Thermoplastic Material Testing for Use in SIGMASOFT and the Effect of Moisture on PA 6/6

DatapointLabs

EST 1995

ISO 17025 Quality

technical center for materials

matereality

software for materials

TestPaks

testing for simulation

picsci

electronic lab notebooks

knowmats

materials in simulation

Our Brands

DatapointLabs

technical center for materials

EST 1995

ISO 17025 Quality

Material testing for new product development

TestPaks

testing for simulation

Material parameters for CAE,
material model validation

matereality

software for materials

Store, analyze, compare any material data,
create CAE material cards, master material files

picsci

electronic lab notebooks

Record & analyze any experimental and simulation data

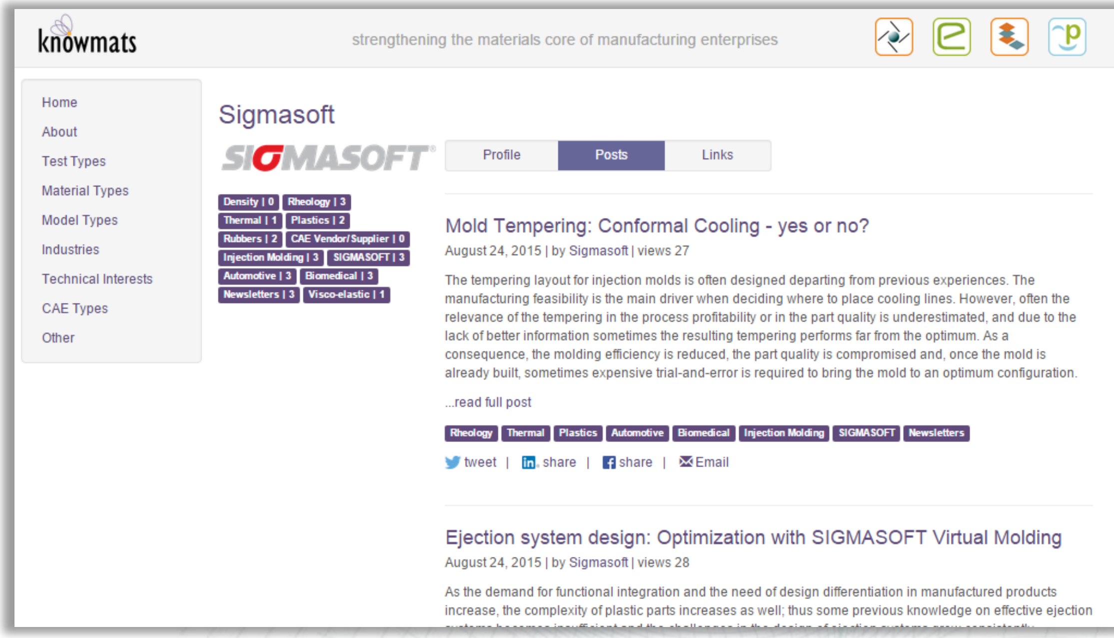
knowmats

materials in simulation

Knowledge resource for CAE users related to materials in simulation

knowmats
materials in simulation

Know Your Materials



Knowmats is a knowledge resource for CAE users related to materials in simulation.

A curated collection of:

- Blog-style posts
- Links to technical papers
- Articles or newsletters

Help simulation professionals perform best-in-class simulation with a better understanding of how materials are represented in FEA and simulation.

Material Testing Expertise

Plastic
Rubber
Film
Metal
Foam
Composite
Cement
Ceramic
Paper
Wire
Fiber

- Product development / R&D support
  - CAE-centric
  - Commitment to simulation accuracy
- All kinds of materials
  - Over 1,800 materials tested each year
- All kinds of material behavior
  - Over 200 physical properties:
    - Mechanical properties
    - Thermal properties
    - Flow properties

Tensile
Compressive
Flexural
Stress-strain
Poisson's ratio
High strain rate
Bulk modulus
Fatigue
Viscoelasticity
Stress relaxation
Creep
Friction
Hyperelasticity
Thermal expansion
Thermal conductivity
Specific heat
PVT
Rheology

Customer Base

- 1200+ companies
- 11 manufacturing verticals
- Product development / R&D
- Globally available at
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Aerospace
Automotive
Appliance
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Consumer products
Electronics
Industrial goods
Materials
Petroleum
Packaging

Required Testing

- Viscosity
- Specific Heat
- DSC Transition Temperatures
- Thermal Conductivity
- PVT
- Linear Shrinkage
- Viscoelastic Properties

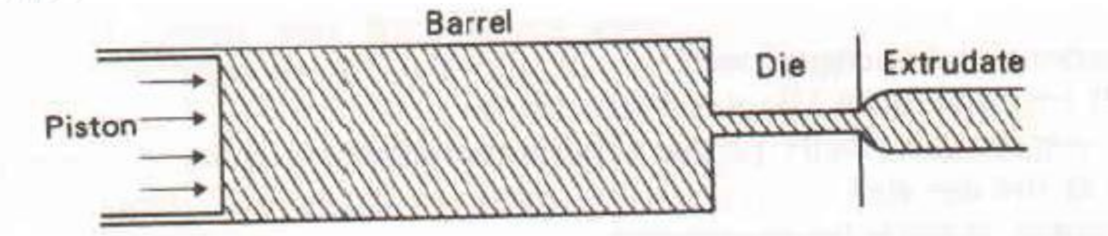
Mold Filling

Packing

Post-Mold
Shrinkage
Warpage

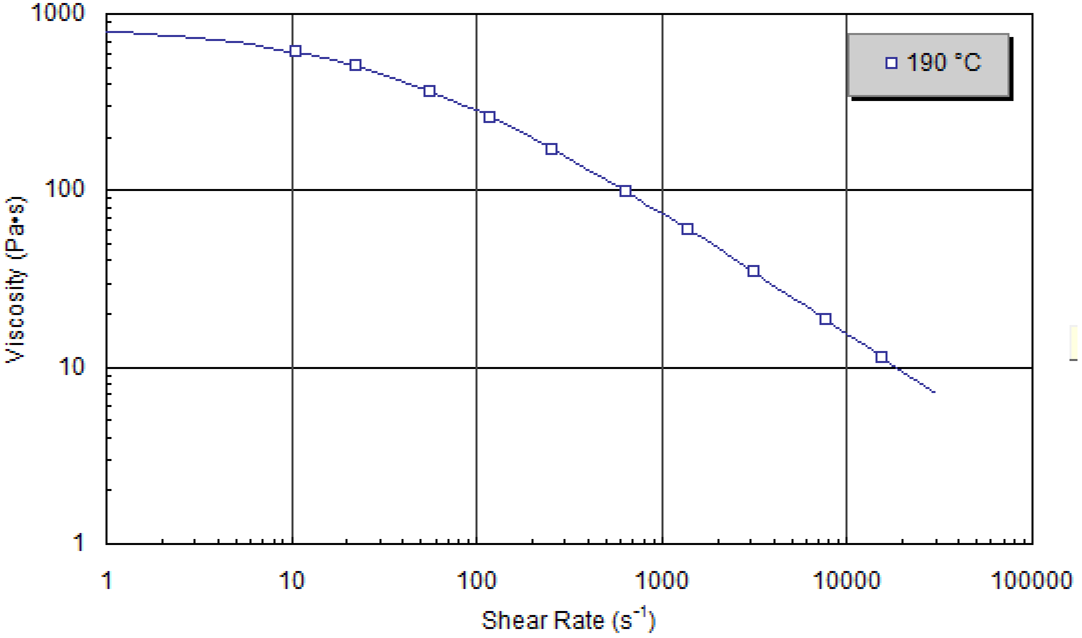
Rheometer Measurement of Viscosity

- Capillary rheometer is used
- Material is extruded through a restriction of known geometry (extremely high tolerance dies)
- Temperature and flow rate are controlled
- Pressure drop across the restriction is used to determine viscosity as a function of shear rate and temperature



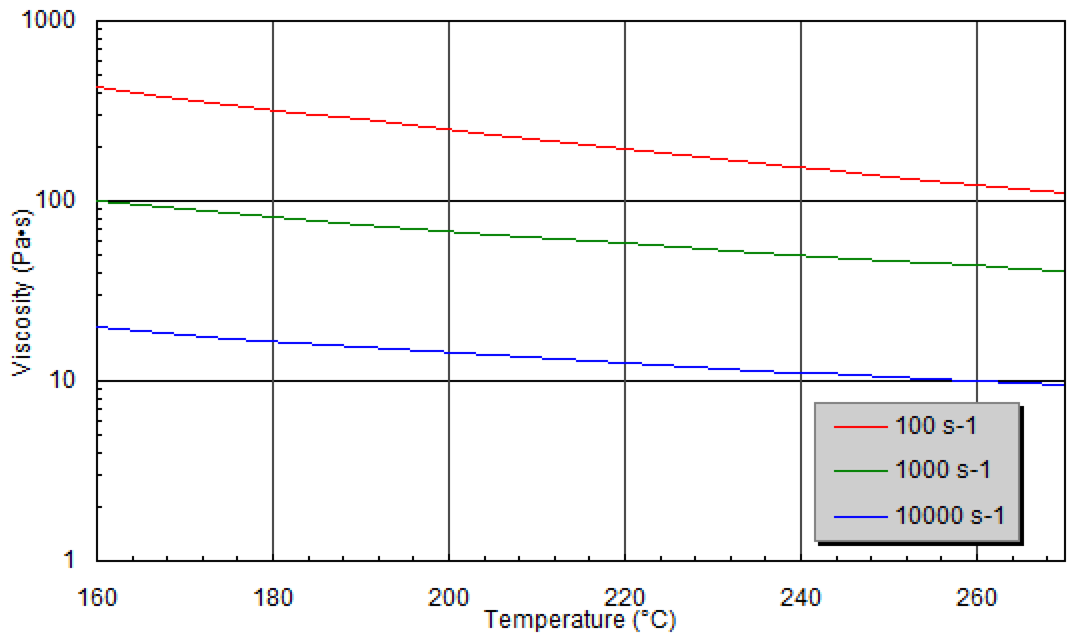
Viscosity Properties

- As shear rate increases, viscosity decreases



Viscosity Properties

- As temperature increases, viscosity decreases



Viscosity Measurements

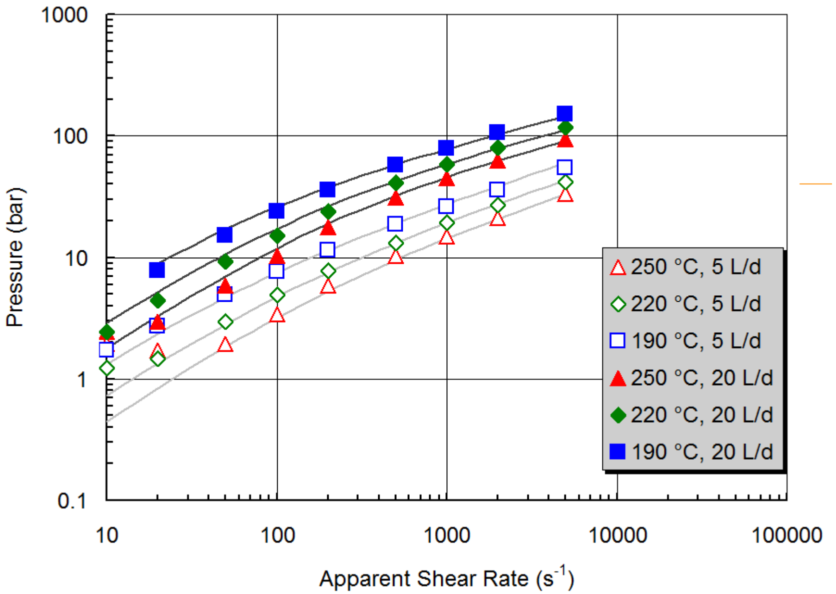
- Apparent Viscosity
- Shear rate: $\dot{\gamma}_a = \dfrac{32Q}{\pi d^3}$
  - Shear stress: $\tau_w = \dfrac{\Delta p d}{4L}$
  - Shear viscosity: $\eta_a = \dfrac{\tau_w}{\dot{\gamma}_a}$

Where: Q = Volume flow rate
Δp = Pressure drop
d = Capillary diameter
L = Capillary length

- Corrections to viscosity
  - Reservoir and friction losses (transducer located at die)
  - End pressure drop (Bagley)
  - Non-parabolic velocity (Rabinowitsch correction)

Bagley Correction Testing

- Bagley Correction
  - Perform viscosity measure on two different die ratios at equal shear rates
  - Evaluate pressure differences between die geometries (capillary diameter remains the same)
  - $\tau = R/2(dP/dL)$

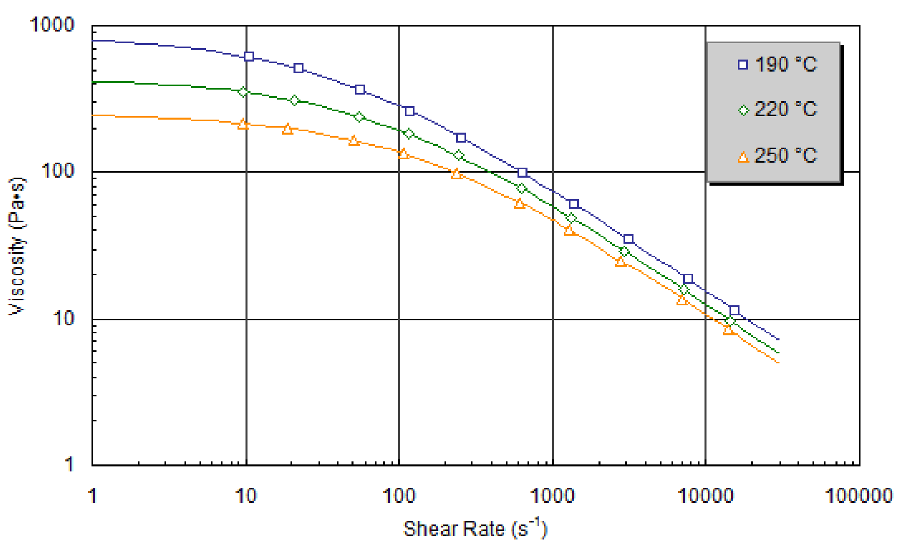


Viscosity Modeling

- Very strong rheological models
  - Cross WLF, Cross Arrhenius
  - Combines a model of shear rate dependency with temperature dependency
  - Allows us to predict beyond testing range

$$\eta(T,\dot{\gamma}) = \frac{\eta_0(T)}{1+\left(\frac{\eta_0\dot{\gamma}}{\tau^*}\right)^{1-n}}, where$$

$$\eta_0(T) = D_1 \exp\left[-\frac{A_1(T-D_2)}{A_2+(T-D_2)}\right]$$



n	0.28400
τ*	32096.1
D1	3.86E+13
D2	263.15
A1	30.87
A2	51.6

Considerations for Testing

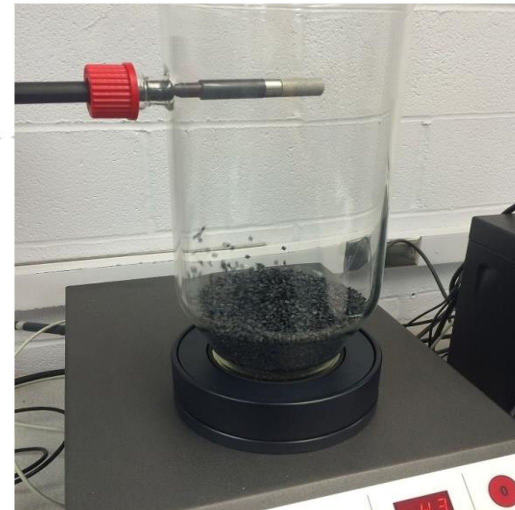
- Limited in shear rates
  - Typically test 10-10000 /s
- Residence times are longer in testing
  - Testing takes several minutes (approx. 6-10 min.)
  - Need to worry about thermal stability
- Processing temperatures are typically higher than test temperatures
- Typically testing is performed at two temperatures within the processing range and one below

Problematic Materials

- Moisture sensitive materials
  - Improperly dried materials cause reduction in viscosity
  - Over-dried materials cause a rise in viscosity
  - PET, PA, PC, PBT etc.
- Highly filled materials
  - Can “log jam” the die entrance
  - Special dies must be used
  - Higher scatter in test data requires engineering judgment on behavior
- Thermally unstable materials
  - Requires very careful attention to residence times
  - PVC

Moisture Study of PA 6/6

- Drying Method Used (Dry)
  - Fluid bed dryer, 10 hrs 110°C
  - KFC titration
  - 0.109% moisture
- Humidification (Wet)
  - Tenny humidification chamber
  - 10 hrs 70% RH, 60°C
  - 0.351% moisture



Viscosity of Dry PA 6/6

Cross/WLF Model

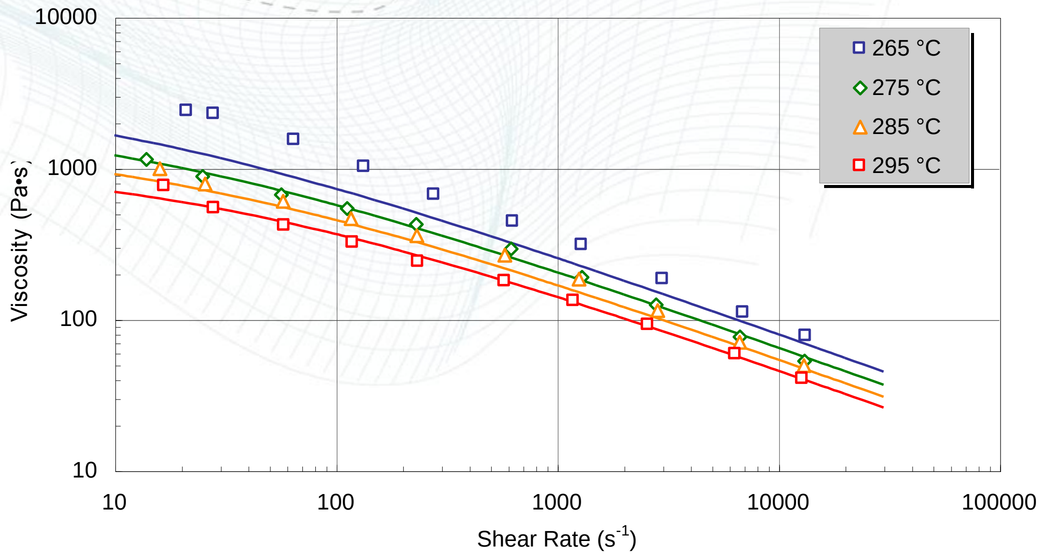
$$\eta(T,\dot{\gamma}) = \frac{\eta_0(T)}{1+\left(\frac{\eta_0\dot{\gamma}}{\tau^*}\right)^{1-n}}, \textit{where}$$

$$\eta_0(T) = D_1 \exp\left[-\frac{A_1(T-D_2)}{A_2+(T-D_2)}\right]$$

Coefficients (SI units)

n	0.47213
τ*	28006.21
D1	5.43E+11
D2	413.15
A1	26.65
A2	51.6

Viscosity vs Shear Rate



Viscosity of Wet PA 6/6

Cross/WLF Model

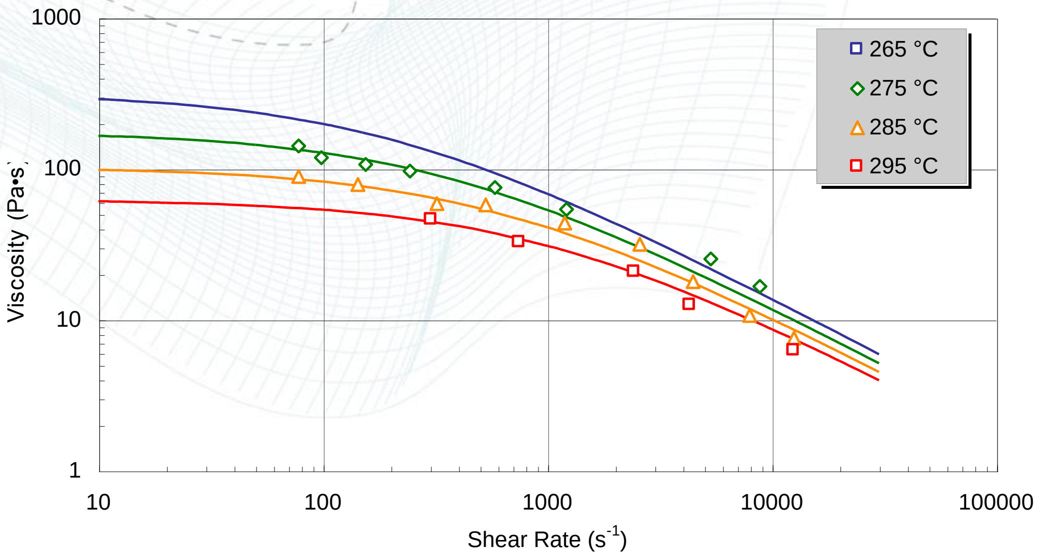
$$\eta(T,\dot{\gamma}) = \frac{\eta_0(T)}{1+\left(\frac{\eta_0\dot{\gamma}}{\tau^*}\right)^{1-n}}, \textit{where}$$

$$\eta_0(T) = D_1 \exp\left[-\frac{A_1(T-D_2)}{A_2+(T-D_2)}\right]$$

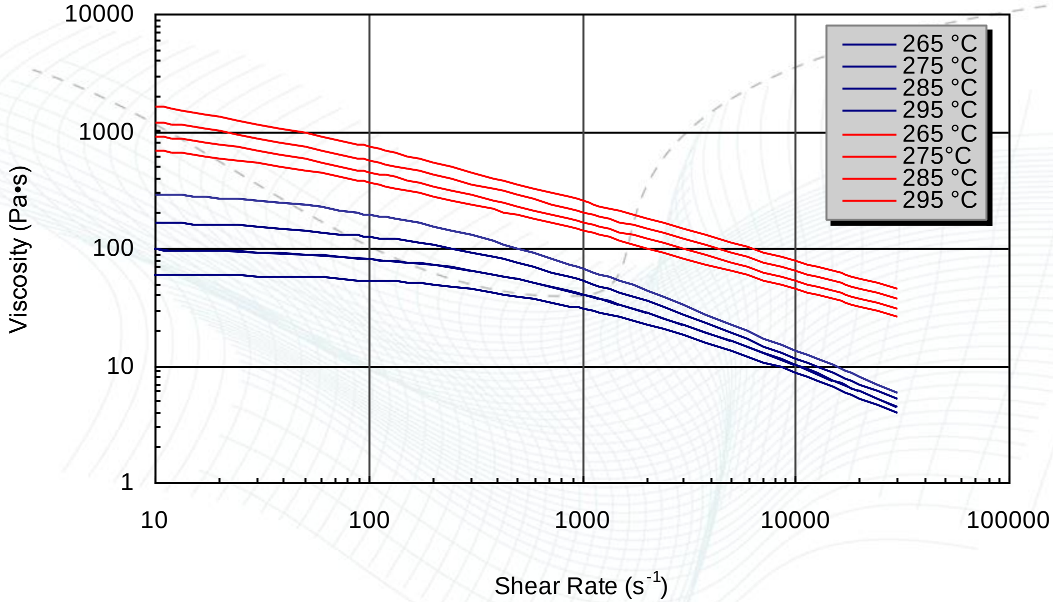
Coefficients (SI units)

n	0.21509
τ*	60816.386
D1	1.34E+20
D2	378.07371
A1	53.68
A2	51.6

Viscosity vs Shear Rate



Wet/Dry Viscosity Comparison



Coefficients (SI units) Dry

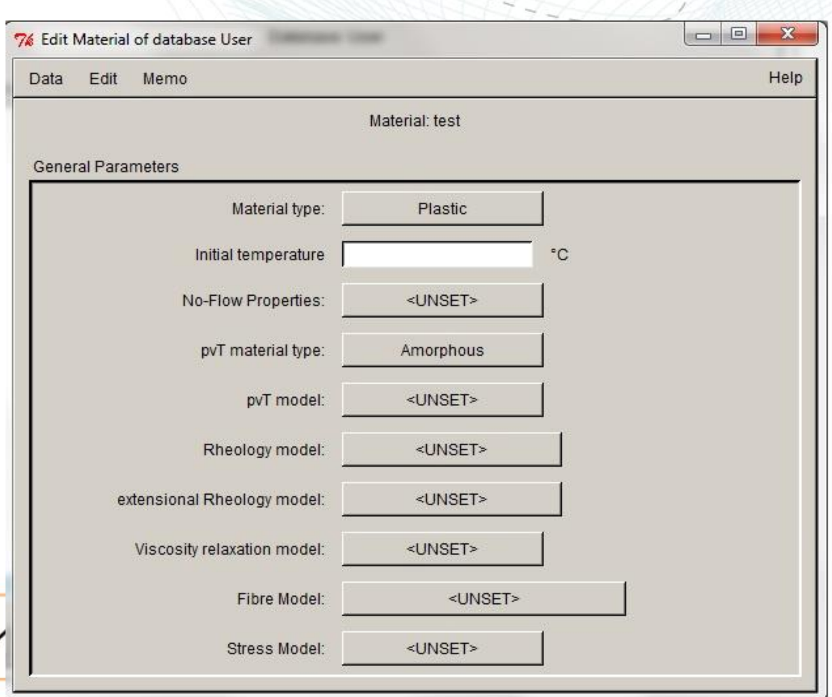
n	0.47213
τ*	28006.21
D1	5.43E+11
D2	413.15
A1	26.65
A2	51.6

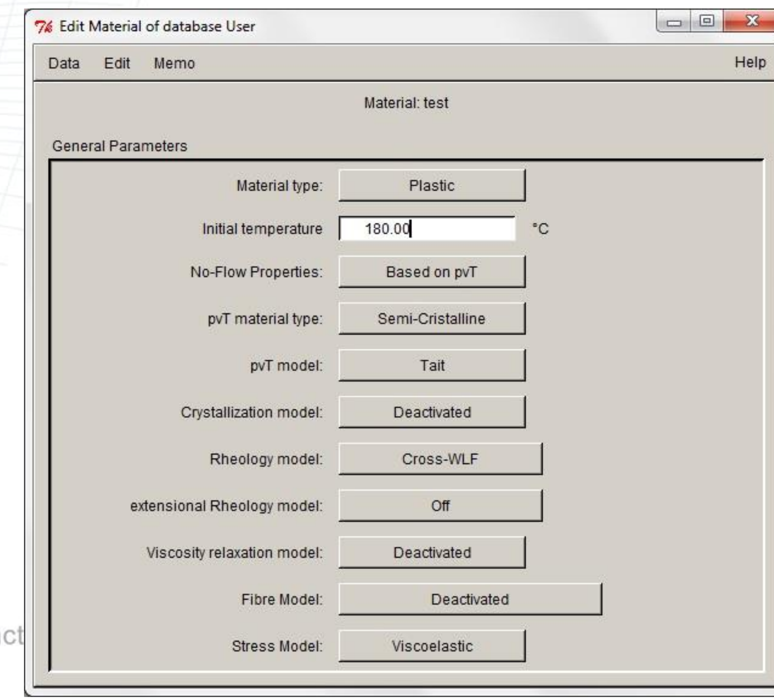
Coefficients (SI units) Wet

n	0.21509
τ*	60816.386
D1	1.34E+20
D2	378.07371
A1	53.68
A2	51.6

Implementation Into SIGMASOFT

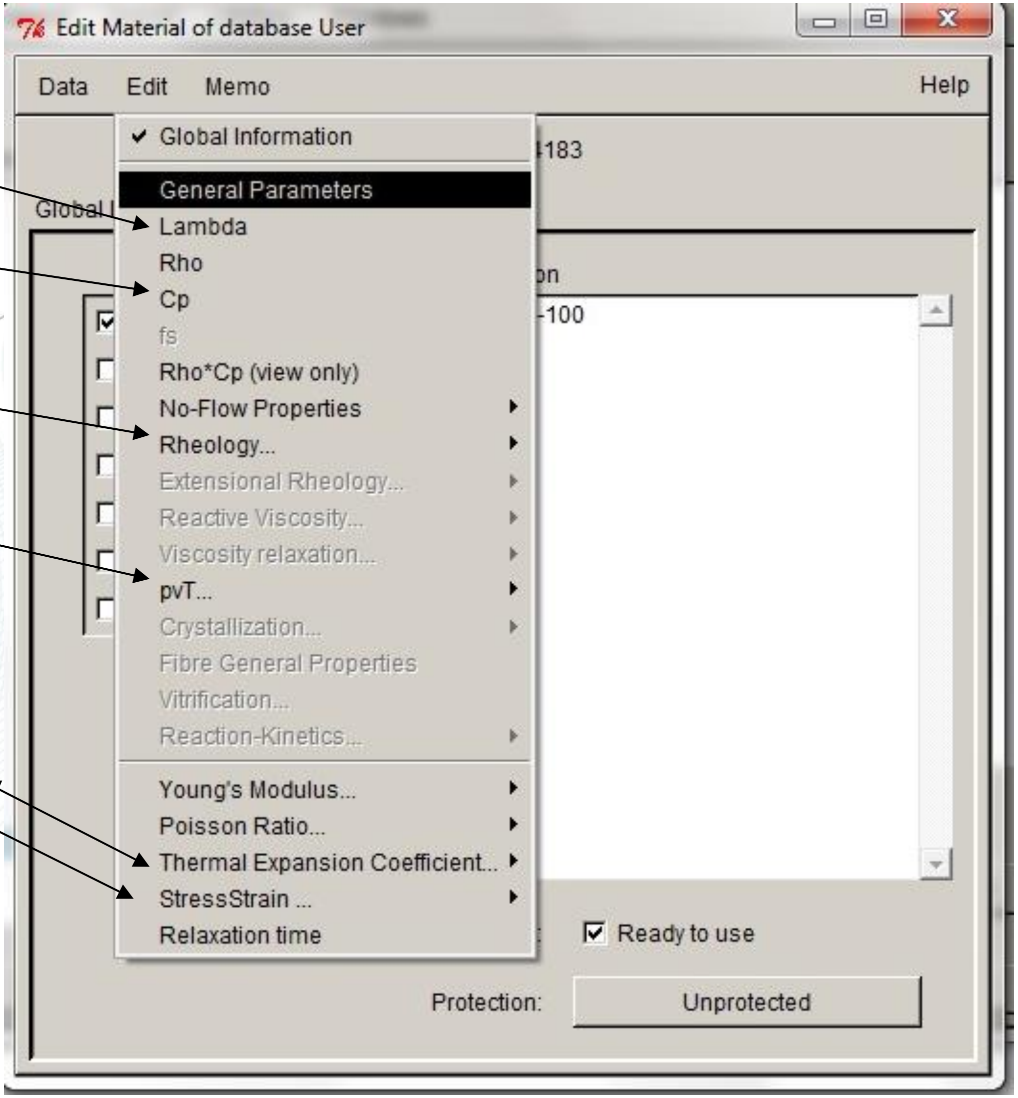
- General parameters
  - Material type → Plastic (Semi-crystalline or Amorphous)
  - Initial temperature → minimum temperature
  - Material models → PVT (Tait), Viscosity (Cross WLF), Stress (Viscoelastic), Fiber Model (Deactivated when viscoelastic is used), Crystallization (Weibull, when semi-crystalline material is selected)





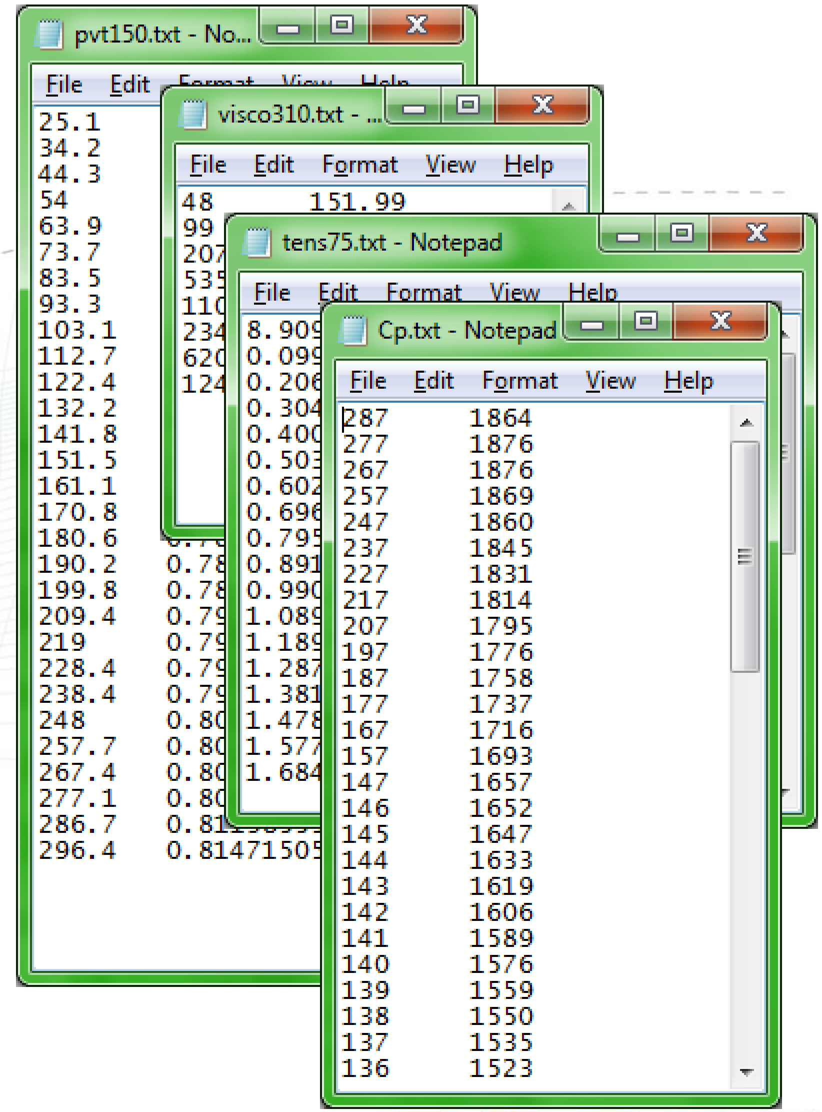
Implementation Into Sigmasoft

- Thermal conductivity
- Specific heat
- Viscosity
- PVT
- CTE
- Mechanicals
- Order of input counts
  - PVT, Cp, Lambda, Visc, CTE, mechanicals



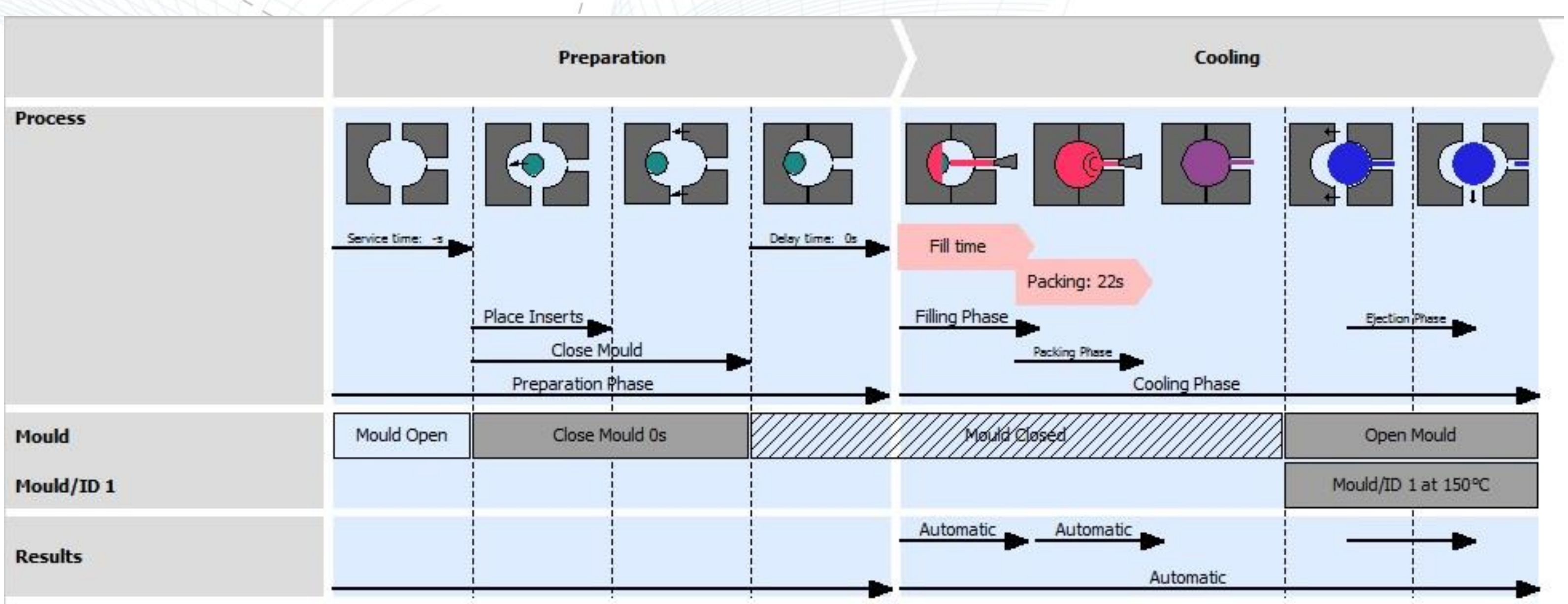
Implementation Into Sigmasoft

- X-Y pairs in text files
  - Viscosity (3)
  - Specific heat (1)
  - Thermal conductivity (1)
  - PVT (4-6)
  - CTE (1)
  - Mechanicals (5)
  - At least 17 input files



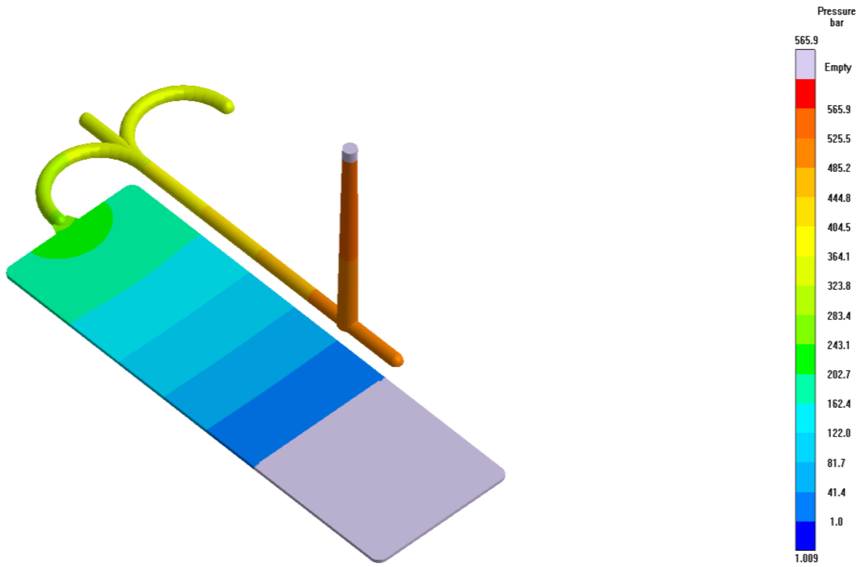
Molding Conditions

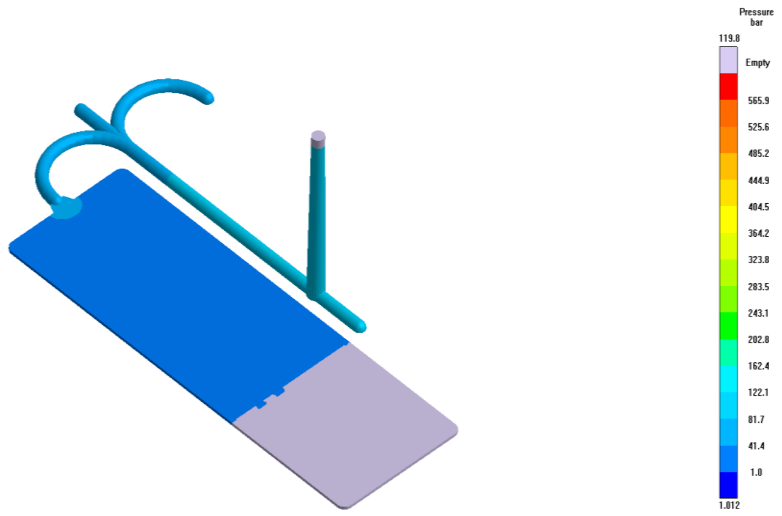
- Flow rate 66 cc/s
- Flow Temperature 300°C
- Mold Temperature 87°C



Mold Filling Pressure

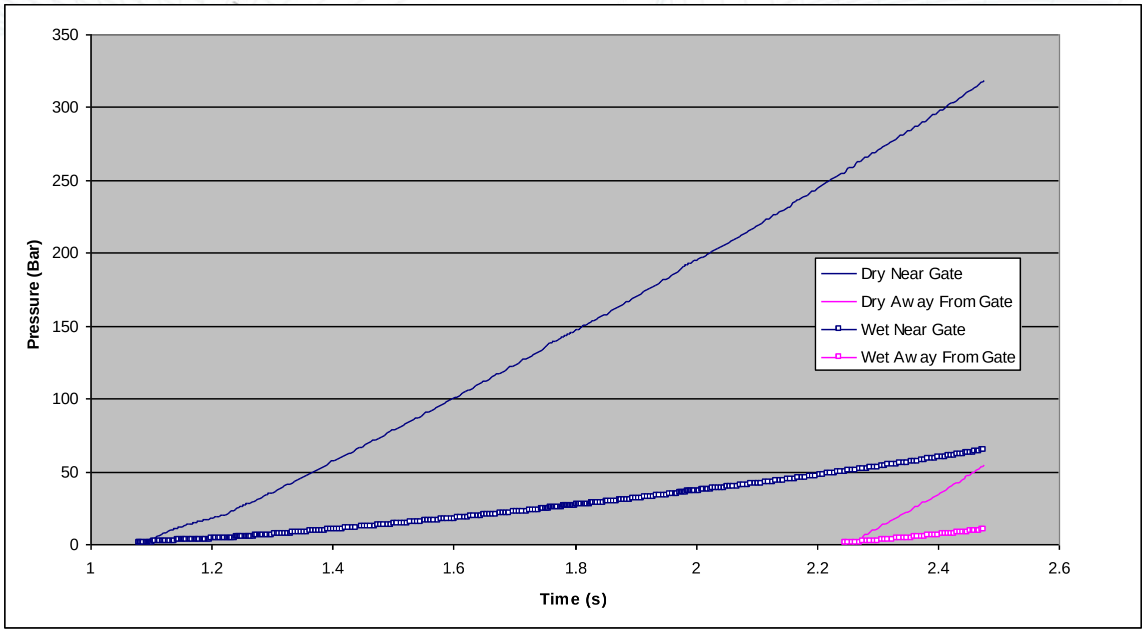
- Look at approx. 75% fill
- Dry→566 bar inlet pressure
- Wet→120 bar inlet pressure





Pressure Profile Near Gate and Away

- Dramatic difference in pressure in mold
- Almost 5 times pressure for only 0.25 % moisture

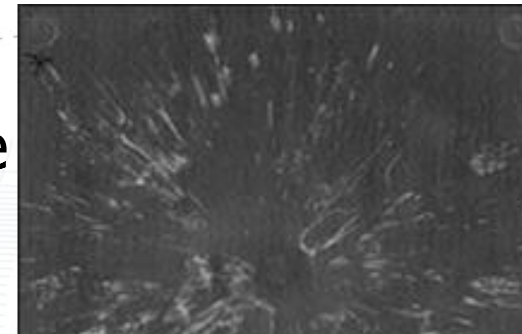


Consequences of Design Based on Wet Material Data

- Mold design underestimates clamping force
- Flow patterns are wrong
- Fiber orientation is wrong
- Fill time is off

Consequences of Molding an Actual Part With Wet Material

- Inferior strength
- Voids from entrapped moisture
- Splay/streaking
- Blisters



Conclusion

- Materials that are subject to moisture
  - PET, PA, PC, PBT Filled Materials
- Always have a target moisture declared
  - Simple dry times and temperatures may not be enough
  - Record actual moisture content
- Be aware that you can over-dry a material as well… to be continued