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PEEK & Bioresorbable Molding Workshop

Overview

+34
YEARS IN BUSINESS

<4%
EMPLOYEE TURNOVER

2
FACILITIES

3 ISO 7 (CLASS 10,000)
CLEANROOMS

+130
EMPLOYEES

+1000
SUCCESFUL PROJECTS

+7000
MOLDS BUILT

13485
ISO CERTIFIED

Factors That Affect the Quality of Molded Parts (Partial List)

MICRO MOLDING | MICRO TOOLING / 3D PRINTING / CT SCANNING | WORLD CLASS EXPERTS, IN-HOUSE CAPABILITIES | MICRO ASSEMBLY

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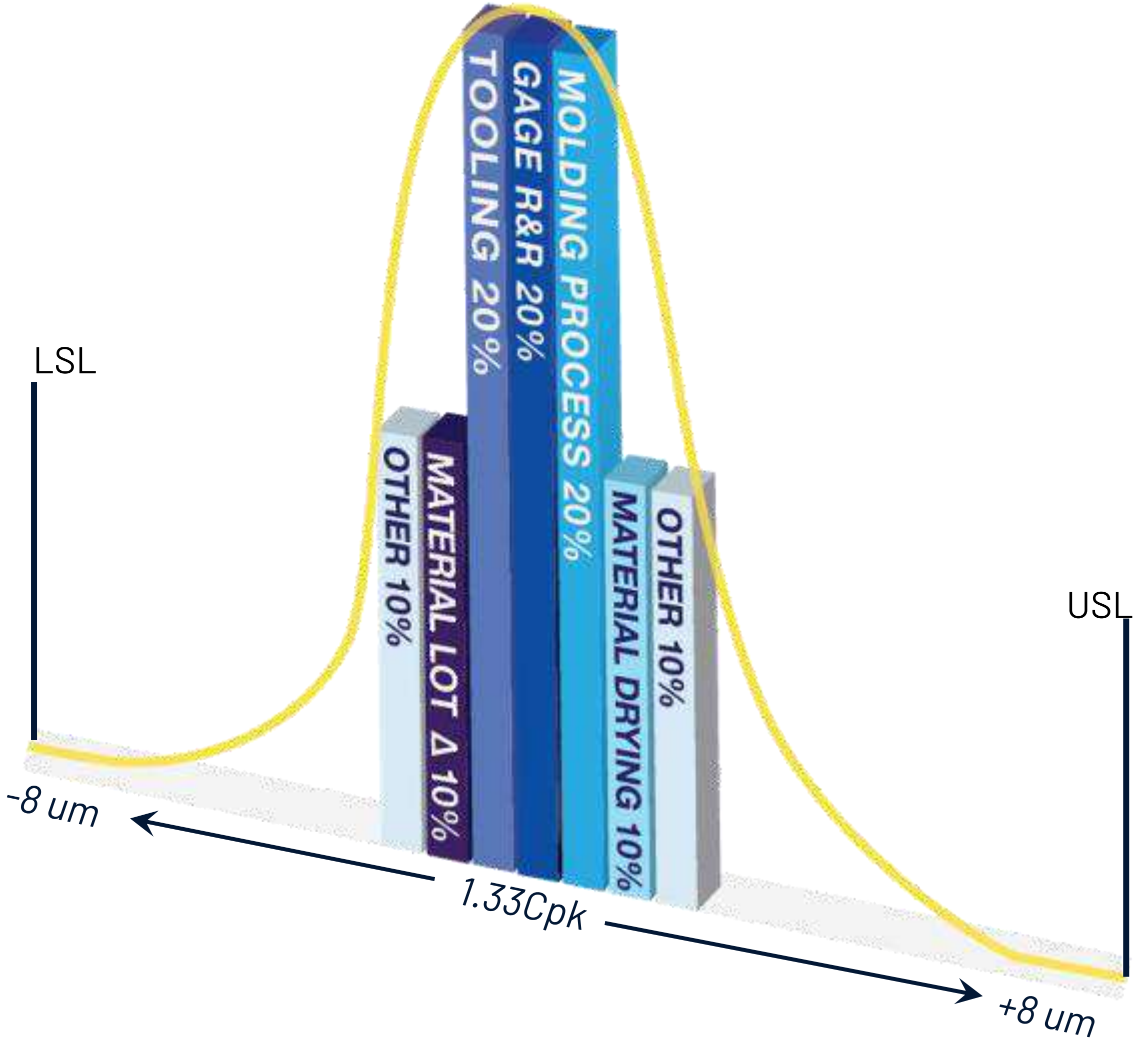
Key Factors That Affect the Quality of Molded Parts –

- Tooling <20%
- Micro Molding Process <20%
- Gage R&R <20%
- Material Lot-to-Lot <10%
- Material Drying <10%
- Other <20%



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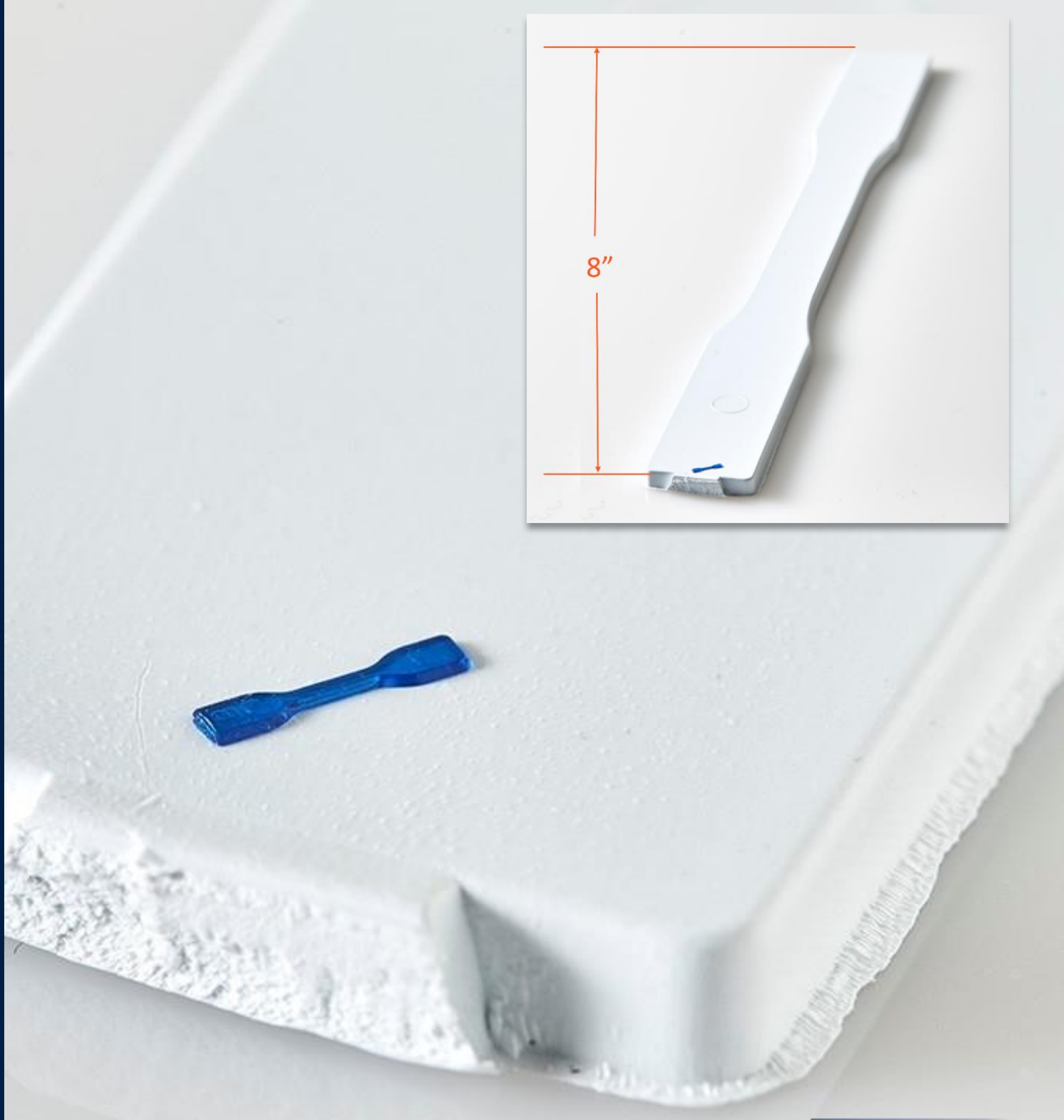
Material Expertise
– Internally Developed Resin Characterization

- Isometric created a Micro Molding Material Library of empirical resin data
- Thickness range from 0.001”- 0.015” (25-375 microns) at 0.200” in micro tensile bar length
- Gate Types: Pin, Edge
- Outputs:
  - Actual shrink (not estimated)
  - Gate style effectiveness to fill
  - Gate vestige with actual gate size/material
  - Thin wall molding test prior to mold building



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Precision Tooling

- +/- 1 micron precision or lower
- Surface finish critical to success – A2 capable
- Scalability
- Expertise in hardened steel combinations
- Development, single cavity, multi-cavity, 2-shot, insert and overmold tooling
- Precision threads/gears
- Core pin diameters less than 0.002" (50 microns)
- Venting capable at 0.0001-0.0002" (3-4 microns)
- Feature sizes of 0.0001" (3 microns)
- Ejector pins to 0.003" (75 microns)

Precision Molding

Injection Unit
- Screw design
- % barrel utilization
- Nozzle design

Resin
- Material properties
- Additives
- Moisture content
- Material lot-lot consistency

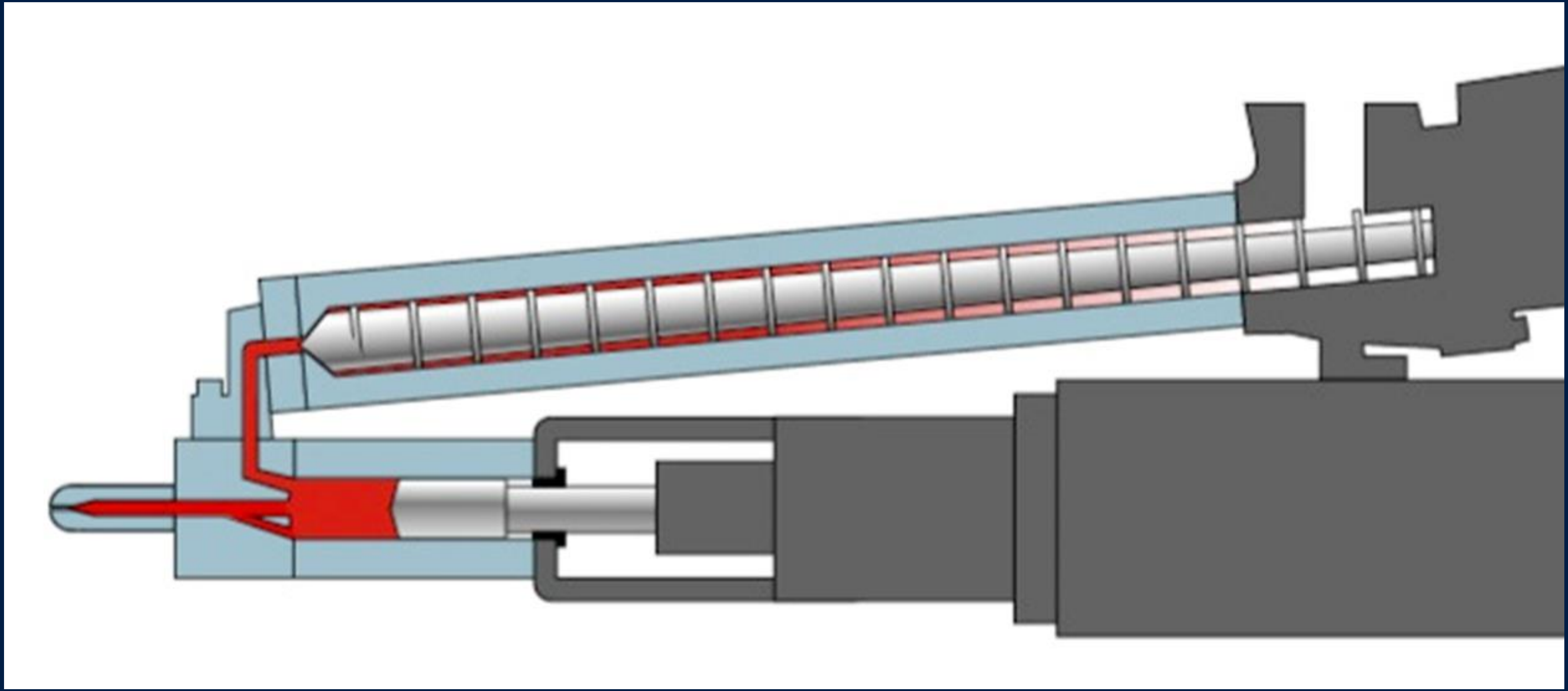
Machine
- Machine design
- Machine quality
- Tonnage
- Parallelism

Mold
- Cooling layout
- Machining precision
- Stiffness
- Venting

Hot runner
- Thermal design
- Runner design
- Heater quality
- Thermocouples
- Plate design
- Machining & Assembly Precision

Processing
- Barrel temp. profile
- Screw rpm
- Back pressure
- Hot runner temperature profile
- Injection velocity profile

Decoupled Plastication & Injection – Sodick



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Fast Response Time – Sodick

Injection Step Response Comparison

	LDDV	LSV	Electric Injection Machine
Drive System	Double Linear Motor Direct	Linear Motor + Pilot Valve	AC Servo + Pulley &Belt AC Servo + Ball Screw Drive
Step Response(ms)	***2～3***	***15~20***	***25～40***
NC Loop Control (micro second)	**50(0.05ms)**	**50(0.05ms)**	**62.5-100 (0.062-0.1ms)**

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PEEK Molding

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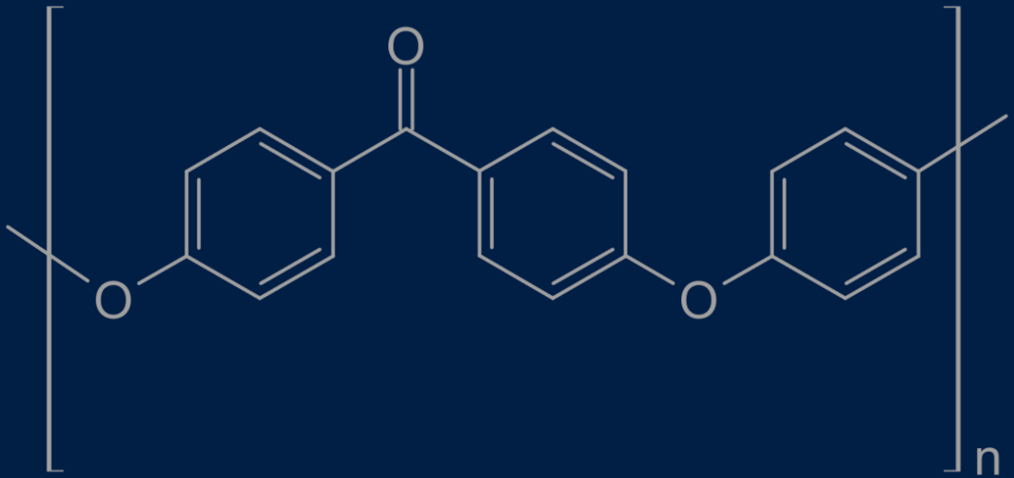
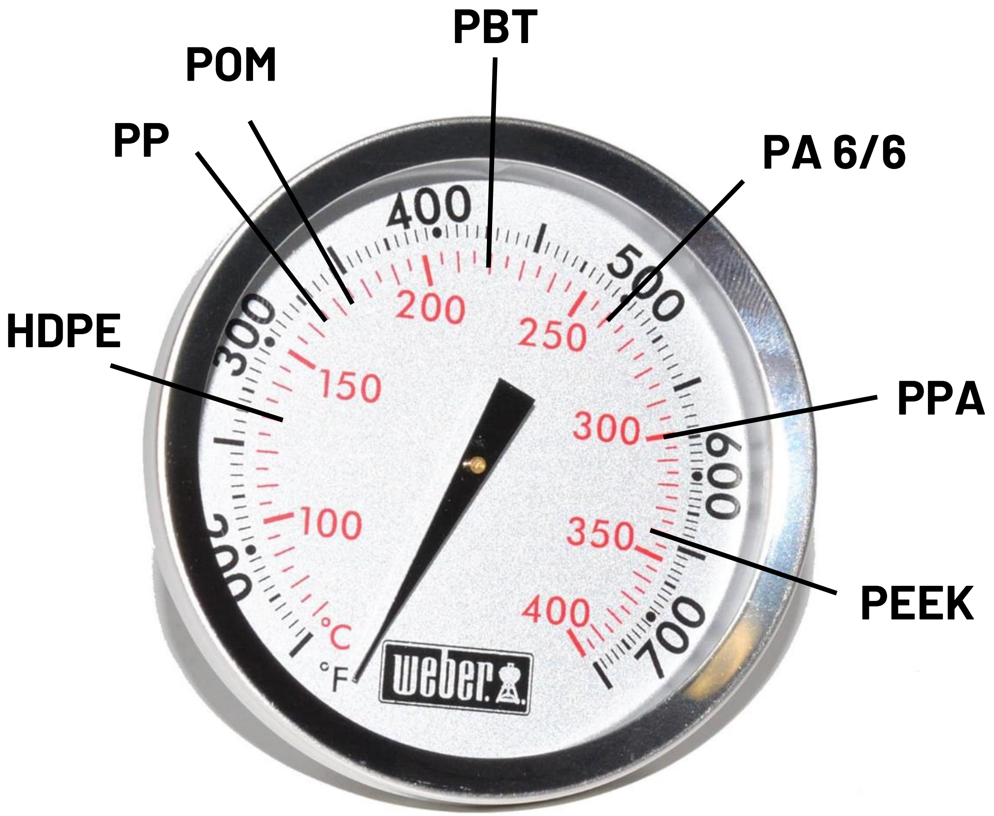
Challenges with PEEK

- High Melting Point
- High Viscosity
- High Melt and Mold Temperatures
- Semi-Crystalline Material
- % Crystallinity
- Fillers/Additives



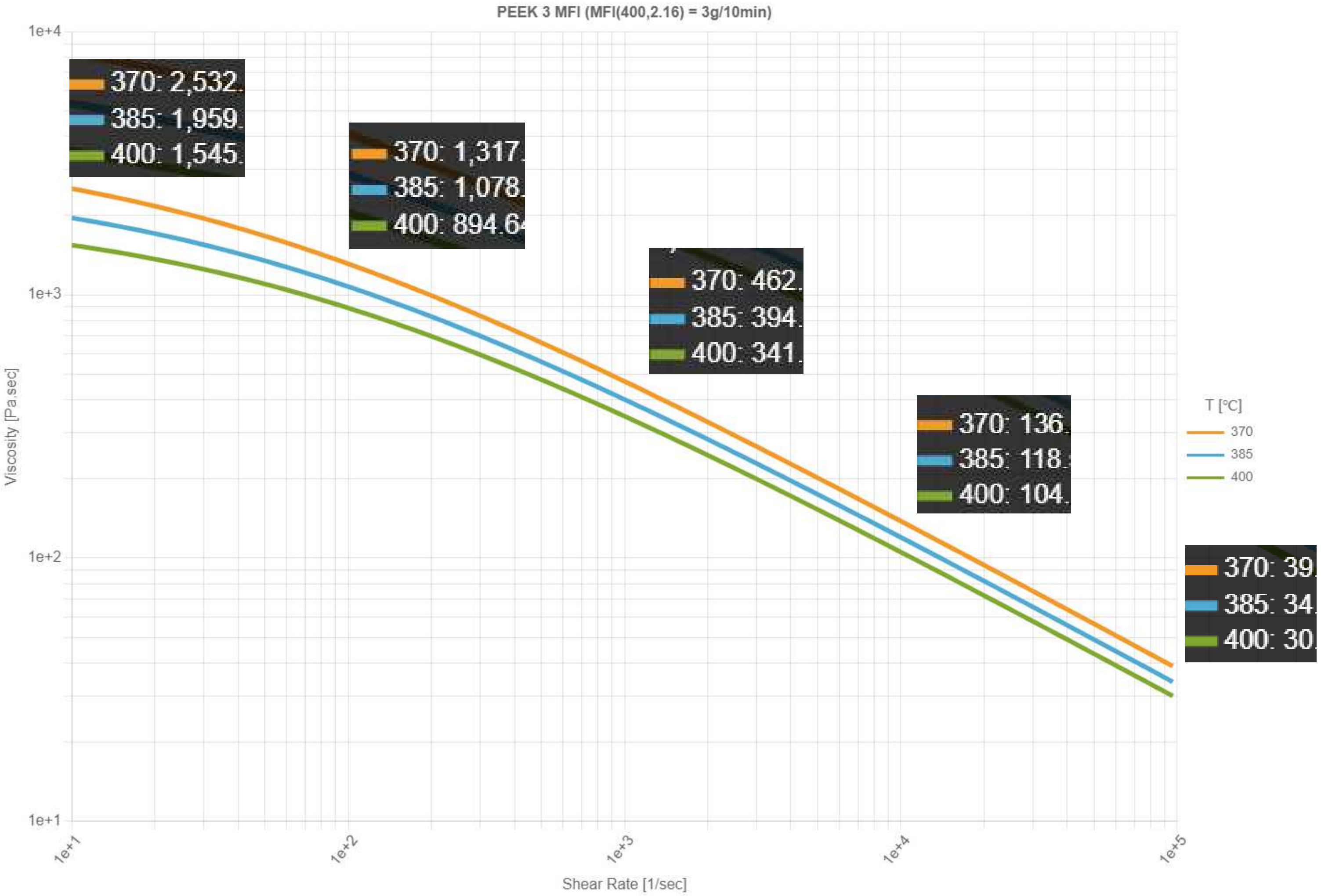
Challenges with PEEK – High Melting Point



Approximate Viscosities of Common Materials

Material	Viscosity @ 70°F Pa.s
Water	0.001
Milk	0.003
SAE 40 Motor Oil	0.67
Castrol Oil	1
Honey	10
Chocolate	25
Ketchup	50
Mustard	70
Sour Cream	100
Peanut Butter	250

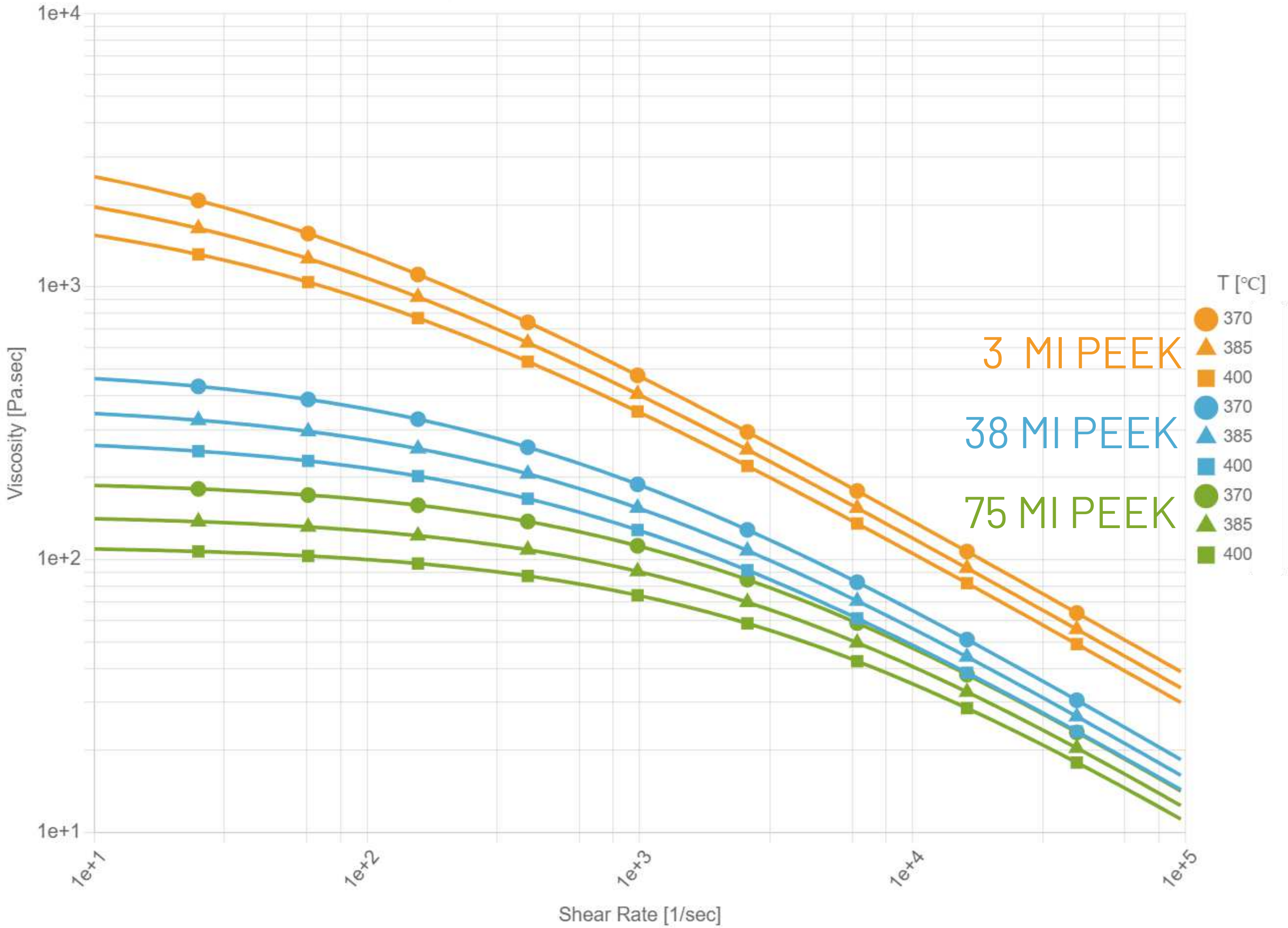
Challenges with PEEK – High Viscosity



Viscosity of 3 MFI PEEK at 400 °C

Shear rate 1/s	Viscosity Pa.s
10	1,545
100	895
1,000	341
10,000	104
100,000	30

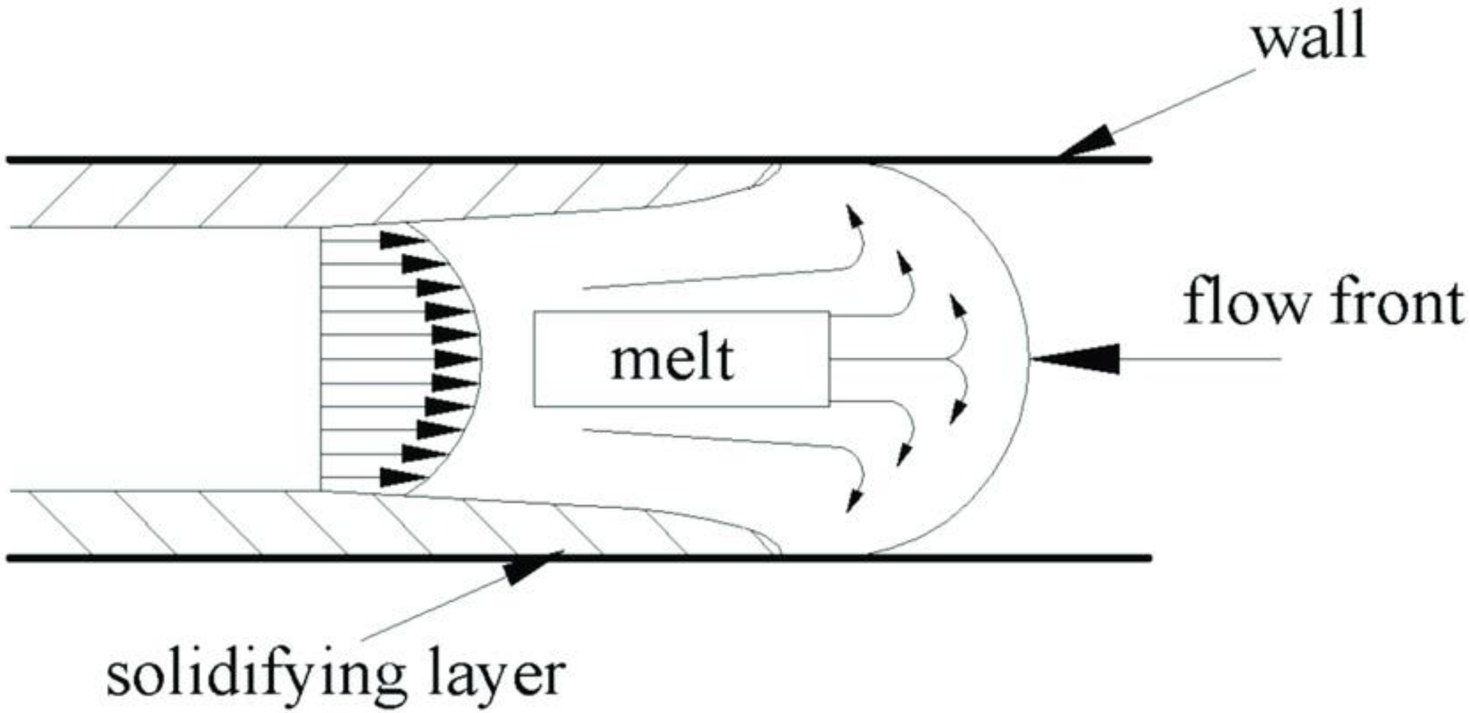
Challenges with PEEK – High Viscosity



Viscosity @1000s^{-1} , 400 ^{o}C

Material	Viscosity Pa.s
3 MFI PEEK	357
38 MFI PEEK	130
75MFI PEEK	74

Challenges with PEEK – High Pressure Drop



$$\Delta P_r = \frac{8.Q.\eta.L}{\pi R^4}$$

Where,
ΔP_r – pressure drop in a round channel
Q – Volumetric flow rate
η – Viscosity
L – length of channel
R – radius of channel

Challenges with PEEK - High Melt & Mold Temps

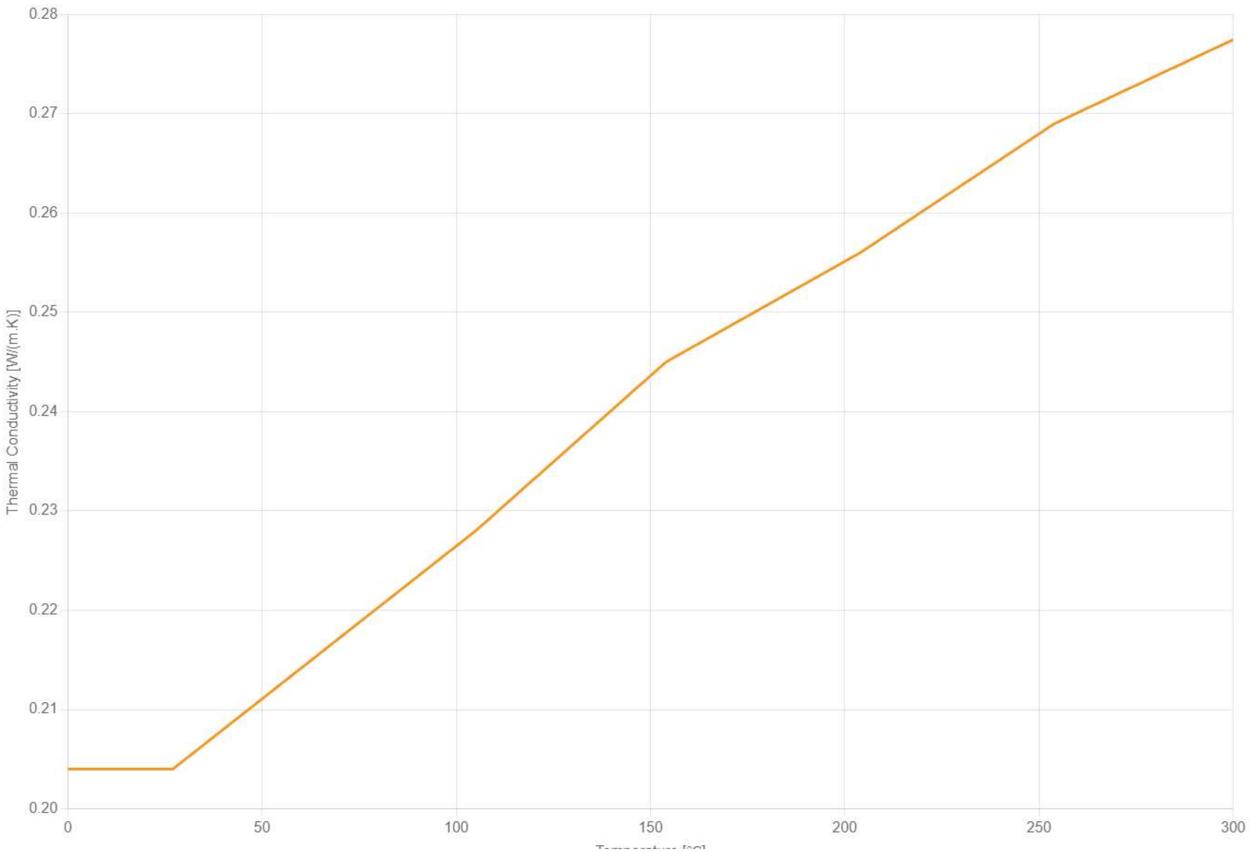
VESTAKEEP®	Tool temperature [°C]	Die [°C]	Zone 3 [°C]	Zone 2 [°C]	Zone 1 [°C]	Hopper [°C]
1000 G	160 - 200	380	370	360	350	40 - 100
1000 CF 30	160 - 210	390	380	4/160	360	40 - 100
1000 CF 40	160 - 210	390	380	4/160	360	40 - 100
2000 G	160 - 200	380	370	4/160	350	40 - 100
2000 GF 30	160 - 200	380	370	4/160	350	40 - 100
2000 FC 30*	160 - 200	380	370	4/160	350	40 - 100
2000 CF 30	160 - 210	390	380	4/160	360	40 - 100
2000 CF 40	160 - 210	390	380	4/160	360	40 - 100
3300 G	160 - 200	390	380	4/160	360	40 - 100
4000G	160 - 200	390	380	4/160	360	40 - 100
4000 GF30	160 - 200	400	385	4/160	360	40 - 100
4000 FC 30*	160 - 200	380	370	4/160	350	40 - 100
4000 CF 30	160 - 210	400	385	4/160	360	40 - 100
4000 CC 20 (Ti02)	160 - 200	400	385	4/160	360	40 - 100
Ultimate	160 - 210	390	380	4/160	360	40 - 100

Challenges with PEEK – Low Thermal Conductivity

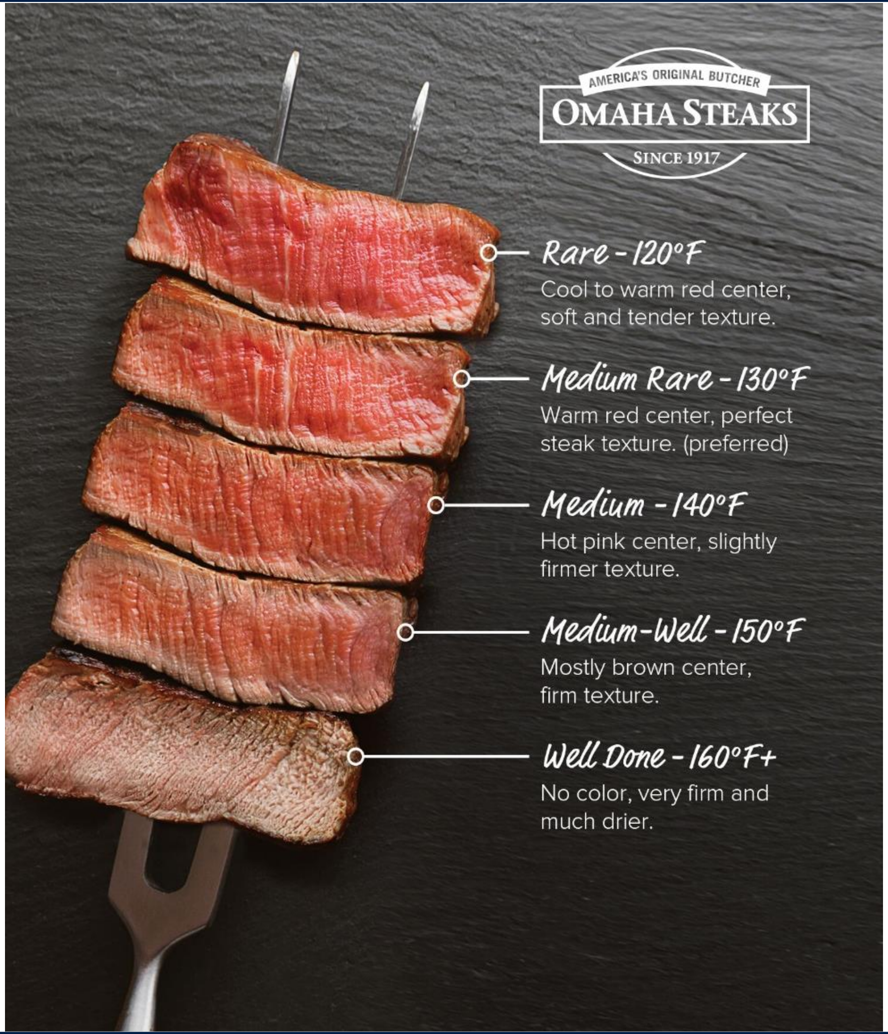
Thermal Conductivity of Different Materials

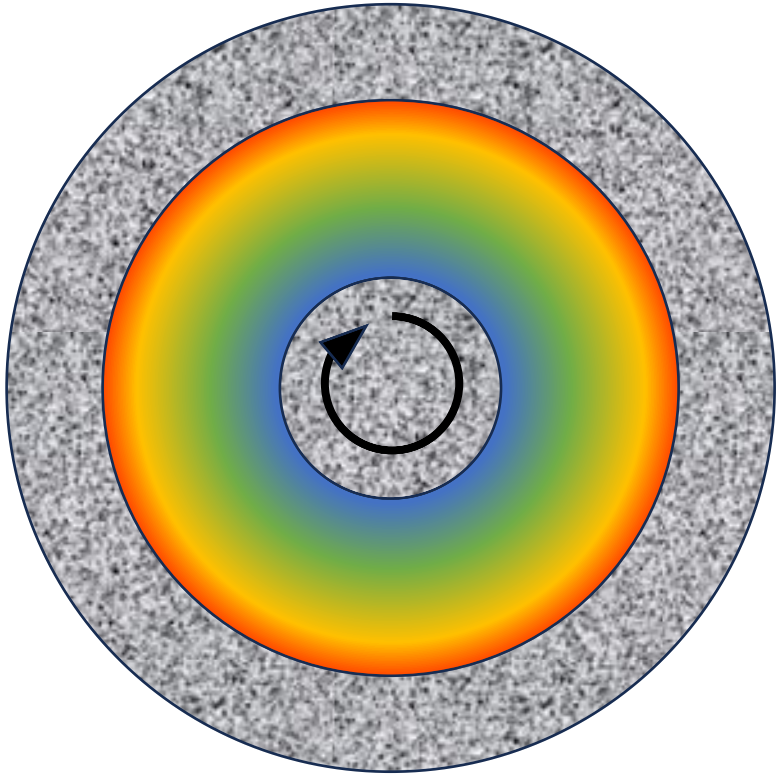
- Copper: ~390-400 W/m·K
- Aluminum: ~205-235 W/m·K
- Stainless Steel: ~14-20 W/m·K
- Steak: ~0.49 W/m·K
- PEEK: ~0.25 W/m·K
- PC: ~0.19-0.22 W/m·K
- PP : ~0.15-0.22 W/m·K
- Air: ~0.024-0.03 W/m·K

78 MFI PEEK



Challenges with PEEK – Low Thermal Conductivity

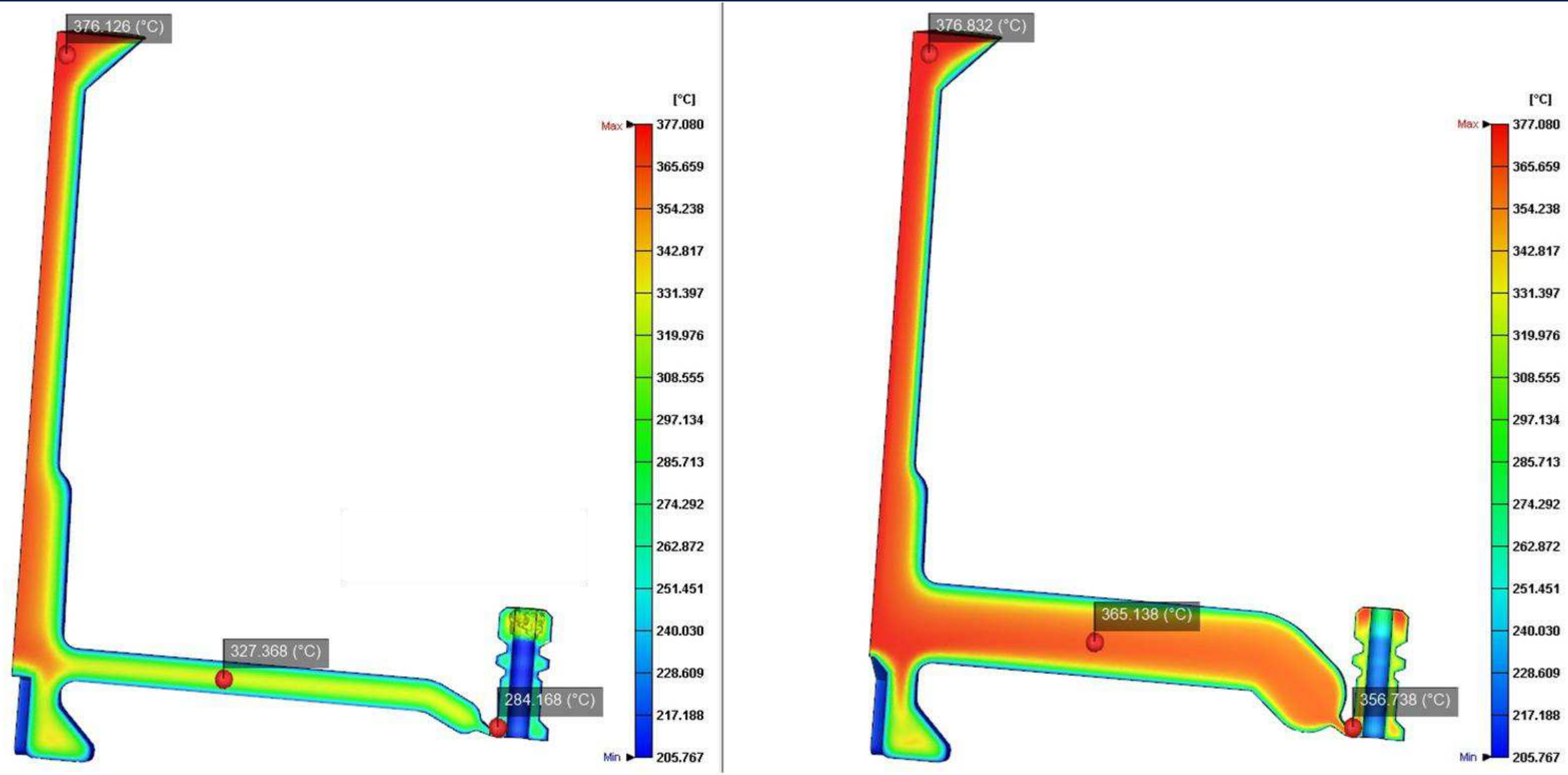




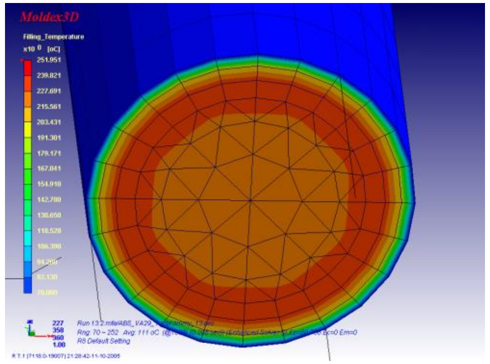
Melt Temperature Profile Depends on:

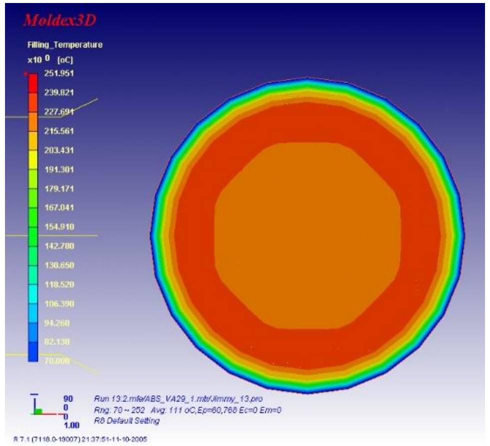
- Barrel temperature profile
- Screw design
- Material viscosity
- Screw RPM
- Back Pressure
- Cycle Time

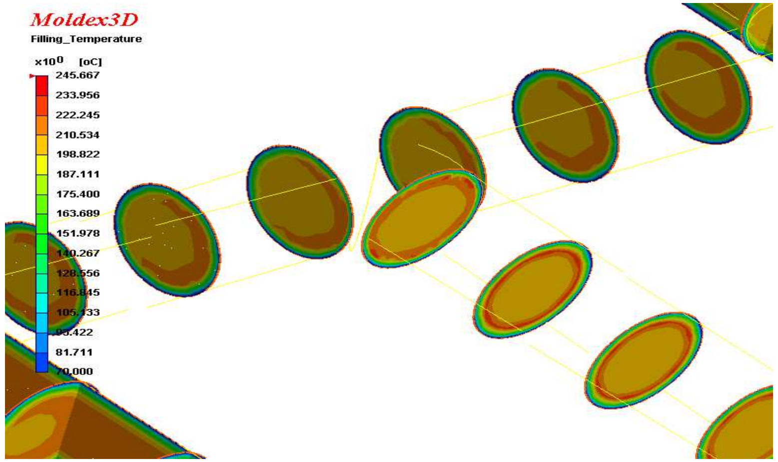
Challenges with PEEK – Runner Sizing

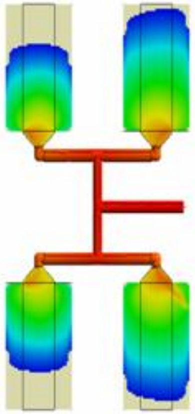


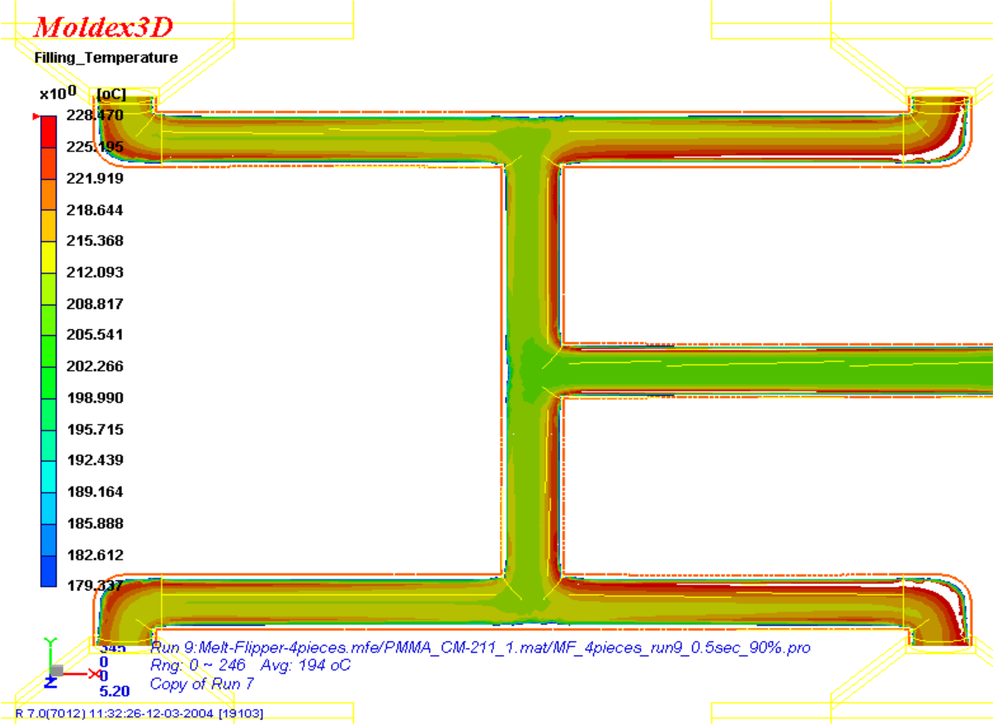
Challenges with PEEK – Filling Imbalance



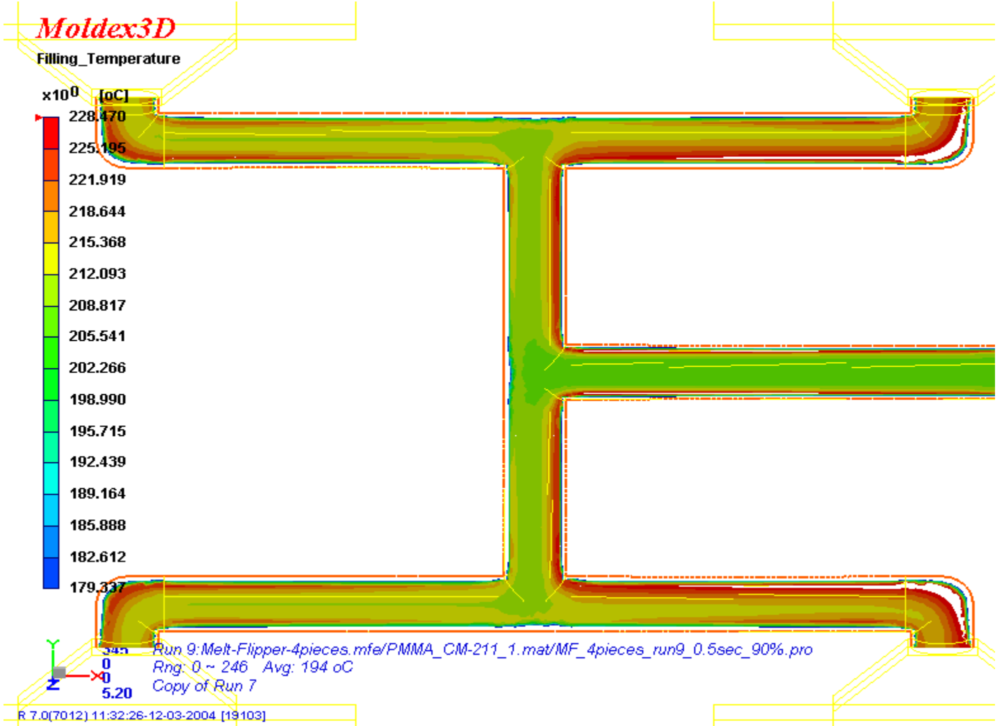


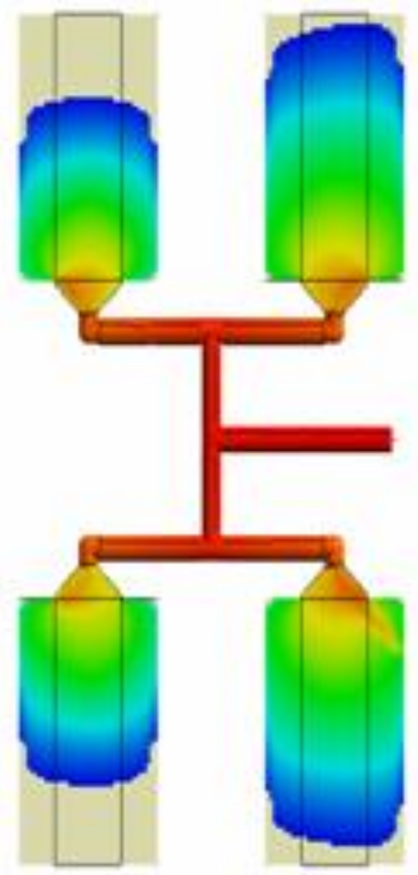






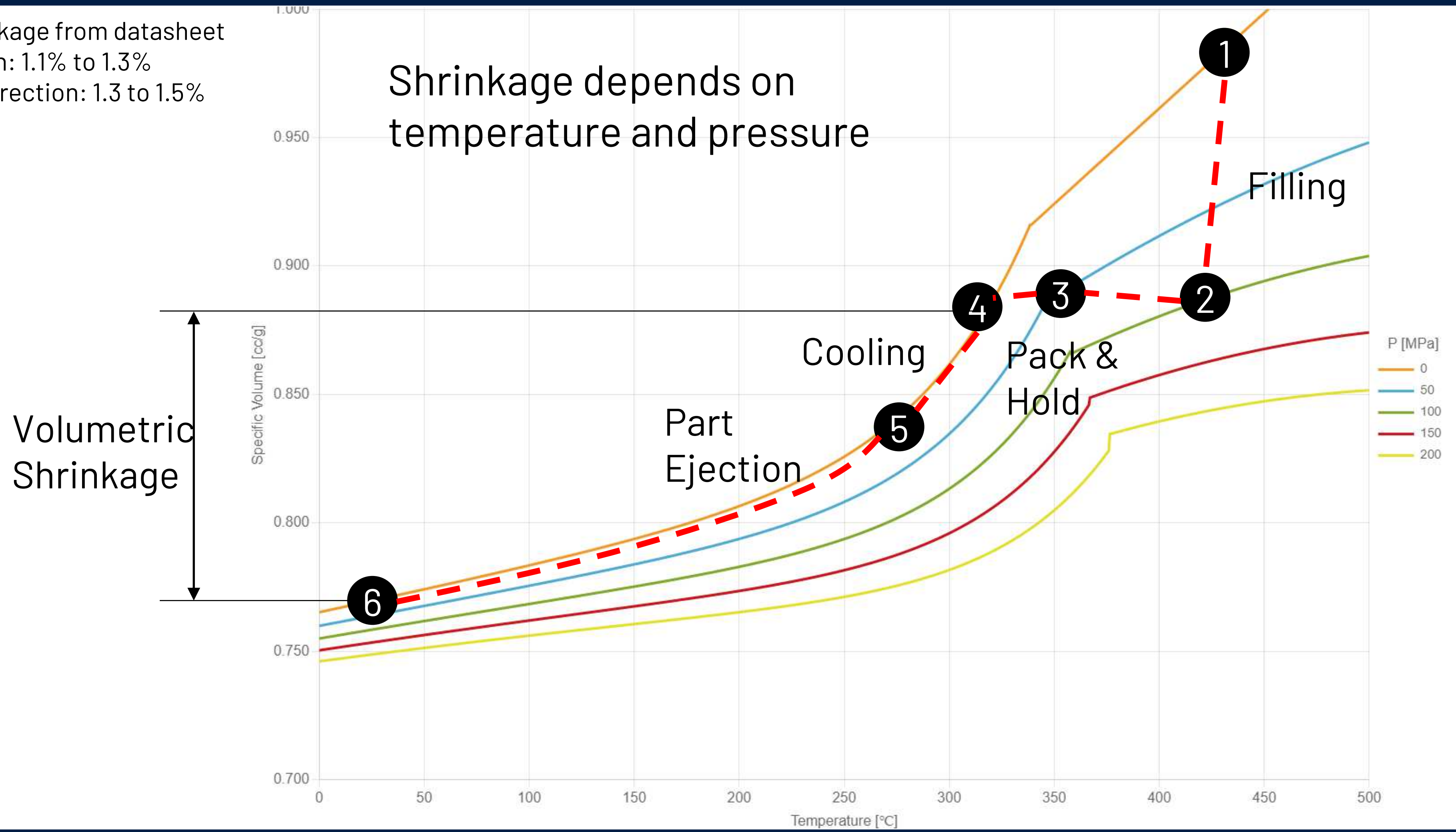
Challenges with PEEK – Filling Imbalance



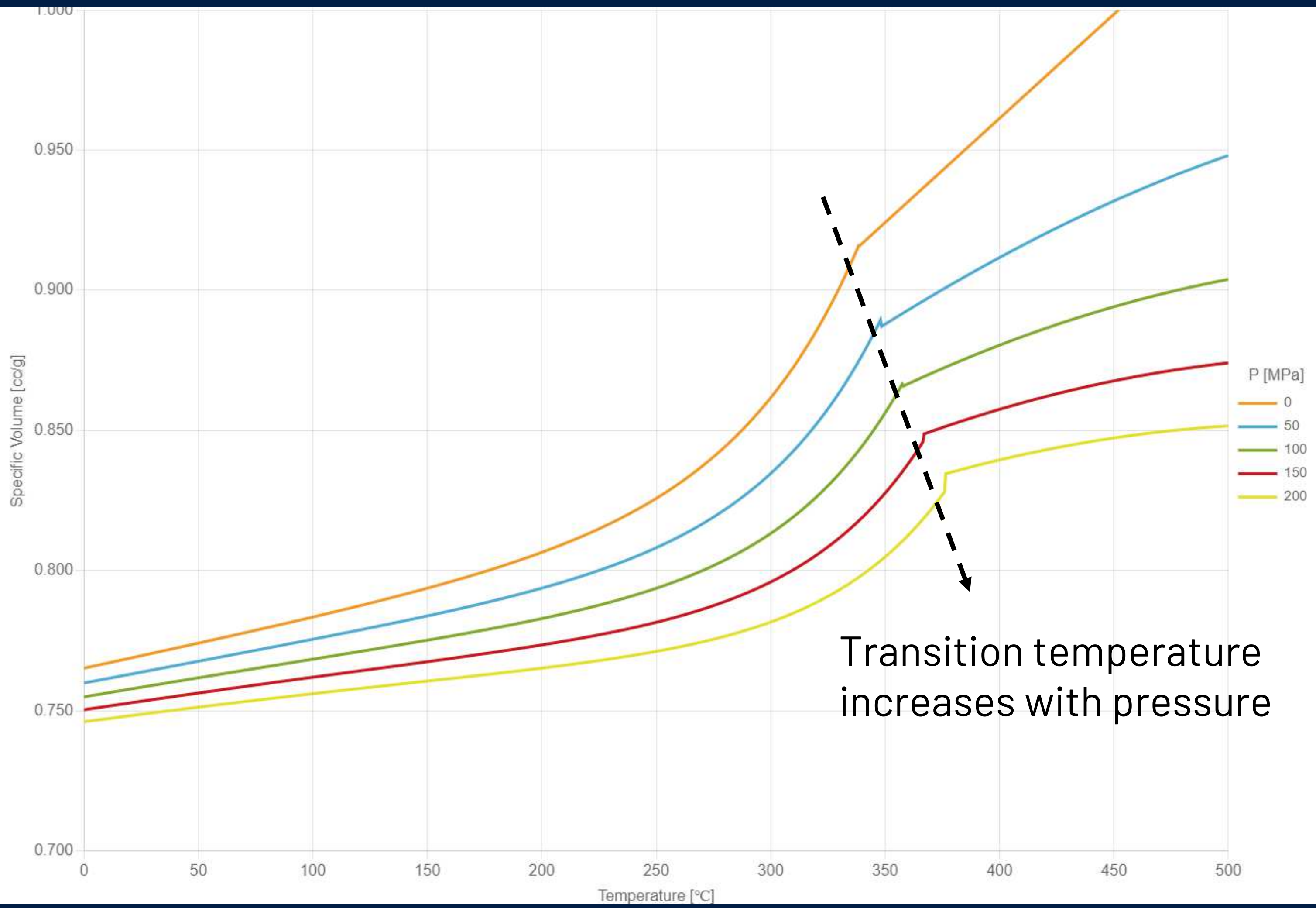


Challenges with PEEK – Shrinkage

Molding Shrinkage from datasheet
Flow Direction: 1.1% to 1.3%
Transverse Direction: 1.3 to 1.5%



Challenges with PEEK – Transition Temperature



Transition temperature increases with pressure

Challenges with PEEK – % Crystallinity

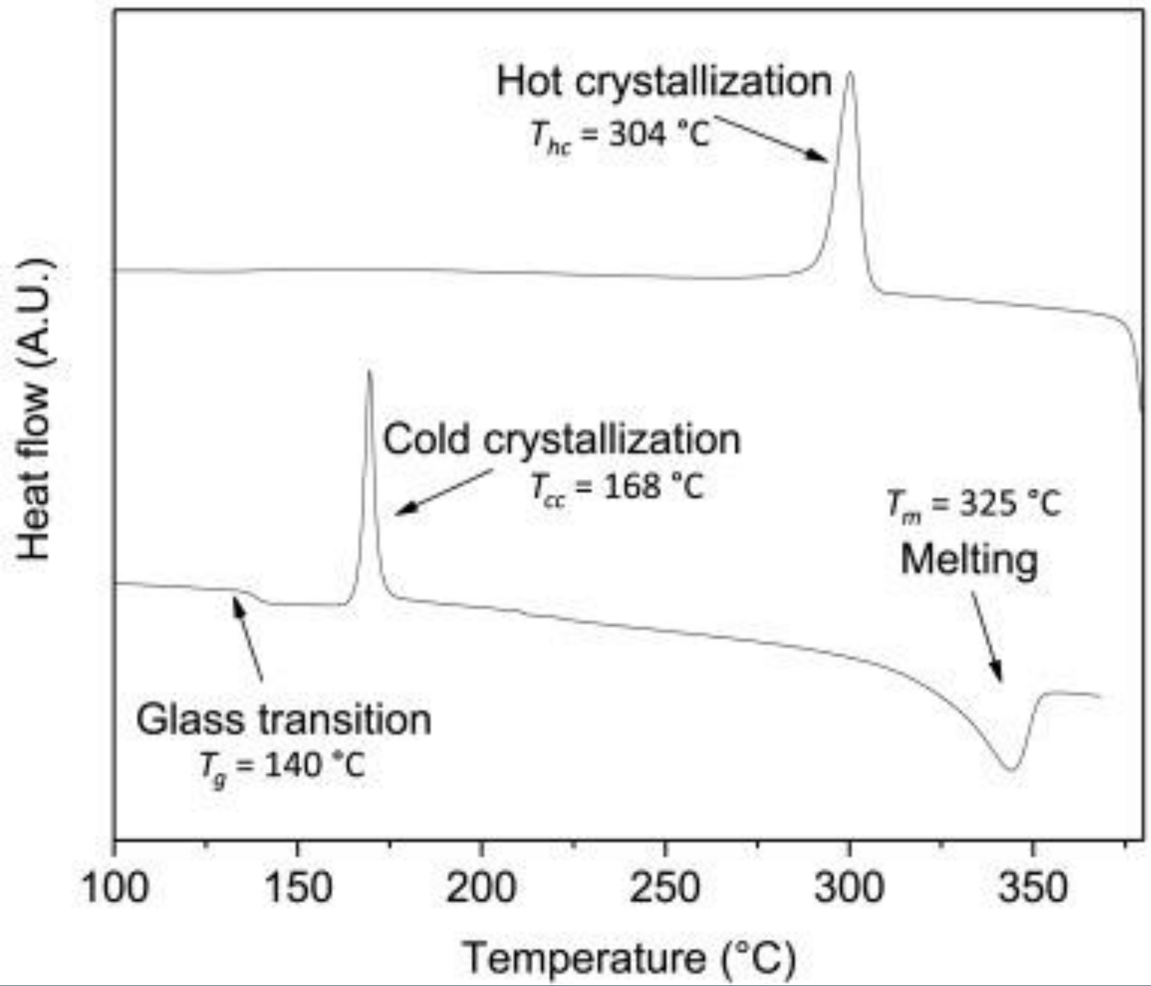
The percent crystallinity is directly related to many of the key properties exhibited by a semi-crystalline polymer including:

- Brittleness
- Toughness
- Stiffness or modulus
- Optical clarity
- Creep or cold flow
- Long term stability
- Barrier resistance (ability to prevent gas transfer in or out)

The percent crystallinity is determined using the following equation:

$$\%\ Crystallinity = \frac{\Delta Hm - \Delta Hc}{\Delta Hm} \text{x } 100\ \%$$

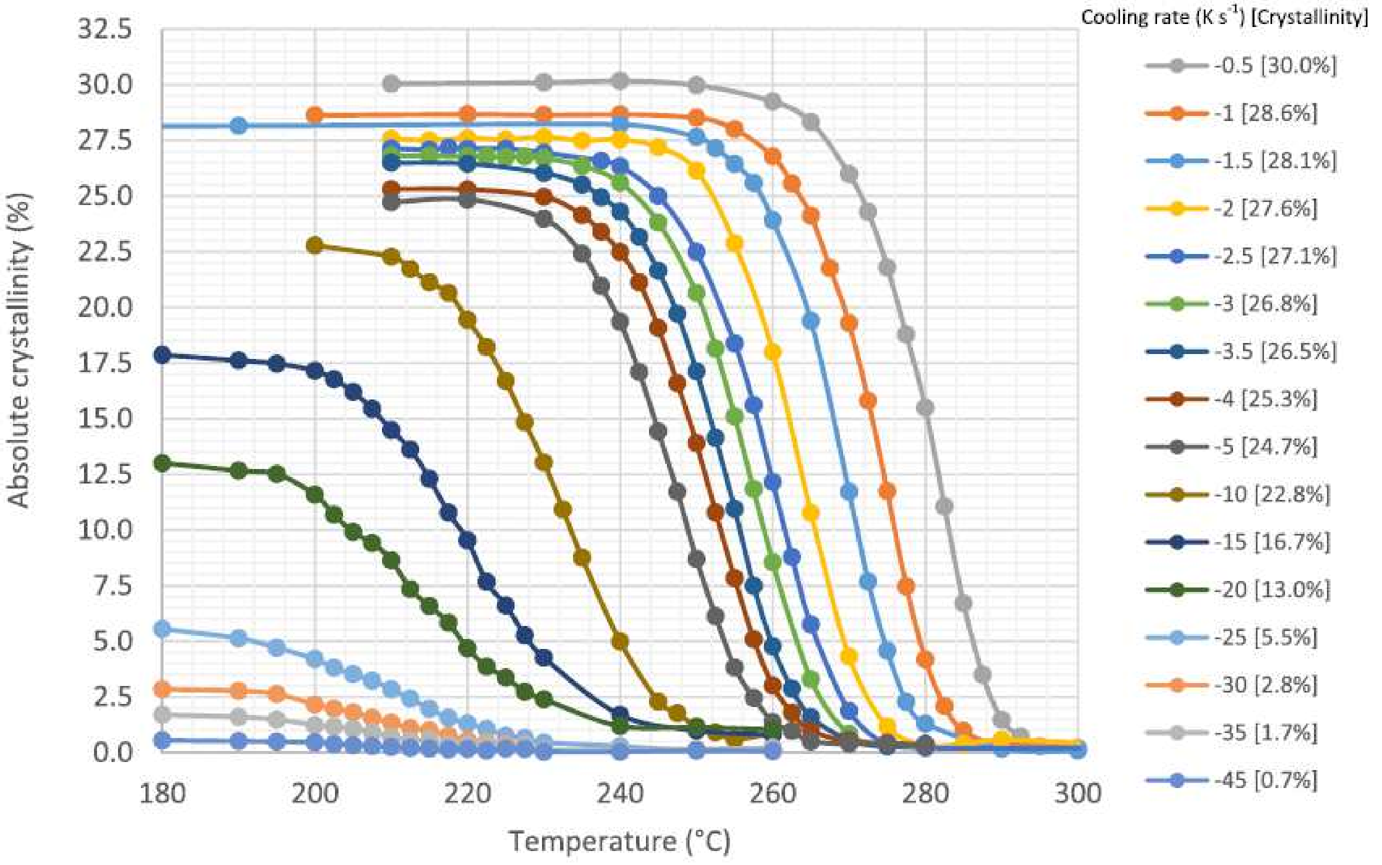
The heats of melting, ΔHm, and cold crystallization, ΔHc, are determined by integrating the areas (J/g) under the peaks.



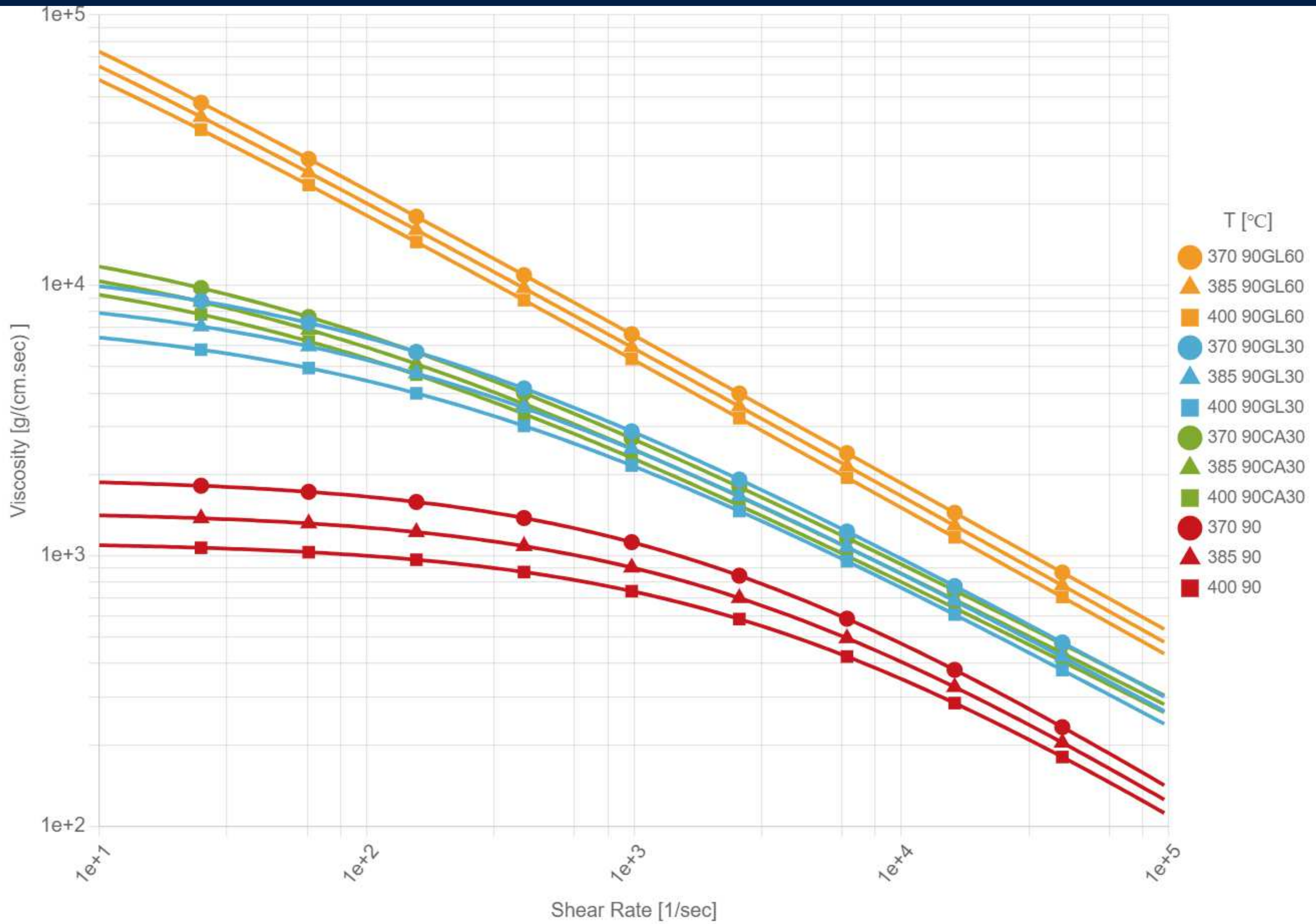
Challenges with PEEK – % Crystallinity

The percent crystallinity of a semi-crystalline polymer primarily depends on:

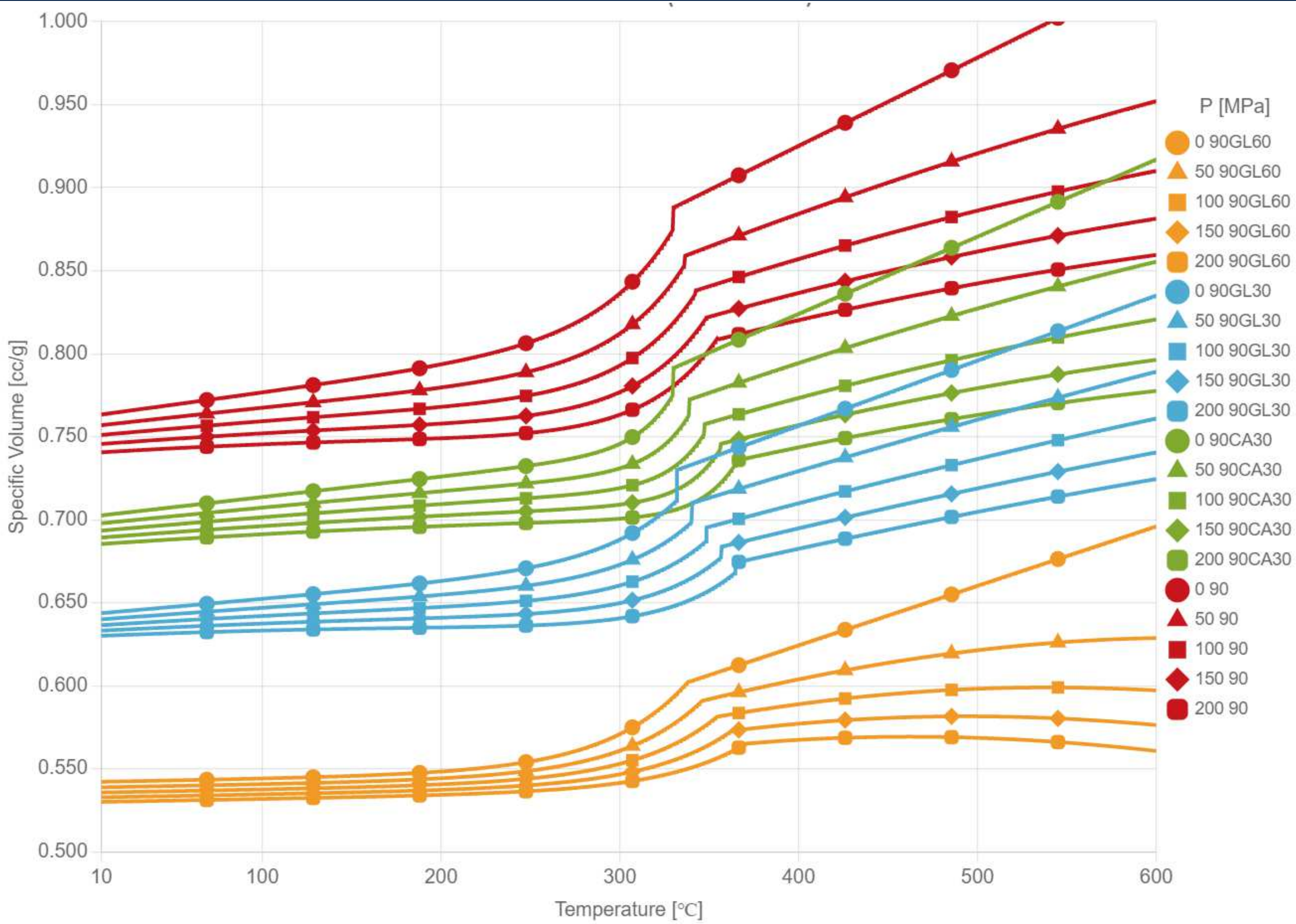
- Material properties
- Rate of Cooling
  - Mold Design
  - Processing Conditions
    - Melt Temp
    - Mold Temp
    - Screw RPM
    - Back Pressure
    - Barrel Temp Profile
    - Peak Injection Pressure
    - Pack + Hold Pressure & Time
    - Cooling Time
- Fillers / Additives
- Annealing



Challenges with PEEK – Fillers



Challenges with PEEK – Fillers



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Bioresorbable Molding

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Bioresorbable Molding

- Molding in a large variety of bioresorbable resins
- Systems in place for:
  - Resin storage and handling
  - Cleaning all contact surfaces inside and outside of the press and mold
  - Specialized packaging and shipping

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Factors That Affect the Quality of Molded Parts
(Partial List)

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Intrinsic Viscosity Testing

- Bioreabsorbable parts must pass Intrinsic Viscosity tests

$$[\eta]=K\cdot M^{a}$$

where:
- $[\eta]$ is the intrinsic viscosity,
- M is the molar mass
- K and a are empirical constants that depend on the specific polymer-solvent system and temperature.

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Intrinsic Viscosity Testing

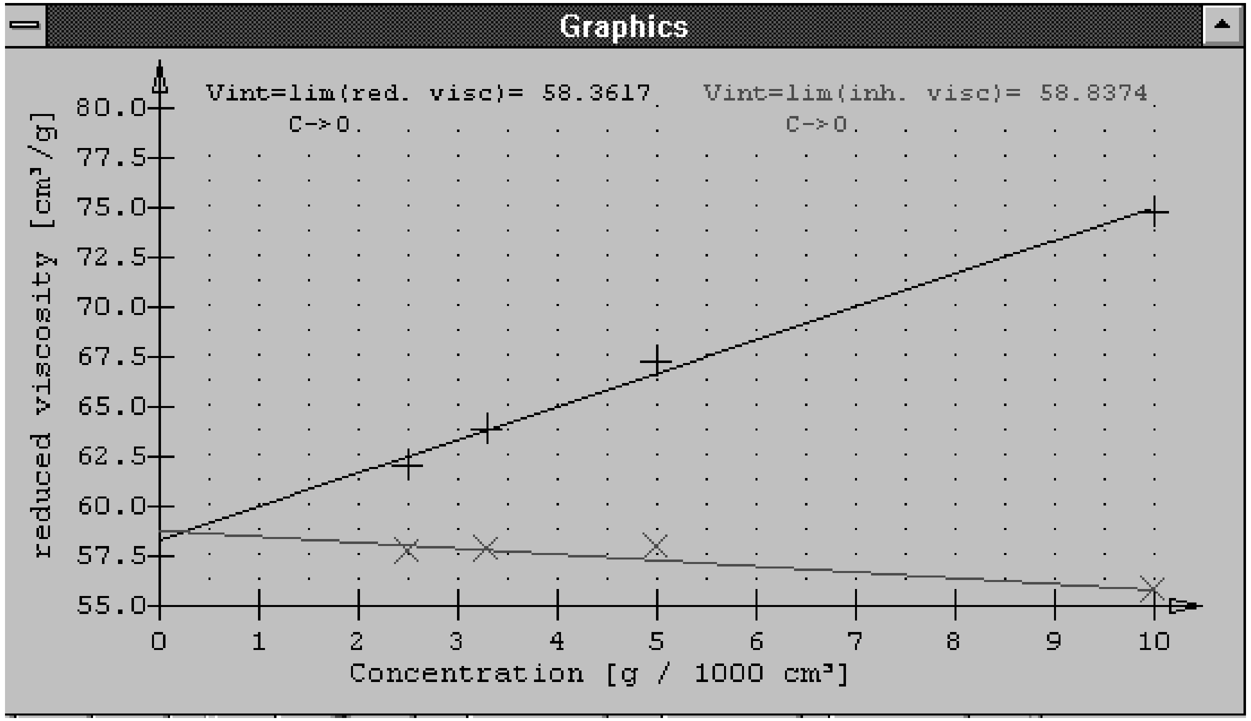
- Bioreabsorbable parts must pass Intrinsic Viscosity tests

$$[\eta] = K \cdot M^{a}$$

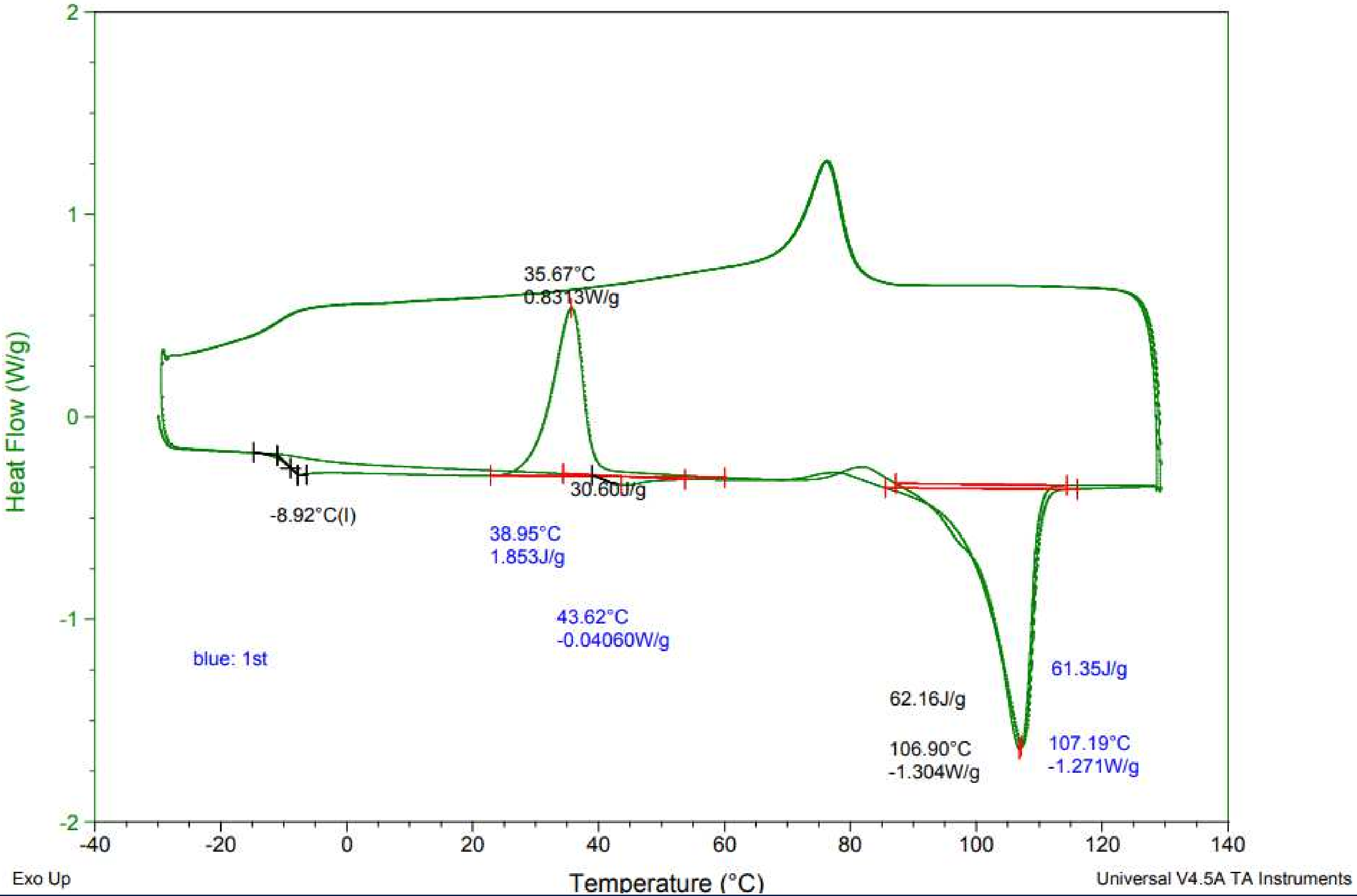
where:

- $[\eta]$ is the intrinsic viscosity,
- M is the molar mass
- K and a are empirical constants that depend on the specific polymer-solvent system and temperature.

Relative Viscosity:	$v_{rel} = \frac{v_{Solution}}{v_{Solvent}}$	Vrel	Relative Viscosity	---
Specific Viscosity:	$v_{spec} = v_{rel} - 1$	Vspec	Specific Viscosity	---
Reduced Viscosity: (Viscosity number, VZ)	$v_{red} = \frac{v_{rel} - 1}{C}$	Vred C	Reduced Viscosity Concentration	cm^3/g g/cm^3
Inherent Viscosity (log. Viscosity number)	$v_{inh} = \frac{\log v_{rel}}{C}$	Vinh C	Inherent Viscosity Concentration	cm^3/g g/cm^3



Polydioxanone (RESOMER® X 206 S)



Polydioxanone (RESOMER® X 206 S)

DESCRIPTION

RESOMER® X 206 S is a semi-crystalline homopolymer of p-dioxanone with an inherent viscosity range of 1.5 – 2.2 dL/g (measured in HFIP). It is supplied in white to off-white granular form and may be used in medical applications.

MECHANICAL PROPERTIES

Measurement according to DIN EN ISO 527-2:2012, test specimens A14 (ISO 20753:2008)

Tensile strength	35–45 MPa
Young's modulus	600–800 MPa
Elongation at break	ca. 250 %

PHYSICAL PROPERTIES

Density	1.38 g/cm³
Melting point	115 °C
Glass transition temperature	-16 °C

PROCESSING

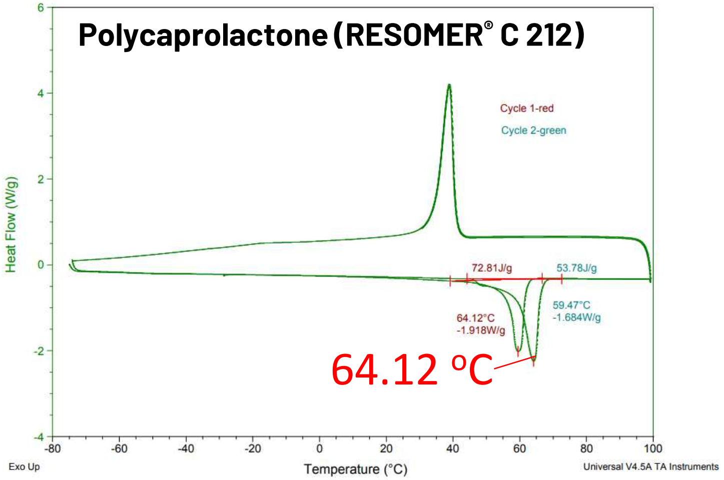
Drying/residual moisture:	< 300 ppm

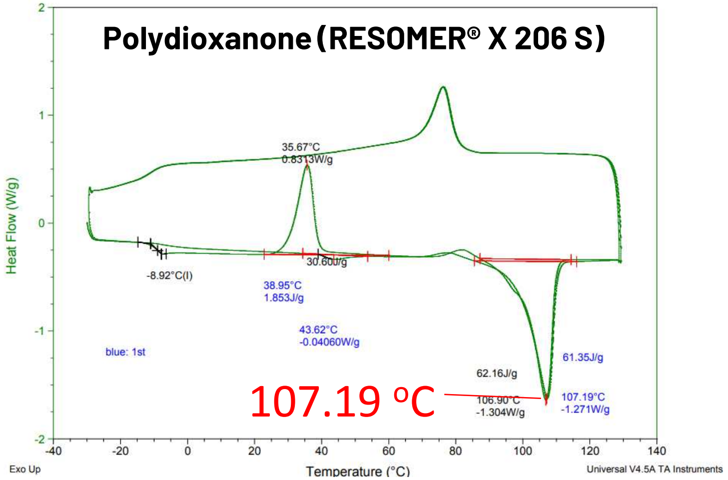
TEMPERATURE SETTINGS

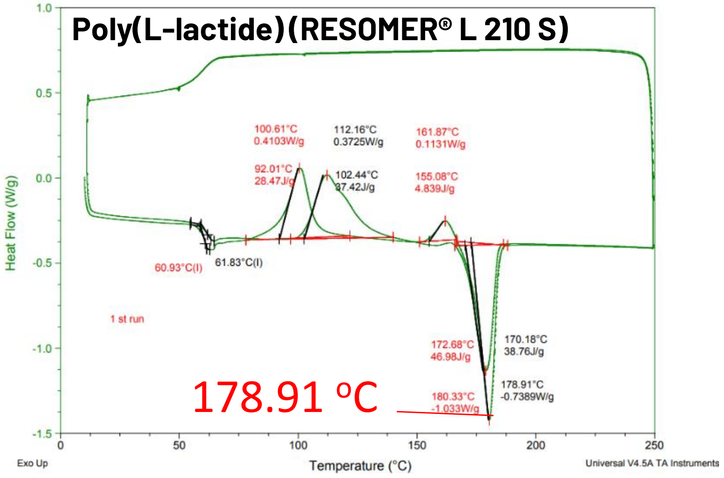
(Arburg 170 S 180-30)

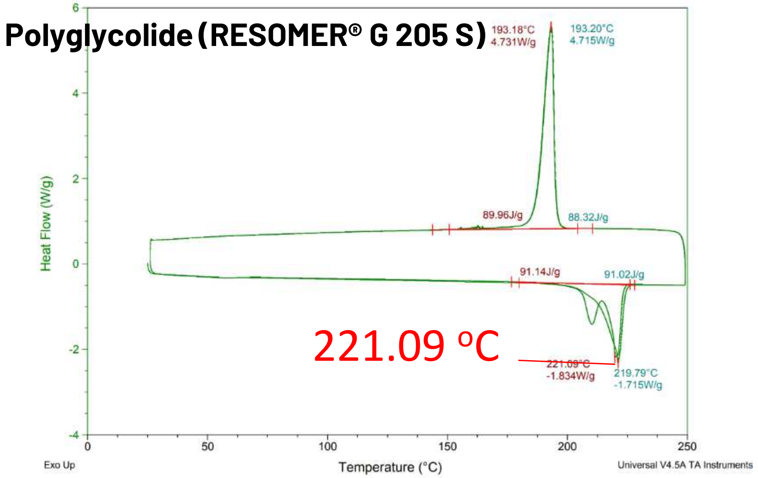
Feed throat:	20 °C
Zone 1:	95–105 °C
Zone 2:	95–105 °C
Zone 3:	105–115 °C
Nozzle:	110–120 °C
Mold temperature:	25 °C

DSC Curves


Polycaprolactone (RESOMER® C 212)
Cycle 1-red
Cycle 2-green
72.81J/g
53.78J/g
59.47°C
-1.684W/g
64.12°C
-1.918W/g
64.12 °C
Heat Flow (W/g)
Temperature (°C)
Exo Up
Universal V4.5A TA Instruments

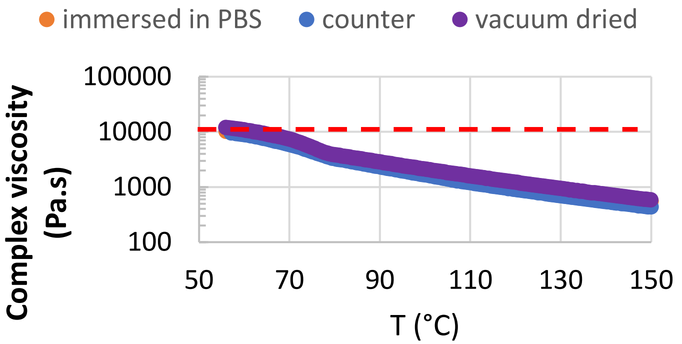

Polydioxanone (RESOMER® X 206 S)
35.67°C
0.8313W/g
30.60J/g
-8.92°C(I)
38.95°C
1.853J/g
43.62°C
-0.04060W/g
blue: 1st
62.16J/g
61.35J/g
107.19 °C
106.90°C
-1.304W/g
107.19°C
-1.271W/g
Heat Flow (W/g)
Temperature (°C)
Exo Up
Universal V4.5A TA Instruments


Poly(L-lactide) (RESOMER® L 210 S)
100.61°C
0.4103W/g
112.16°C
0.3725W/g
161.87°C
0.1131W/g
92.01°C
28.47J/g
102.44°C
37.42J/g
155.08°C
4.839J/g
60.93°C(I)
61.83°C(I)
1 st run
172.68°C
46.98J/g
170.18°C
38.76J/g
178.91 °C
180.33°C
-1.033W/g
178.91°C
-0.7389W/g
Heat Flow (W/g)
Temperature (°C)
Exo Up
Universal V4.5A TA Instruments

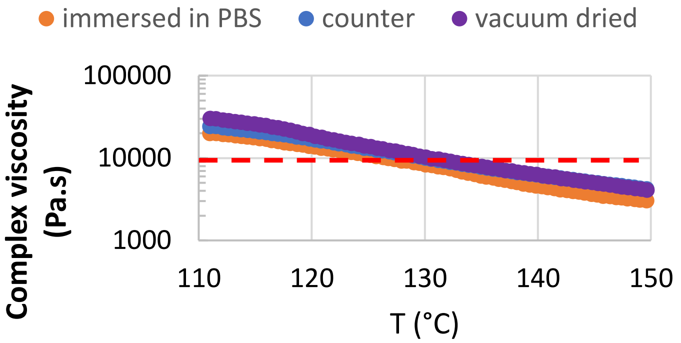

Polyglycolide (RESOMER® G 205 S)
193.18°C
4.731W/g
193.20°C
4.715W/g
89.96J/g
88.32J/g
91.14J/g
91.02J/g
221.09 °C
221.09°C
-1.834W/g
219.79°C
-1.715W/g
Heat Flow (W/g)
Temperature (°C)
Exo Up
Universal V4.5A TA Instruments

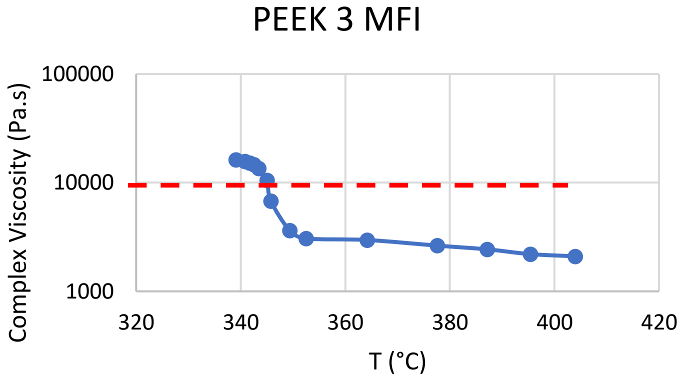
Complex Viscosity Curves

Polycaprolactone (RESOMER® C 212)
Inherent viscosity 1.13 - 1.38 dl/g

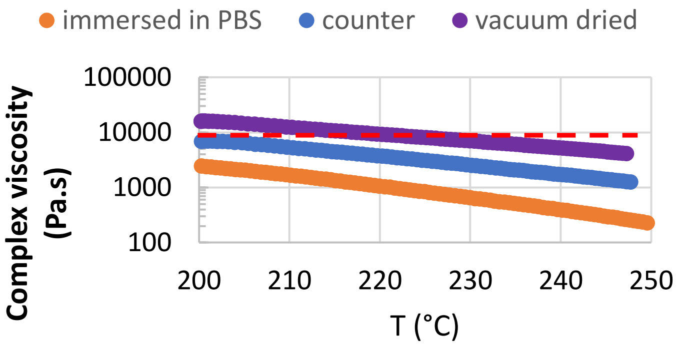


Polydioxanone (RESOMER® X 206 S)
Inherent viscosity 1.5 - 2.2 dl/g

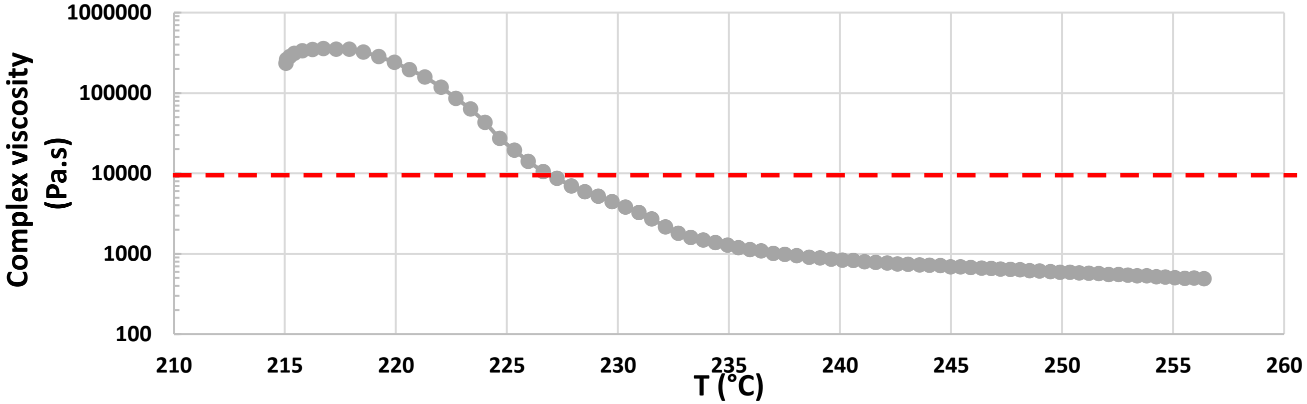




Poly(L-lactide) (RESOMER® L 210 S)
Inherent viscosity 3.3 - 4.3 dl/g



Polyglycolide (RESOMER® G 205 S)
Inherent viscosity 1.05 - 1.25 dl/g



Bioresorbable Molding

Injection Unit
- Screw design
- % barrel utilization
- Residence time
- Nozzle design

Resin
- Material Handling
- Material Drying

Mold
- Runner design
- Gate design
- Cooling layout
- Venting

Hot runner
- Residence time
- Thermal design
- No stagnation
- Runner design
- Heater quality
- Thermocouples

Processing
- Barrel temp. profile
- Screw rpm
- Back pressure
- Hot runner temperature profile
- Injection velocity profile

Primary Causes of Thermal Degradation of Bioresorbable Polymers

- Moisture
- High temperatures
- Long residence time
- Excessive shear
- Stagnation
- Machine startup and shut down procedures

Thank You!

Questions?

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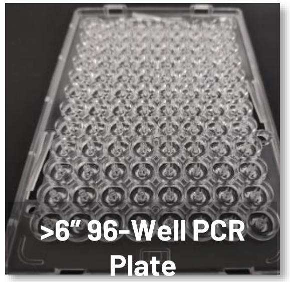

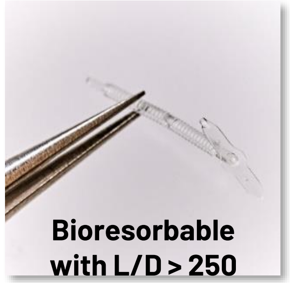

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