Perspective-
Material Modeling and Mold Analysis

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A look back

- Advent of simulation- early successes
- Melt-solid transitions- the case for a unified material model
- Post-fill- PVT and the prediction of shrinkage
- Viscous heating- impact on flow behavior, degradation
- Why CRIMS has to work so hard

Advent- pre 1990

- Solid scientific study into rheology (Hieber et al)
- Very strong rheological models
- Relatively simple simulation- fill patterns
  - Modest effect of phase change
  - Rheology, thermal property controlled behavior

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

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

$$T^* = D_2 + D_3 P$$

η Viscosity $(Pa.\mathrm{sec})$

$\dot{\gamma}$ Shear Rate (sec^{-1})

T Temperature (C)

P Pressure (Pa)

Unknowns: $D_1\ D_2\ D_3\ A_1\ A_2\ \tau^*\ N$

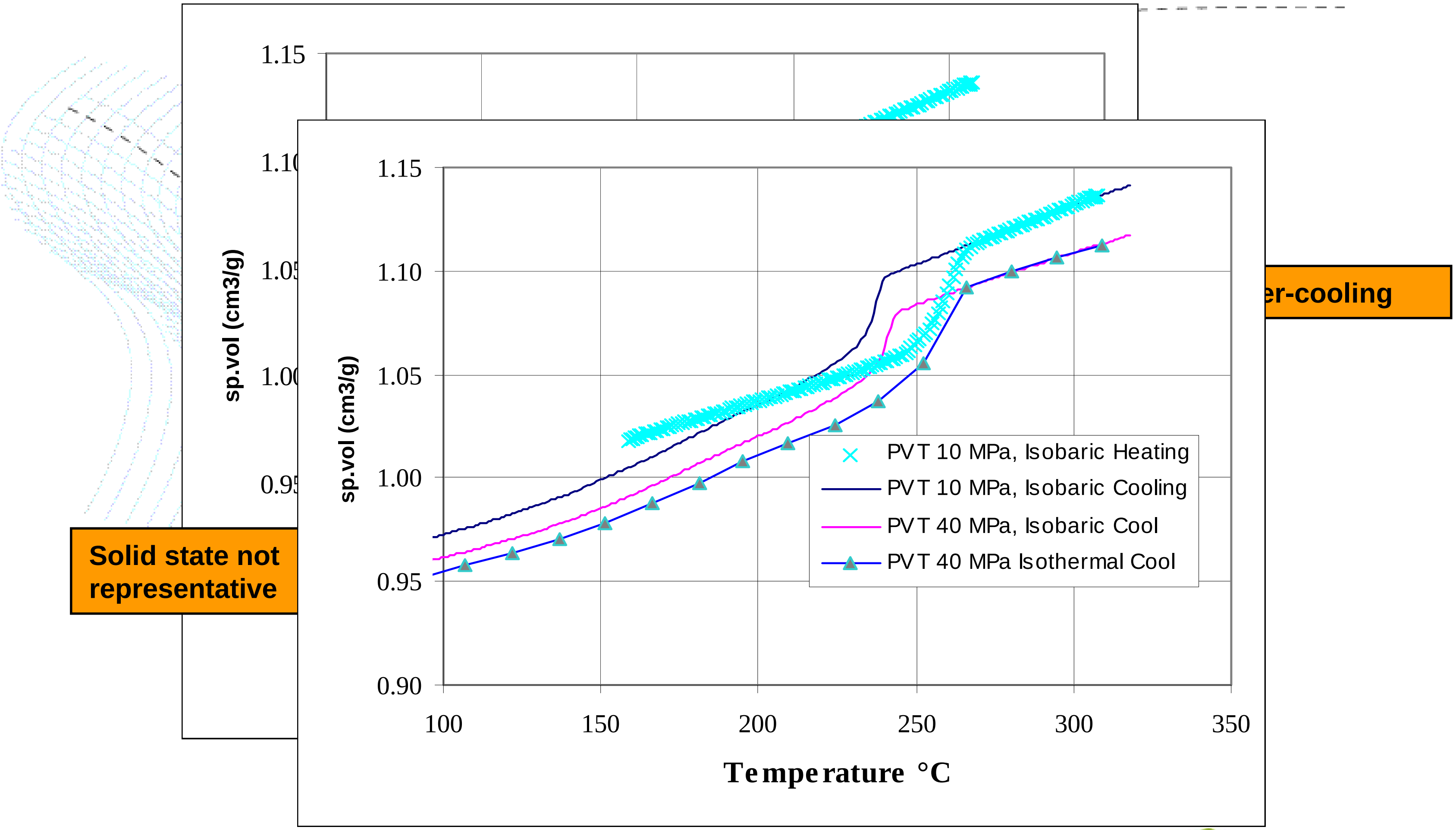
Post-Filling Challenges

- Simulation highly sensitive to very slightly varying property behavior (PVT)
  - Location/nature of transition
  - Absolute values of PVT properties

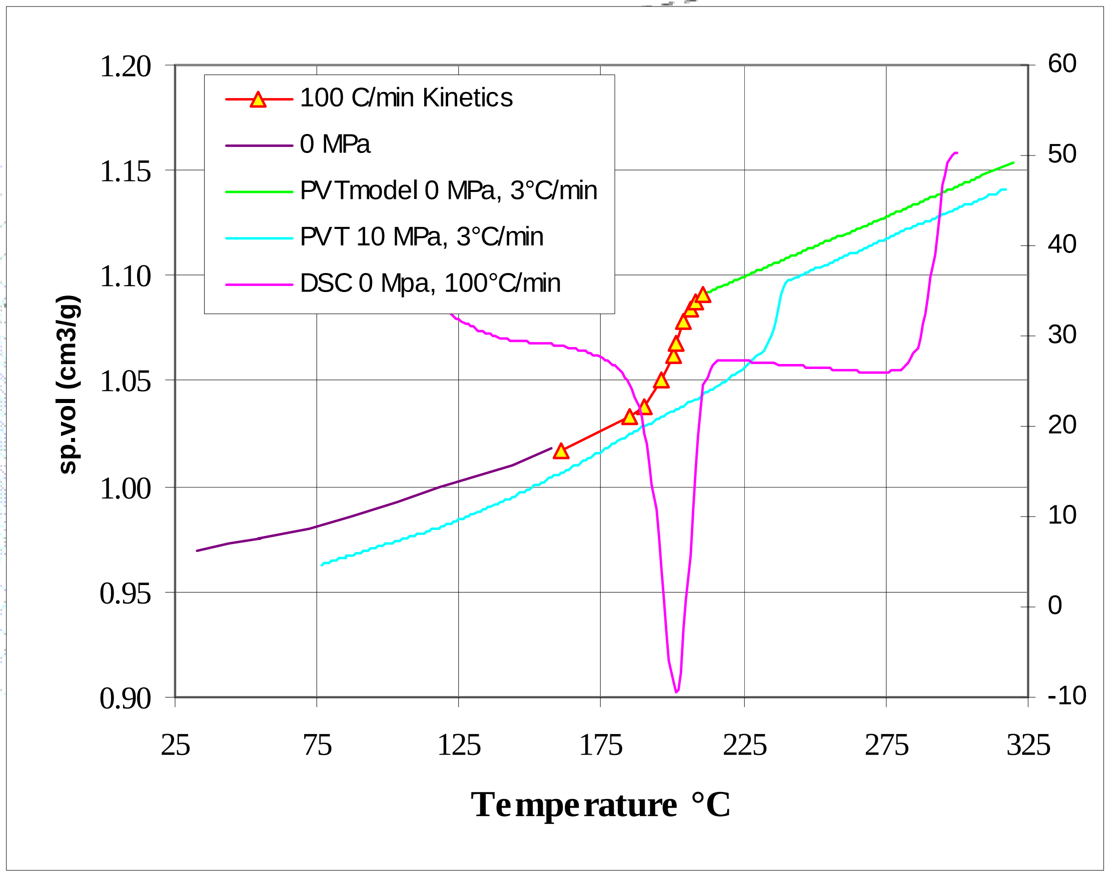
The PVT controversy

- C-MOLD- process is in cooling- measure PVT in cooling
- Moldflow- Measure PVT while heating

The PVT controversy- Realities



Accounting for rate with DSC



Lobo, Gordon Conference 98, Antec 99

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Limitations

- Good for quiescent situations
- Supercooling effect overpredicted when there is flow
  - Transition is closer to heating transition when shear effects present

What about high-rate PVT

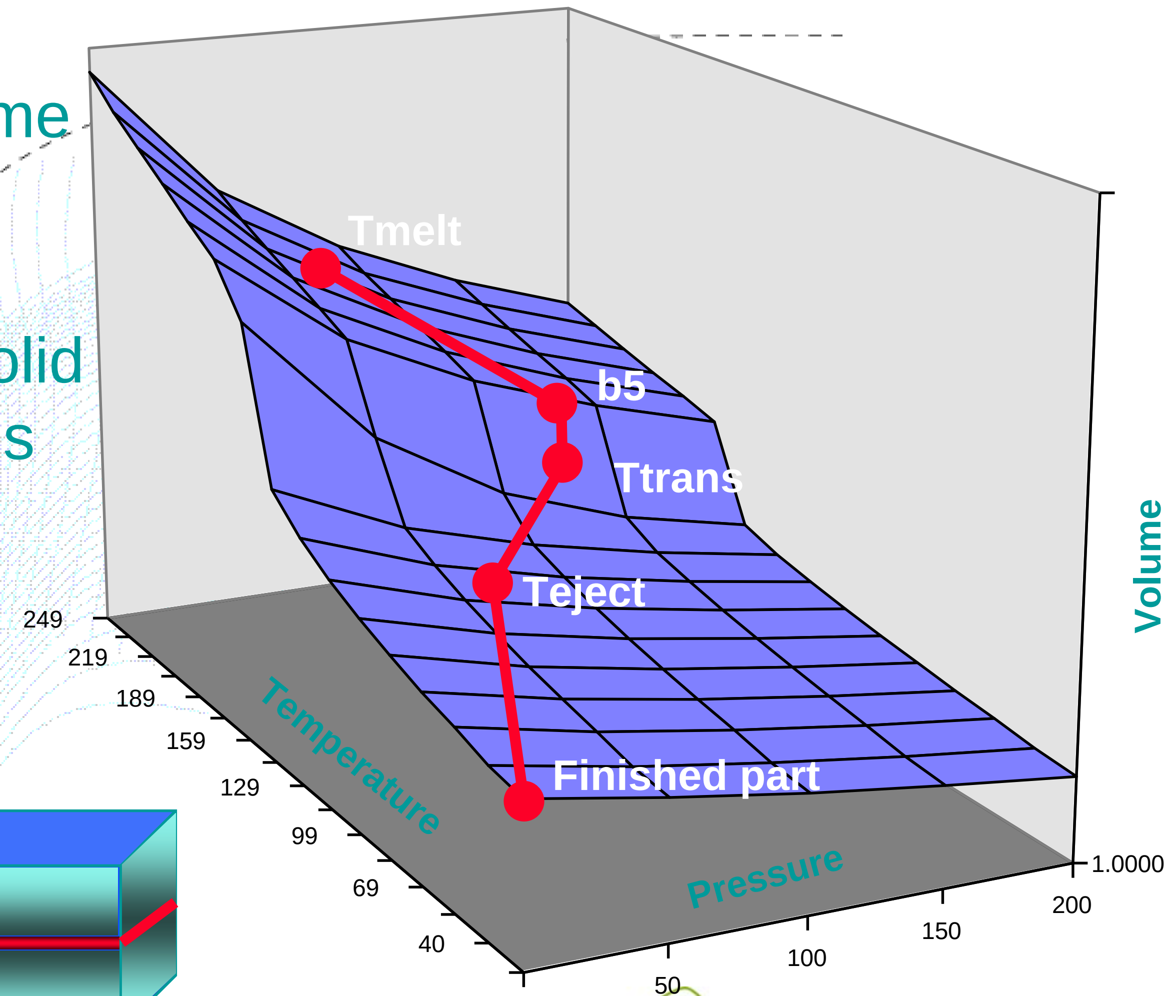
- Solid state data in PVT cooling will always be wrong
  - No instrument can reproduce the unique frozen layer morphology or shear state of the injection molding process

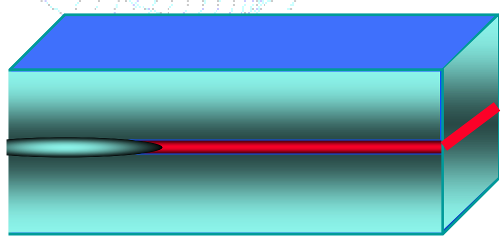
Current Compromise

- Use PVT heating data
  - Reasonable transition location
  - Good representation of solid state PVT behavior

Shrinkage in simulation

- Change in volume in PVT data on cooling
- Starts at melt-solid transition- Ttrans





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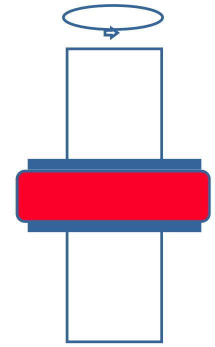
Consequences

- Small changes in Ttrans=large change in shrinkage
- Must be grounded in PVT data of an injection-molded part

Melt-Solid transition

- DSC based methods
  - Easy to get high cooling rates
  - Quiescent material
- Shown to be not-representative
  - Transitions are shear rate dependent

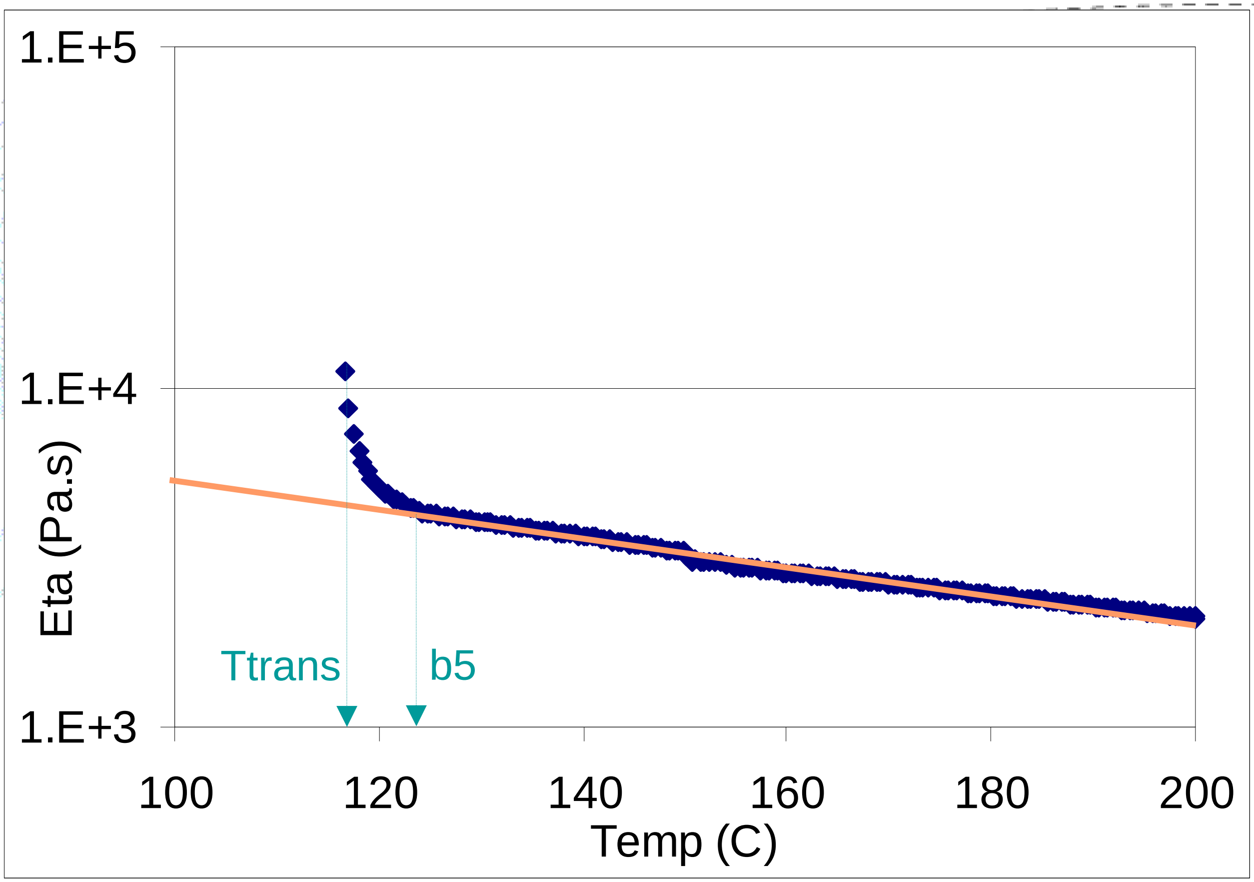
Melt-Solid transition



- DMA based methods
- High shear rate can be applied
- Slower cooling rates
- Also measures temp sensitivity of viscosity
- Set Ttrans based on modulus- material too stiff to flow

(See Lobo MUG2000)

DMA for Semi-crystalline plastic



Unified Material Model

- Capillary Viscosity at Process temp
- DMA cooling experiment at slow rate high frequency
  - Ttrans, b5
  - Temp sensitivity of viscosity (D1, D2)
- PVT in heating at same slow rate
- Thermal conductivity and specific heat transitions shifted to Ttrans