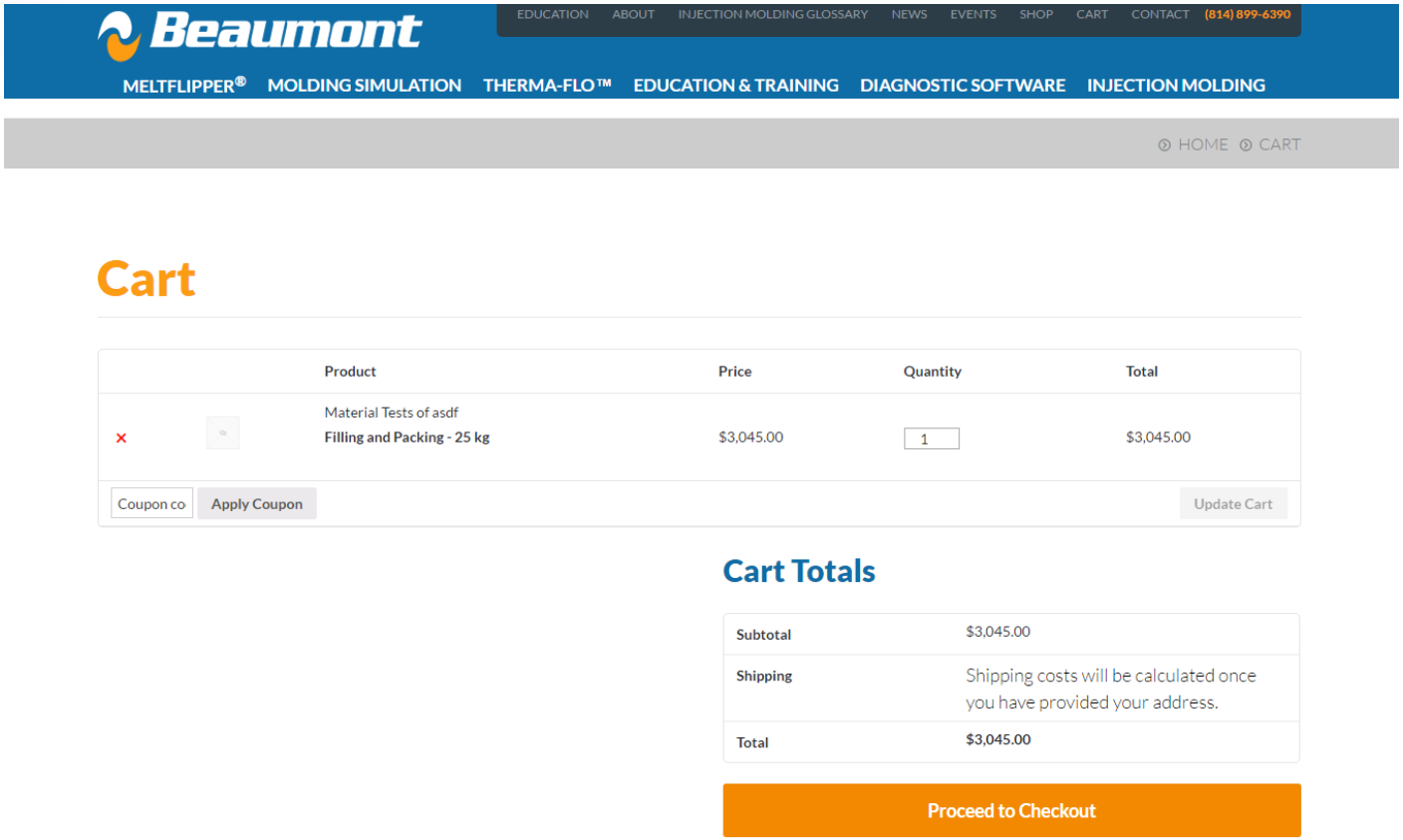
Filler 2 Status (% and type)

Filler Status ( ) Not Confidential ( ) Confidential

Pick Test"s" To Be Performed

Test	Description	Material	Price
Filling (MPL-110)	Includes: Shear Viscosity by IMR, Specific heat, Thermal Conductivity and Mold Validation, Supplemental CTE and mechanical data is used, unless provided by customer.	25 kg	$1,550
Filling (MPL-110)	Includes: Shear Viscosity by IMR, Specific heat, Thermal Conductivity and Mold Validation, Supplemental CTE and mechanical data is used, unless provided by customer.	25 kg	$1,550
Filling and Packing (MPL-125)	Includes: pvT, Shear Viscosity by IMR, Specific heat, Thermal Conductivity and Mold Validation. Supplemental CTE and mechanical data is used, unless provided by customer.	25 kg	$3,045
Filling, Packing, and Shrinkage (MPL-135)	Includes: Moldflow Filling and Packing plus Shrinkage test. Supplemental CTE and mechanical data is used, unless provided by customer.	50 kg	$6,195
Filling, Packing, Shrinkage and Warpage (MPL-150)	Includes: Moldflow Filling, Packing and Shrinkage plus CTE and Mechanicals test.	50 kg	$7,545

How do I order material characterization?



The Future

- Duplicate
- Low hanging fruit
  - Ease of ordering
  - Decrease lead times
    - Online ordering
    - Collaboration with Beaumont Advanced Processing
    - Machining of test specimens from mechanical plaques
- Future research
  - Collaboration with Australia
  - Internal research

The Future

Beaumont Technologies

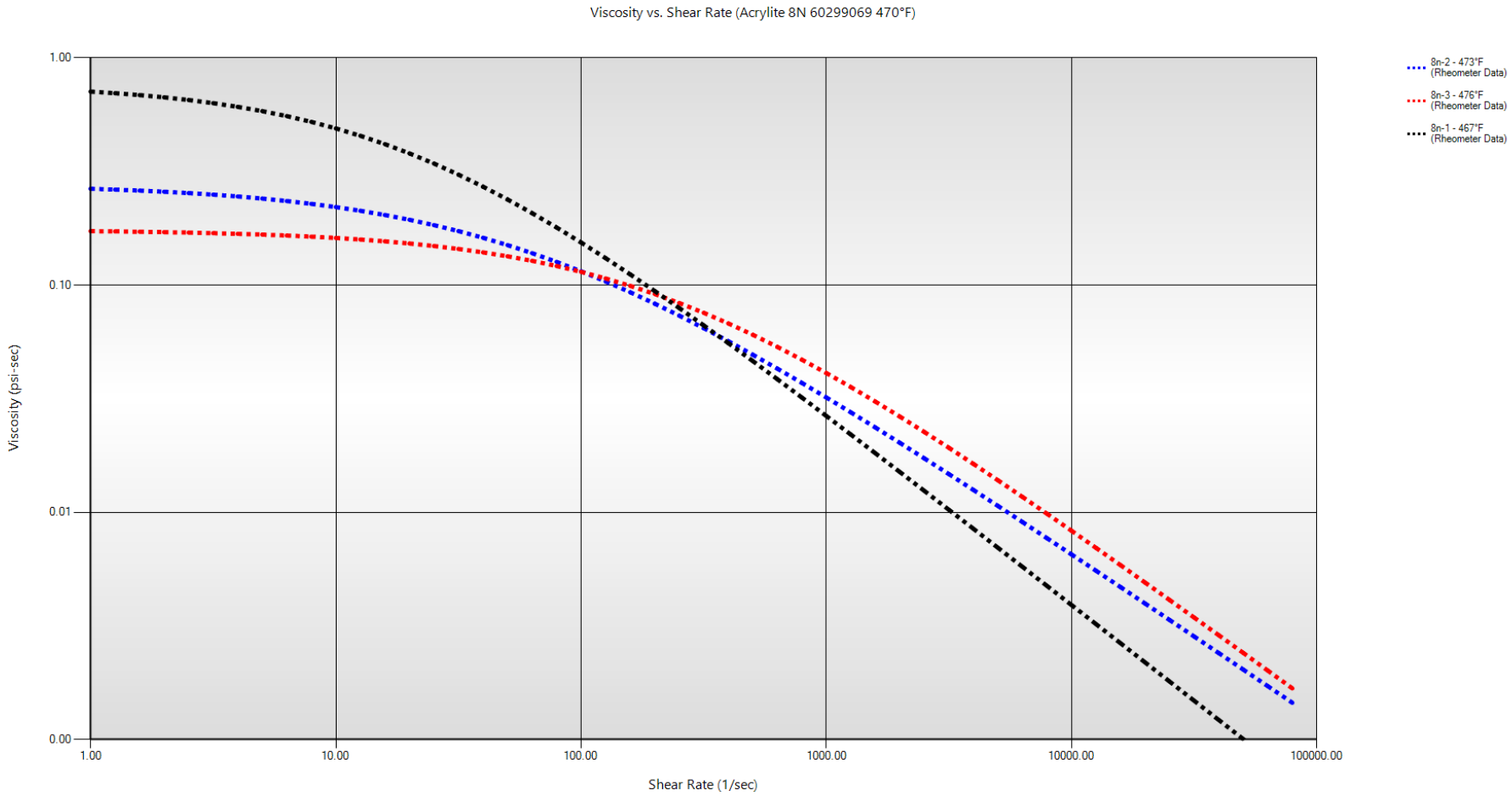
1999

The Future

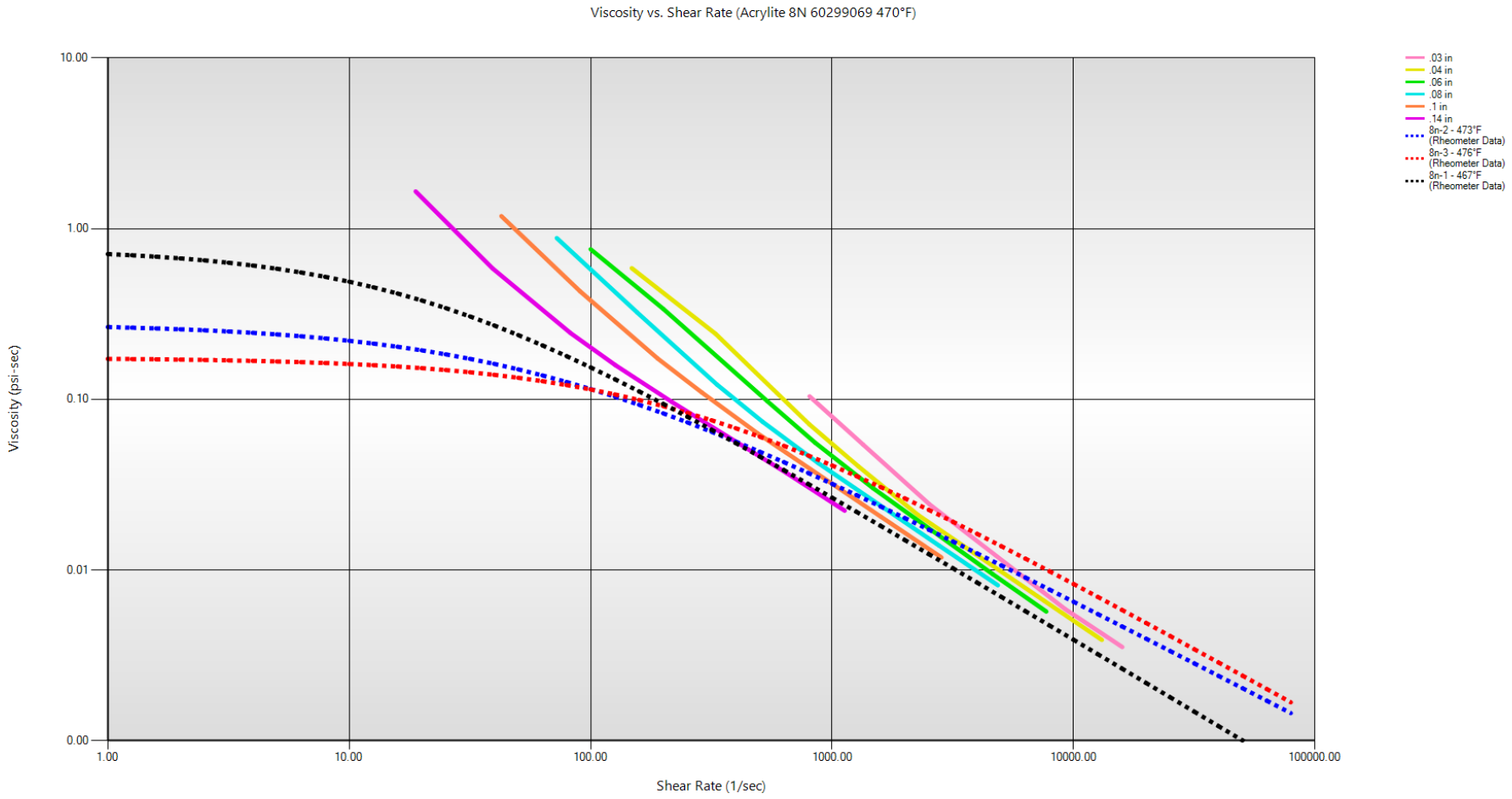
Beaumont Advanced Processing

Beaumont Technologies

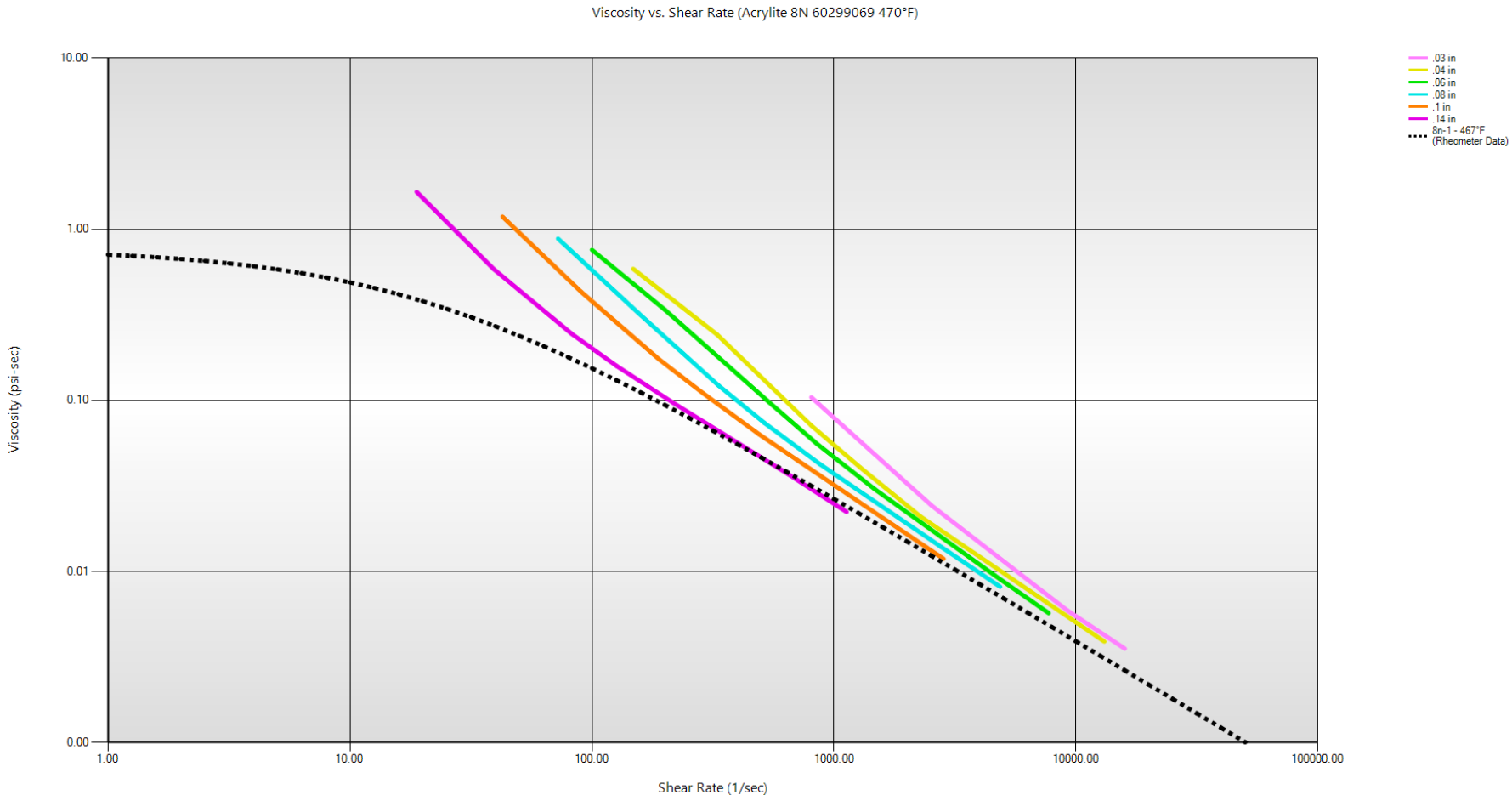
The Future


Viscosity vs. Shear Rate (Acrylite 8N 60299069 470°F)
Viscosity (psi-sec)
1.00
0.10
0.01
0.00
1.00
10.00
100.00
1000.00
10000.00
100000.00
Shear Rate (1/sec)
8n-2 - 473°F (Rheometer Data)
8n-3 - 476°F (Rheometer Data)
8n-1 - 467°F (Rheometer Data)

The Future


Viscosity vs. Shear Rate (Acrylite 8N 60299069 470°F)
Viscosity (psi-sec)
10.00
1.00
0.10
0.01
0.00
1.00
10.00
100.00
1000.00
10000.00
100000.00
Shear Rate (1/sec)
.03 in
.04 in
.06 in
.08 in
.1 in
.14 in
8n-2 - 473°F (Rheometer Data)
8n-3 - 476°F (Rheometer Data)
8n-1 - 467°F (Rheometer Data)

The Future


Viscosity vs. Shear Rate (Acrylite 8N 60299069 470°F)
Viscosity (psi-sec)
10.00
1.00
0.10
0.01
0.00
1.00
10.00
100.00
1000.00
10000.00
100000.00
Shear Rate (1/sec)
.03 in
.04 in
.06 in
.08 in
.1 in
.14 in
8n-1 - 467°F (Rheometer Data)

Beaumont Contact info

Webpage: http://www.beaumontinc.com/material-testing/moldflow-material-characterization/

Email: info@beaumontinc.com

Phone: 814-899-6390

Current Address: 1524 East 10th St. Erie, PA

New Address: 6100 W. Ridge Rd. Erie, PA