Research Directions in Autodesk® Simulation Moldflow®

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Class Summary

This class will review new functionality in Autodesk® Moldflow® Insight software that represents the current research directions in Moldflow development. We will discuss several capabilities, including 3D injection compression molding, conformal cooling support, 3D heater elements, crystallization analysis, breakage of long fibers and properties of LFT composites, bi-injection molding, multiple cylinder support for 3D gas injection, buckling analysis for 3D warp, improved wall slip calculation, viscoelastic residual stress, ejection force prediction, and analysis of mold fatigue.

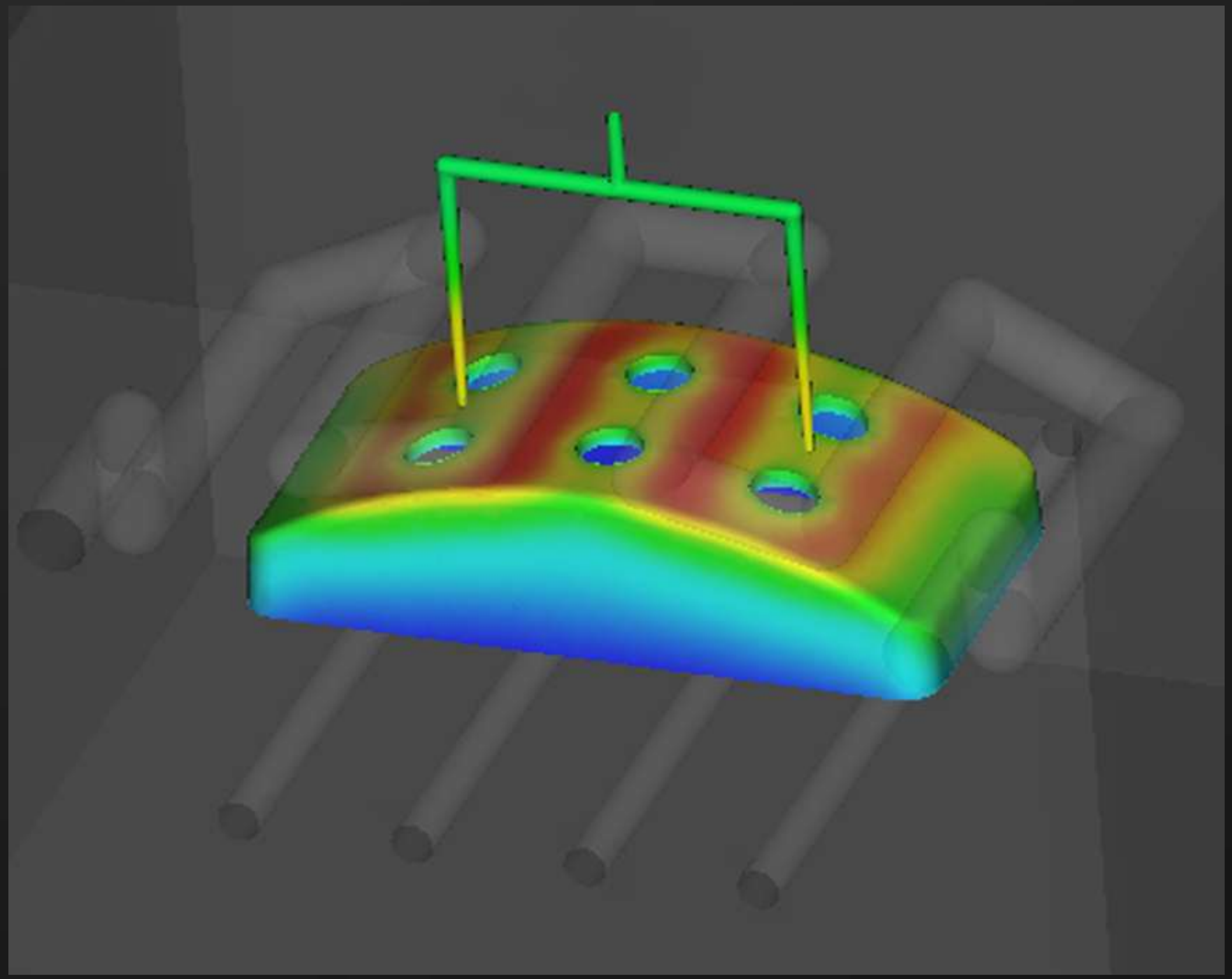
Learning Objectives

At the end of this class, you will be able to:

- Model injection compression and compression process of 3D part
- Achieve improved process simulation accuracy
- Evaluate mechanical property predictions for long fiber composites
- Pre-empt ejection problems in mold design

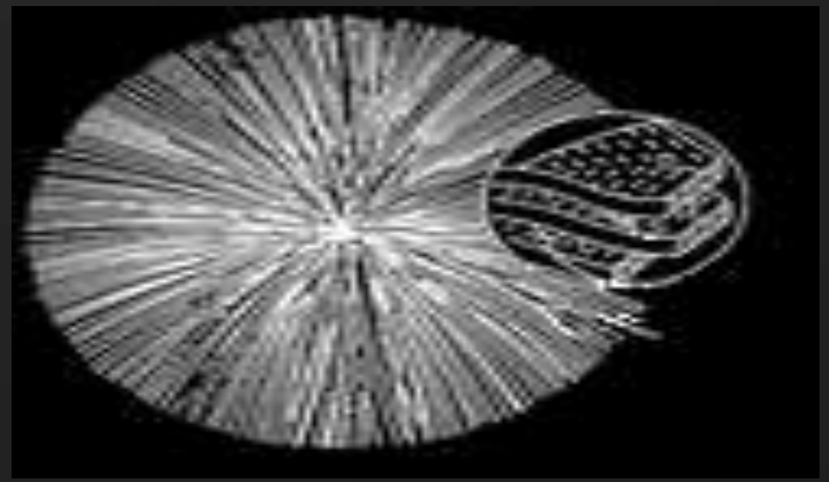
Content

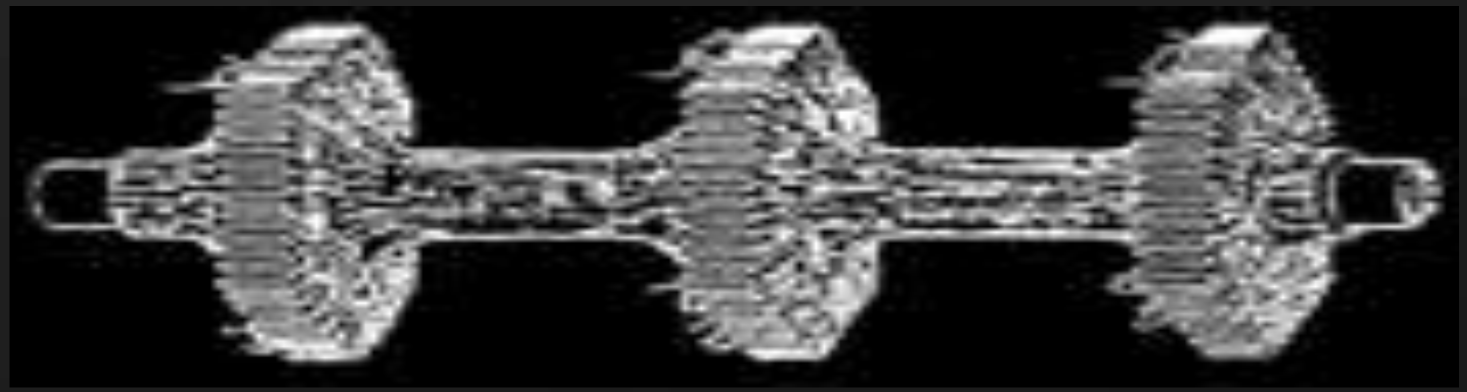
- **Autodesk Simulation Moldflow Insight 2013**
  - Crystallization
  - Long Fiber Analysis
  - Other Improvements
- **Scandium Technology Preview (2013)**
  - Viscoelasticity
  - Wall Slip
  - New analysis types
  - New result types
- **Some Research Topics**
  - New Integrations with Autodesk Mechanical Simulation

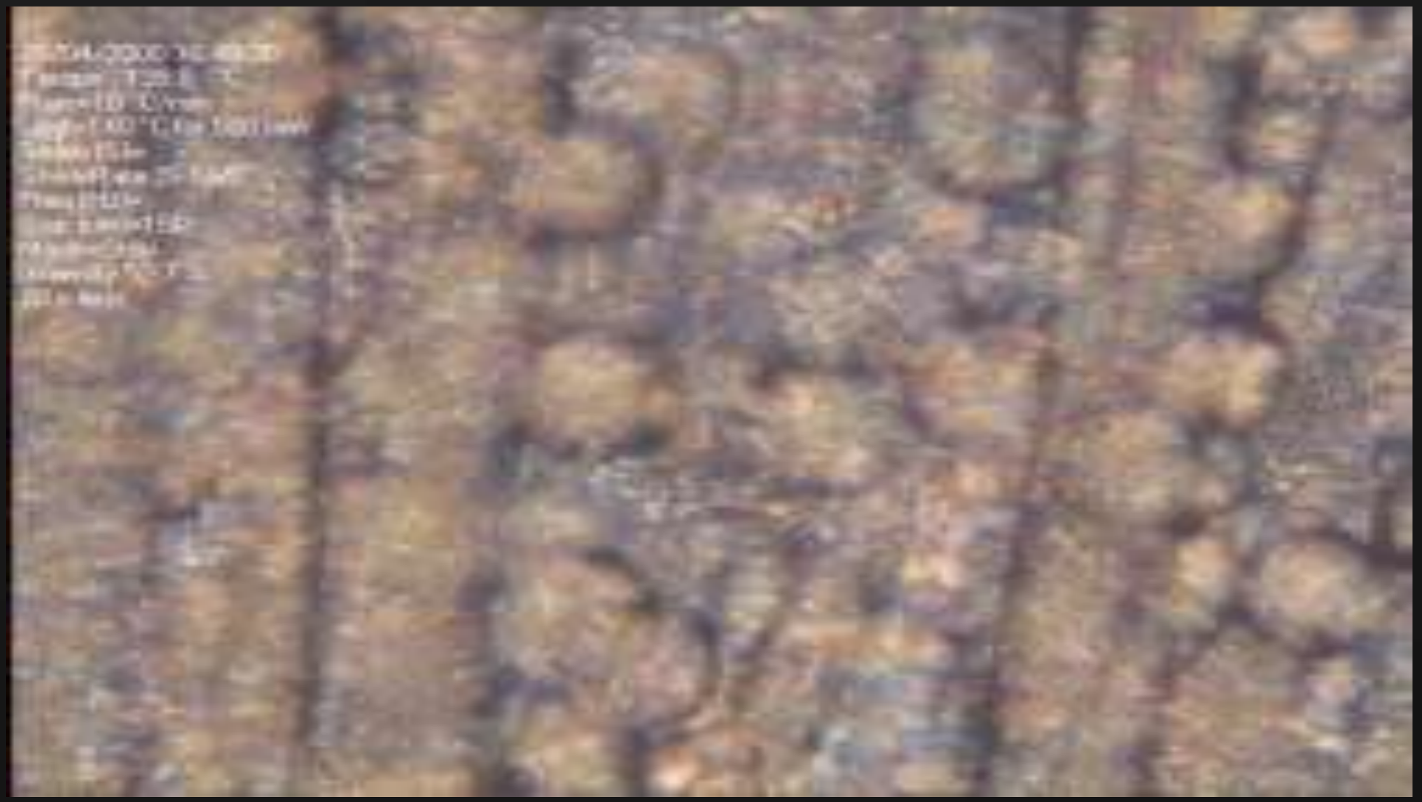


Overview – Crystallization Kinetics

- Motivation for Crystallization analysis
- Theory
- Material Data
- Results
- Validation Examples:
  - Shrinkage

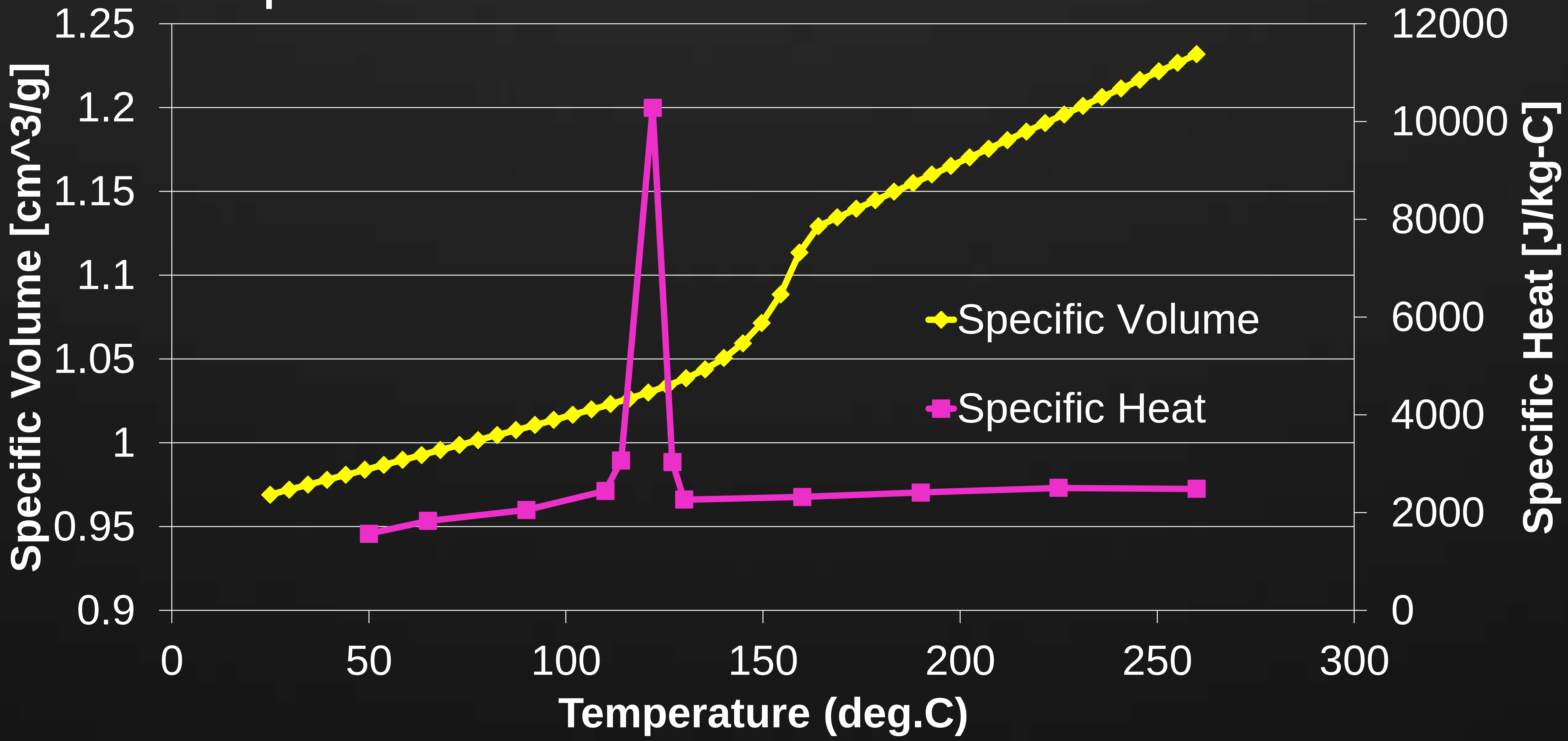






Why Crystallization?

- Solidification
  - Single transition temperature?



PP, 20% talc filled
Sumitomo, Noblen BZE62F5B

Cooling Rate Effect on Solidification

Measured Specific Volume during cooling

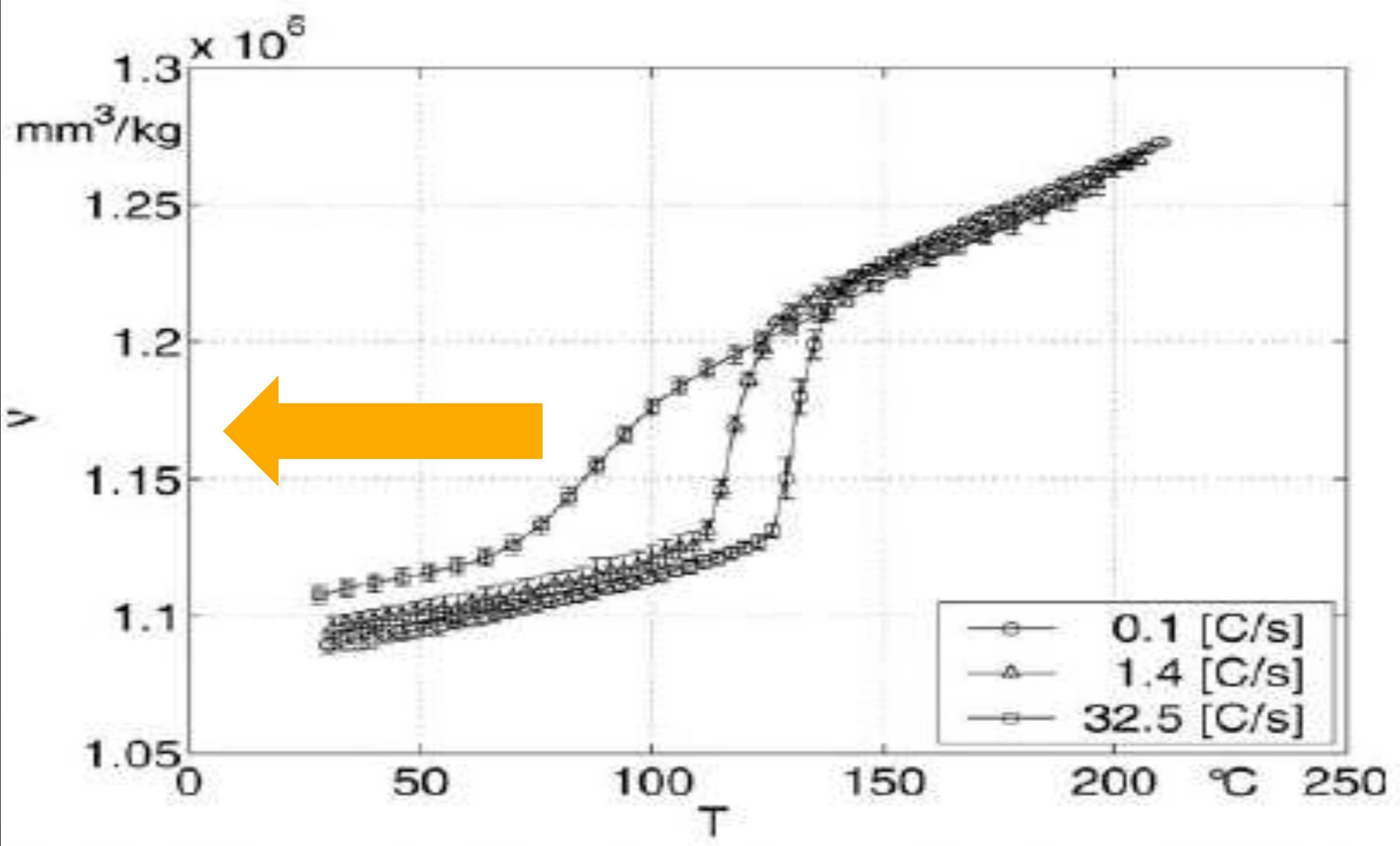


Fig. 9. Influence of cooling rate an the specific volume of i-PP at a pressure of 40 MPa. Average cooling rates during crystallization are given in the figure

van der Beek et. al. Inter. Polymer Processing, 20, 111-120, (2005).

Shear Rate Effect on Solidification

Measured Specific Volume during cooling after shearing

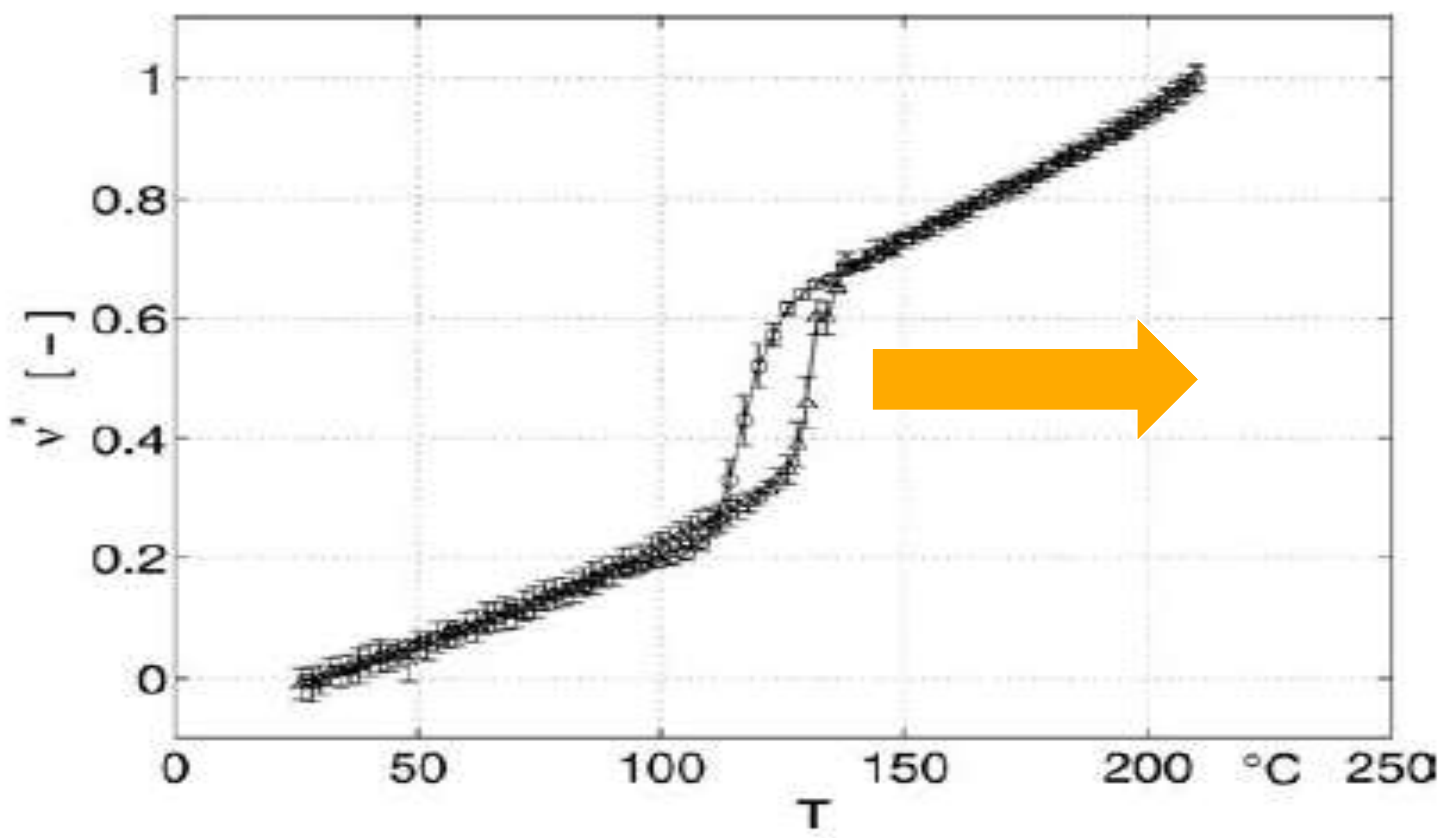


Fig. 10. Influence of shear flow an the normalized specific volume of i-PP. Shear is applied as a step function at 139 °C, with a shear rate of 38.5 l/s to a total shear of 117. Specific volume with (△) and without shear flow (○) is obtained at an average cooling rate during crystallization of 1.4 °C/s and a pressure of 40 MPa

Image: IME Technologies

van der Beek et. al. Inter. Polymer Processing, 20, 111-120, (2005).

Model of crystallization kinetics

$$G(T) = G_0 \exp\left[-\frac{U^*}{R(T-T_\infty)}\right]\exp\left[-\frac{f\cdot K_g}{T(T_m^0 - T)}\right],$$

$$T_\infty = T_g - 30, \quad f = \frac{(T+T_m^0)}{2T}$$

$$N = N_0 + N_f$$

$$\ln N_0 = a_N(T_m^0 - T) + b_N$$

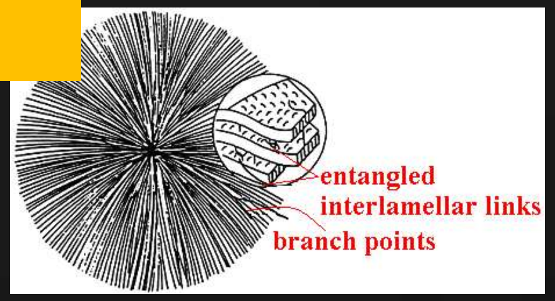
$$\dot{N}_f + \frac{1}{\lambda_N} N_f = f(\Delta F_f, T)$$

(Growt … ity)

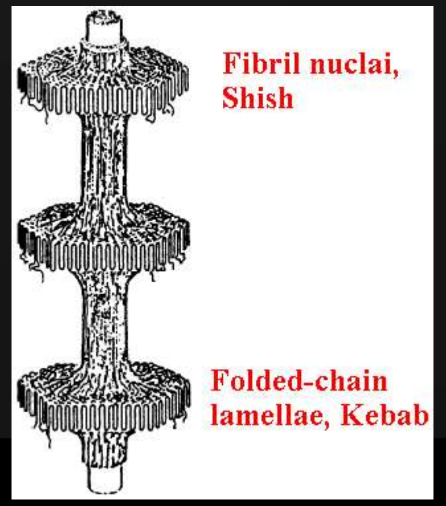
- This model was patented by Moldflow & Univ of Sydney
- Autodesk has exclusive commercialization rights

a_N, b_N, T^0_m, G_0 & K_g Are determined from DSC Experiments for each material grade

$$\phi = \frac{4\pi}{3}\int_0^t \dot{N}_0(s)\left[\int_s^t G(u)\,du\right] ds$$



$$\psi = \pi\int_0^t \dot{L}_{total}(s)\left[\int_s^t G(u)\,du\right]^2 ds$$



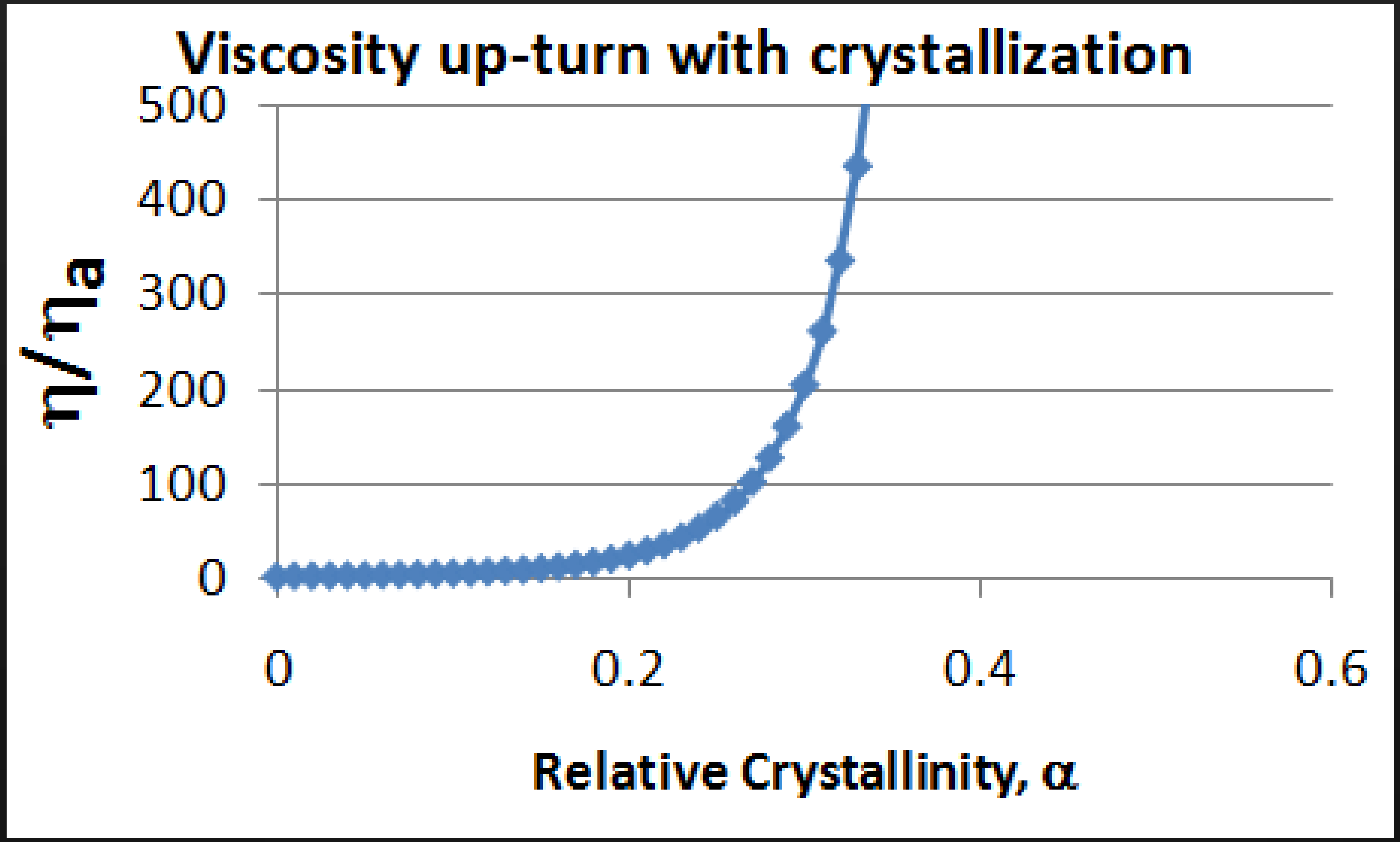
$$\alpha = 1 - \exp\left[-(\phi + \psi)\right]$$

Hadinata et al. PPS 23

Effect of Crystallization on Viscosity

Viscosity

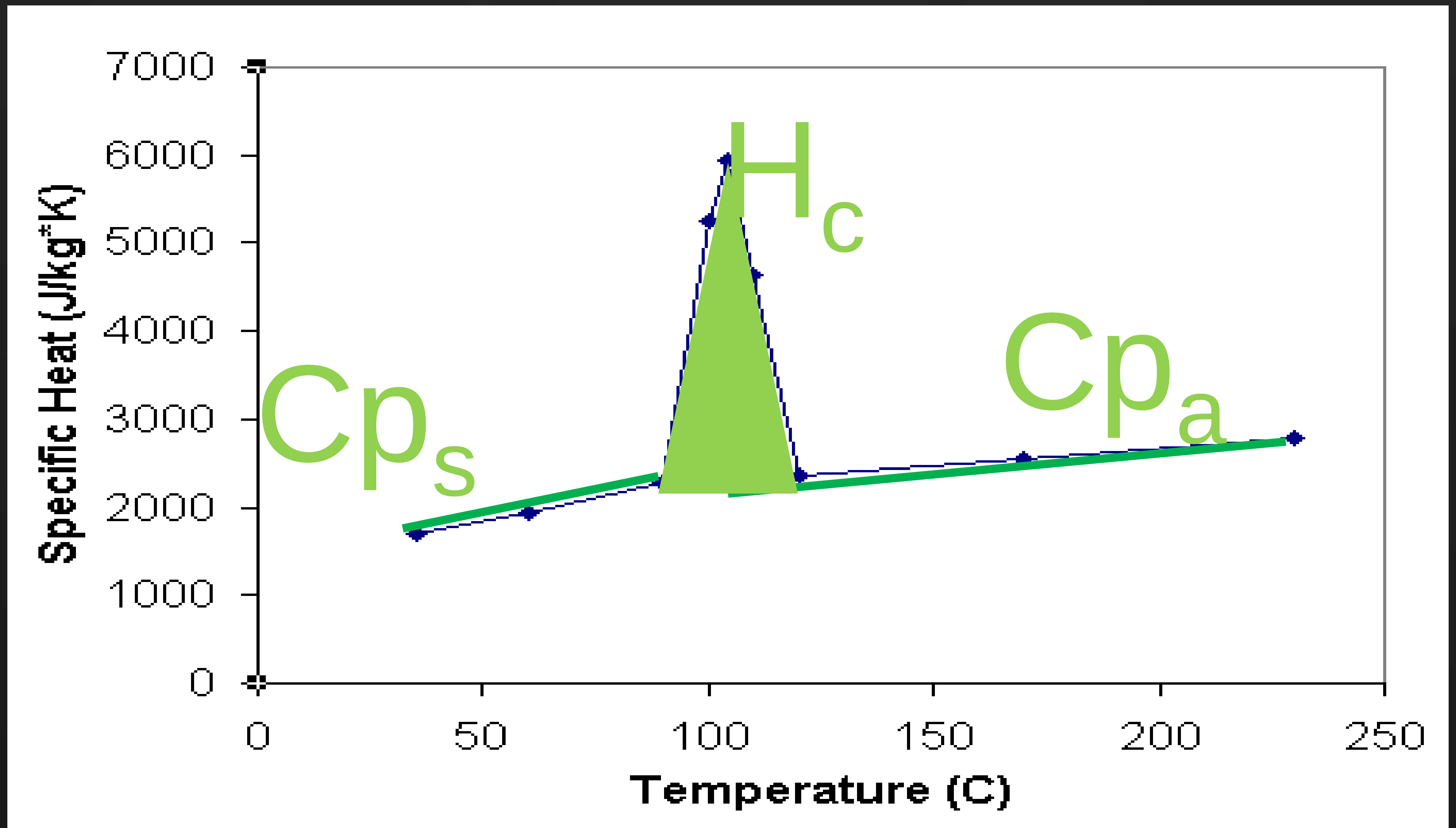
$$\eta(\dot{\gamma}, T, \alpha) = \eta_a(\dot{\gamma}, T)\left(1 + \frac{(\alpha / A)^{\beta_1}}{(1-\alpha / A)^{\beta}}\right), \alpha < A$$



Effect of Crystallization on Specific Heat

Specific Heat

$$c_p(\alpha, T) = \alpha c_{p_s}(T) + (1-\alpha) c_{p_a}(T)$$



Latent Heat term

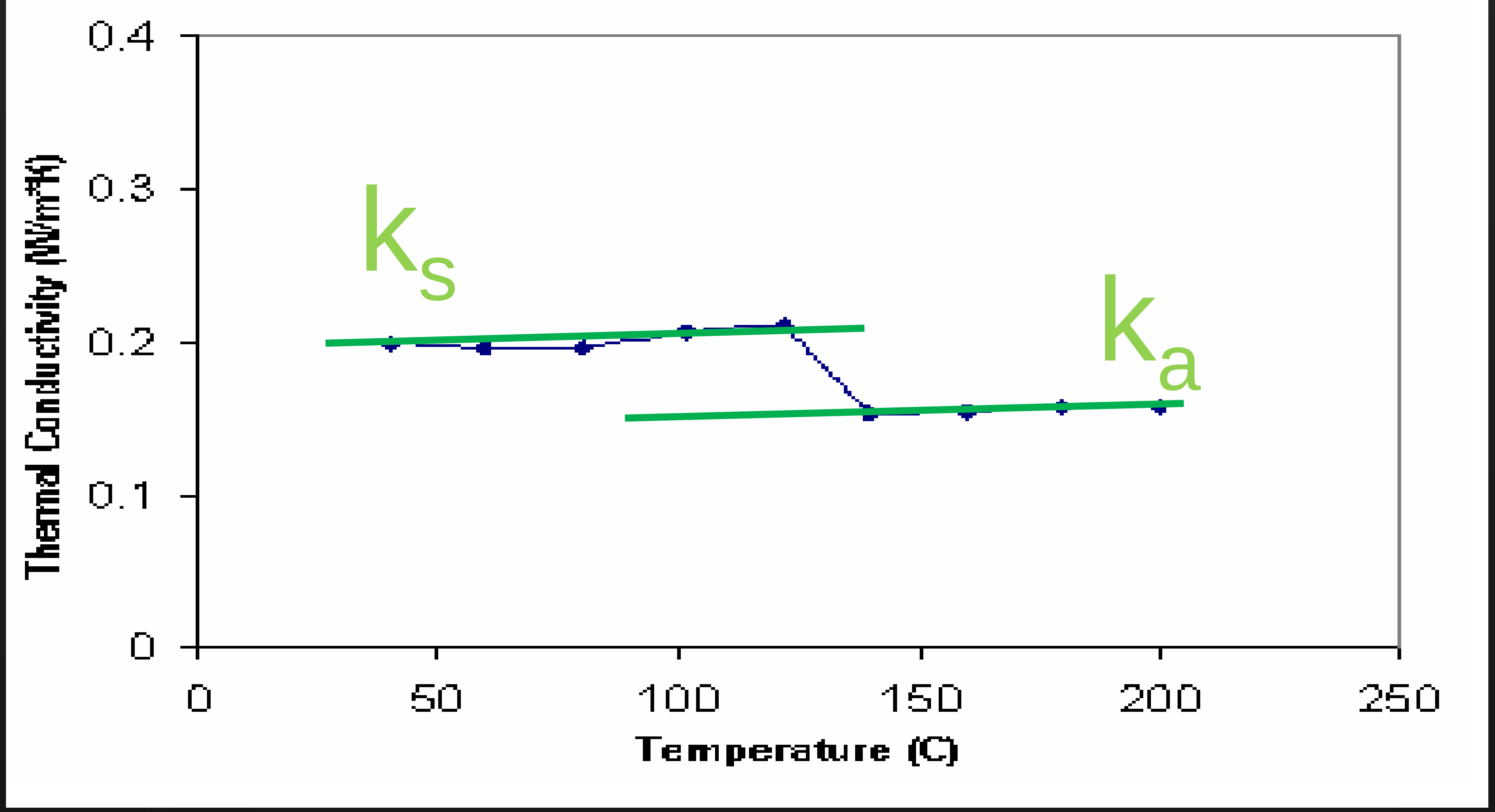
Temperature

$$\rho(\alpha) c_p(\alpha) \frac{DT}{Dt} = k(\alpha)\nabla^2 T + \boldsymbol{\sigma} : \mathbf{D} + \rho_c H_c \chi_\infty \frac{\partial \alpha}{\partial t} - \frac{T}{\rho(\alpha)} \frac{\partial \rho(\alpha)}{\partial T} \frac{Dp}{Dt}$$

Effect of Crystallization on Conductivity

Thermal Conductivity

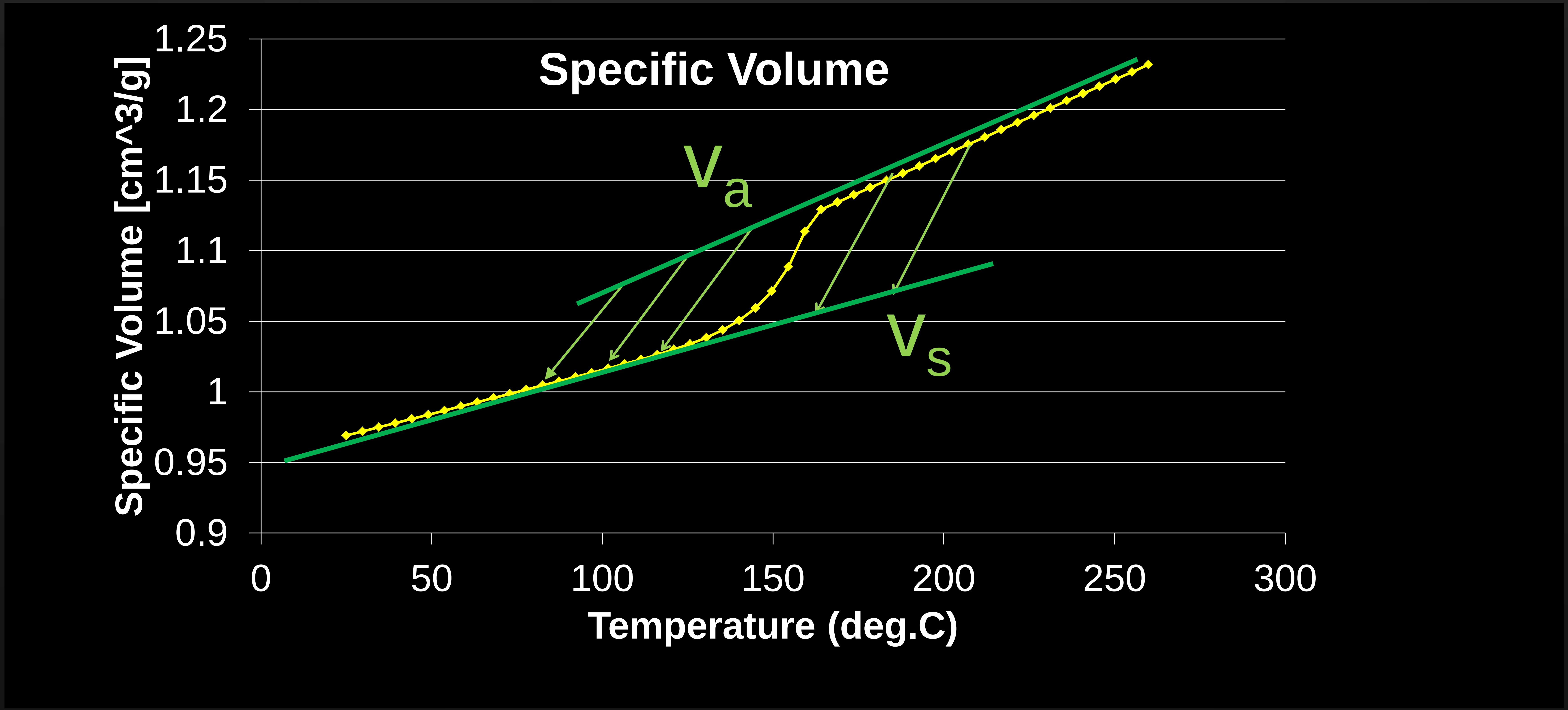
$$k(T) = \alpha k_s(T) + (1-\alpha) k_a(T)$$



Effect of Crystallization on PVT

PVT / Density

$$v = \alpha v_s(p,T) + (1-\alpha) v_a(p,T)$$



Crystallization Effect on Flow

- Calculate relative crystallinity (α) due to flow induced nucleation and temperature:

Viscosity

$$\eta(\dot{\gamma},\alpha) = \eta_a \left(1 + \frac{(\alpha/A)^{\beta_1}}{(1-\alpha/A)^{\beta}}\right), \ \alpha < A$$

Specific Heat

$$c_p(\alpha,T) = \alpha c_{p_s}(T) + (1-\alpha) c_{p_a}(T)$$

Thermal Conductivity

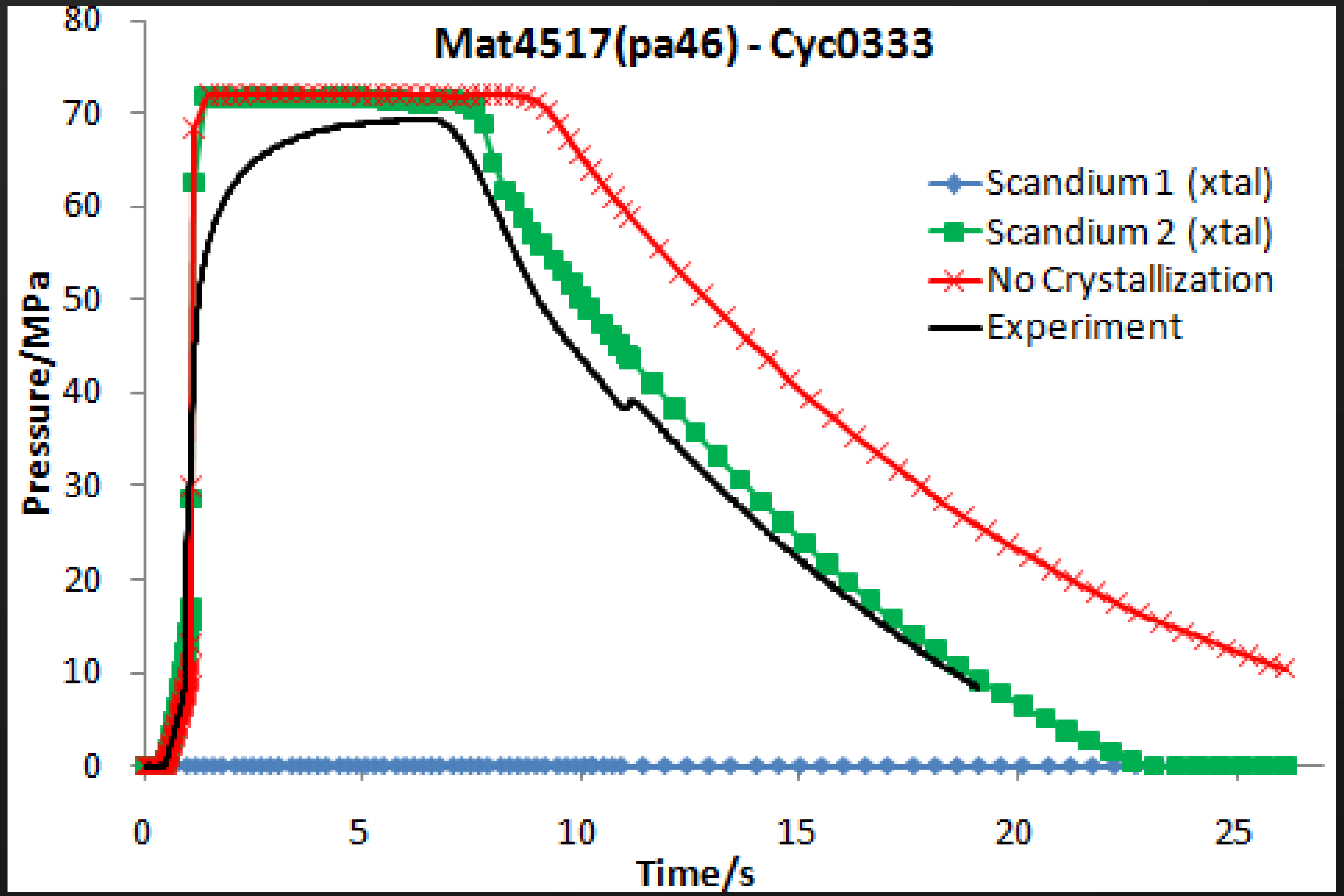
$$k(T) = \alpha k_s(T) + (1-\alpha) k_a(T)$$

Density

$$v = \alpha v_s(p,T) + (1-\alpha) v_a(p,T)$$

Temperature

$$\rho(\alpha)\, c_p(\alpha) \frac{DT}{Dt} = k(\alpha)\nabla^2 T + \boldsymbol{\sigma} : \mathbf{D} + \rho_c H_c \chi_\infty \frac{\partial \alpha}{\partial t} - \frac{T}{\rho(\alpha)} \frac{\partial \rho(\alpha)}{\partial T} \frac{Dp}{Dt}$$



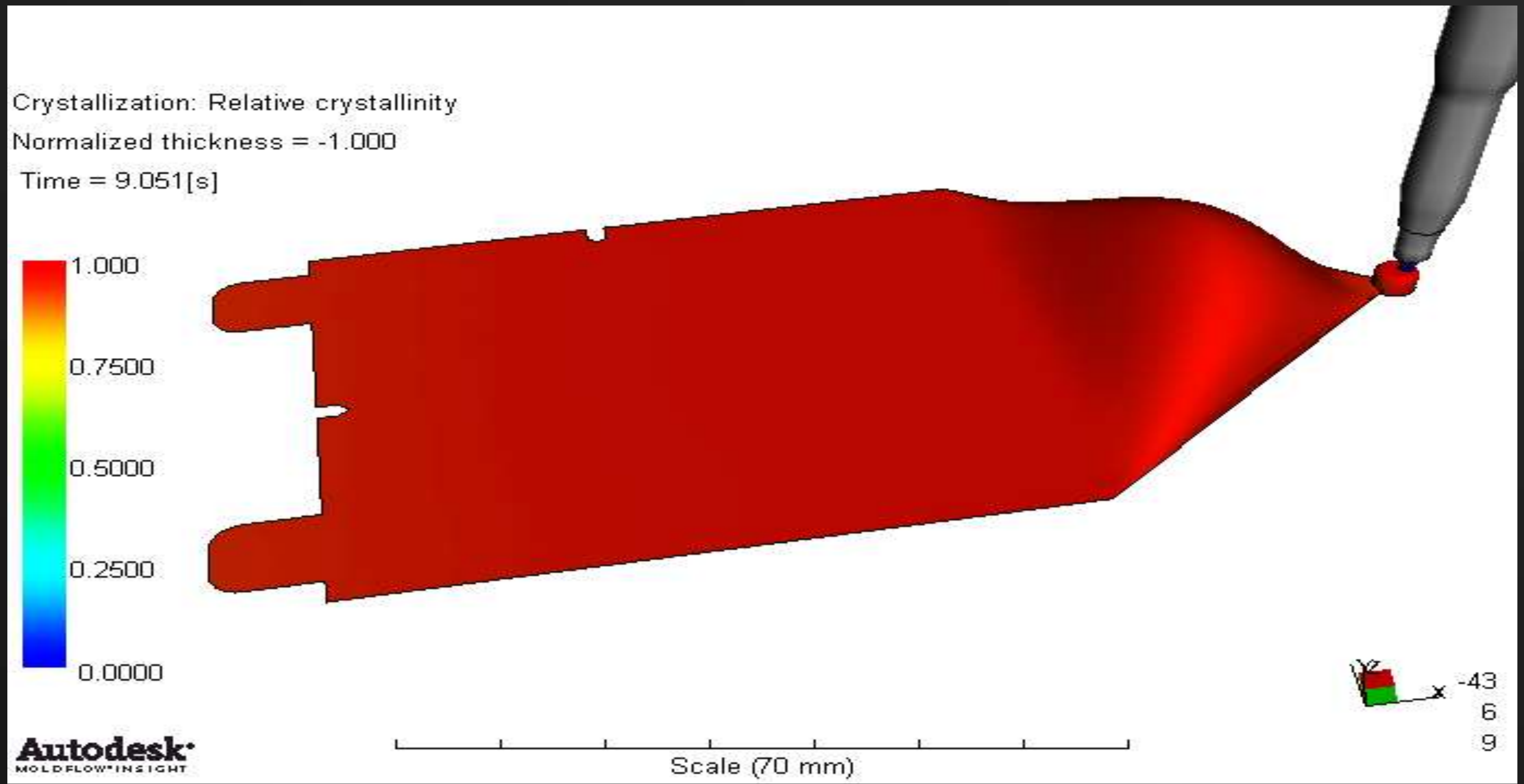
Crystallization: Material Data Availability

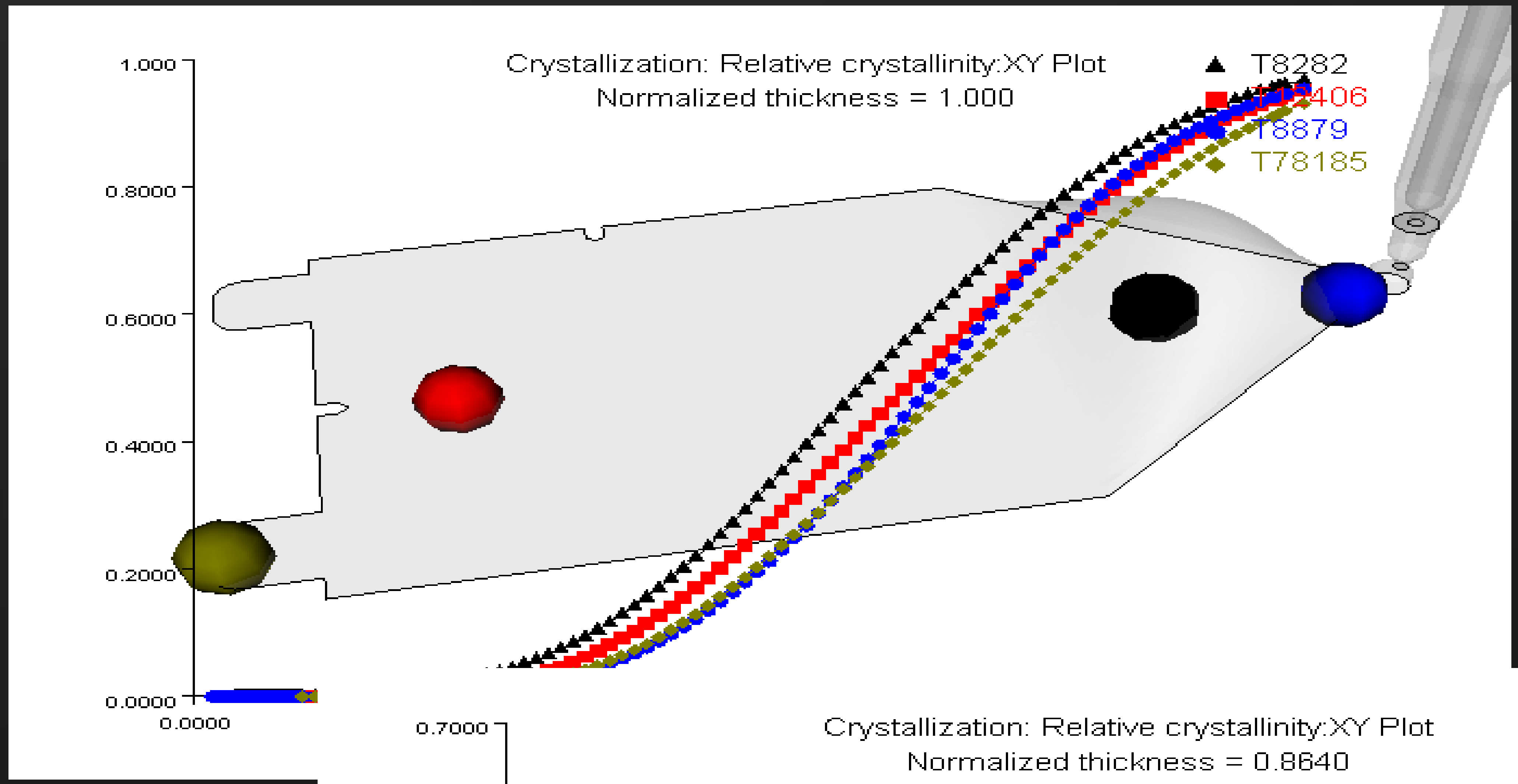
- 20 grades have been characterised
  - 10 unfilled
  - 10 fiber filled
- Other grades populated with generic parameters from these 20
  - Not considered accurate

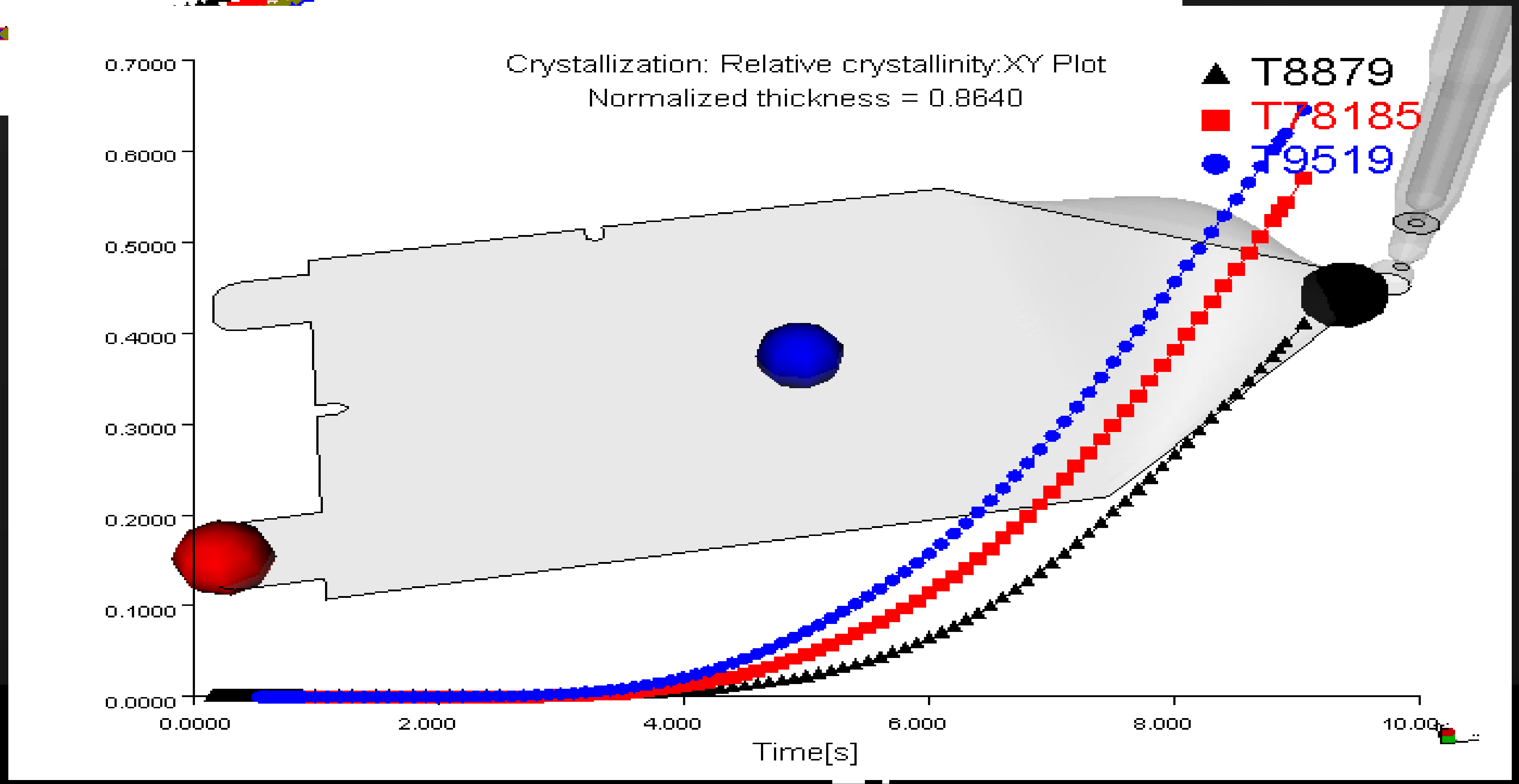
- Material characterisation for Crystallization is available from Autodesk Moldflow Laboratory

Relative Crystallinity Result

- Varies through thickness and with time



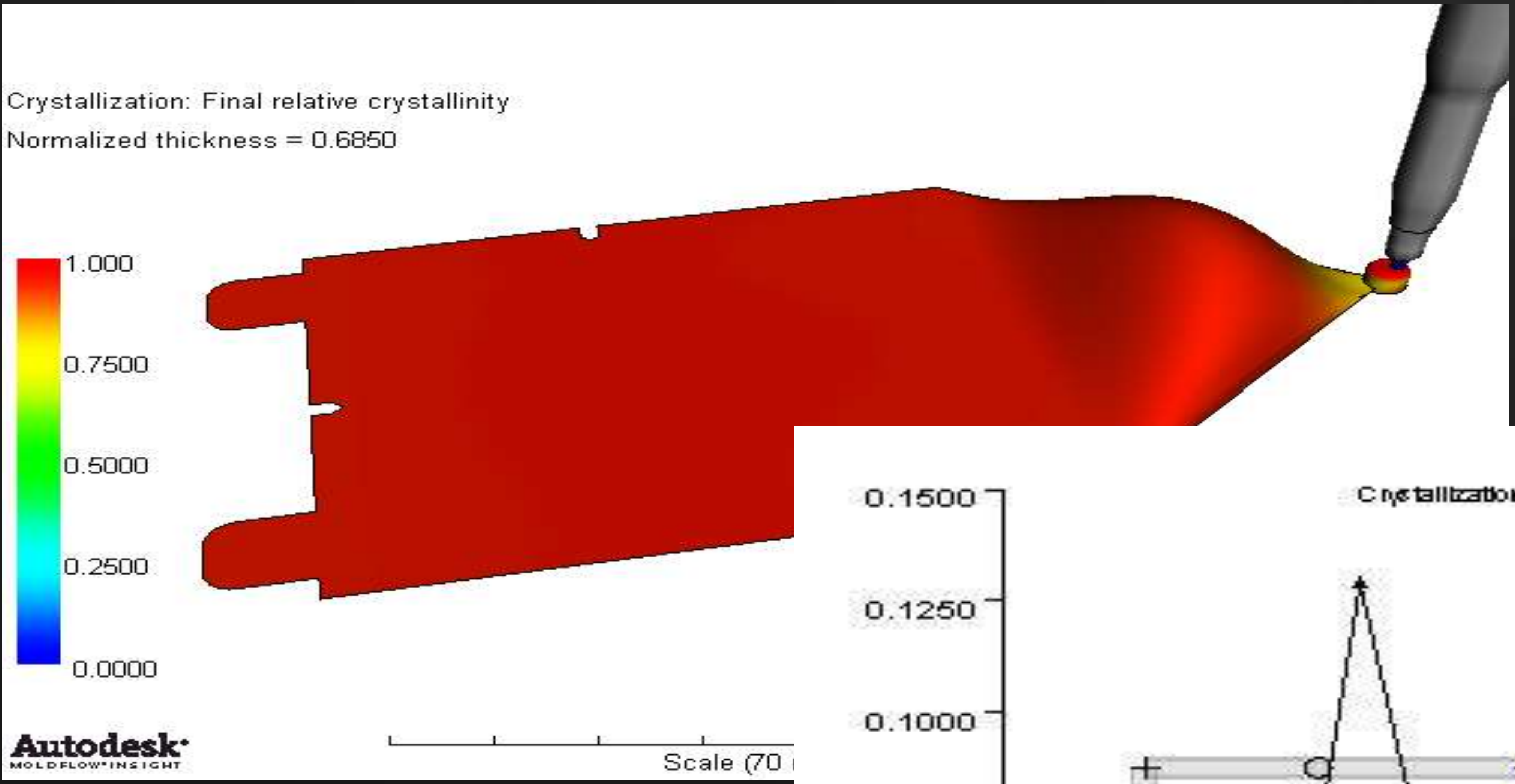


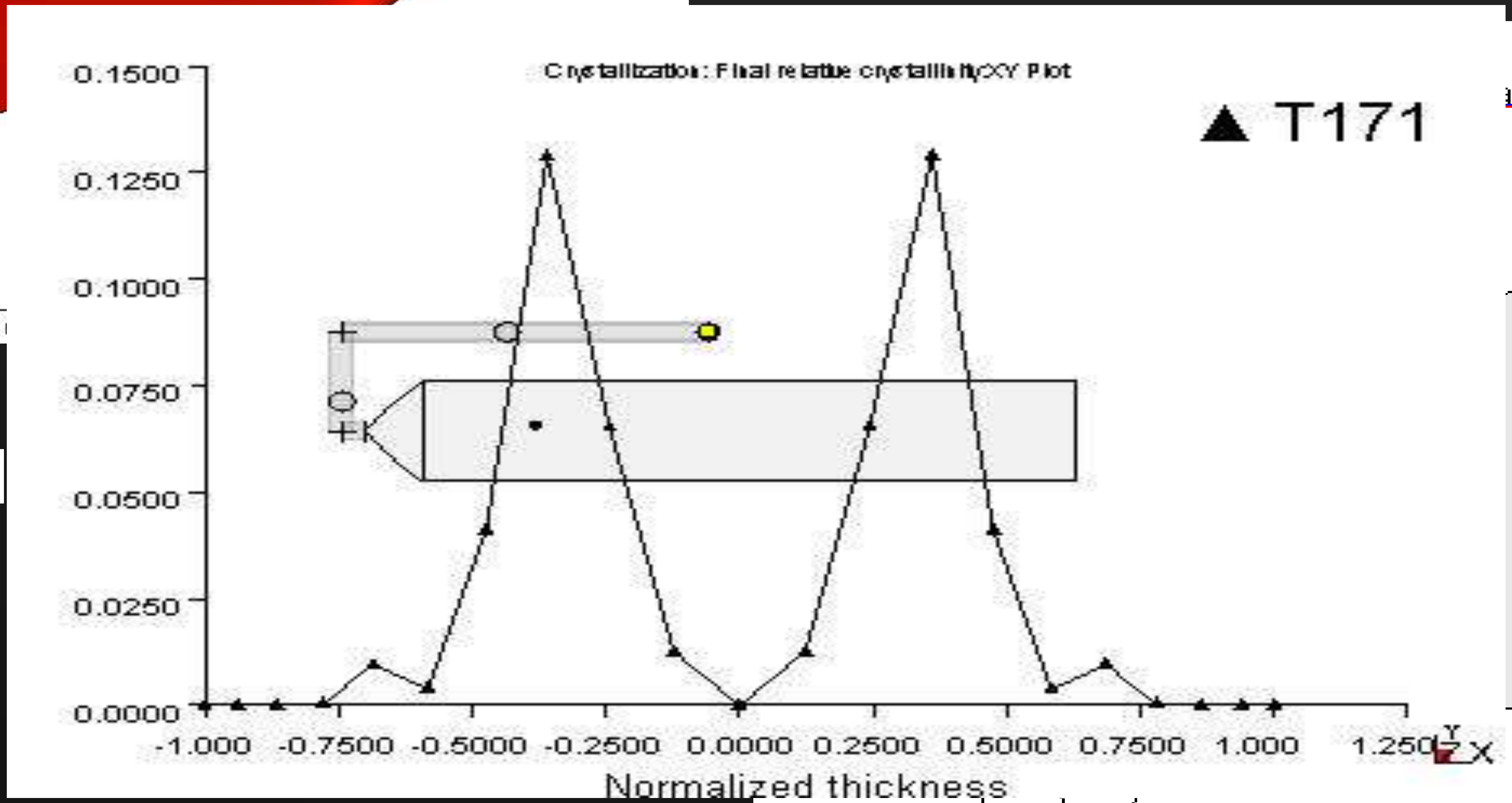


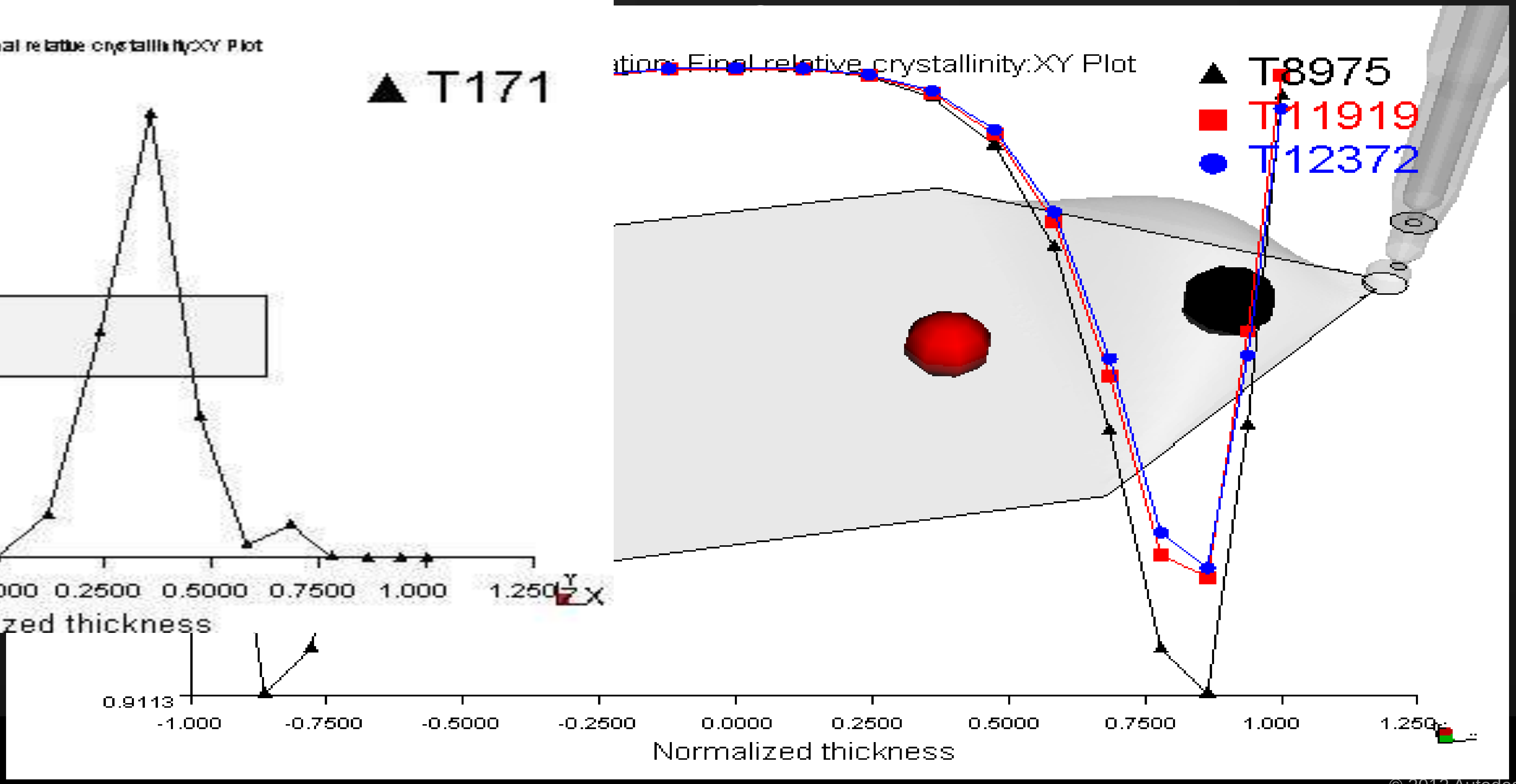
Model courtesy of Mogens Papsøe
NovoNordisk, Denmark

Final Relative Crystallinity

- Continues the crystallization calculation post-ejection



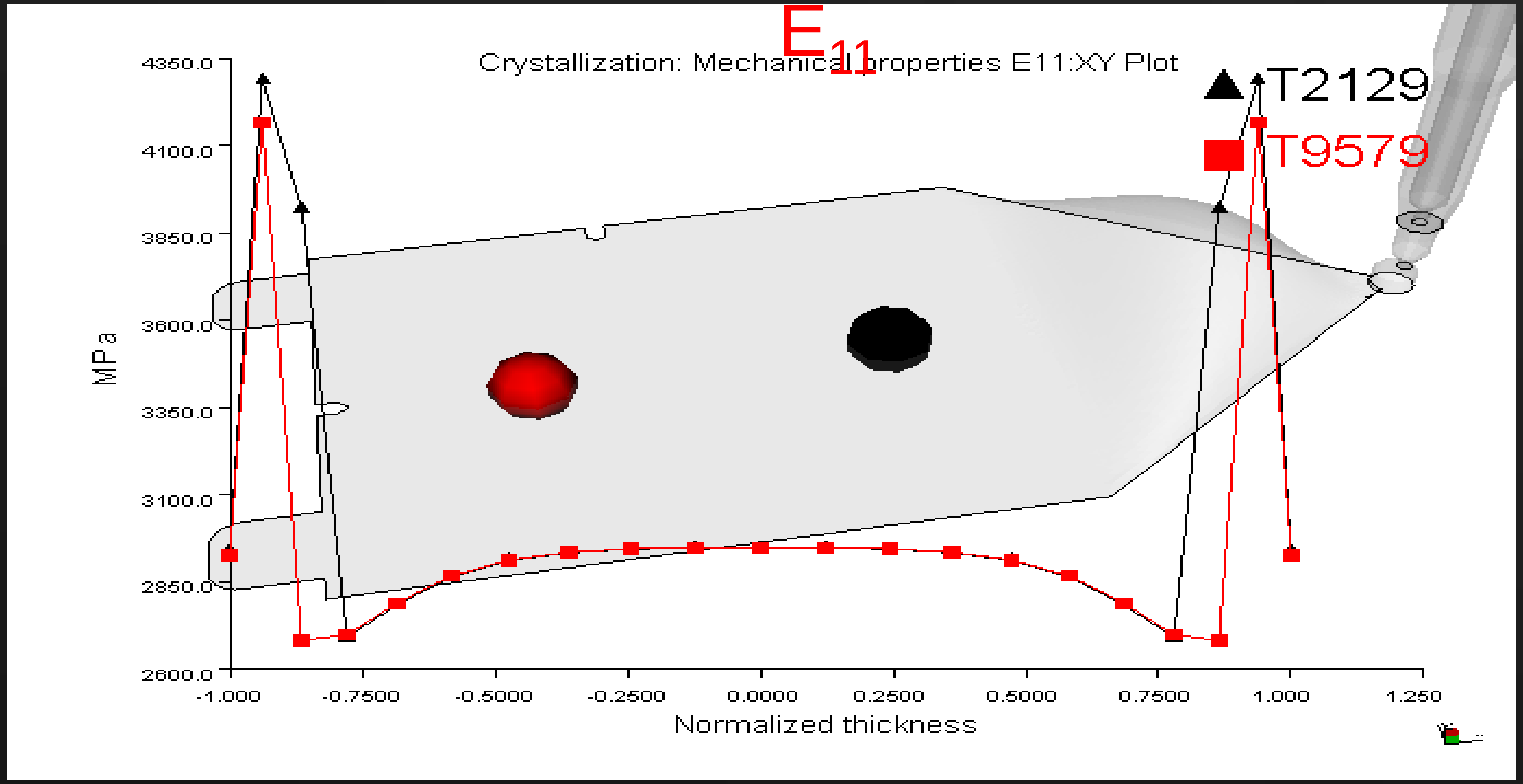


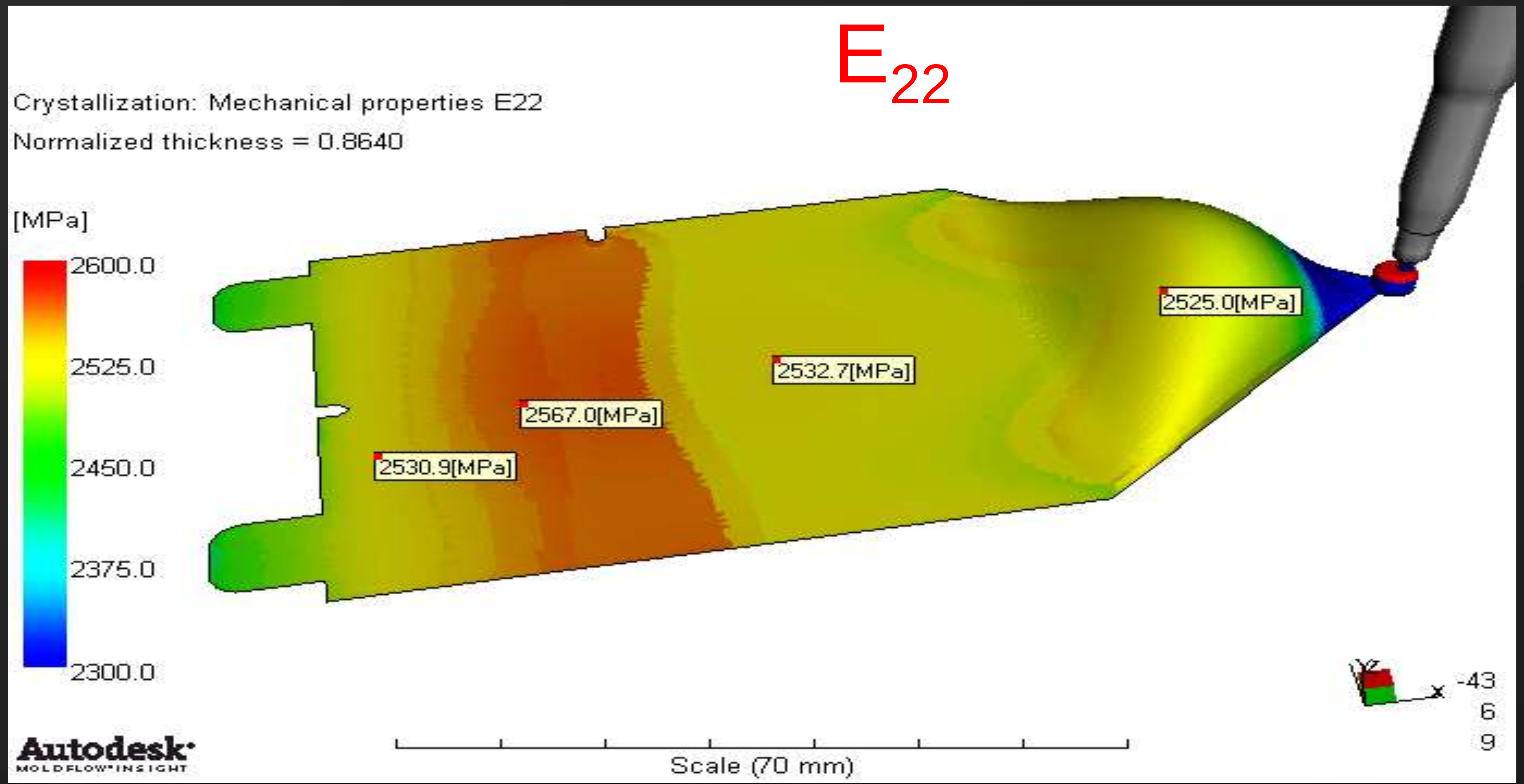


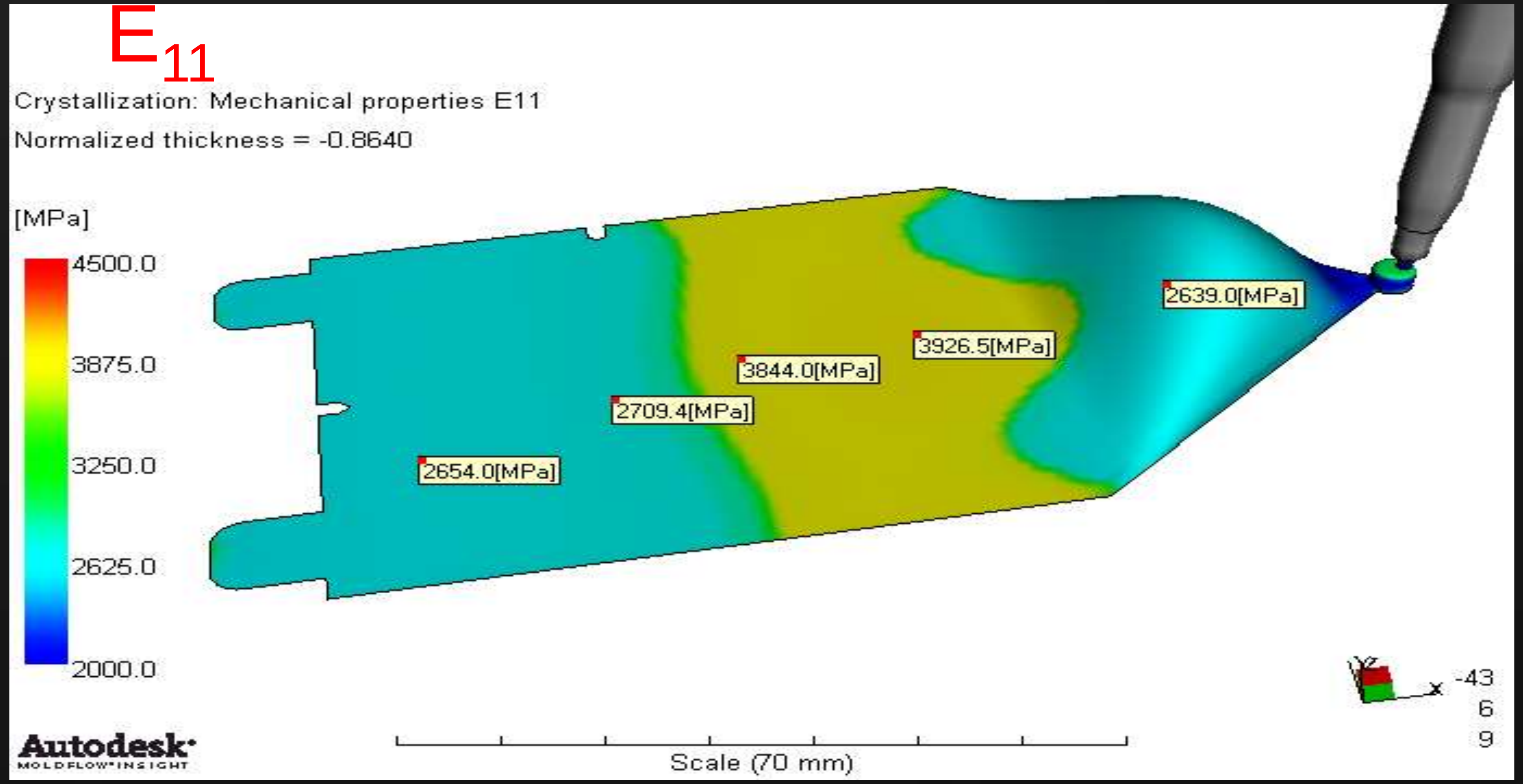
PET can have low Final Crystallinity

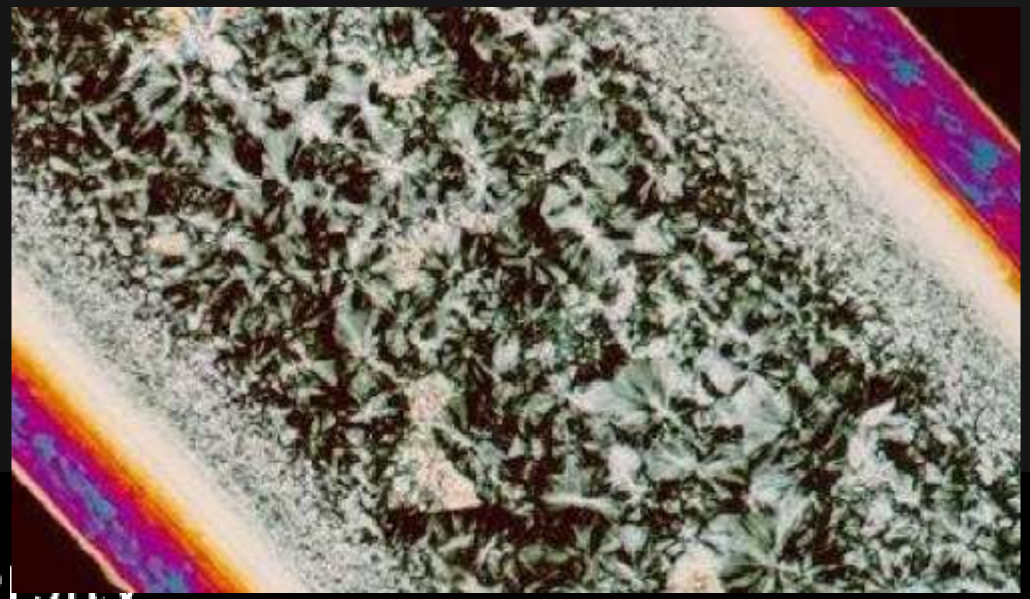
Predicted Modulus, E_{11} & E_{22}

- Varies through thickness
- Resolved in flow direction



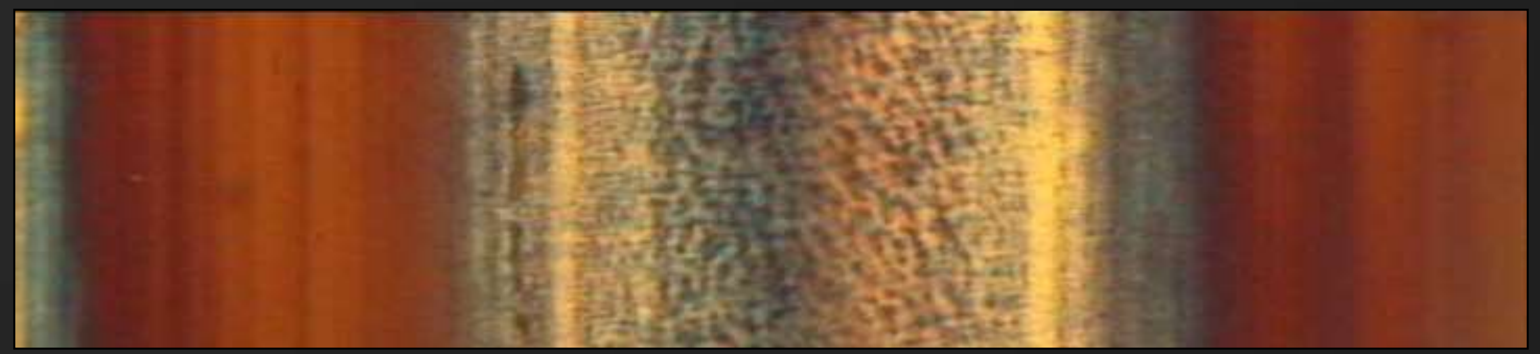




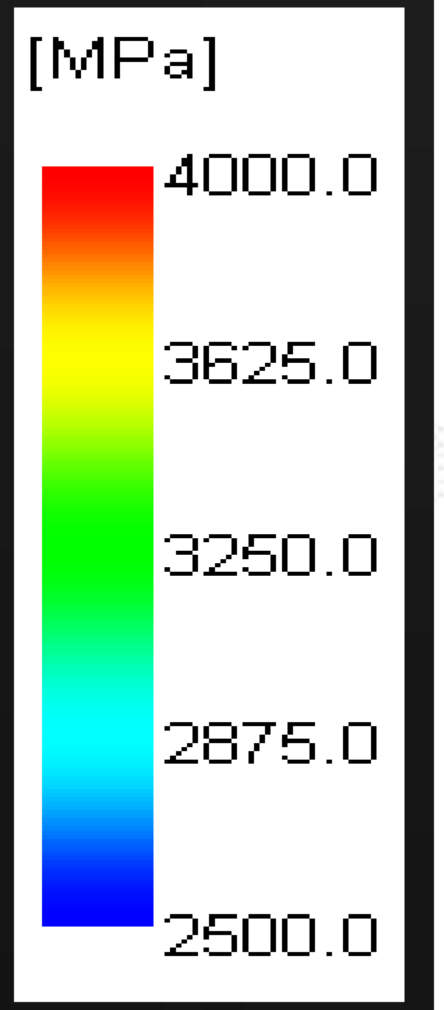


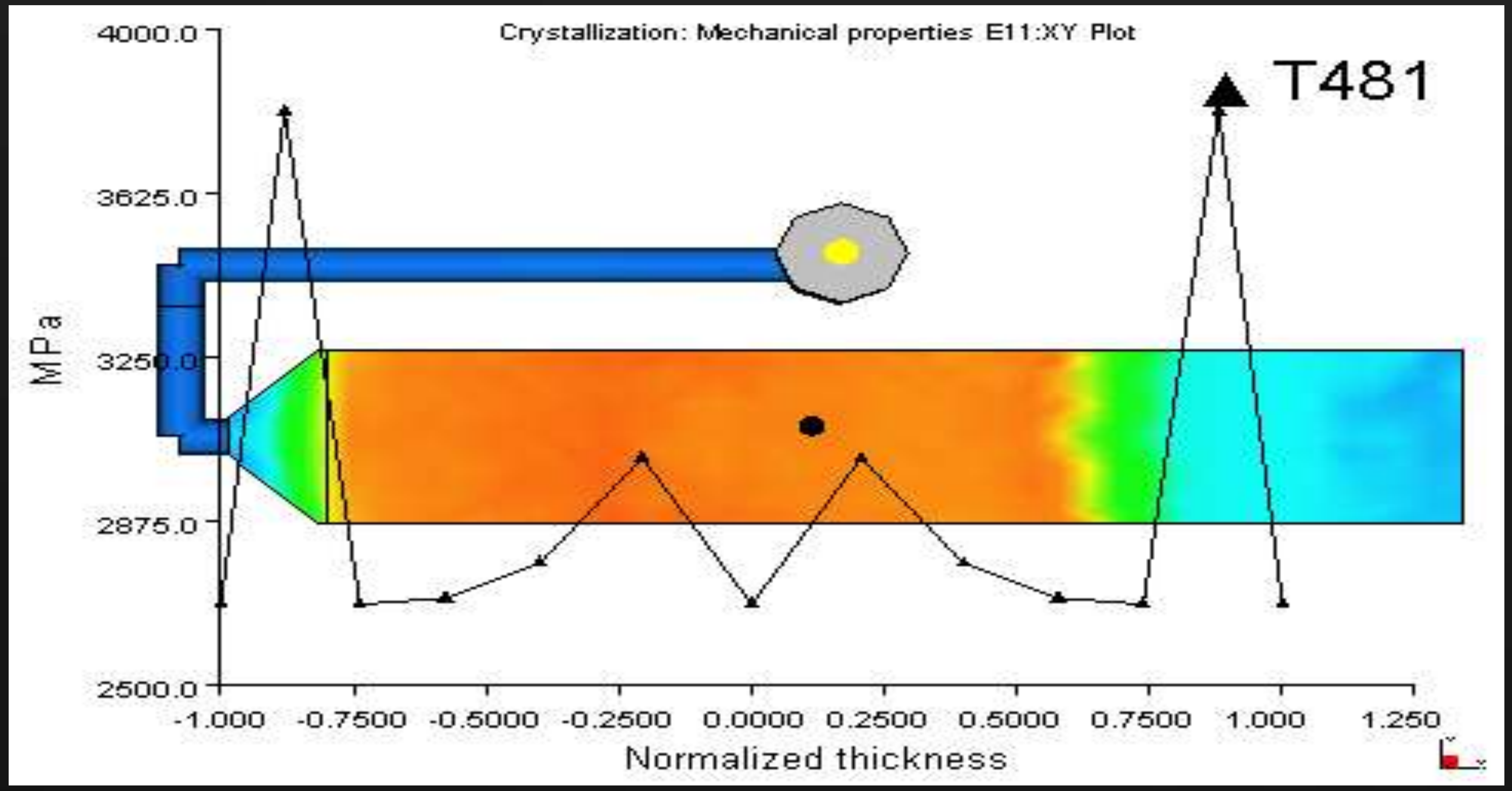
Linear Stiffness Modulus from Crystallization

- Anisotropy in stiffness due to morphology
  - Unfilled PBT
  - Normalised Thickness = 0.88

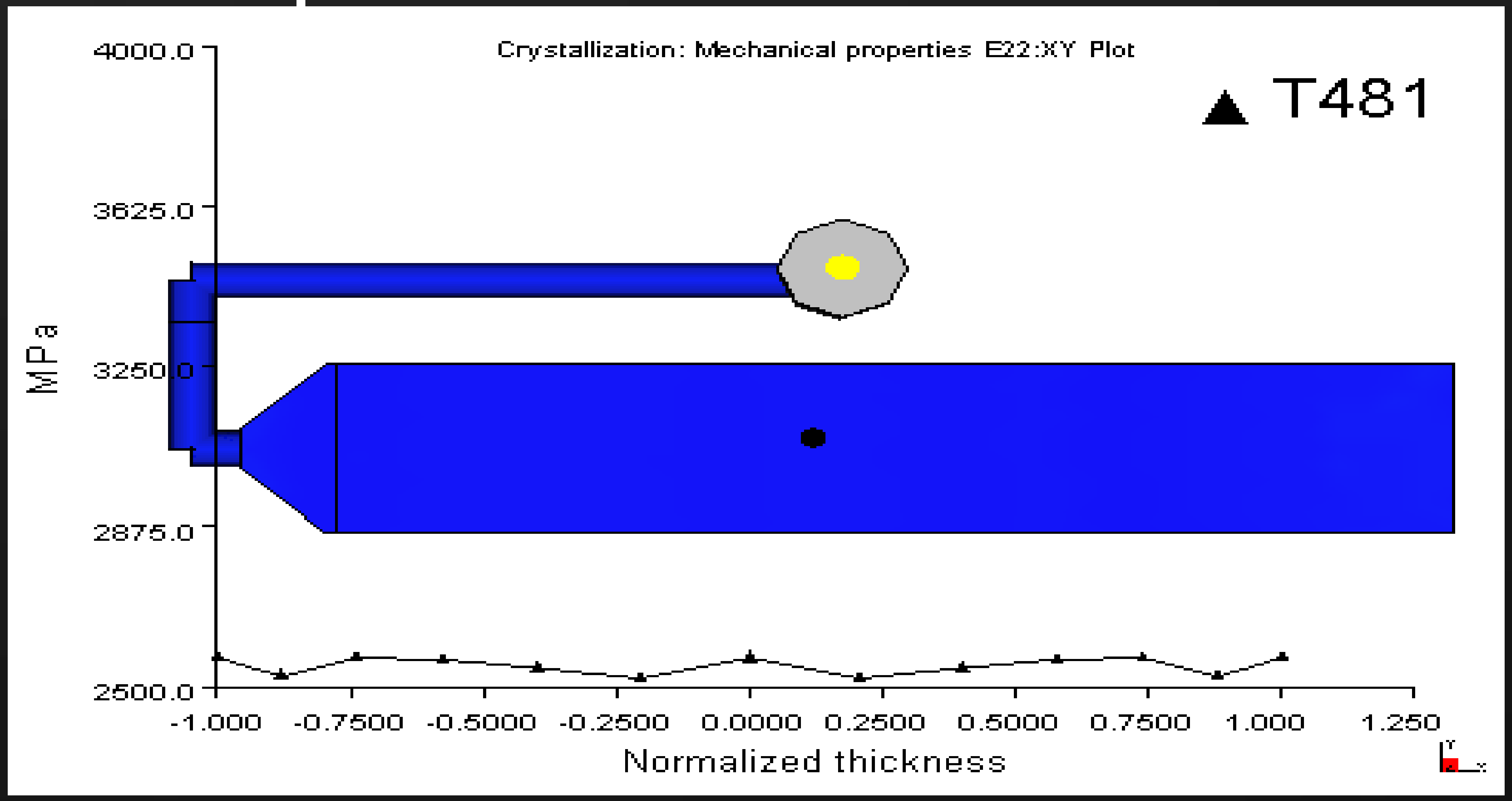


Flow Direction





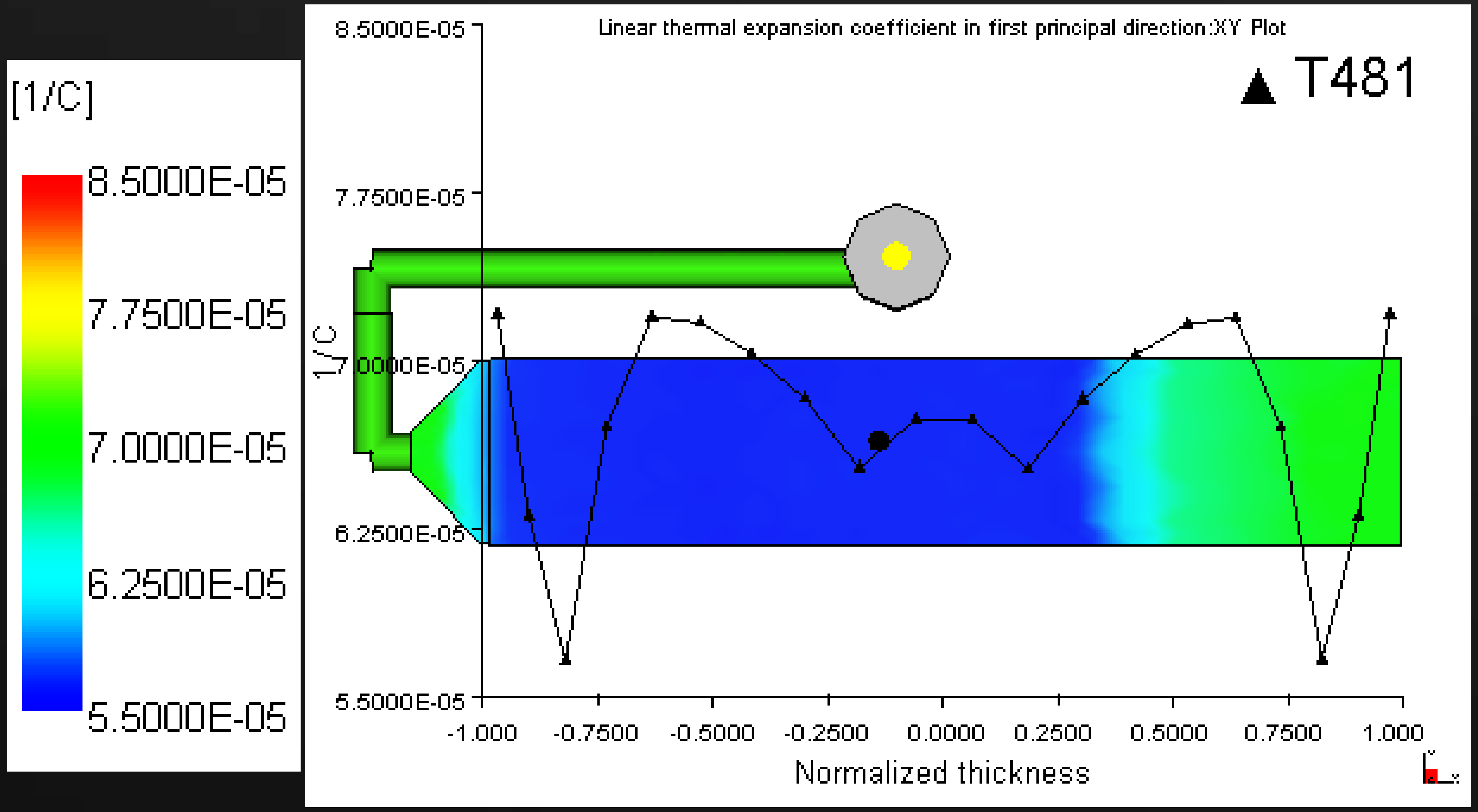
Perpendicular Direction



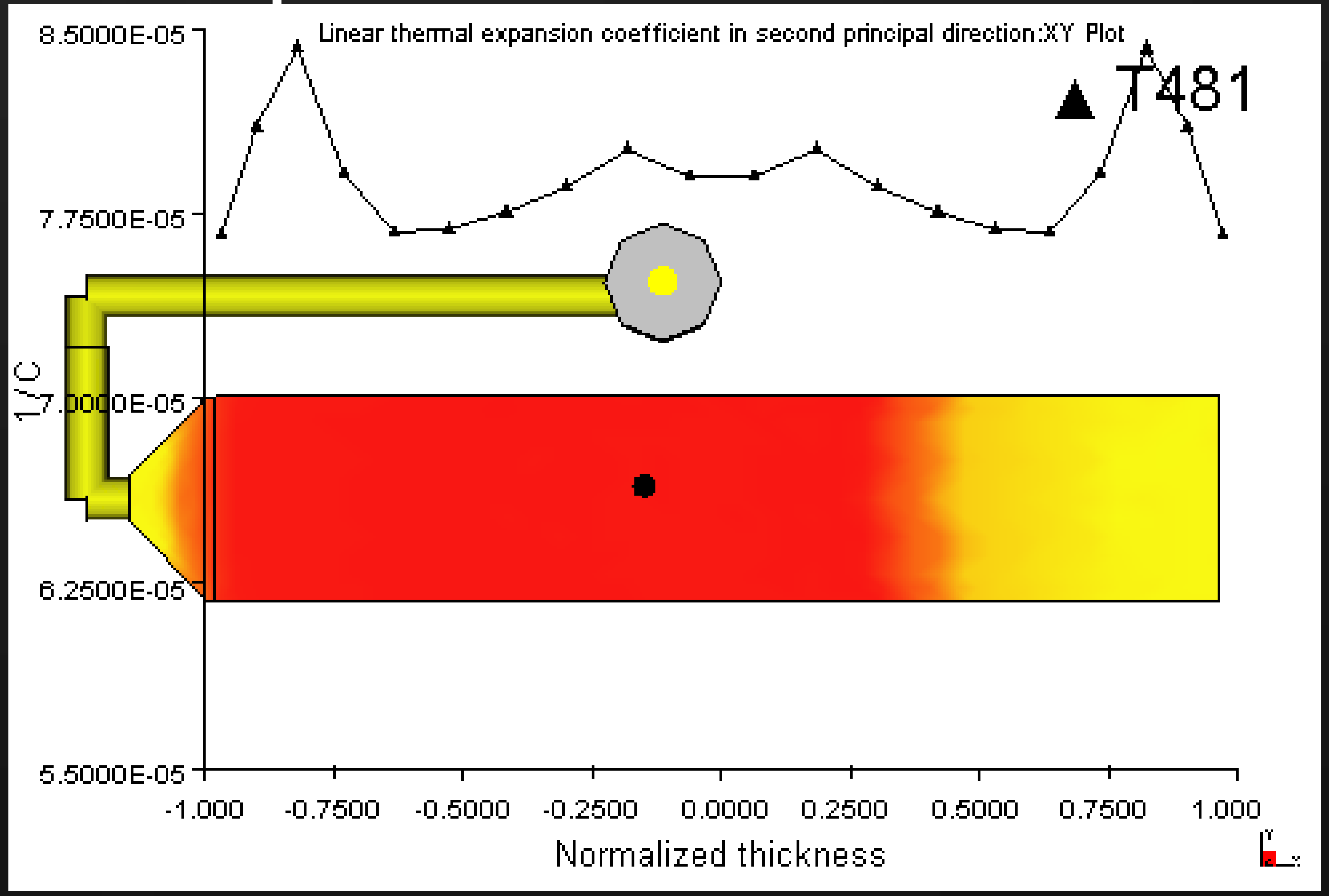
Coefficient of Linear Thermal Expansion from Crystallization

- Anisotropy in thermal expansion coefficient due to morphology
  - Unfilled PBT
  - Normalised Thickness = 0.82

Flow Direction

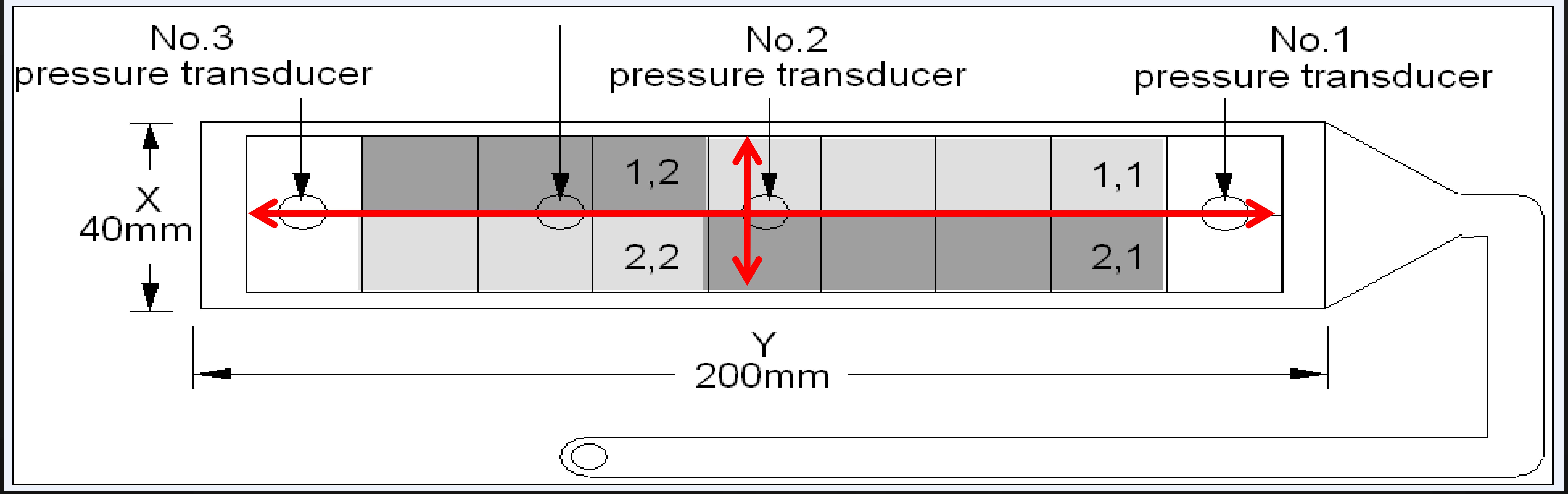


Perpendicular Direction



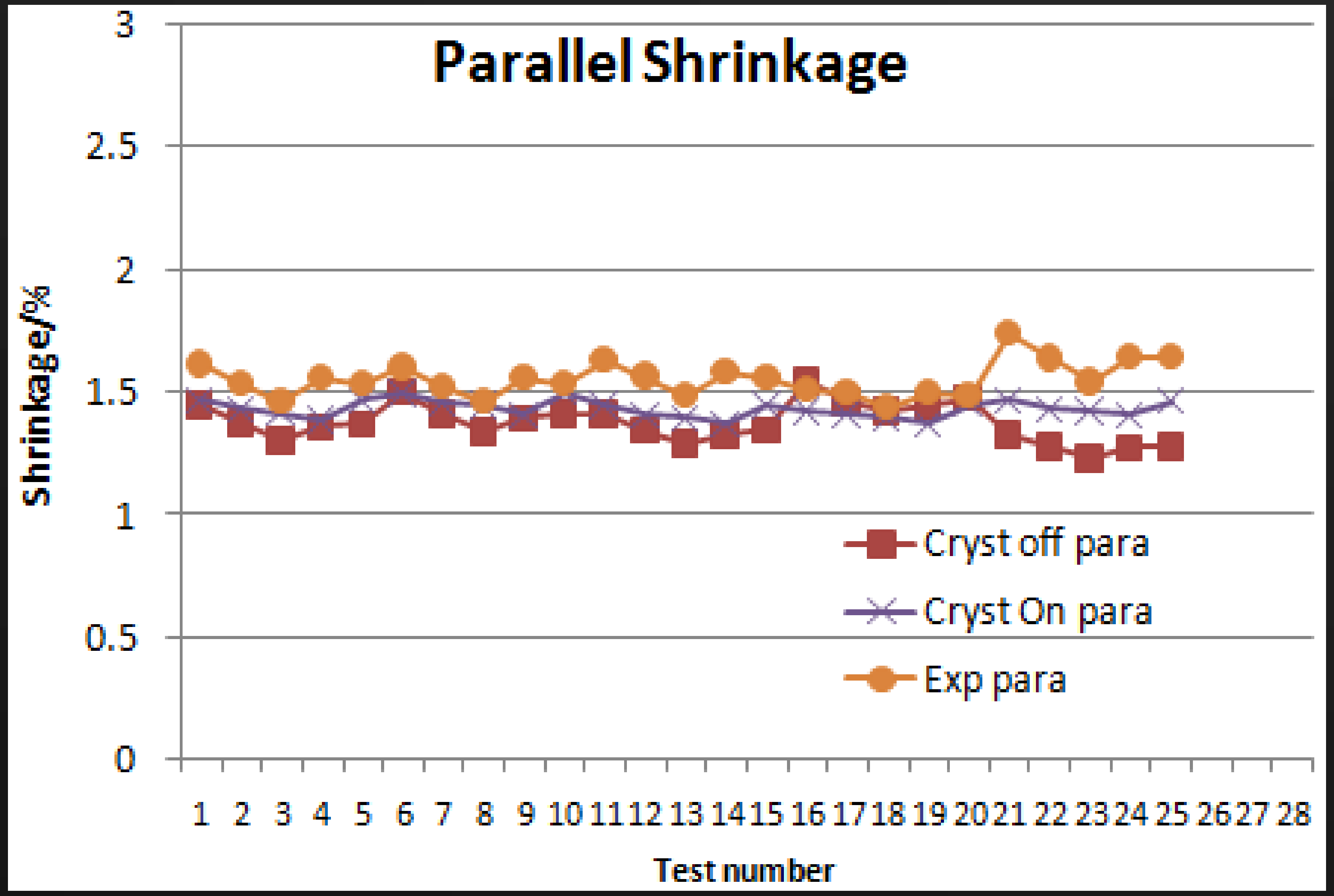
Validation of Linear Shrinkage Prediction

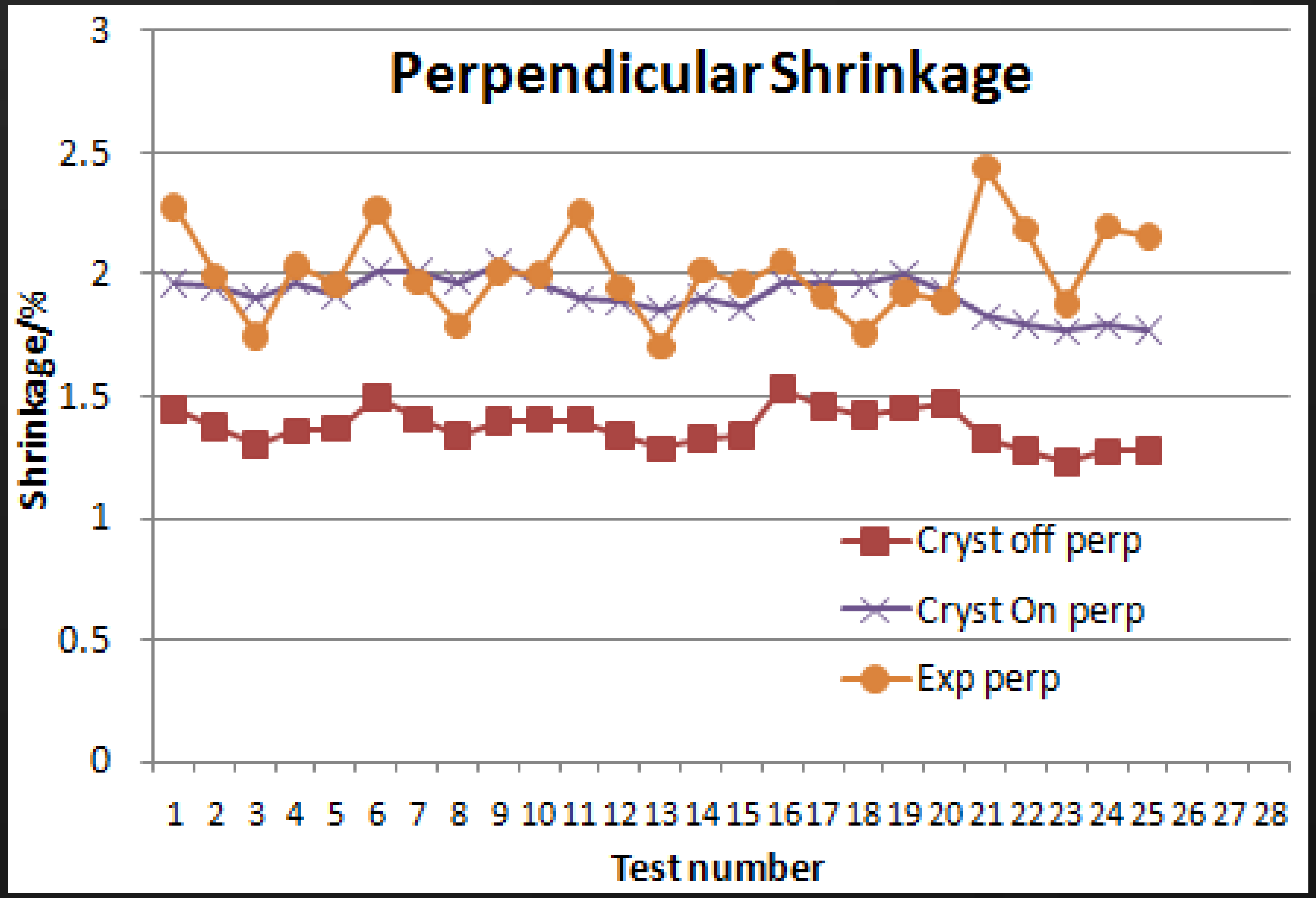
- Shrinkage measured in the flow direction (parallel) and across the flow direction (perpendicular) on long rectangular plaque
  - Can assume uni-directional flow
  - Various plaque thicknesses are tested



Prediction of Linear Shrinkage with Crystallization

- Improvement in Linear Shrinkage level and Shrinkage Anisotropy



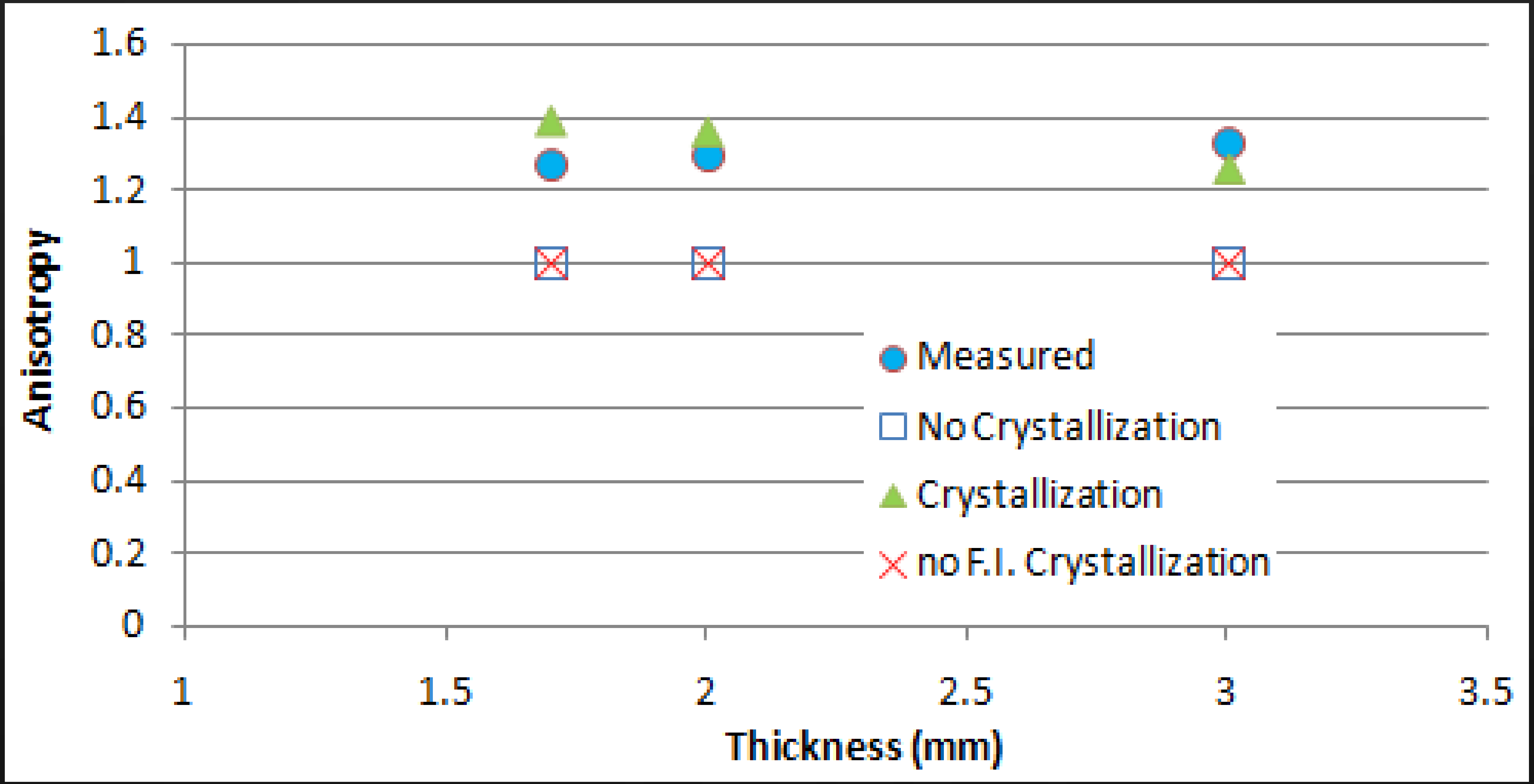


Unfilled PBT

Shrinkage correction (CRIMS) is not used in this example

Shrinkage Prediction without Flow Induced Crystallization

- Anisotropy = Perpendicular Shrinkage / Parallel Shrinkage



Unfilled PBT

Shrinkage correction (CRIMS) is not used in this example

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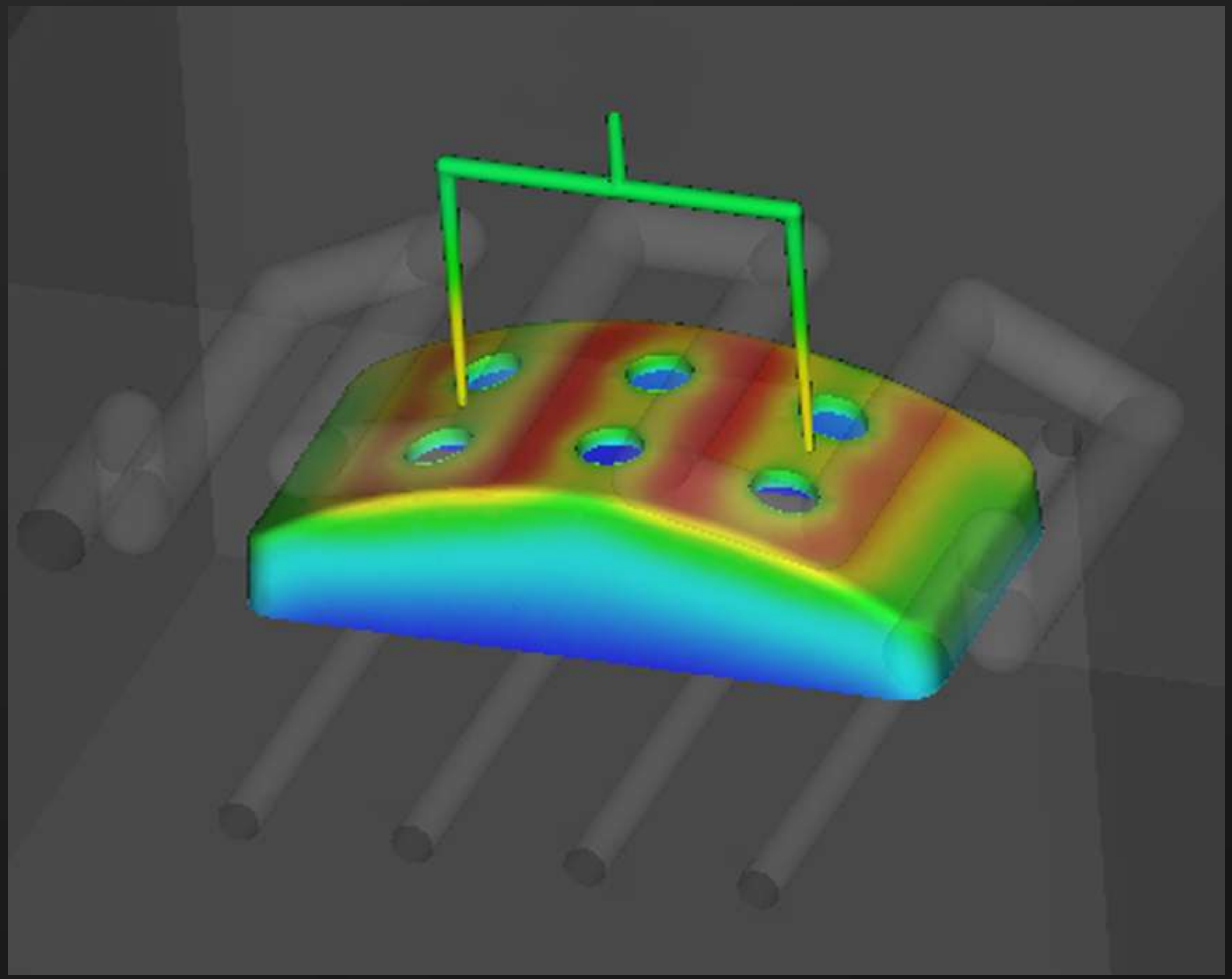
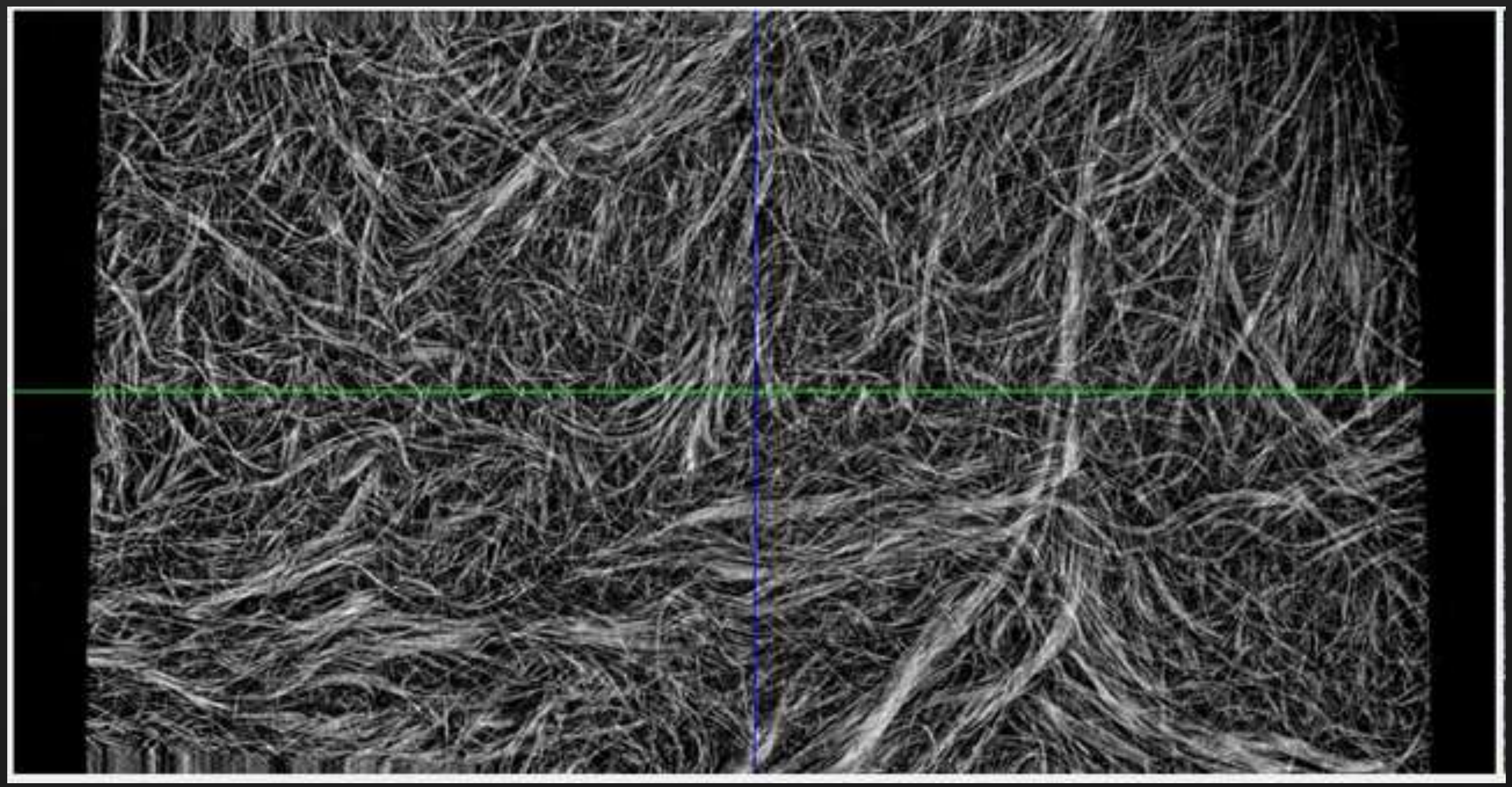


Advances in Fiber Composite Prediction

- Orientation Theory
- Validation Case Studies
  - Short Fiber
  - Long Fiber
- Long Fiber Breakage Theory
  - Validation Case Studies



RSC Model Captures Slow Orientation Kinetics

- Folgar-Tucker model was modified with two phenomenological assumptions of:
  - Reducing eigenvalue growth rate of orientation tensor by κ ($\kappa \leq 1$)
  - Keeping eigenvector rotation rate of orientation te… r unchanged
- **R**educed **S**train **C**losure (RSC) model is w…

$$\frac{D\mathbf{A}}{Dt} = (\mathbf{W}\cdot\mathbf{A} - \mathbf{A}\cdot\mathbf{W}) + \xi(\mathbf{D}\cdot\mathbf{A} \; \ldots \; - \kappa)(\mathbb{L} - \mathbb{M}:\mathbb{A})]:\mathbf{D})$$
$$+ 2\kappa C_I\dot{\gamma}(\mathbf{I} - 3\mathbf{A})$$

  - Closure term $\mathbb{A}:\mathbf{D}$ is replac… $- \kappa)(\mathbb{L} - \mathbb{M}:\mathbb{A})]:\mathbf{D}$
  - Diffusion term reduce… κ
- κ controls the rat… el…
  - As κ decreases, … ases
  - κ is determined by … experimental data

Patented

by Delphi & University of Illinois

Autodesk has exclusive commercialization rights

❖ Wang, J., J. F. O'Gara, and C. L. Tucker III. "An … e Model for Slow Orientation Kinetics in Concentrated Fiber Suspensions: Theory and Rheological Evidence." *Journal of Rheology* **52**(5): 1179–1200 (2008).

ARD Model Accounts for Anisotropic Interactions

- Isotropic diffusion term in Folgar-Tucker model is replaced with anisotropic diffusion to represent fiber interactions in long fibers
  - Rotary diffusion is defined on the surface of the unit sphere traced by all orientations of the unit vector
- **A**nisotropic **R**otary **D**iffusion (ARD) model is written as

$$\frac{D\mathbf{A}}{Dt} = (\mathbf{W}\cdot\mathbf{A} - \mathbf{A}\cdot\mathbf{W}) + \xi(\mathbf{D}\cdot\mathbf{A} + \mathbf{A}\cdot\mathbf{D} - 2\mathbb{A}:\mathbf{D}) + \dot{\gamma}(2\mathbf{C} - 2(\mathrm{tr}\mathbf{C})\mathbf{A} - 5(\mathbf{C}\cdot\mathbf{A} + \mathbf{A}\cdot\mathbf{C}) + 10\mathbb{A}:\mathbf{C})$$

  - Rotary diffusion tensor $\mathbf{C}$ is constructed from $\mathbf{A}$ and $\mathbf{D}$ as

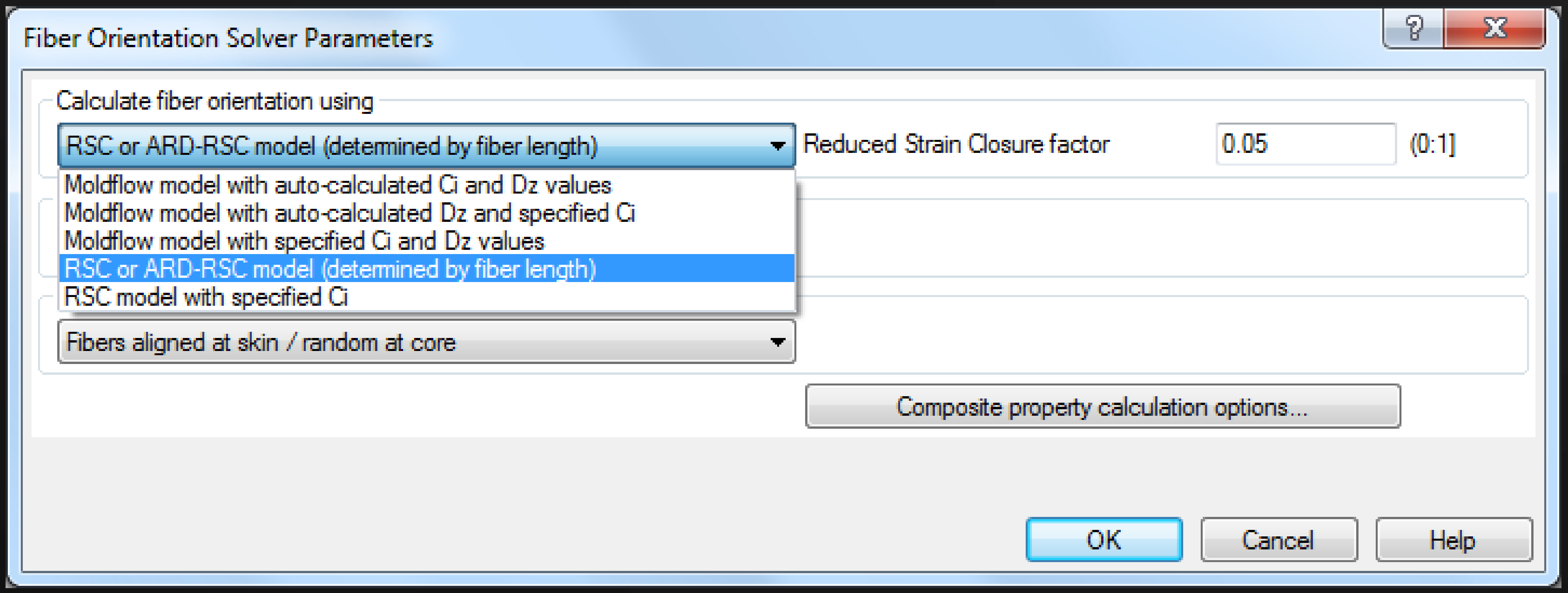
$$\mathbf{C} = b_1 + b_2\mathbf{A} + b_3\mathbf{A}^2 + b_4\frac{\mathbf{D}}{\dot{\gamma}} + b_5\frac{\mathbf{D}^2}{\dot{\gamma}^2}$$

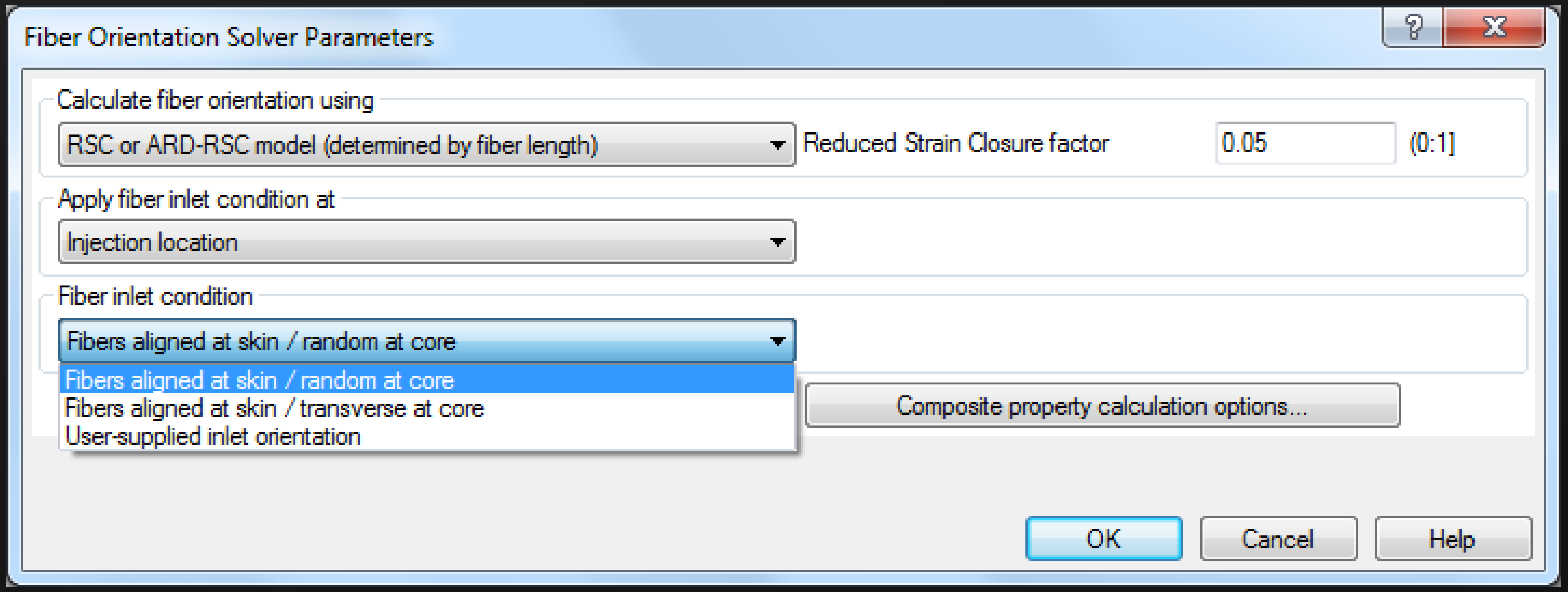
  - b_i (i = 1, …, 5) are scalar constants and selected by matching experimental steady-state orientation and requiring stable orientation
  - RSC model can also be incorporated with ARD model

❖ Phelps, J. and C. L. Tucker III. "An Anisotropic Rotary Diffusion Model for Fiber Orientation in Short- and Long-Fiber Thermoplastics." *Journal of Non-Newtonian Fluid Mechanics* **156**(3): 165–176 (2009).

New in Insight 2012 Fiber Solver

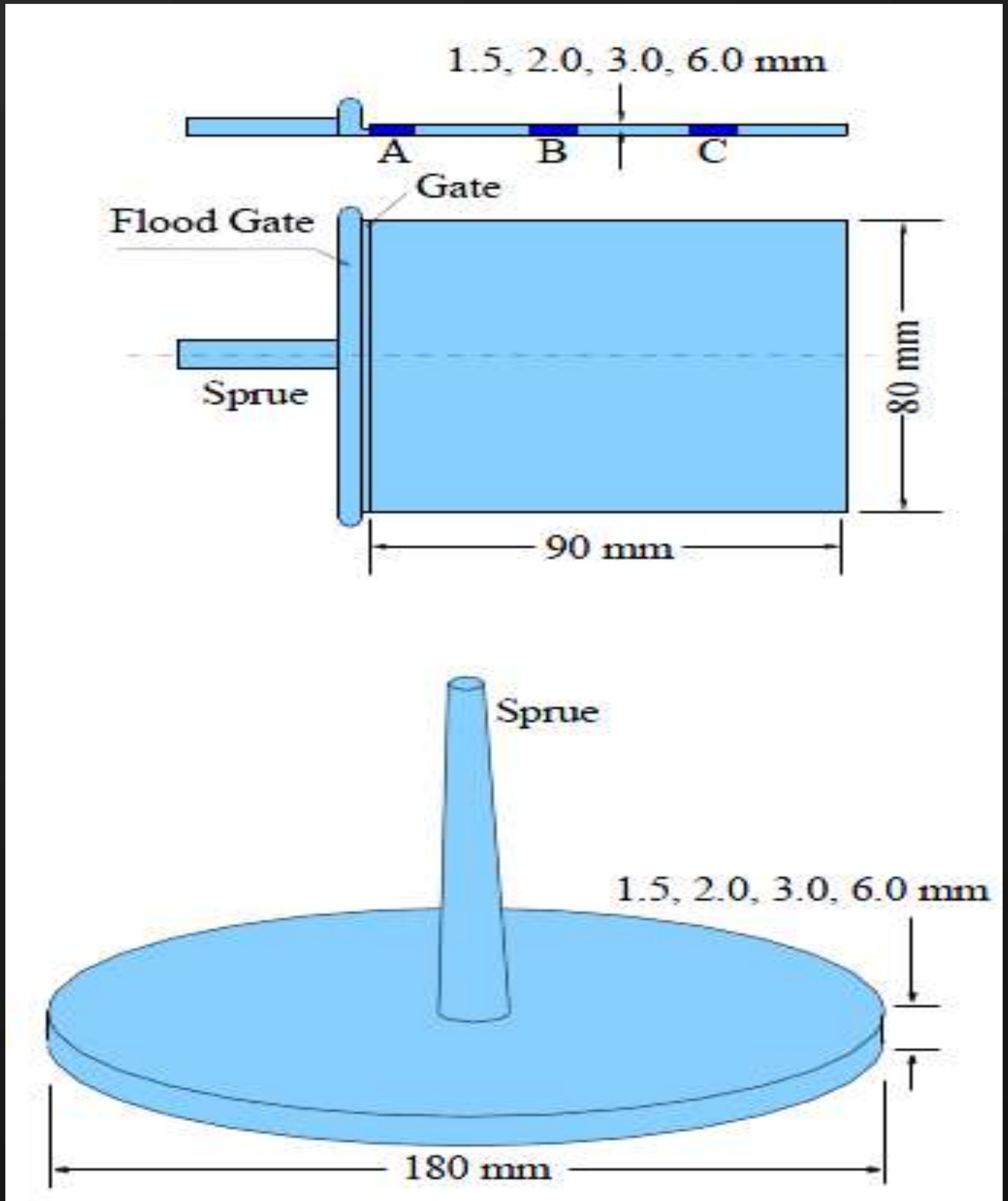
- Midplane/Dual Domain
  - New set of CRIMS data for RSC (short fibers) and ARD-RSC (long fibers) models
  - Updated CRIMS correlation
  - Default inlet orientation changed to “aligned at skin/random at core”
  - Fiber orientation calculation in beam elements, and option of gate or injection location to apply inlet orientation
- 3D
  - Improved orientation calculation for more accurate predictions



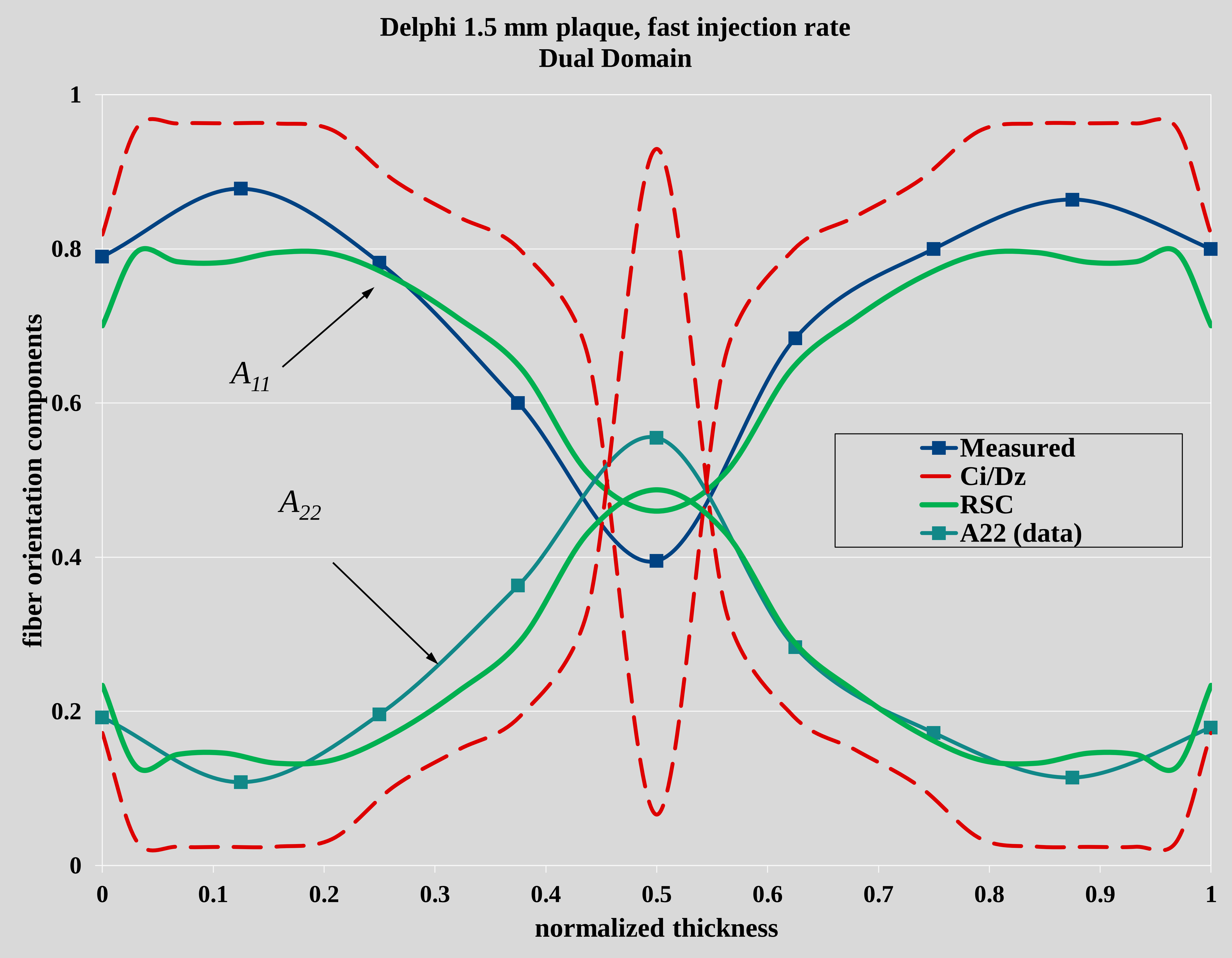


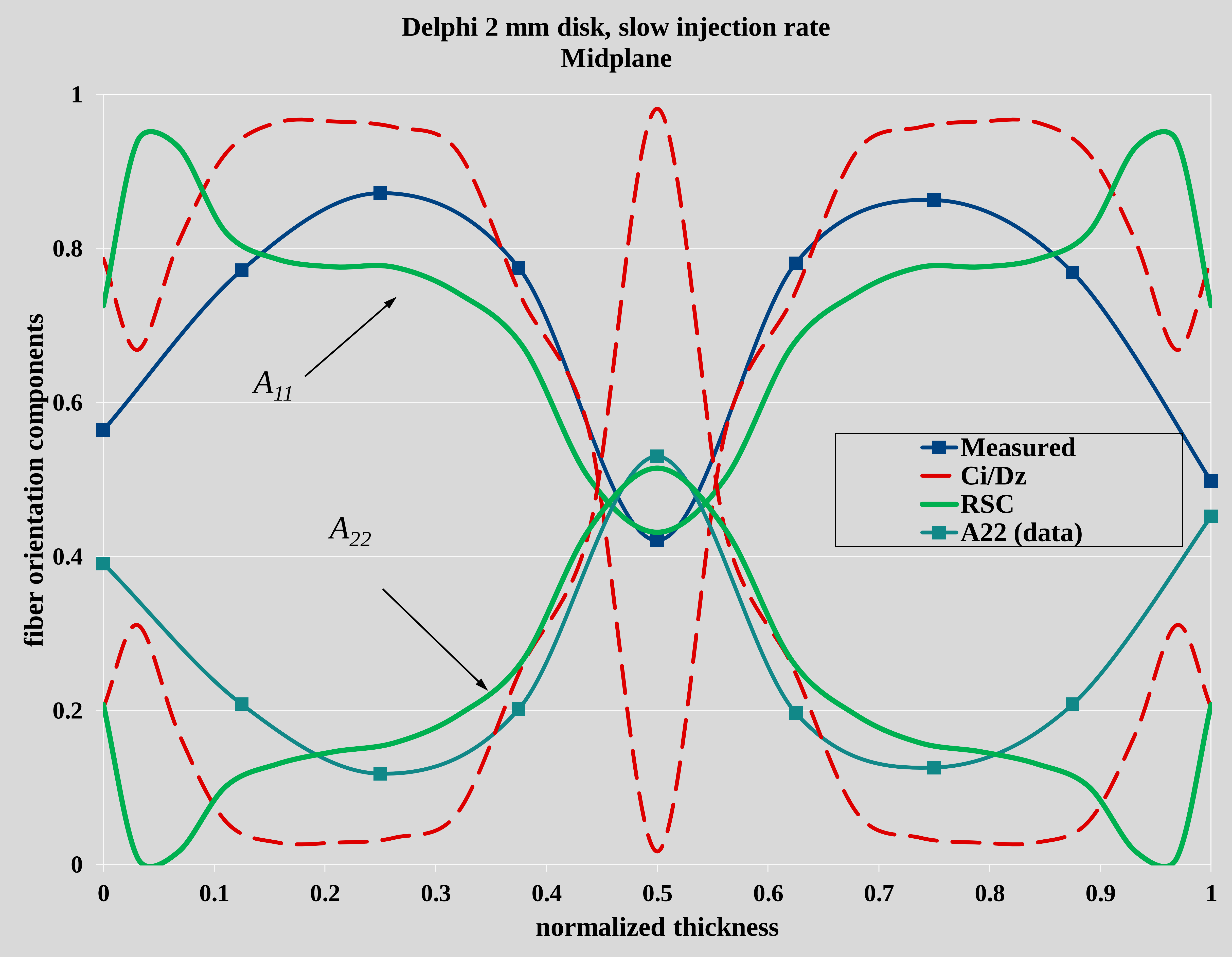
Fiber Orientation Measured in a Series of Part

- Parts were injection-molded by Delphi and PNNL/ORNL
  - End-gated ISO plaques and center-gated disks, in different thicknesses and filled at different injection rates
  - Short-fiber-reinforced PBT in Delphi parts
  - Long-fiber-reinforced PP in PNNL-ORNL parts
- Fiber orientation was measured by Delphi and PNNL/ORNL for their respective parts
  - Cut on centerline and radial direction
  - Image scan and data extraction on cross-sections at A, B, C



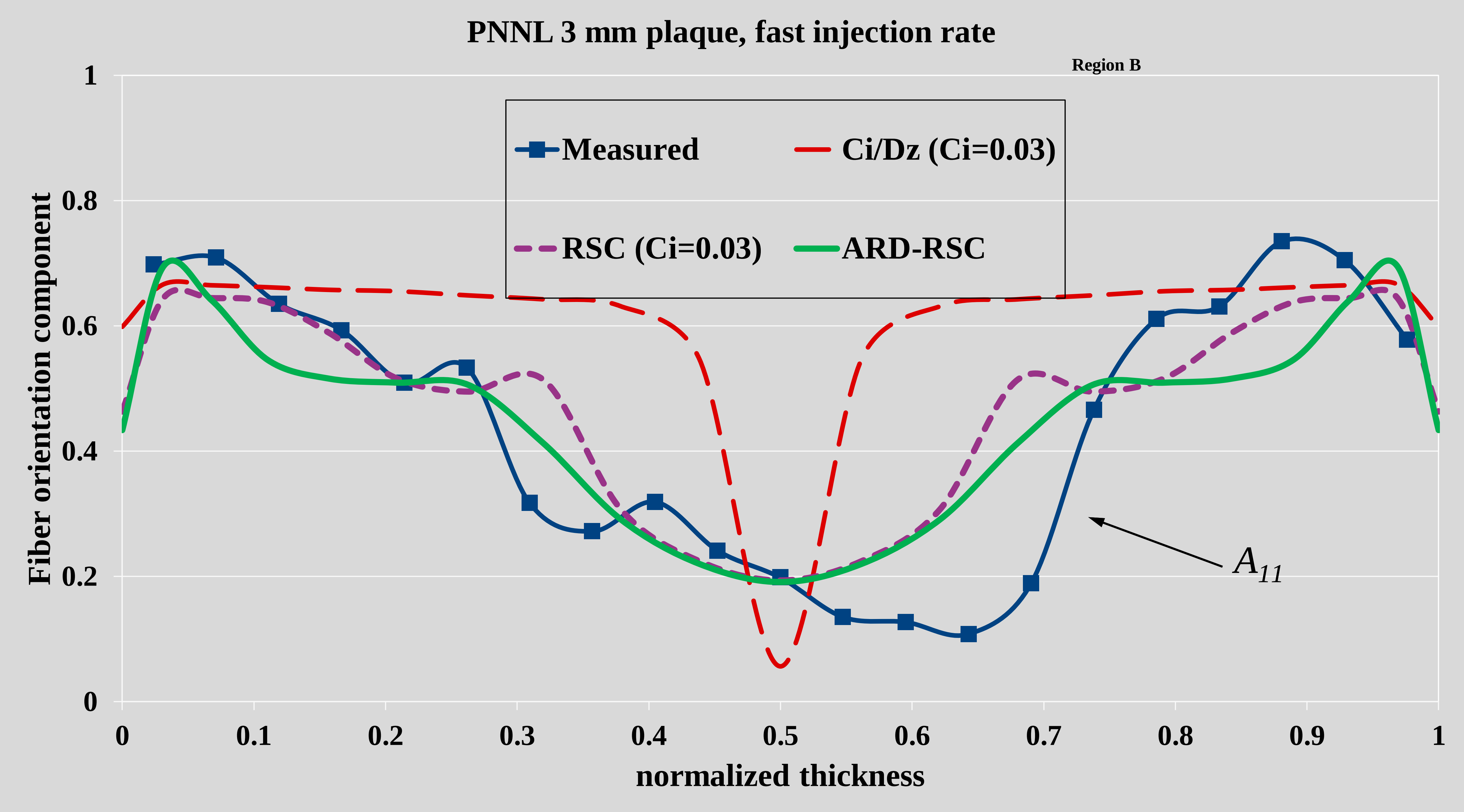
RSC Model Gives Good Predictions (Midplane/DD)

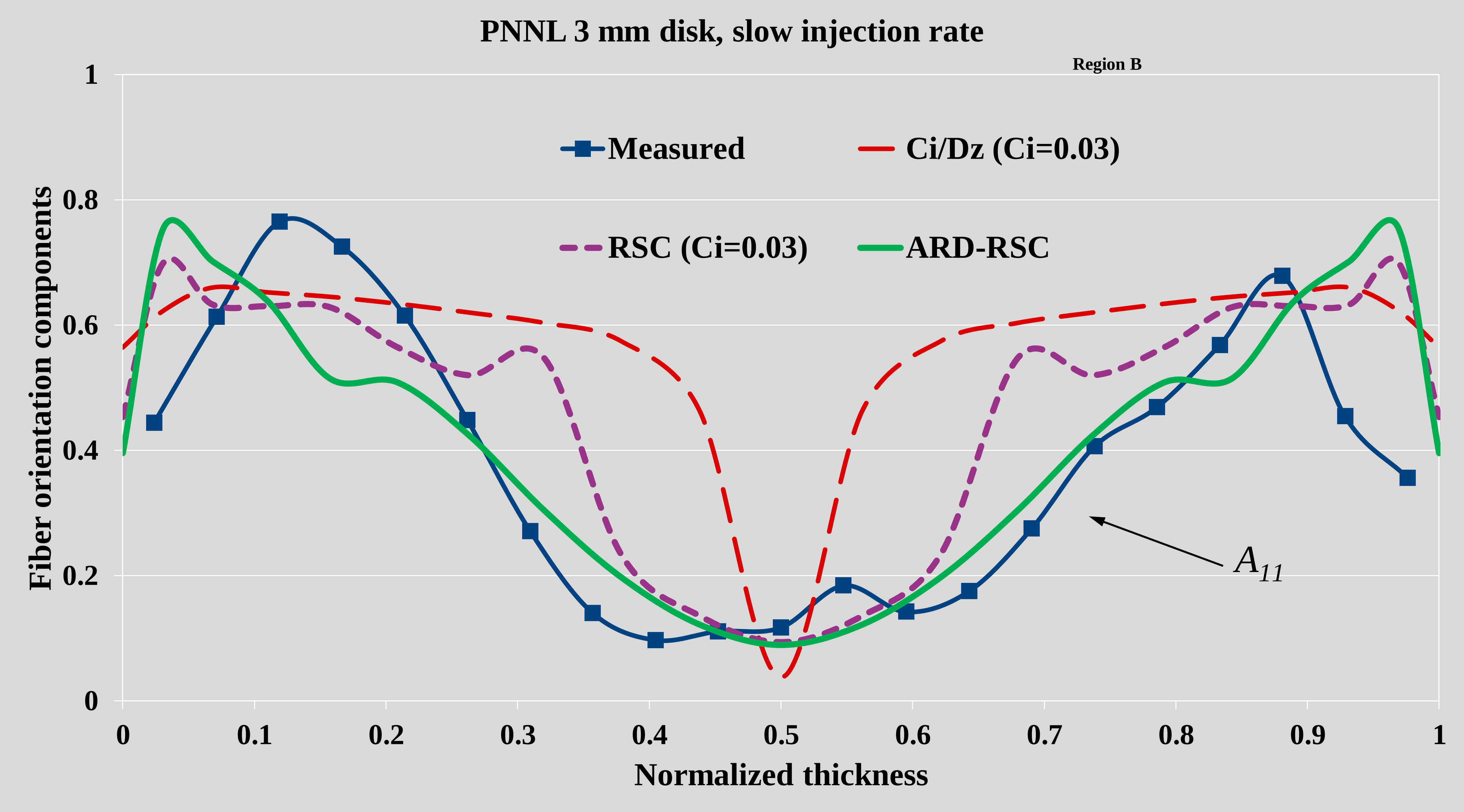




ARD-RSC Gives Good Predictions for Long-Fiber 3mm Plaque and Disk (Midplane)

- Predictions by ARD-RSC model show good agreement with data



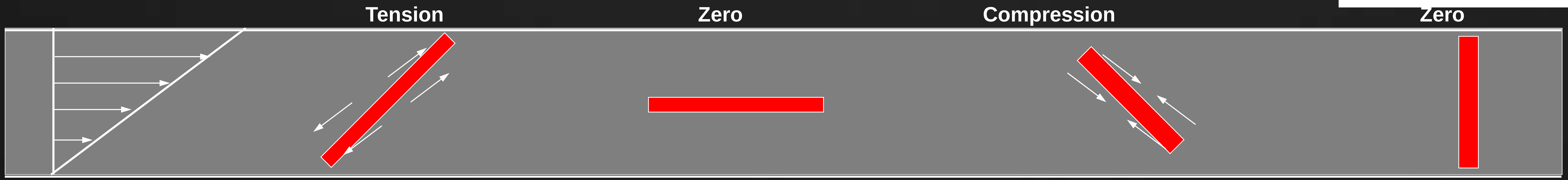


Fiber Breakage Model

- Phelps-Tucker Model
  - Probability of breakage of fibers length l_i

Dinh & Armstrong Model / Critical Buckling Force

$$F_i / F_{crit} = \frac{8 \varsigma \eta_m l_i^4}{\pi^3 E_f d_f^4} (D : A) > 1$$



$$\overline{P_i} = C_b \ \gamma \ \max\{0, \ [1 - \exp(1 - F_i / F_{crit})]\}$$

C_b: Strain Rate Coefficient Parameter

ς: Dimensionless Drag Coefficient (Dg)

Fiber Breakage Model

- Probability of creating a fiber of length l_k from a fiber of length l_i

$$R_{ik} = G_{norm}\left(l_i, \frac{l_k}{2}, Sl_k\right)$$

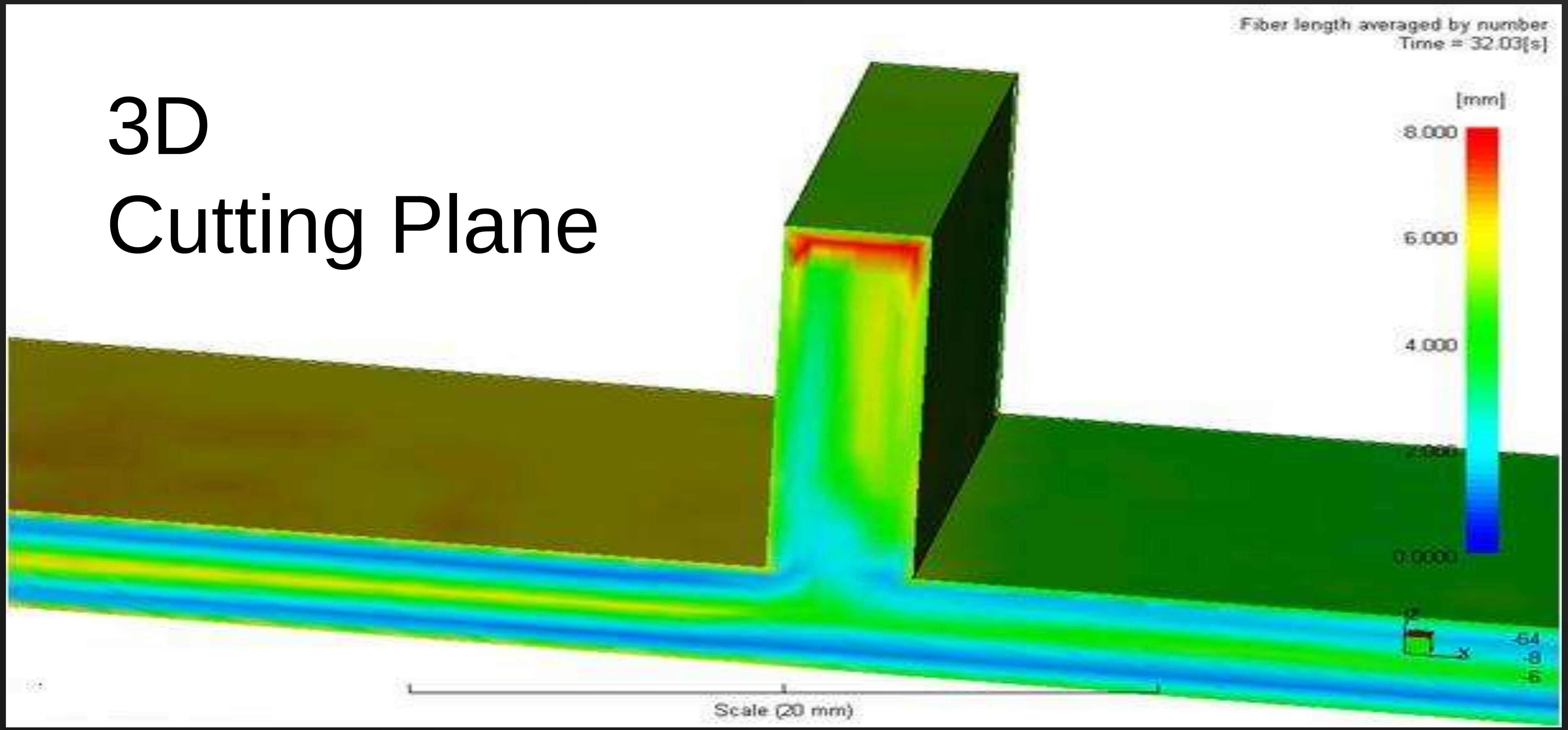
S: Distribution Parameter

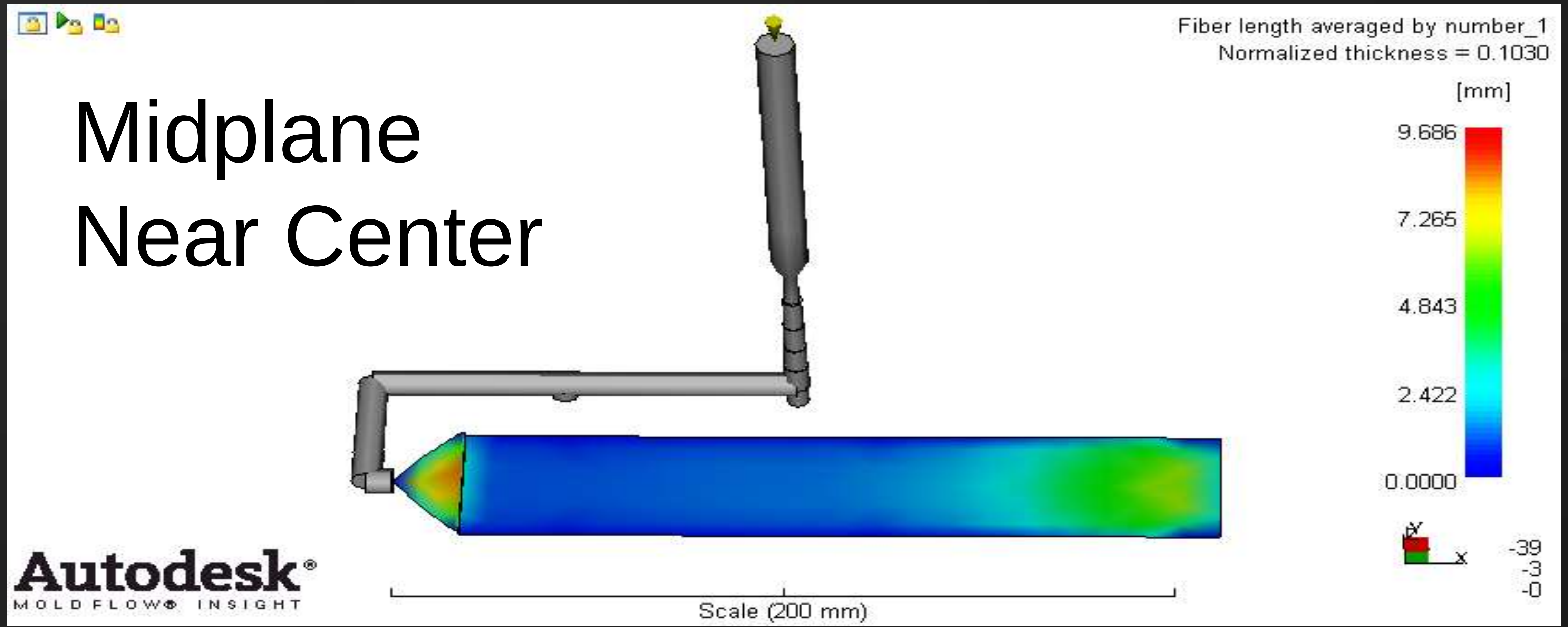
$\overline{N}_{i,t}$: Number of fibers of length l_i which exist at time t

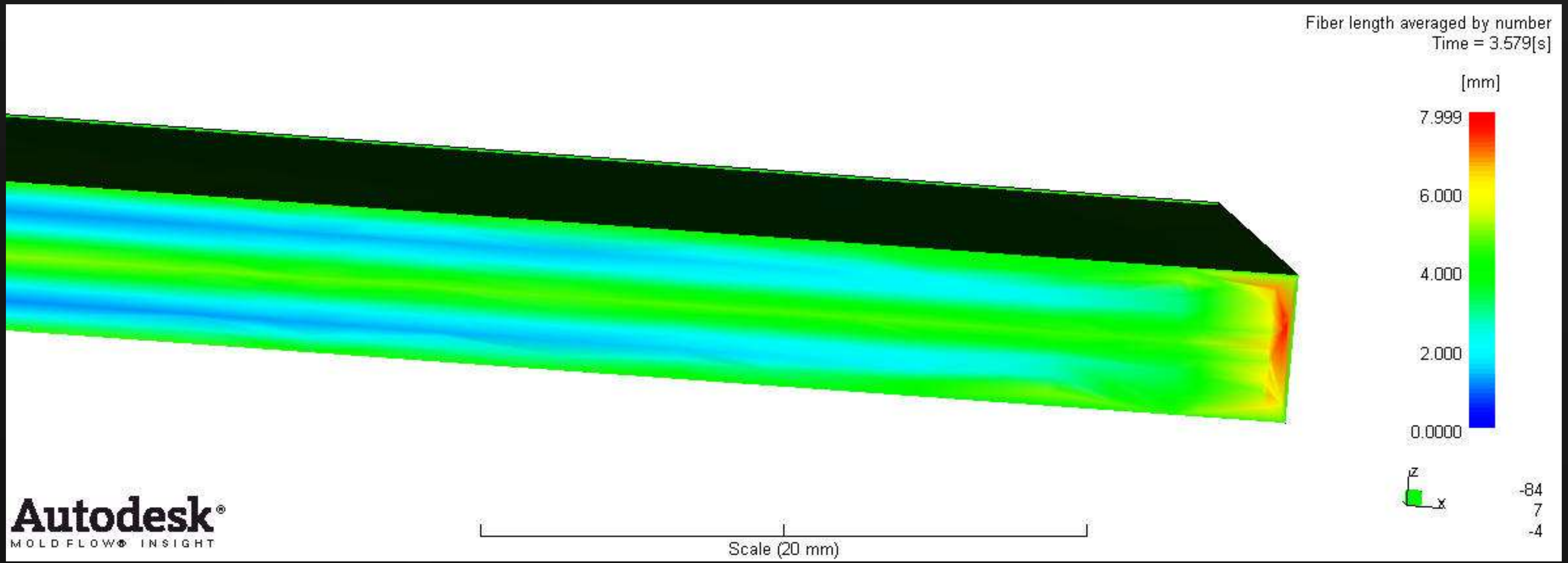
$$\overline{N}_{i,t+\Delta t} = \overline{N}_{i,t} - \overline{P}_i \overline{N}_{i,t} \Delta t + \sum_{k|k \geq i}^{M} \overline{R}_{ik} \overline{N}_{k,t} \Delta t$$

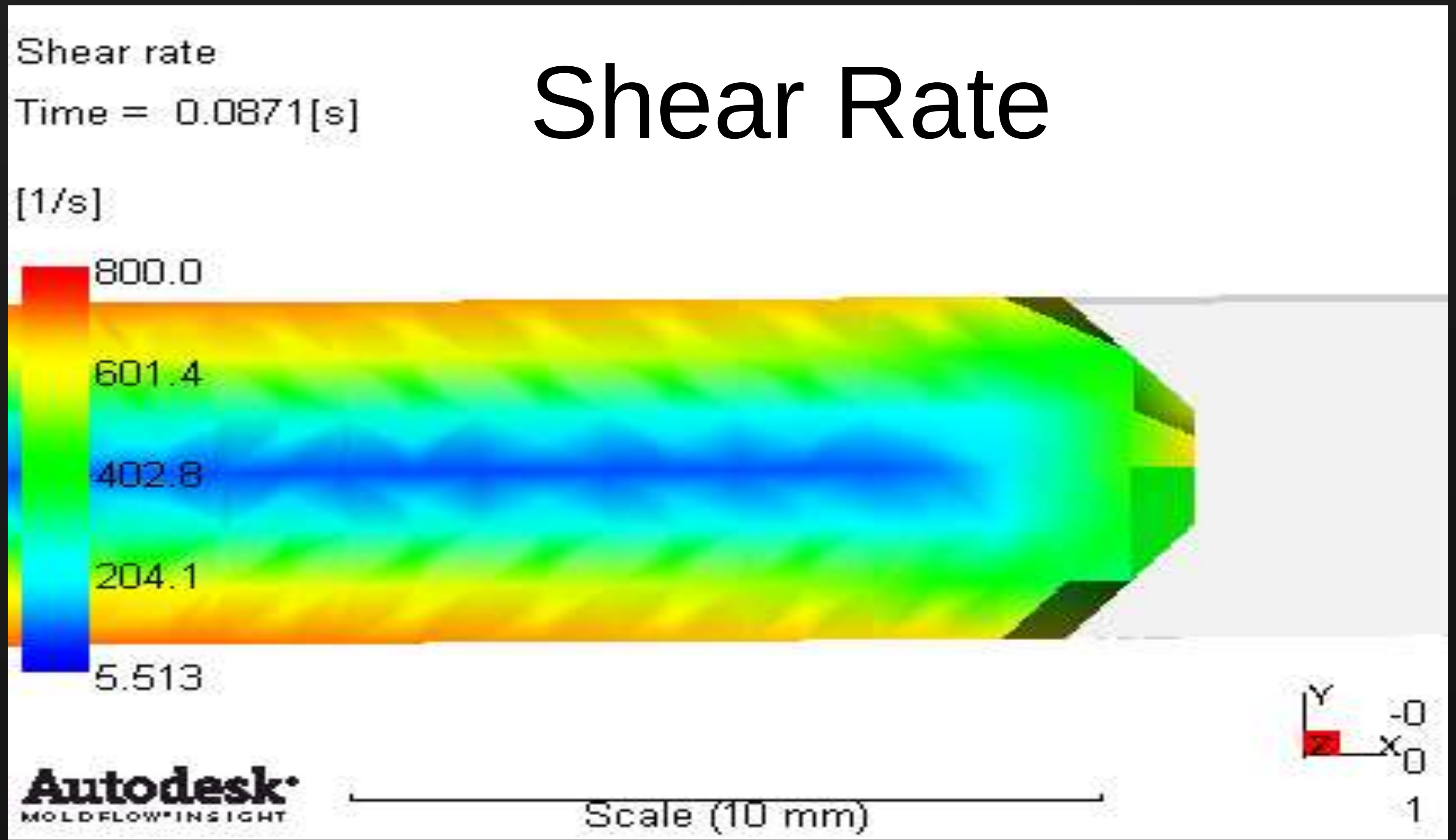
$$i = 1, 2, \ldots, M;$$

Fiber Length Distribution in 3D
Some long fibers pushed to the end?

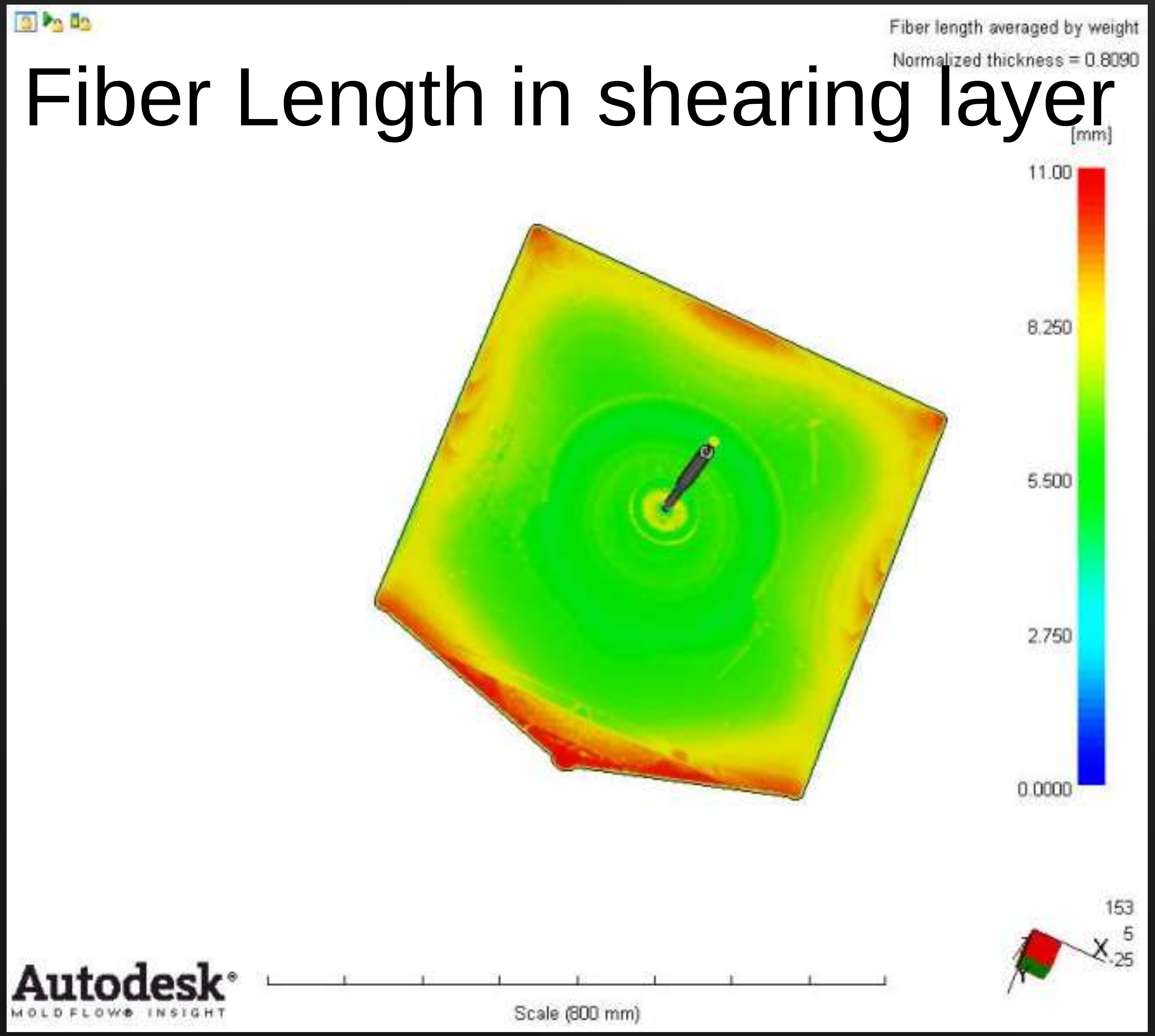




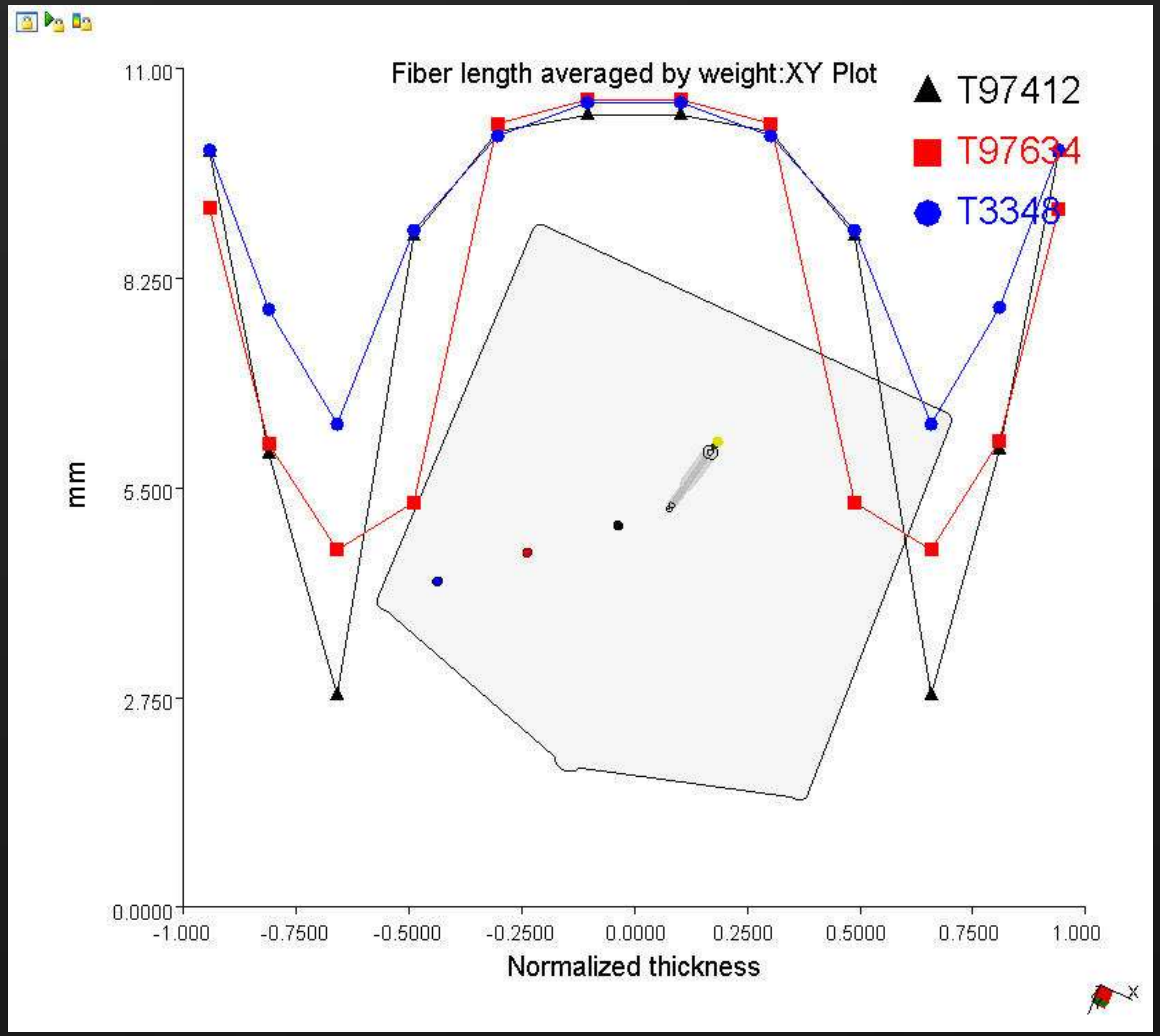




Predicted Fiber Length Distributions



Midplane



3D

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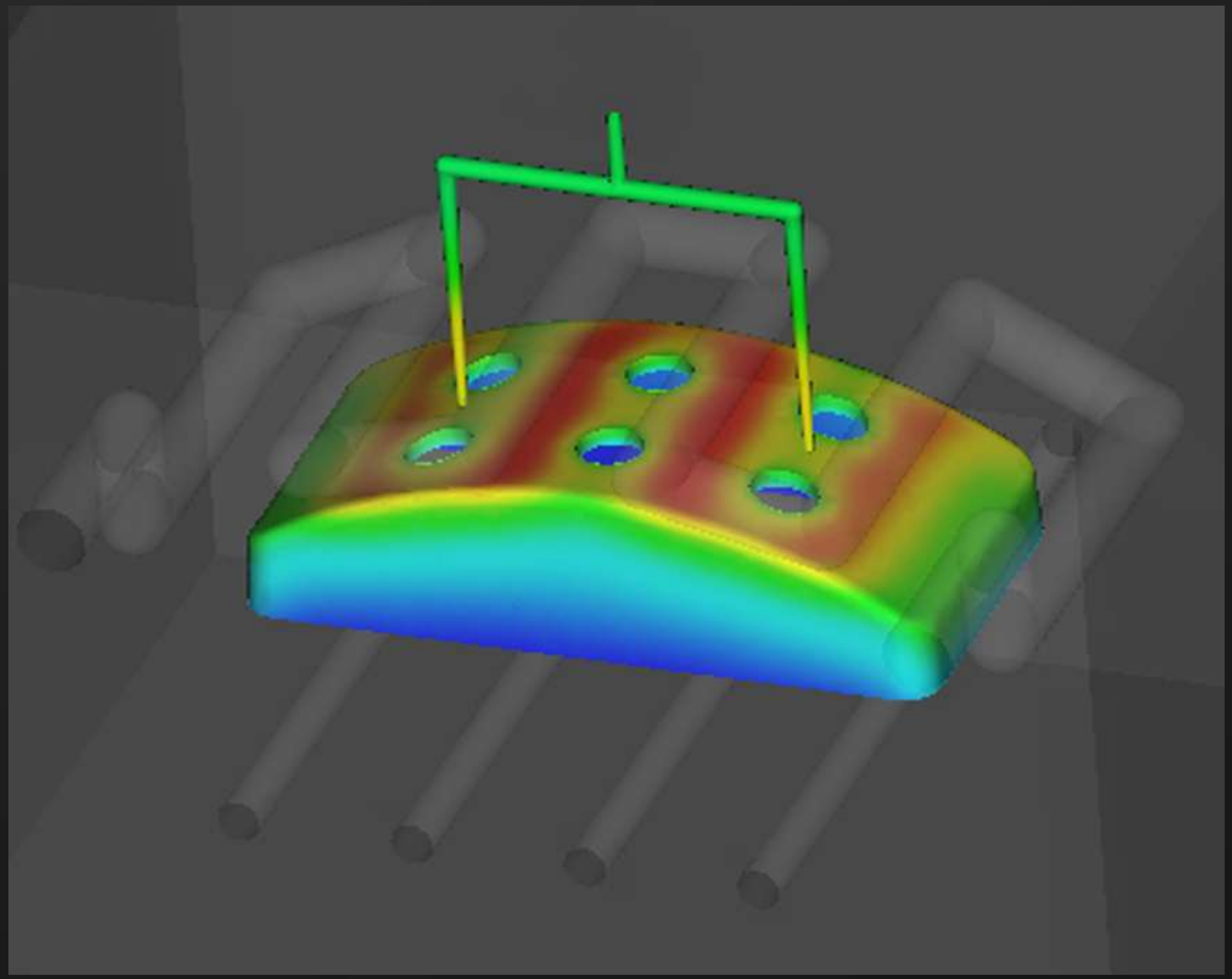
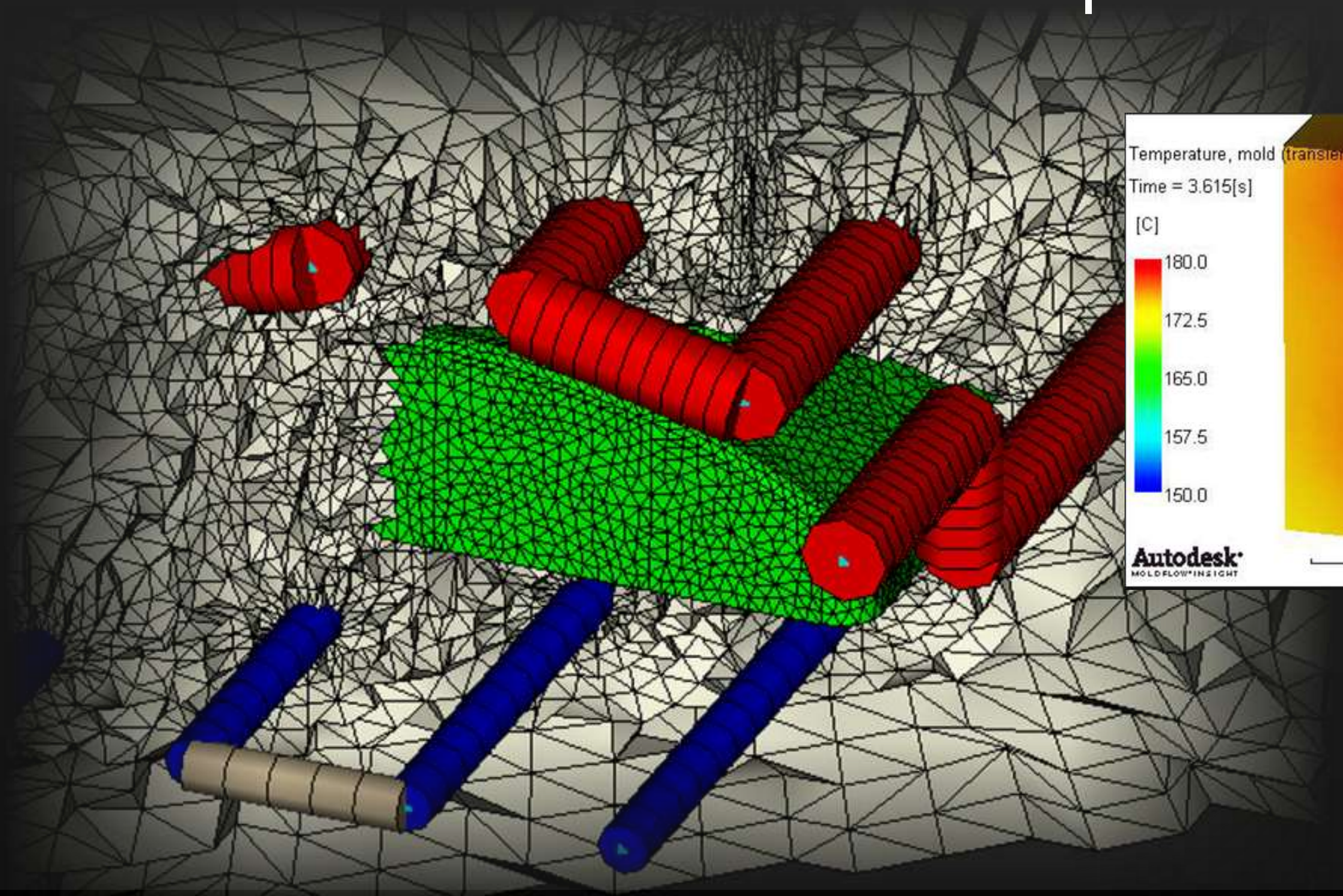
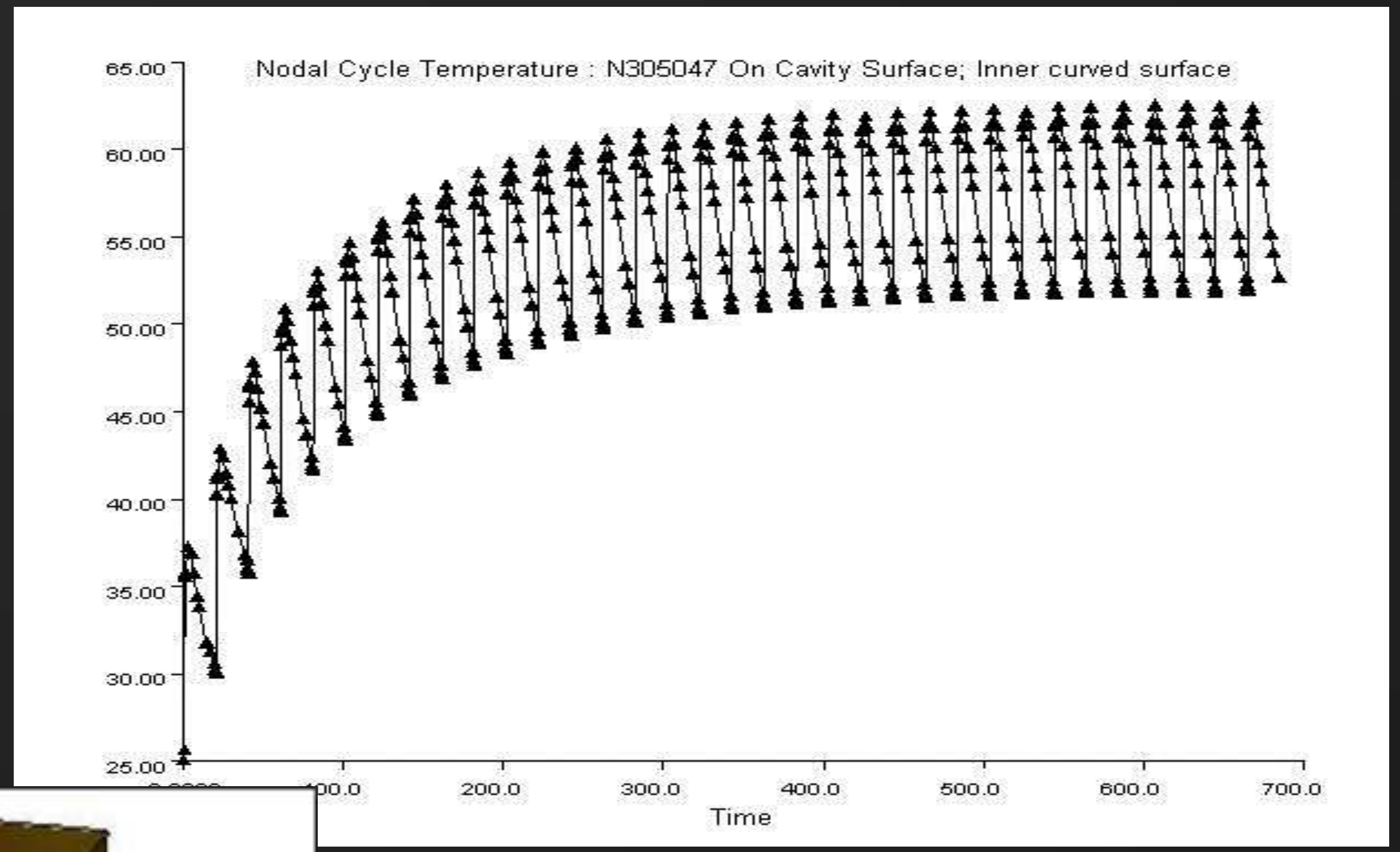
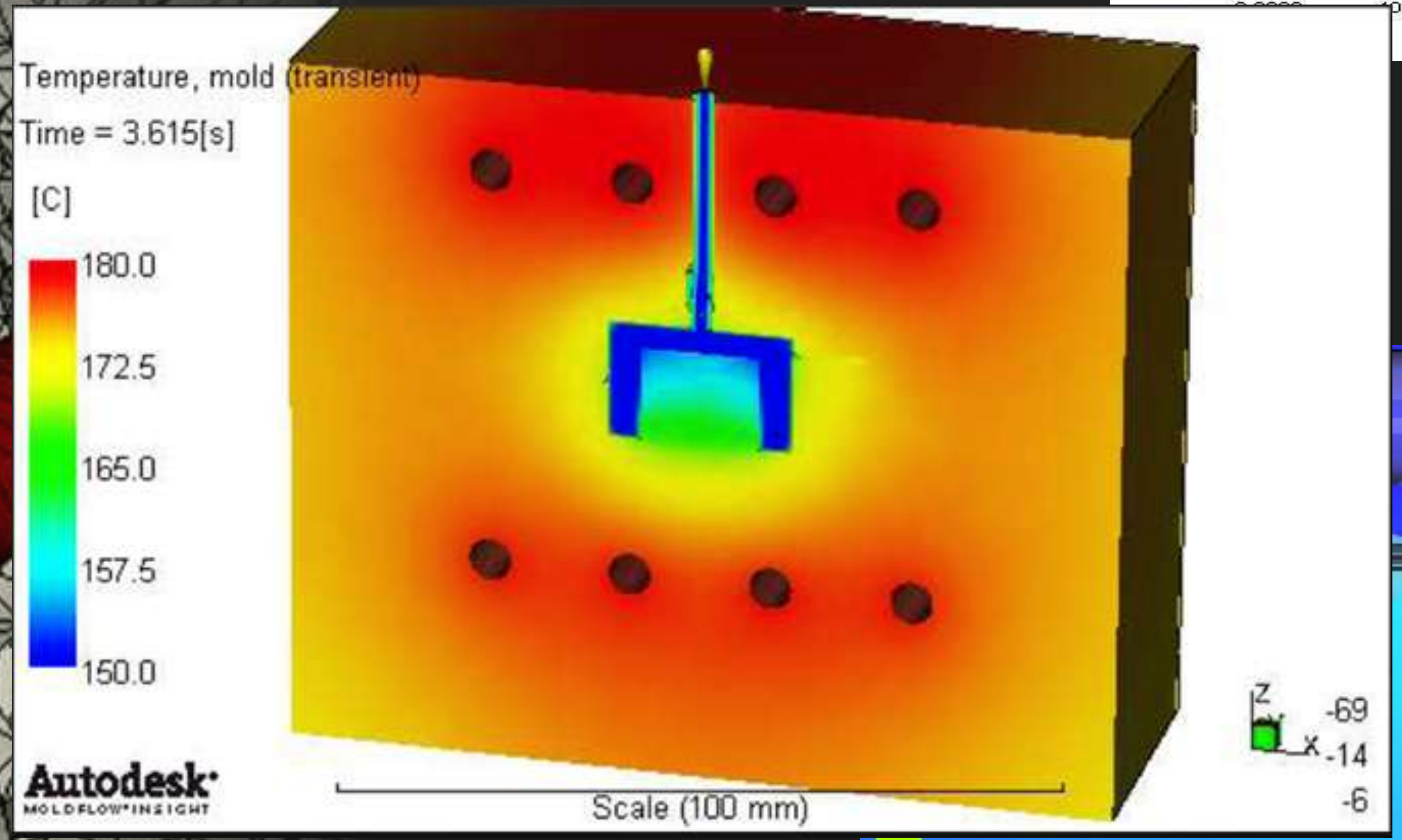


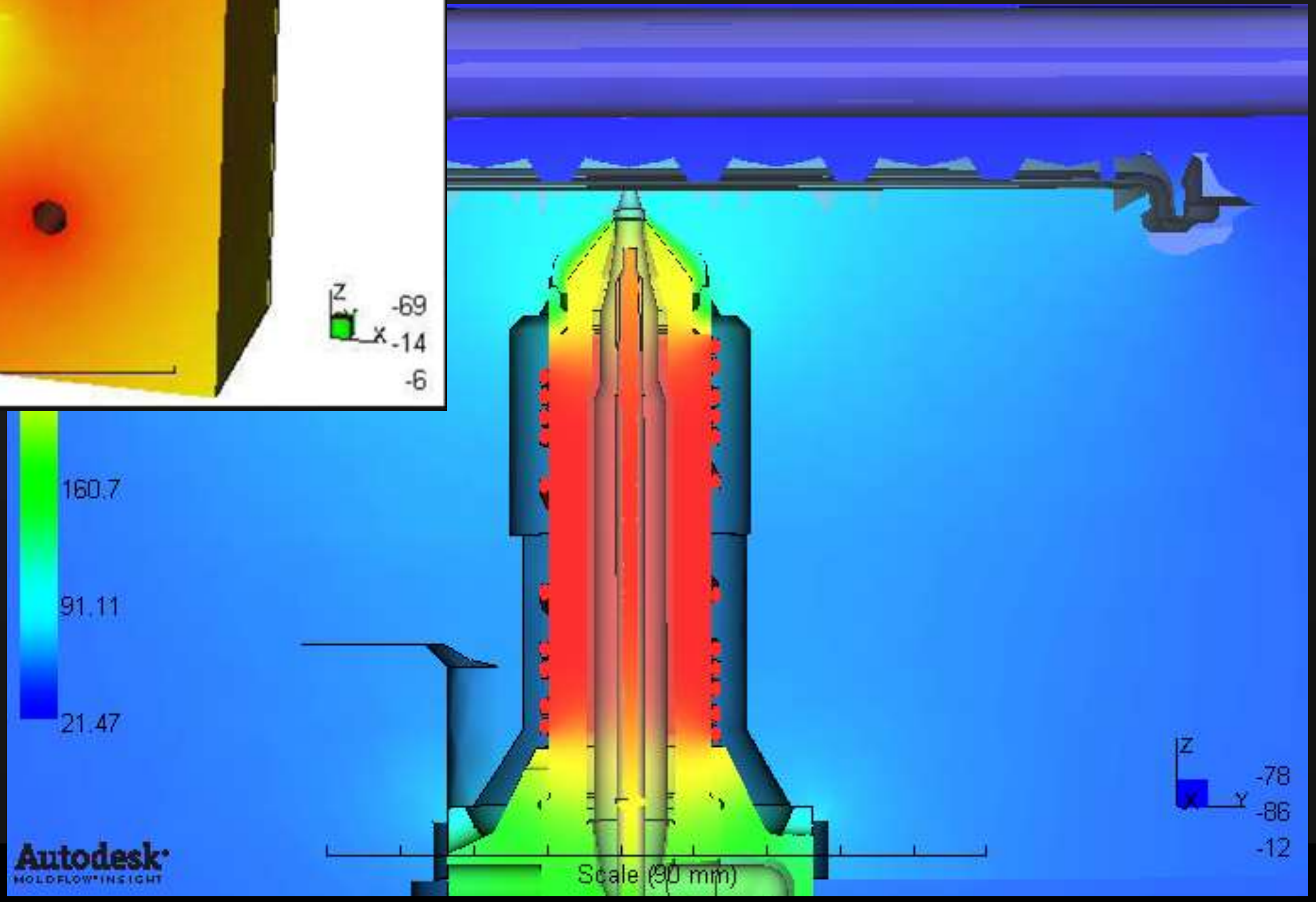
Mold Thermal Analysis - Cool (FEM)

- With Transient Cool Option
- Uses tetrahedral elements to represent the mold



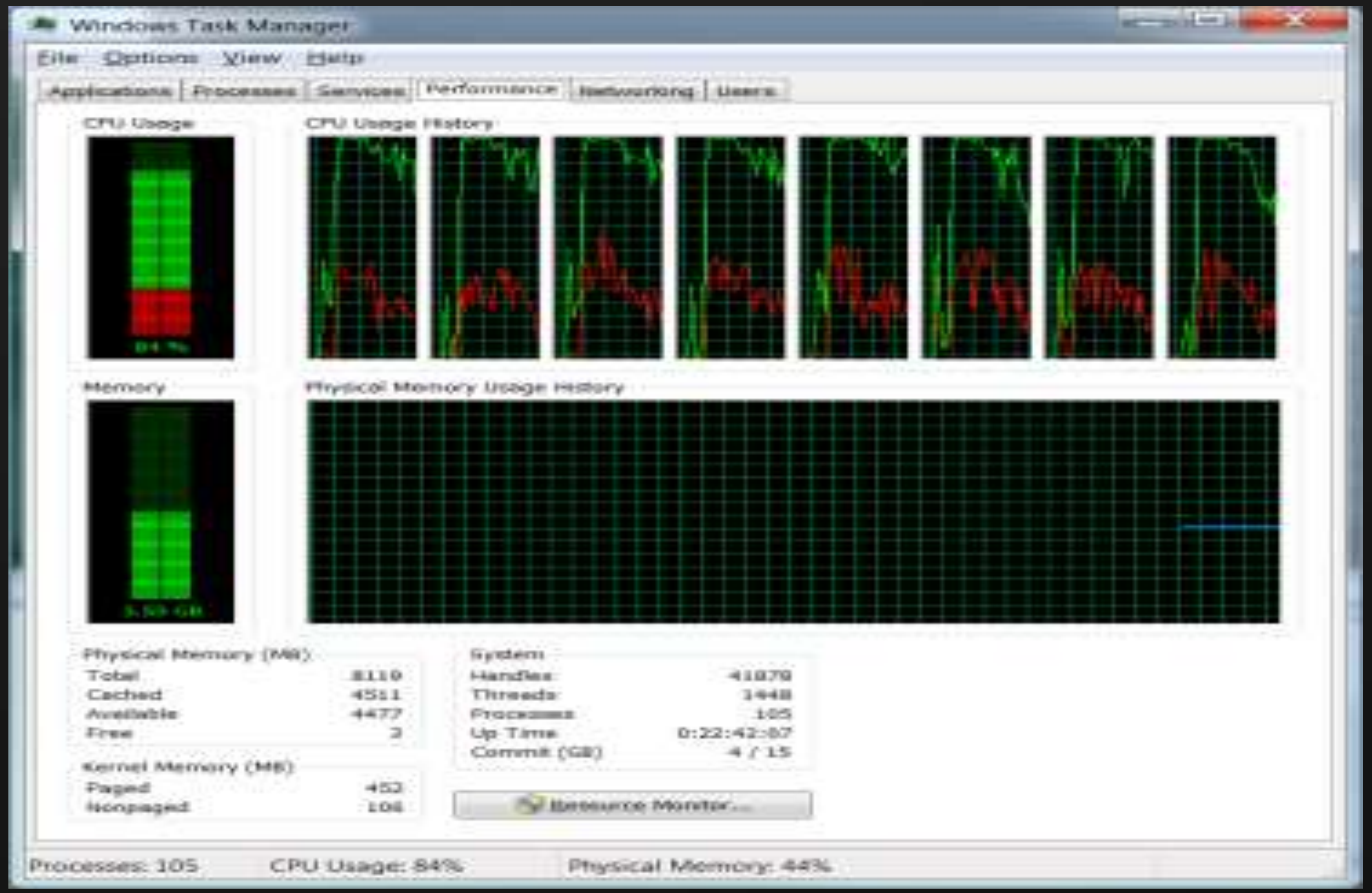






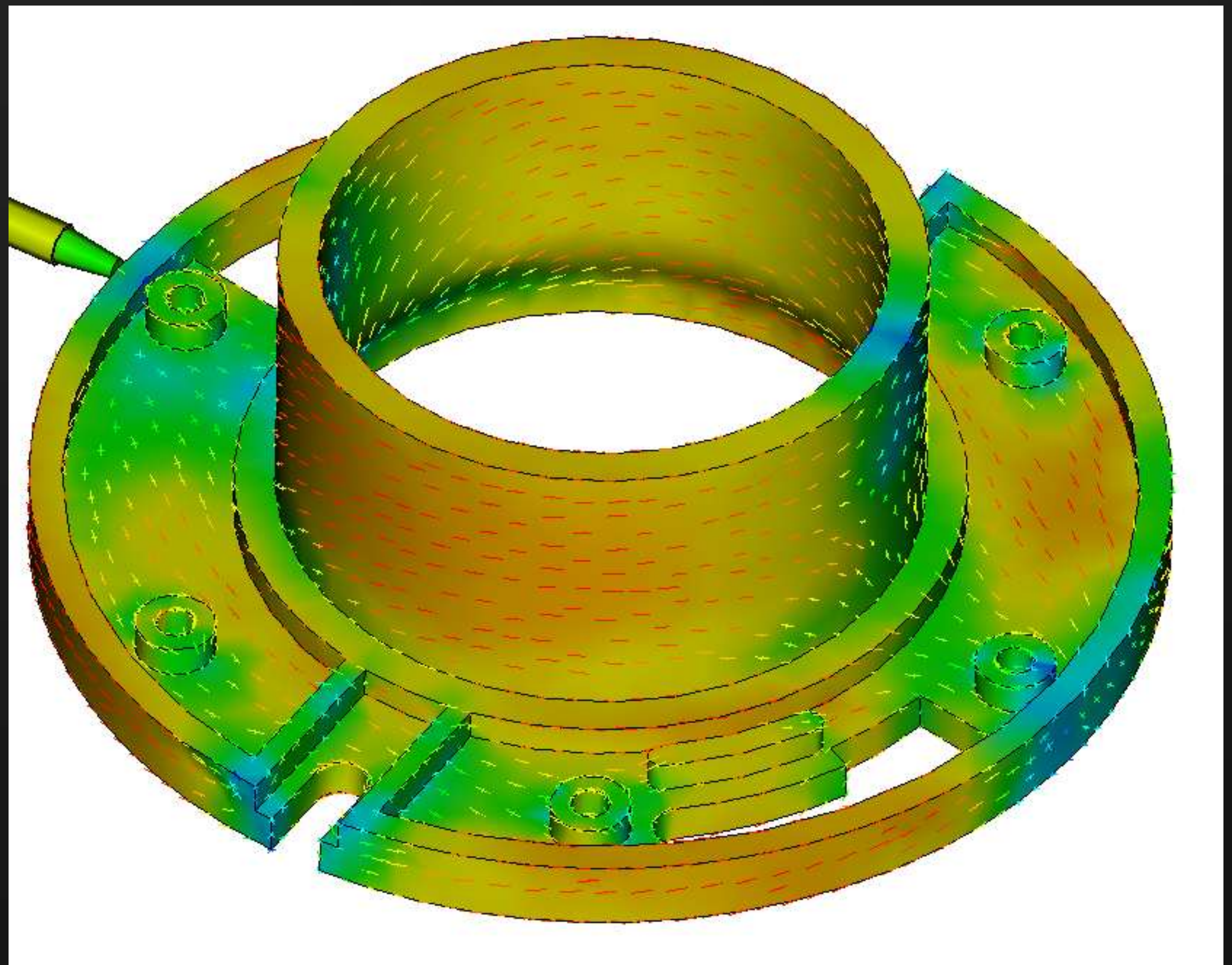
Speed Improvements in Moldflow 2013

- Midplane & Dual-Domain Flow now use multiple cores
  - Average x2 speed-up
- 3D Parallelization now on for all processes
- Automatically optimize number of cores (Insight or Adviser)
  - Specify number of cores (Insight)
- Improved 3D Parallelization for Linux
- GPU now used by: 3D Flow, 3D Warp & Cool (FEM)
  - AMD and Nvidia cards supported
  - Must be Double Precision cards
- UI Speed Improvements



Other Improvements in Moldflow 2013

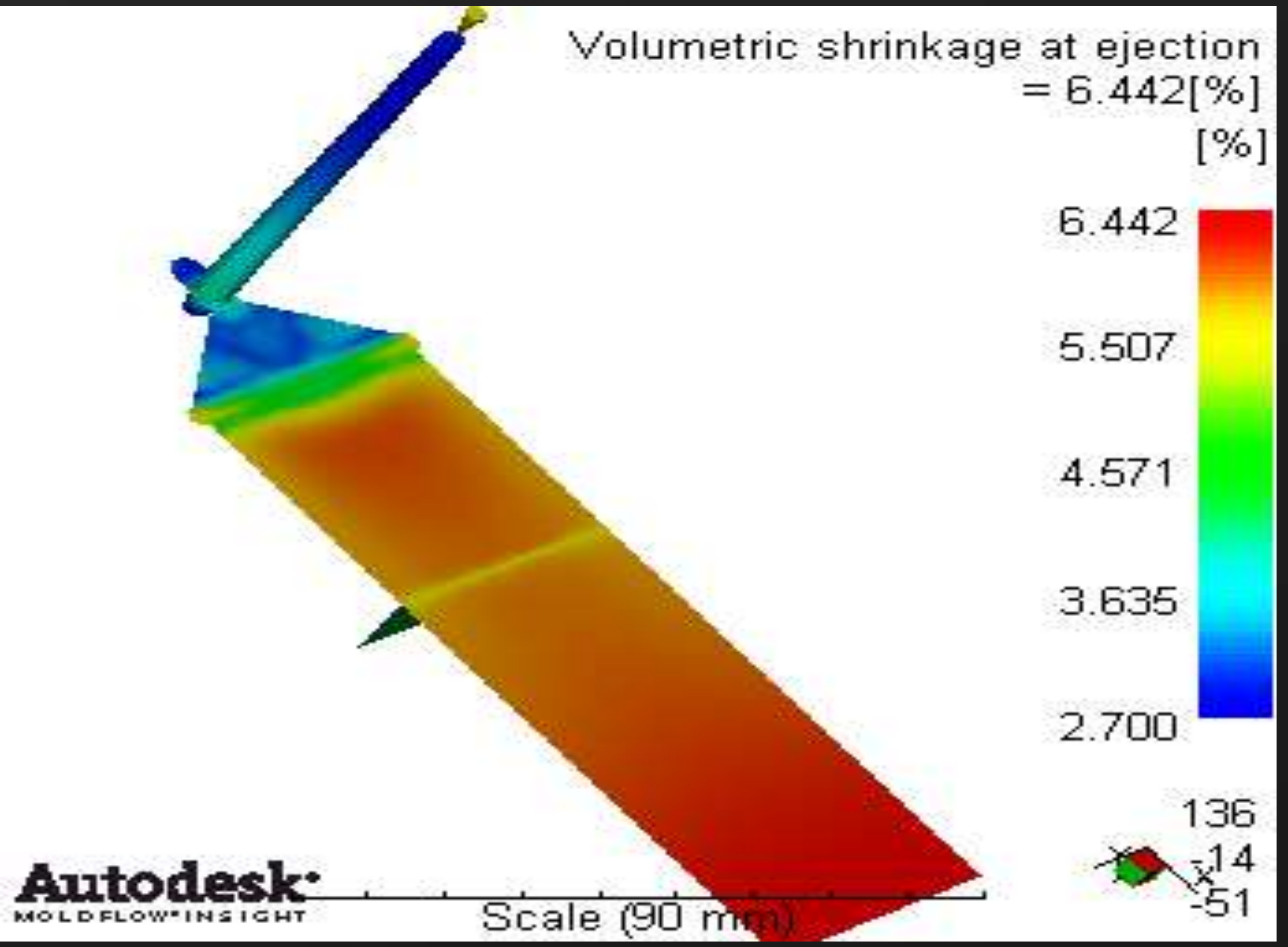
- Improved Temperature Convection accuracy for 3D Flow
  - This improves filling symmetry
- Fiber Orientation prediction for 3D Reactive Molding processes
- More realistic Automatic Injection Time for 3D
  - Typically faster injection than 2012
- 3D Node Layer Number Result Plot
  - Non-default Result

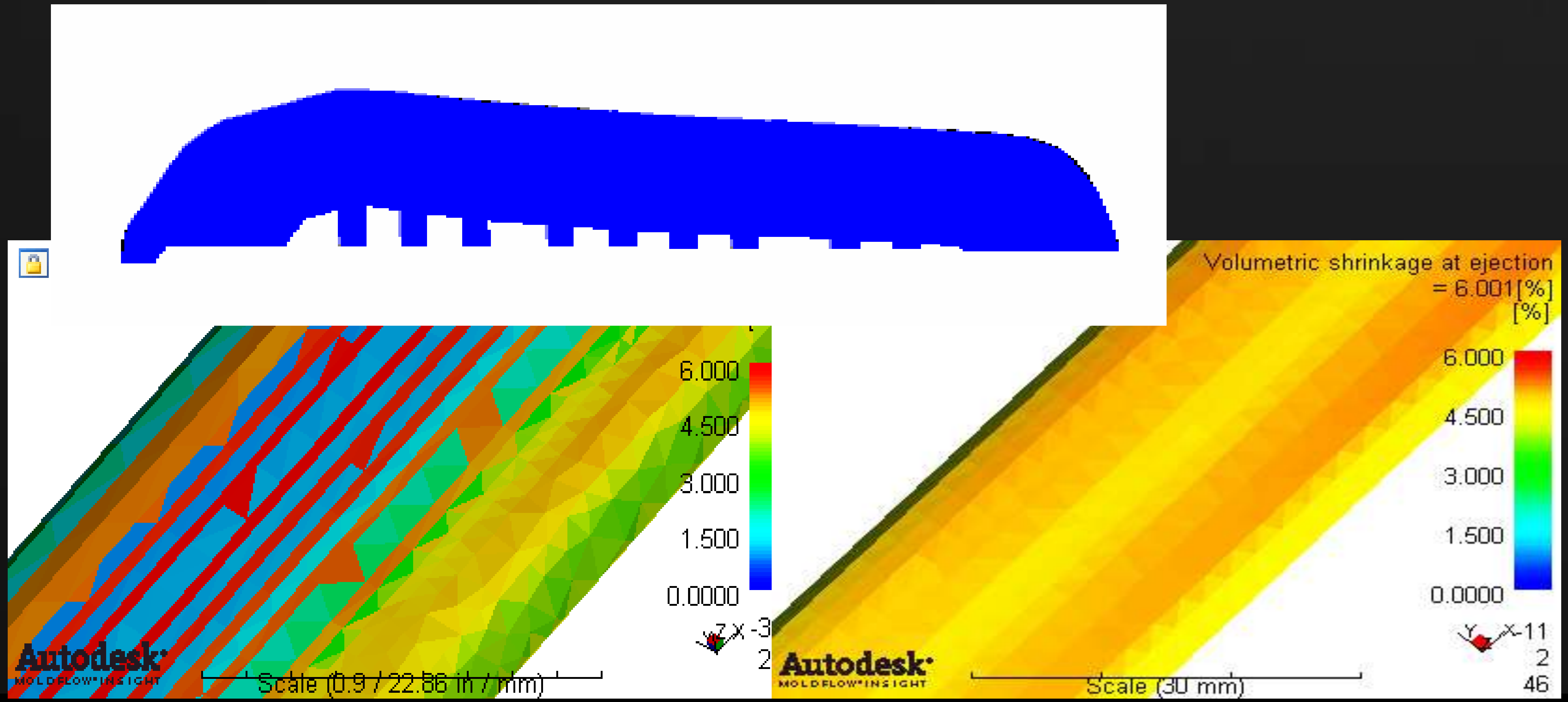


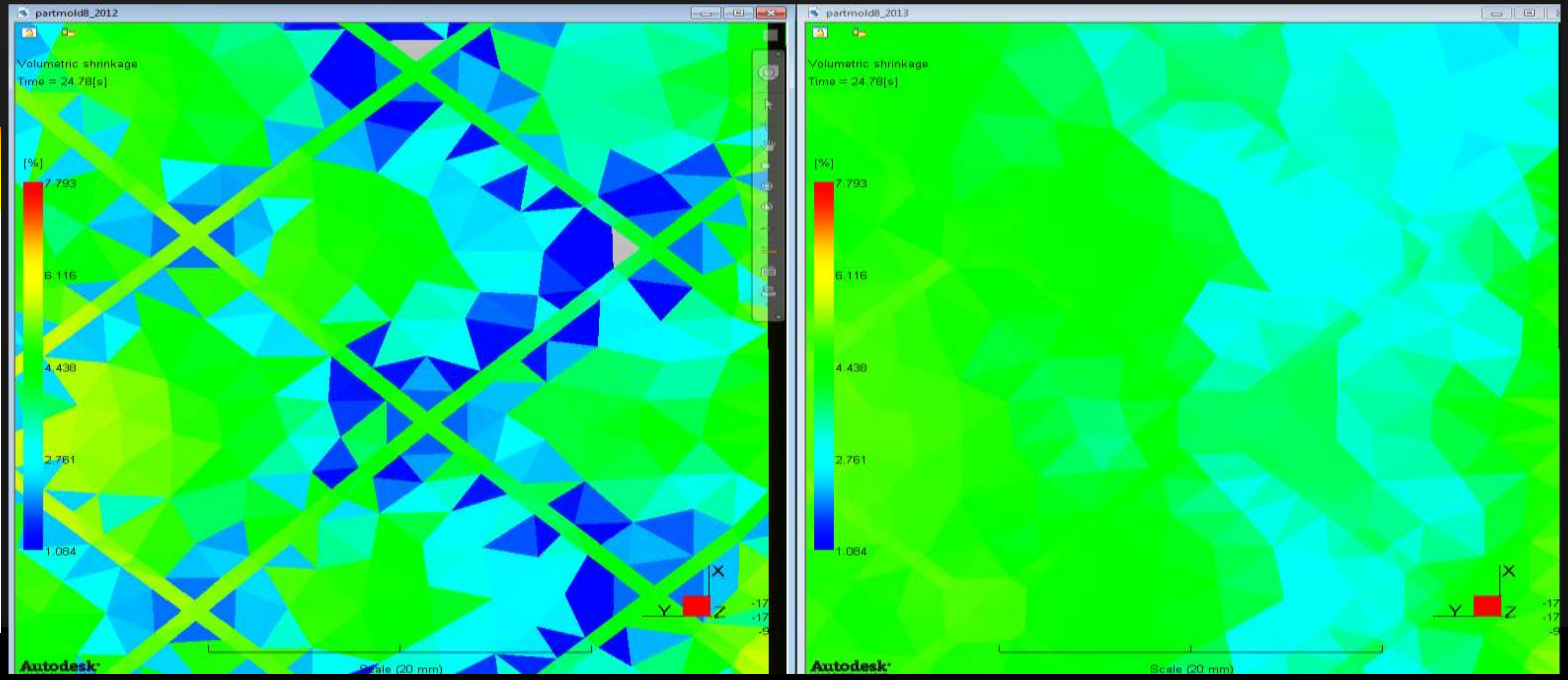
3D Reactive Molding
Fiber orientation overlaid with Mechanical properties

Improve Volumetric shrinkage at thin ribs

- Previous thickness averaging error at thin ribs now fixed
  - Caused low shrinkage under or near rib
- Now fixed for Dual-Domain (in 2013 version)
  - Was Fixed for Midplane in 2012
  - Also influenced residual stress and sink index







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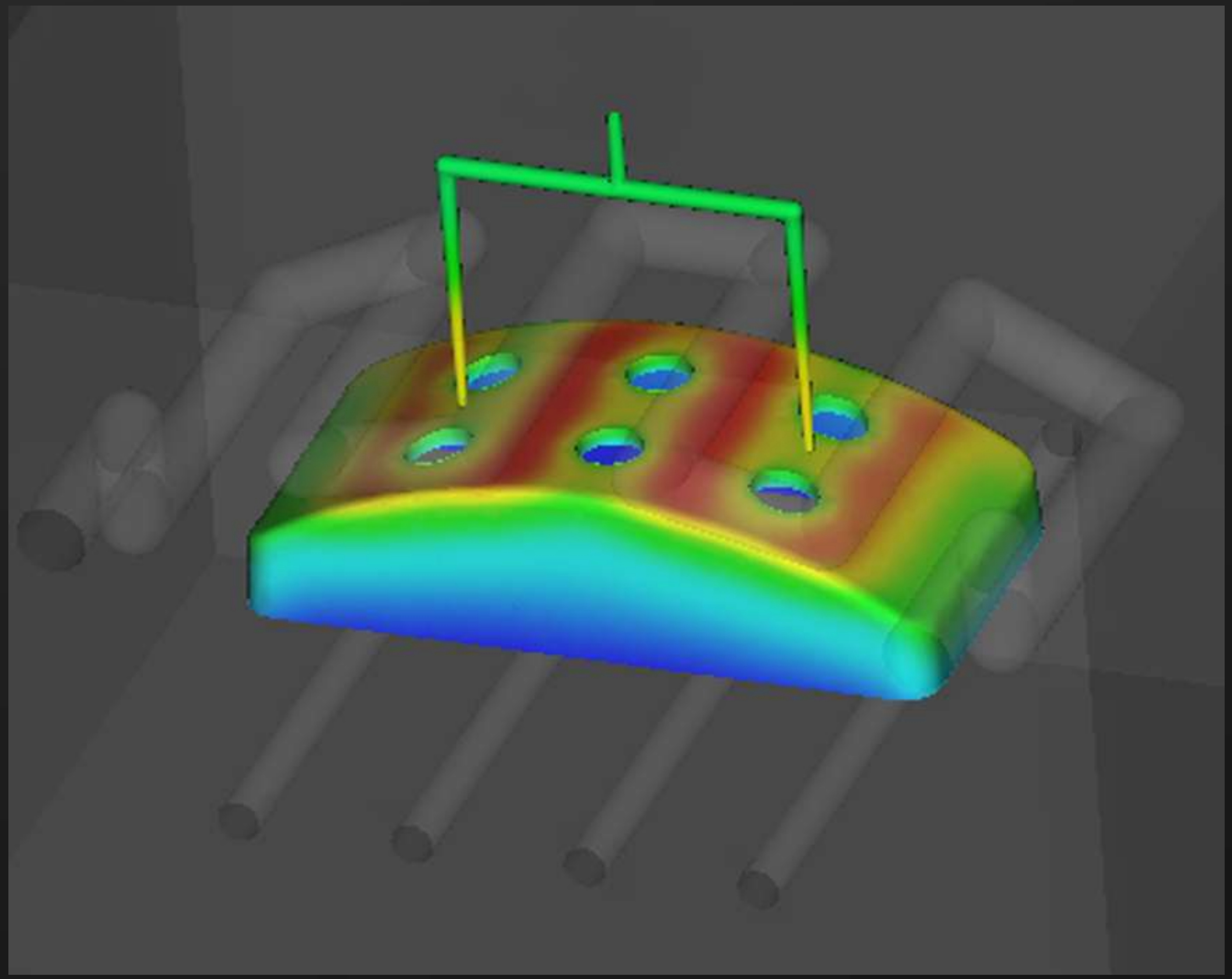
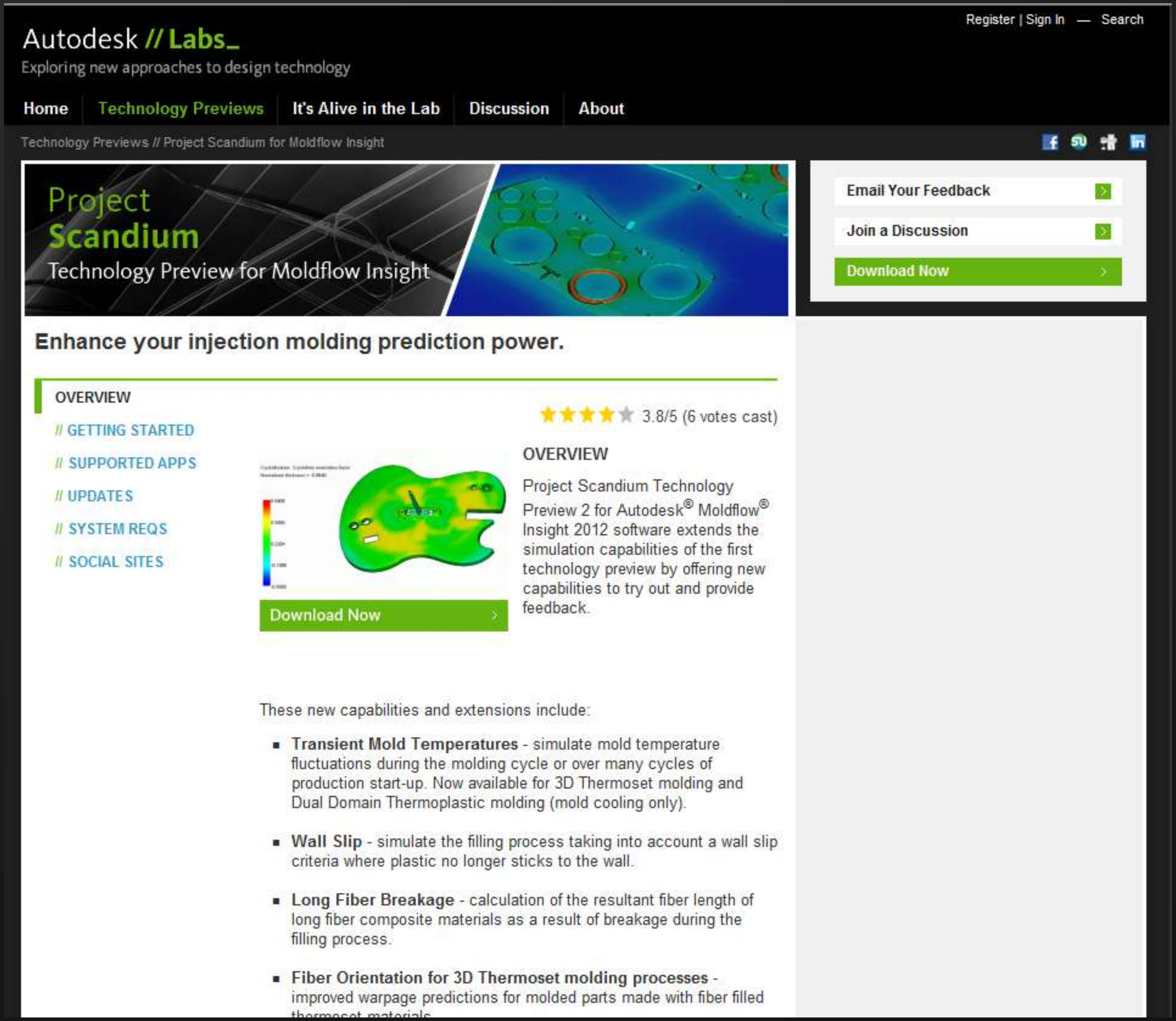


Scandium Technology Preview

- Free download
  - labs.autodesk.com
- English, Windows only
- Requires current Autodesk Moldflow Insight license
- Provides extended functionality and new prototype features for testing and user feedback

No guarantee that these features will survive or graduate to the official release



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The Company assumes no obligation to update these forward-looking statements to reflect events that occur or circumstances that exist or change after the date on which they were made.

Viscoelastic Warpage

Stresses arise from mechanical and thermal strains according to the a viscoelastic stiffness tensor

$$\sigma_{ij} = \int_0^t c_{ijkl}(\xi(t) - \xi(t'))\left(\frac{\partial \varepsilon_{kl}}{\partial t'} - \alpha_{kl}\frac{\partial T}{\partial t'}\right) \mathrm{d}t'$$

Stiffness tensor

Mechanical Strains

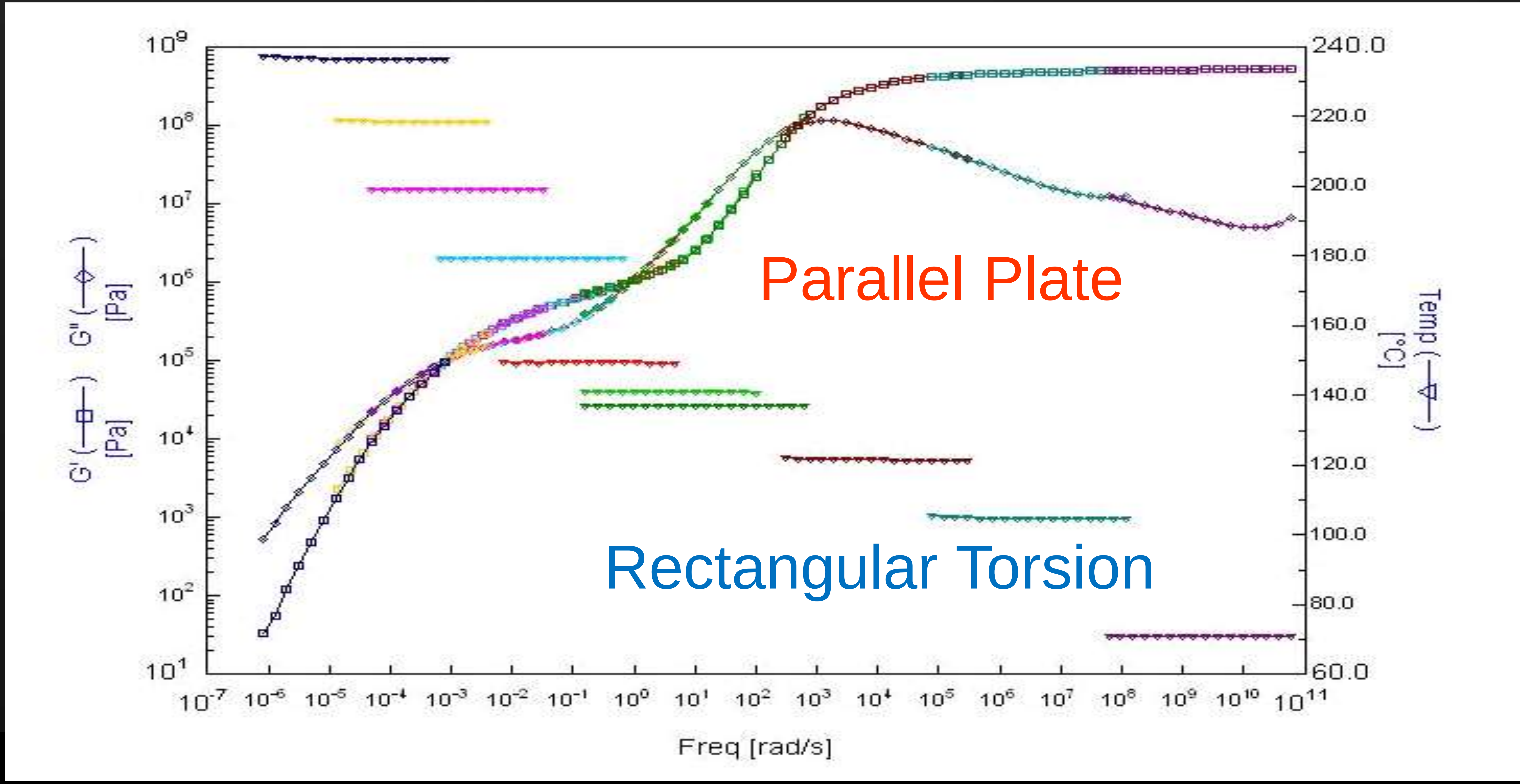
Thermal Strains

The stiffness tensor is relaxed according to time and temperature

$$F(t) = \sum_{k=1}^{N} g_k \exp\left(-\frac{t}{\lambda_k}\right)$$

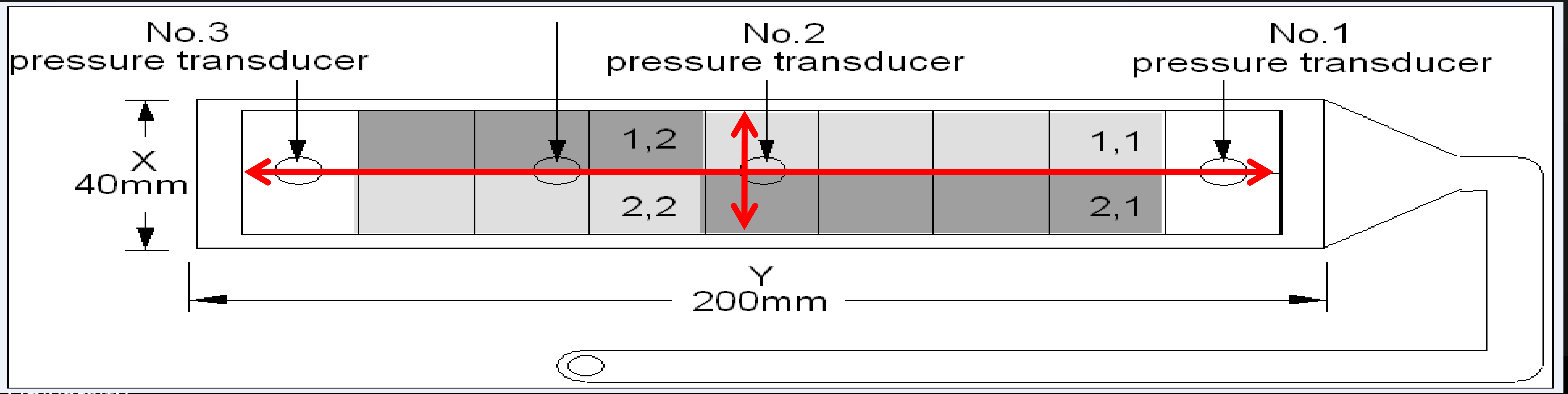
Dynamic Modulus Time-Temperature Superposed

- Visco-elastic data used for Birefringence and Viscoelastic Residual Stress Calculations
- Measured on parallel-plate rheometer



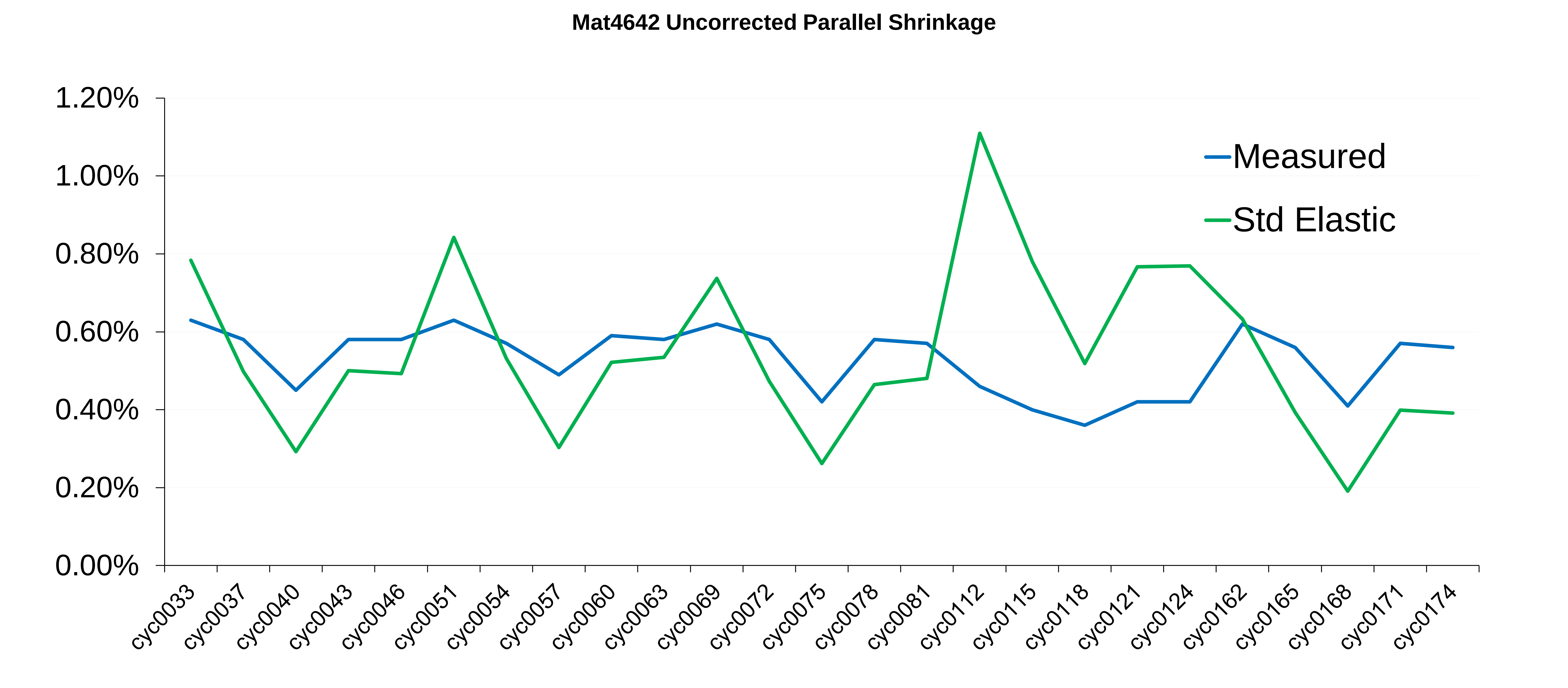
Viscoelastic Warpage for MP and DD

- This viscoelastic model has been implemented in Midplane and Dual-Domain in Scandium Technology Preview
- Requires viscoelastic material data to be measured
- Viscoelastic simulation gives more realistic process sensitivity to packing pressure and packing/cooling time variation
- Validate using Shrinkage molding data



Linear Shrinkage on Tagdie Moldings

Standard (elastic) model shows too much process sensitivity

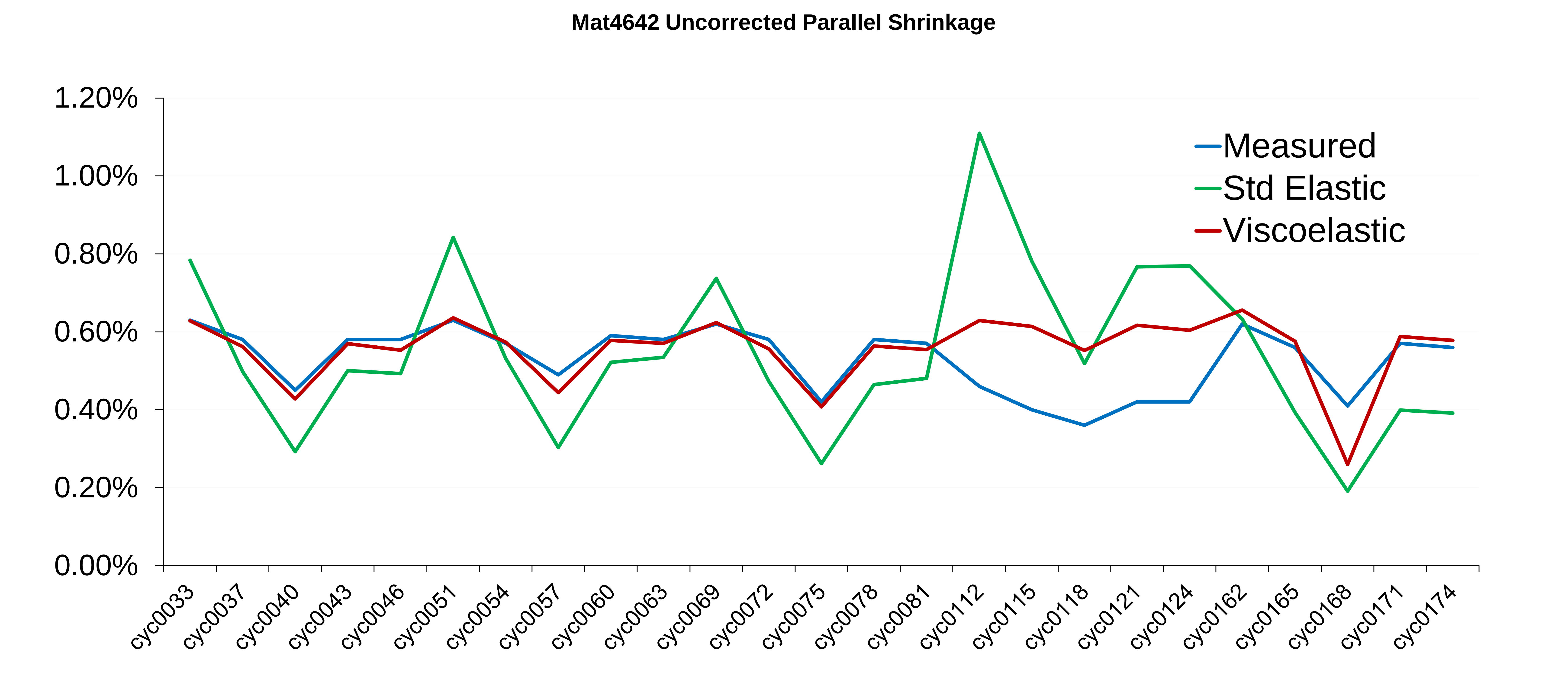


Uncorrected (no CRIMS) shrinkage in the flow direction for an Amorphous non-fiber material. (HIPS)

Viscoelastic Warpage on Tagdie Moldings

Viscoelastic model shows much better process sensitivity

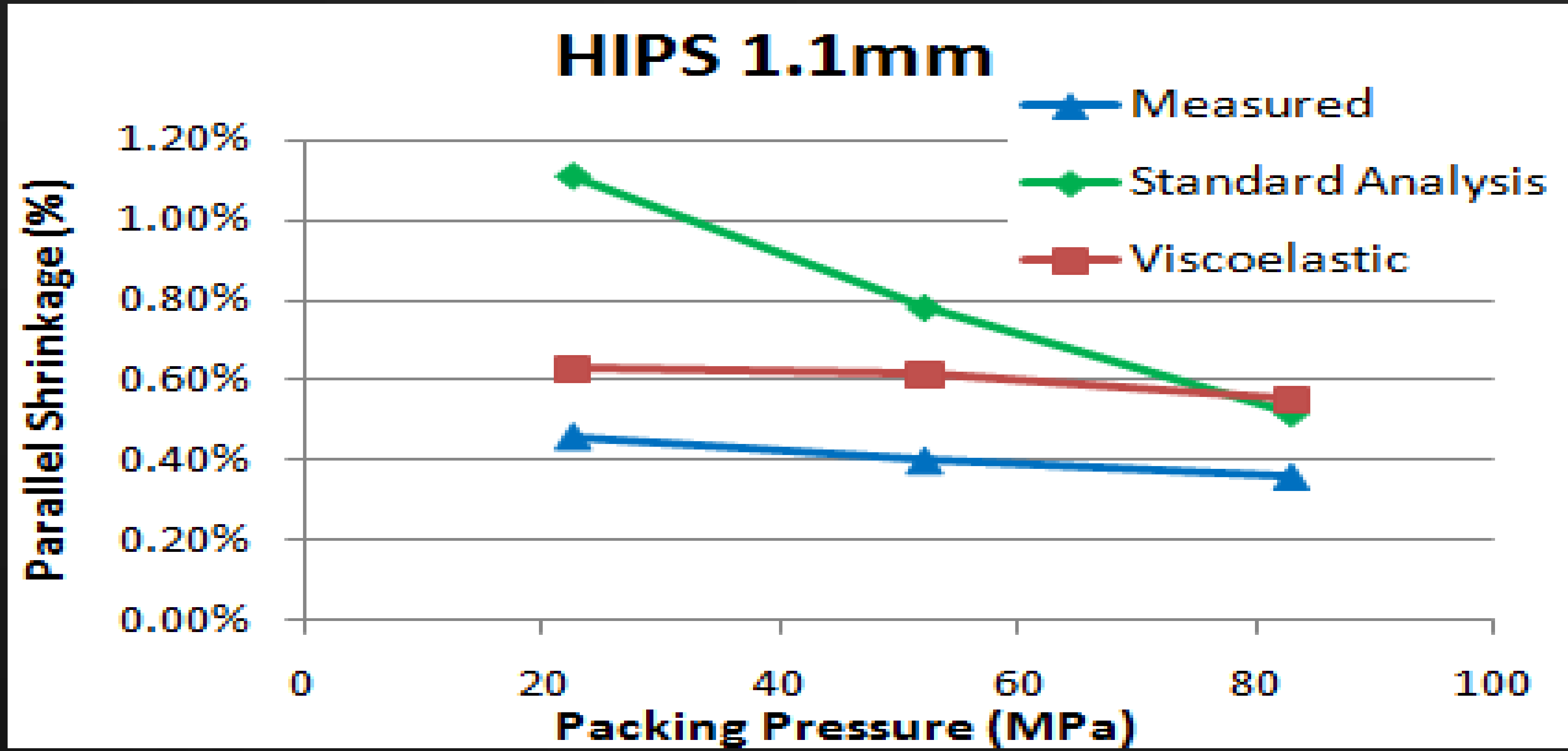
Perpendicular Shrinkage shows a similar improvement trend.

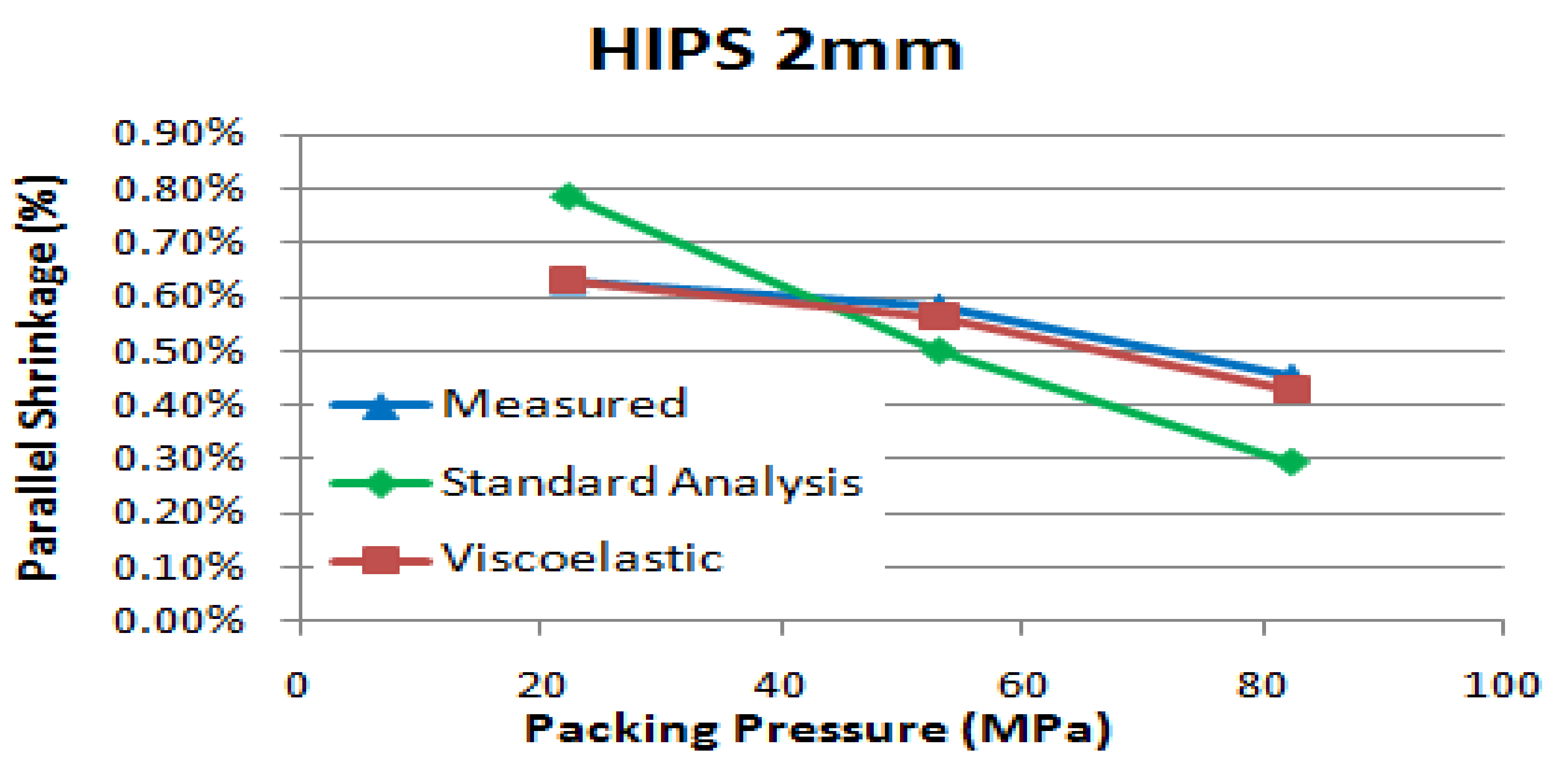


Uncorrected (no CRIMS) shrinkage in the flow direction for an Amorphous non-fiber material. (HIPS)

Viscoelastic Warpage on Tagdie Moldings

Examine trend with respect to Packing Pressure variation





Uncorrected (no CRIMS) shrinkage in the flow direction for an Amorphous non-fiber material. (HIPS)
Perpendicular Shrinkage shows a similar trend.

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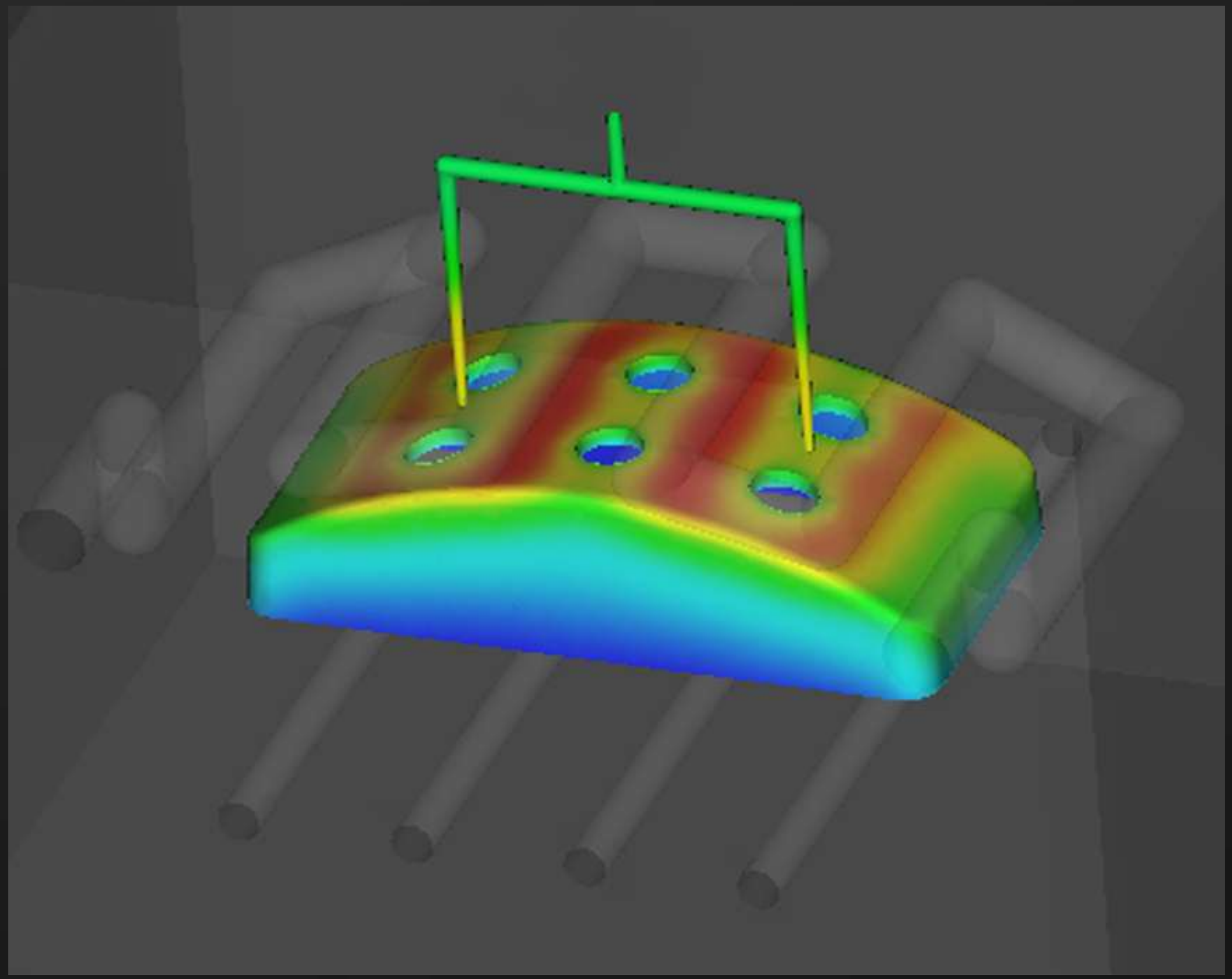
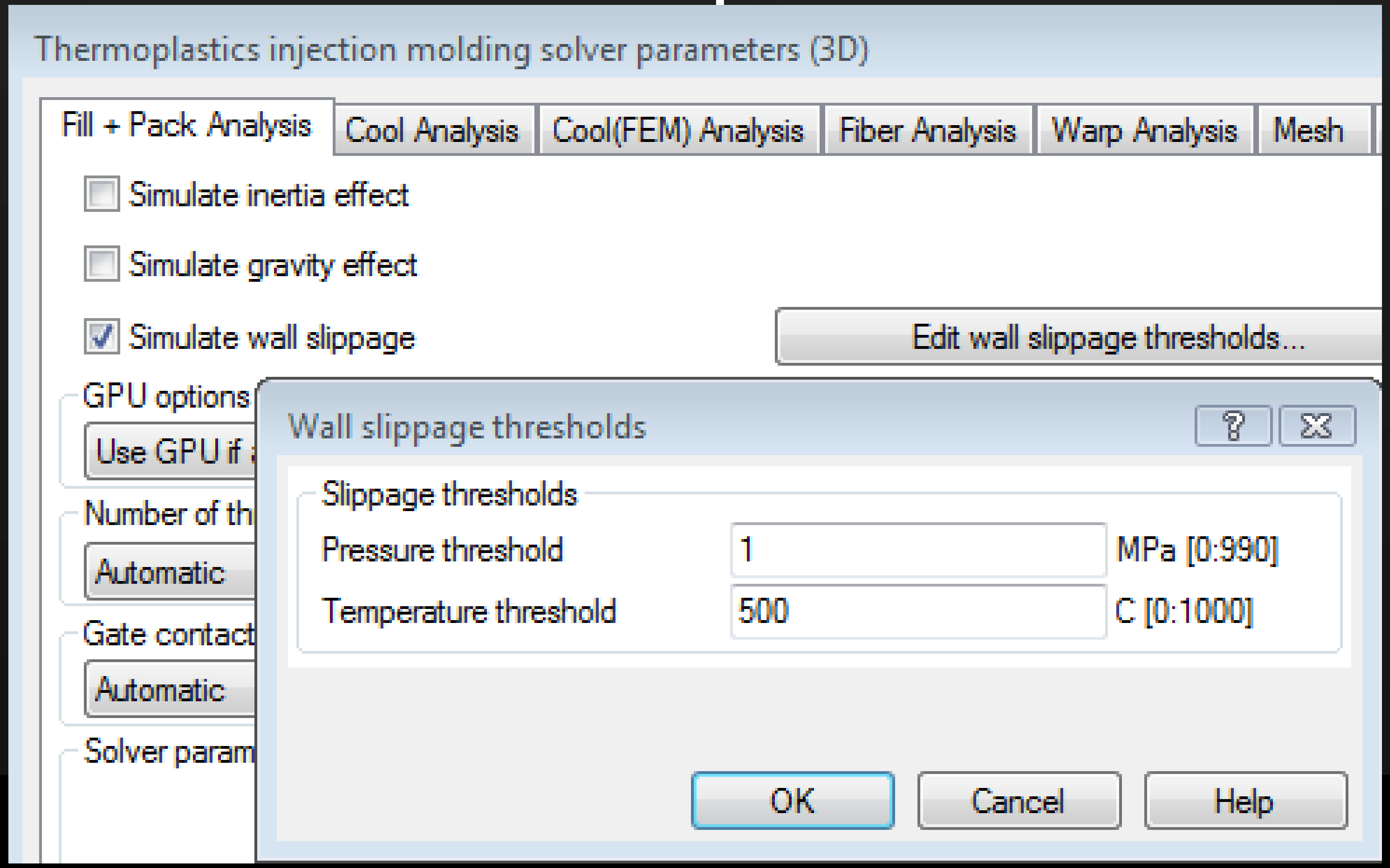
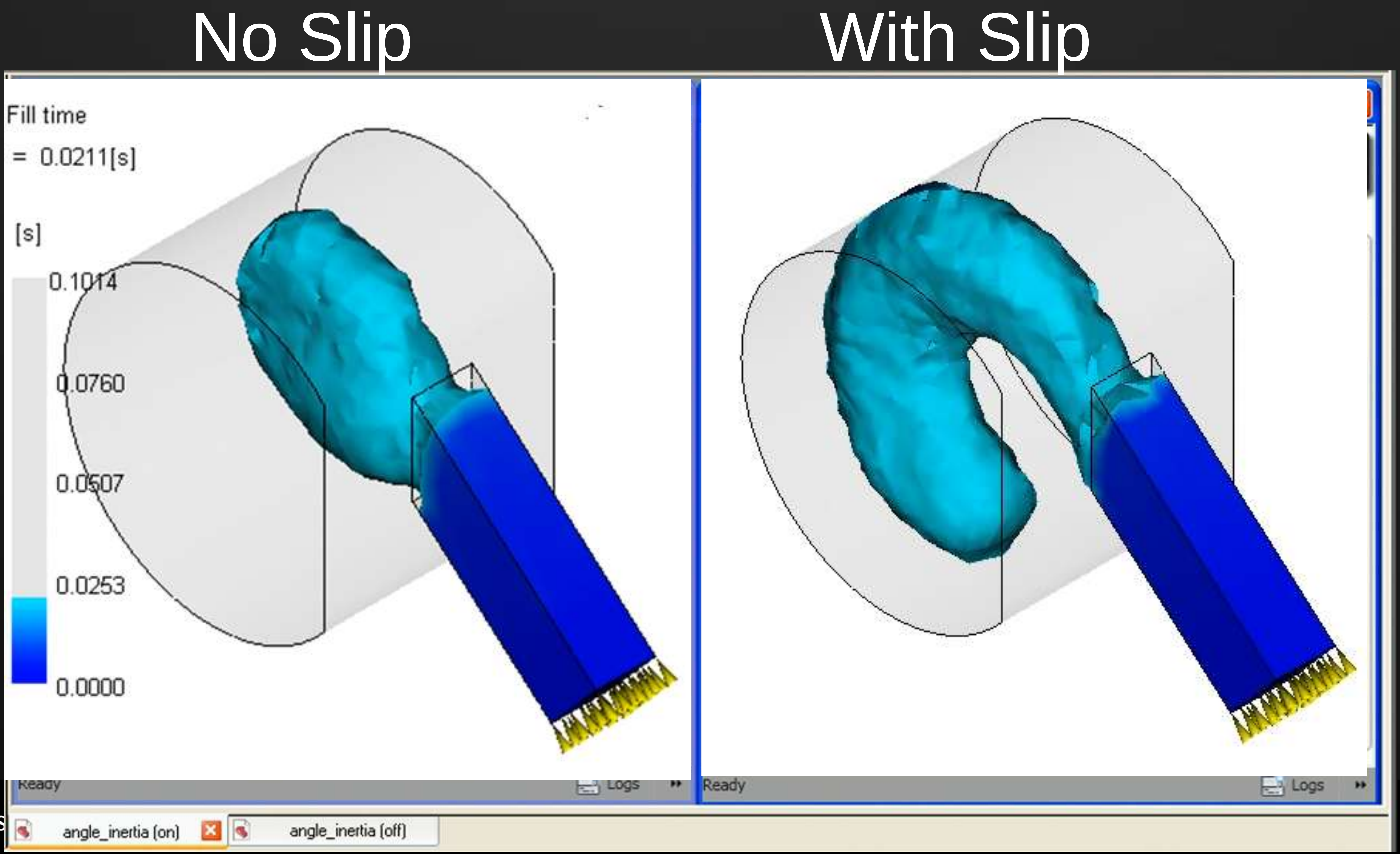


Wall-Slip for 3D Flow

- Summary: Simulate wall slip to allow for more accurate prediction of jetting.
- Available in Scandium Technology Preview 2
- Allows free slip at wall if:
  - Local Pressure is below Pressure Threshold,   or
  - Local Wall Temperature is above Temperature Threshold



Wall-Slip for 3D Flow



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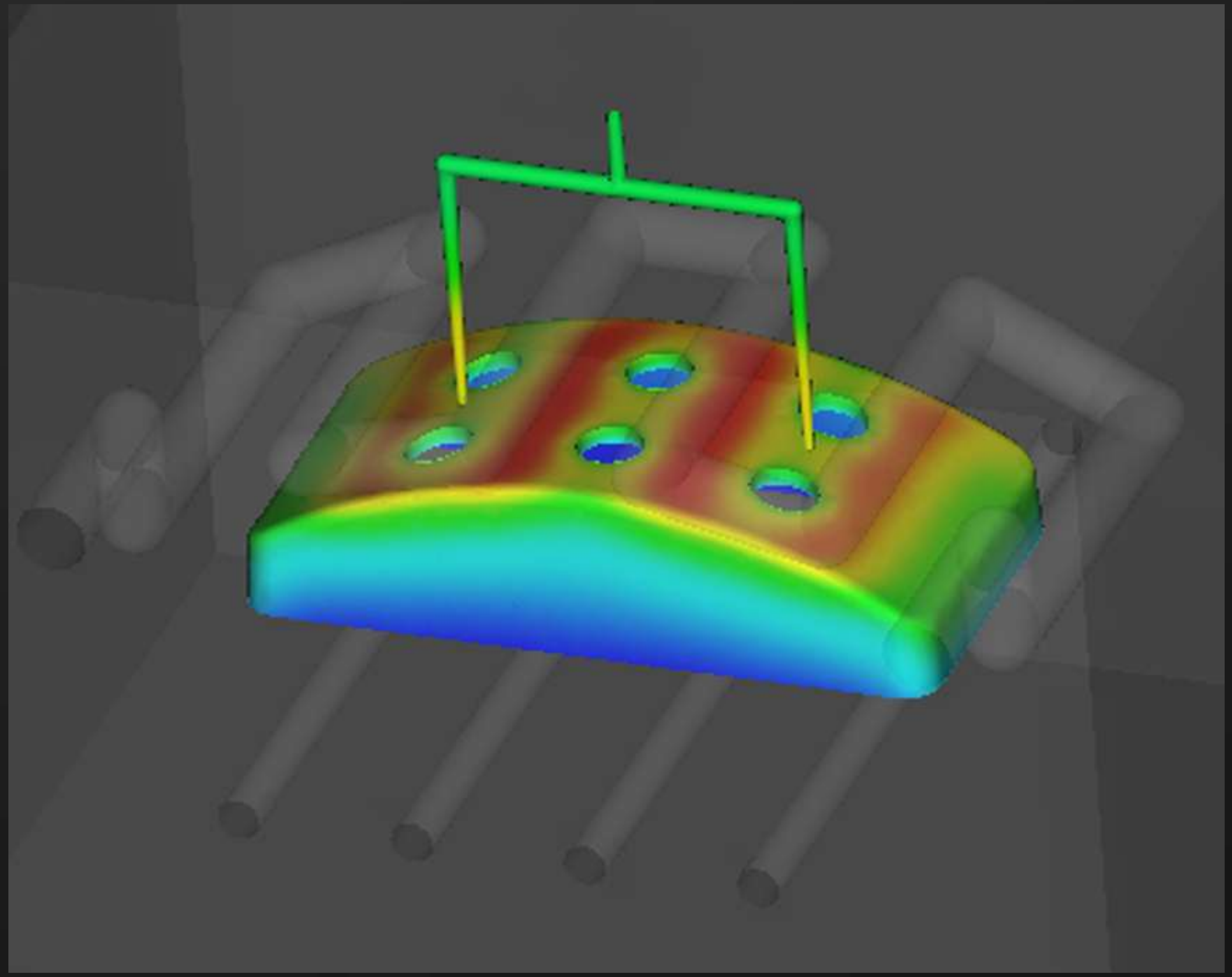
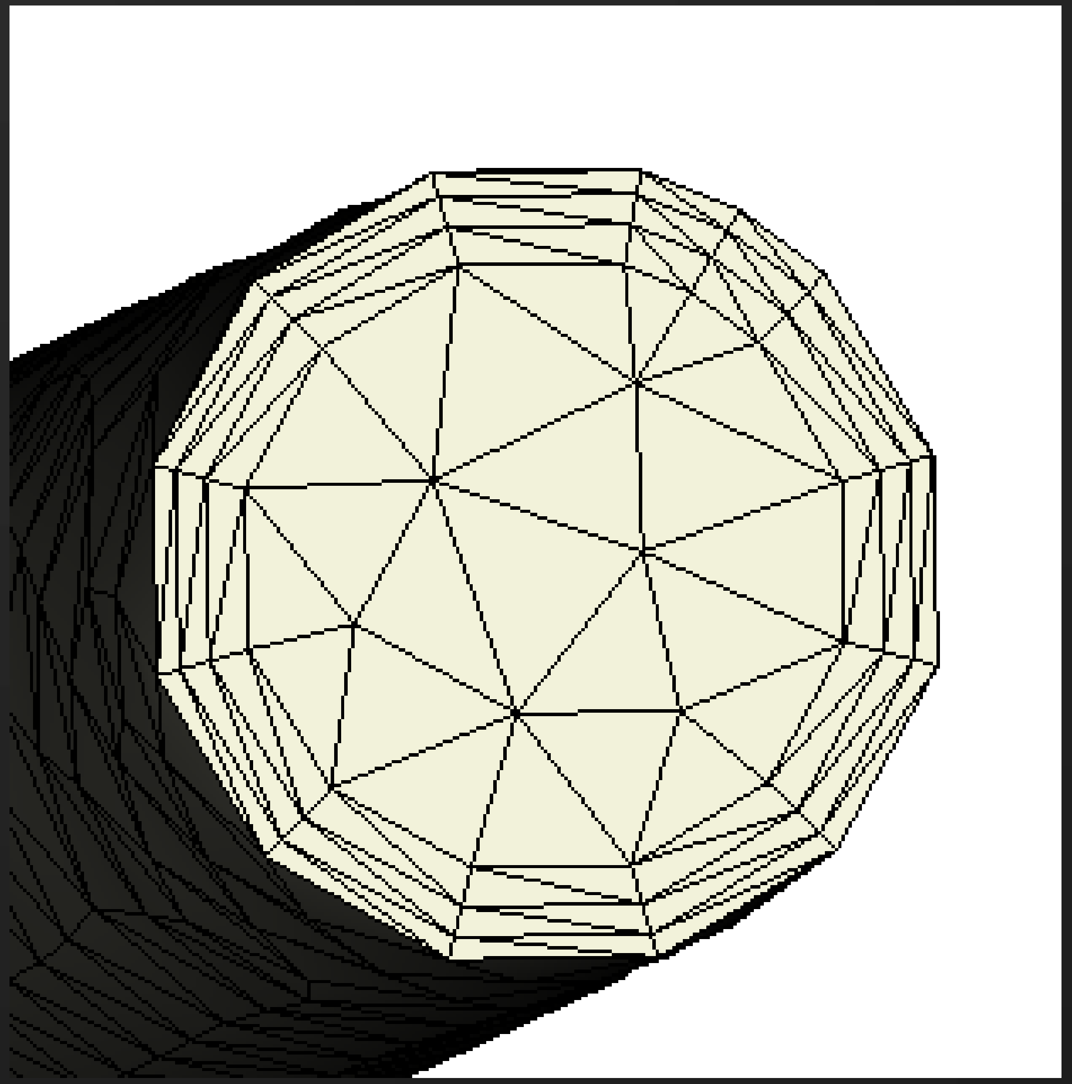
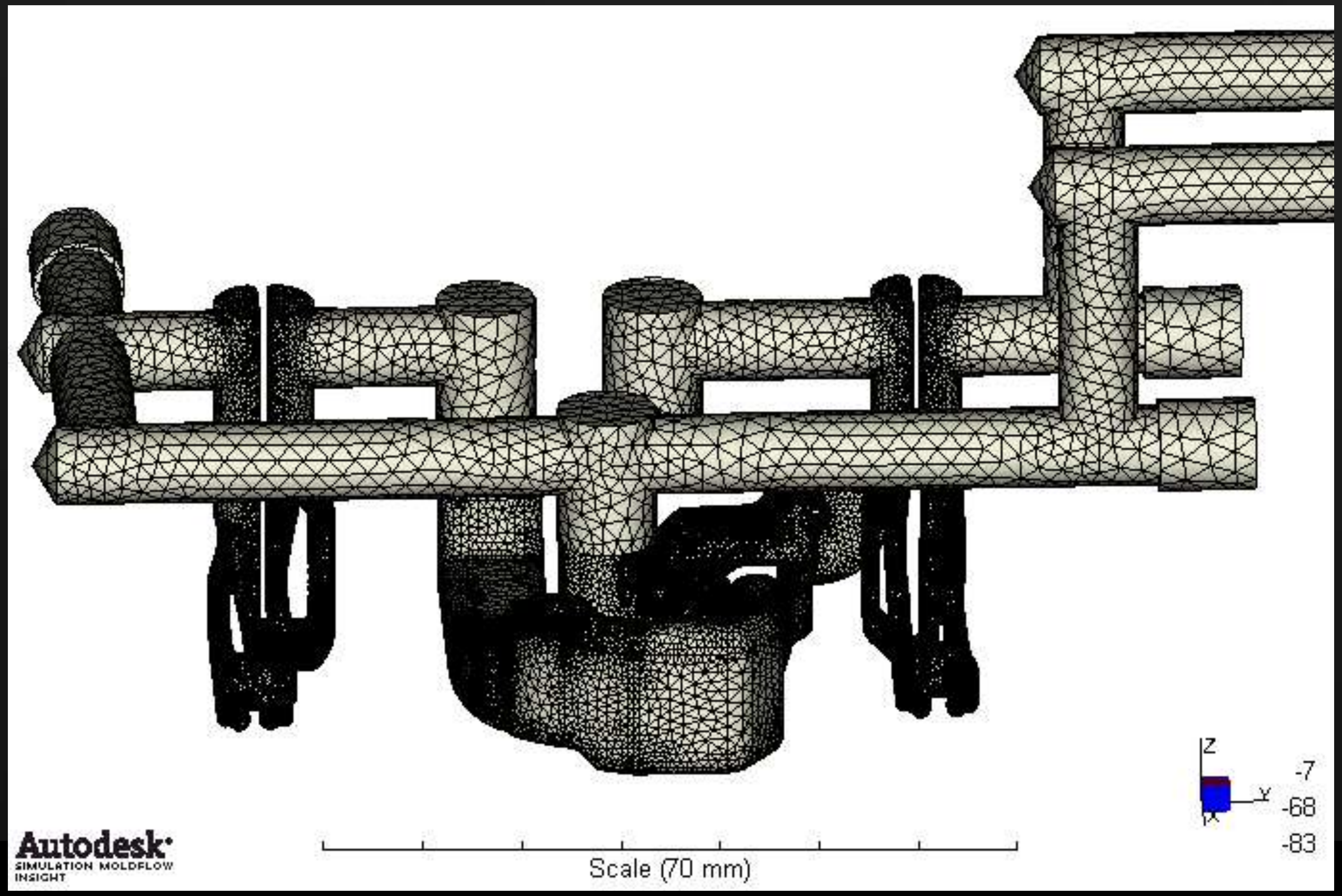
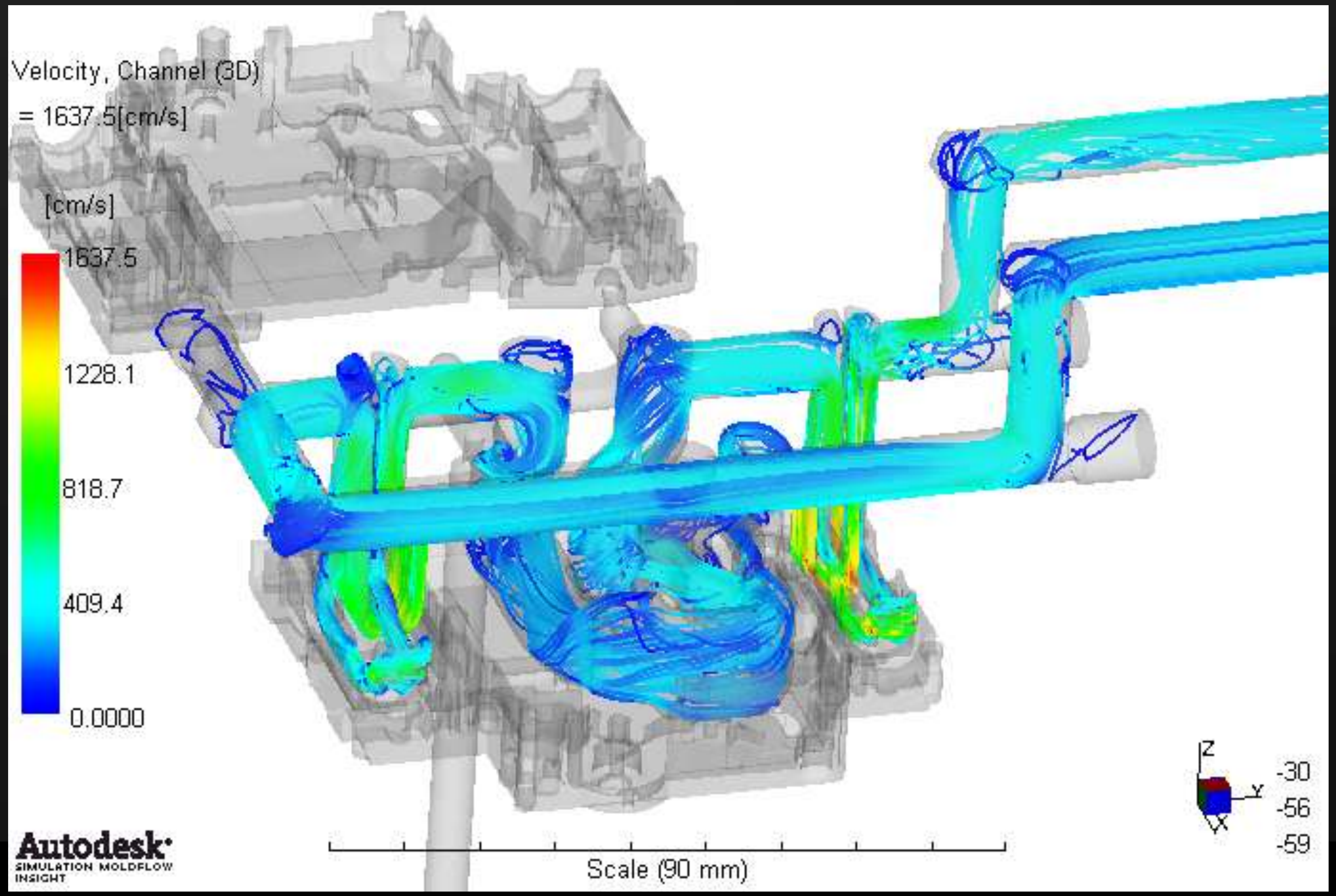


Use CFD for Coolant 3D meshing and Flow Solver

- Meshing is optimized for low viscosity water flow
  - Boundary layer meshing (Enhancement layer)
  - Mesh refinement in areas of high curvature

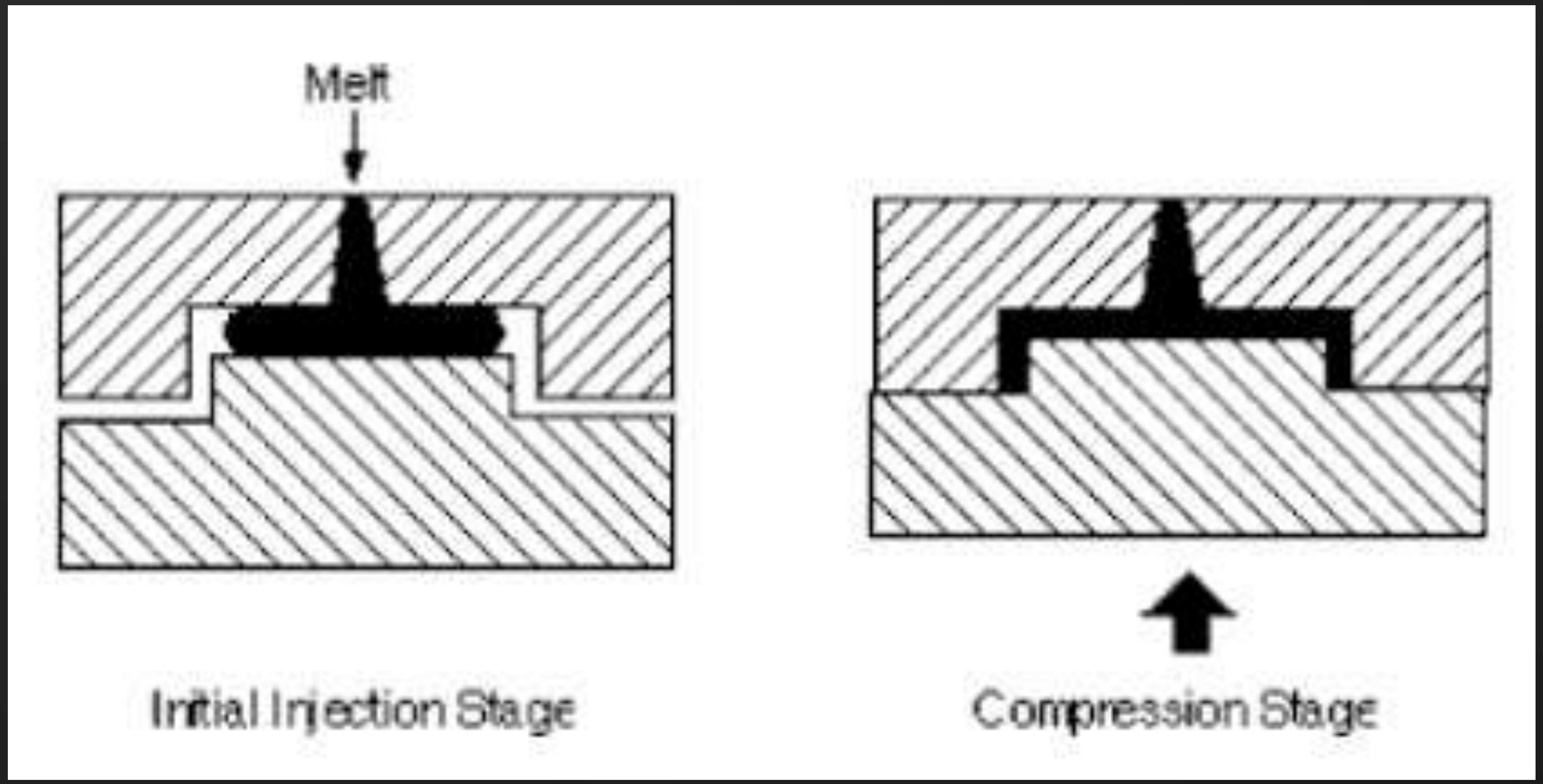


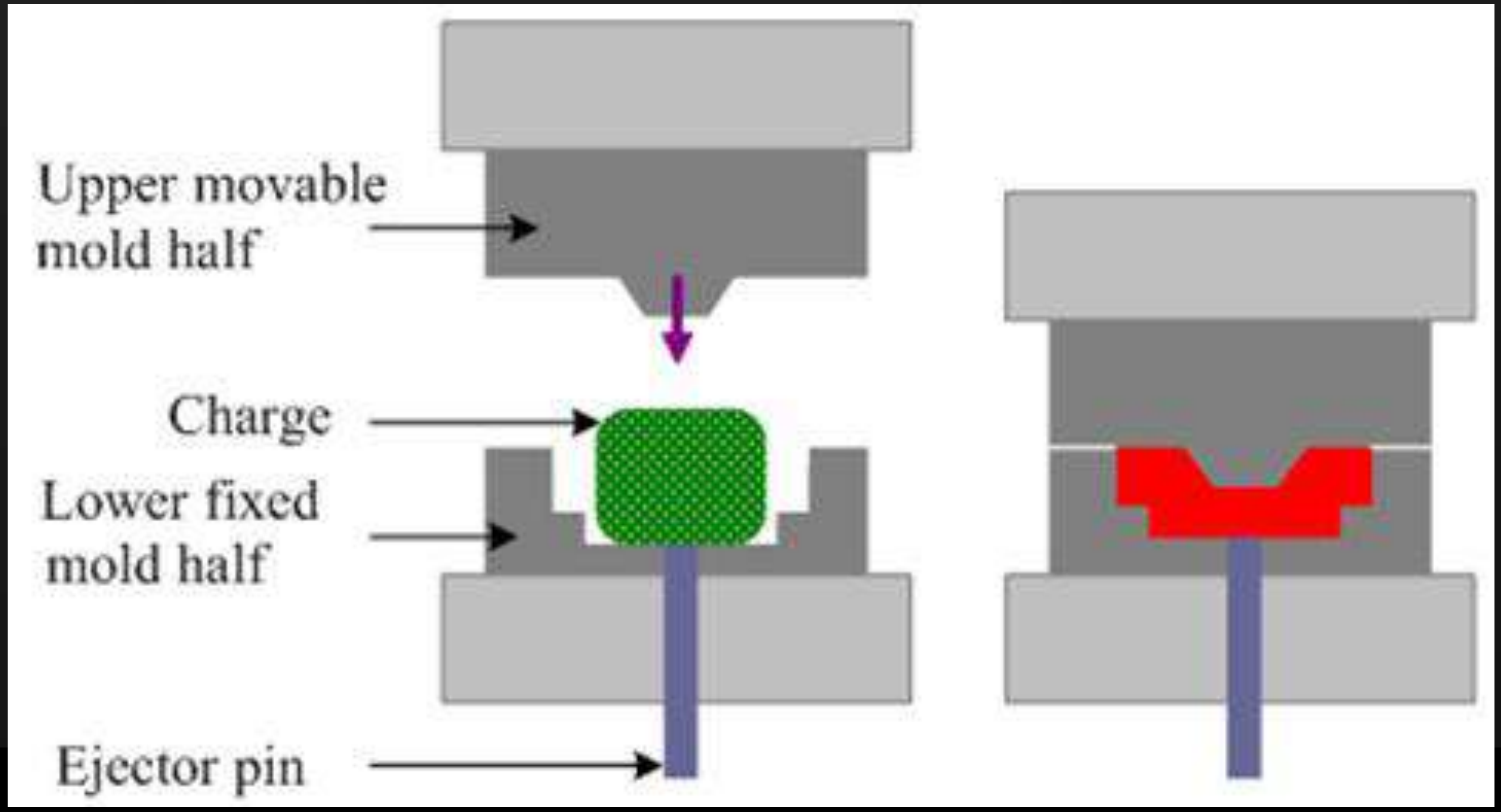




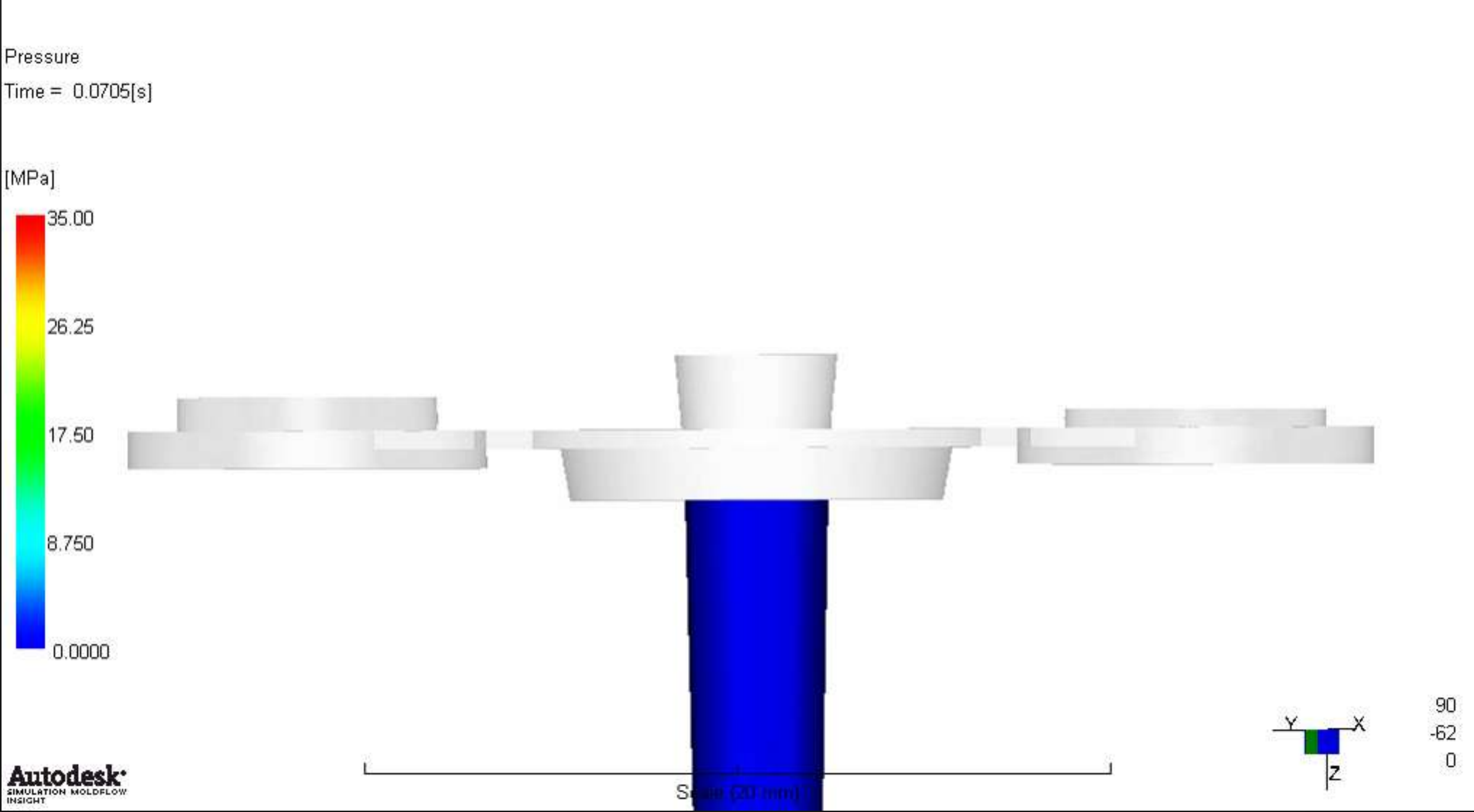
Compression Moulding (3D)

- 3D Mesh Simulation for:
  - Injection-compression molding
    - Cavity is partially filled by injection
  - Compression molding
    - Initial charge placed into open cavity
- Thermoplastics or Thermoset.



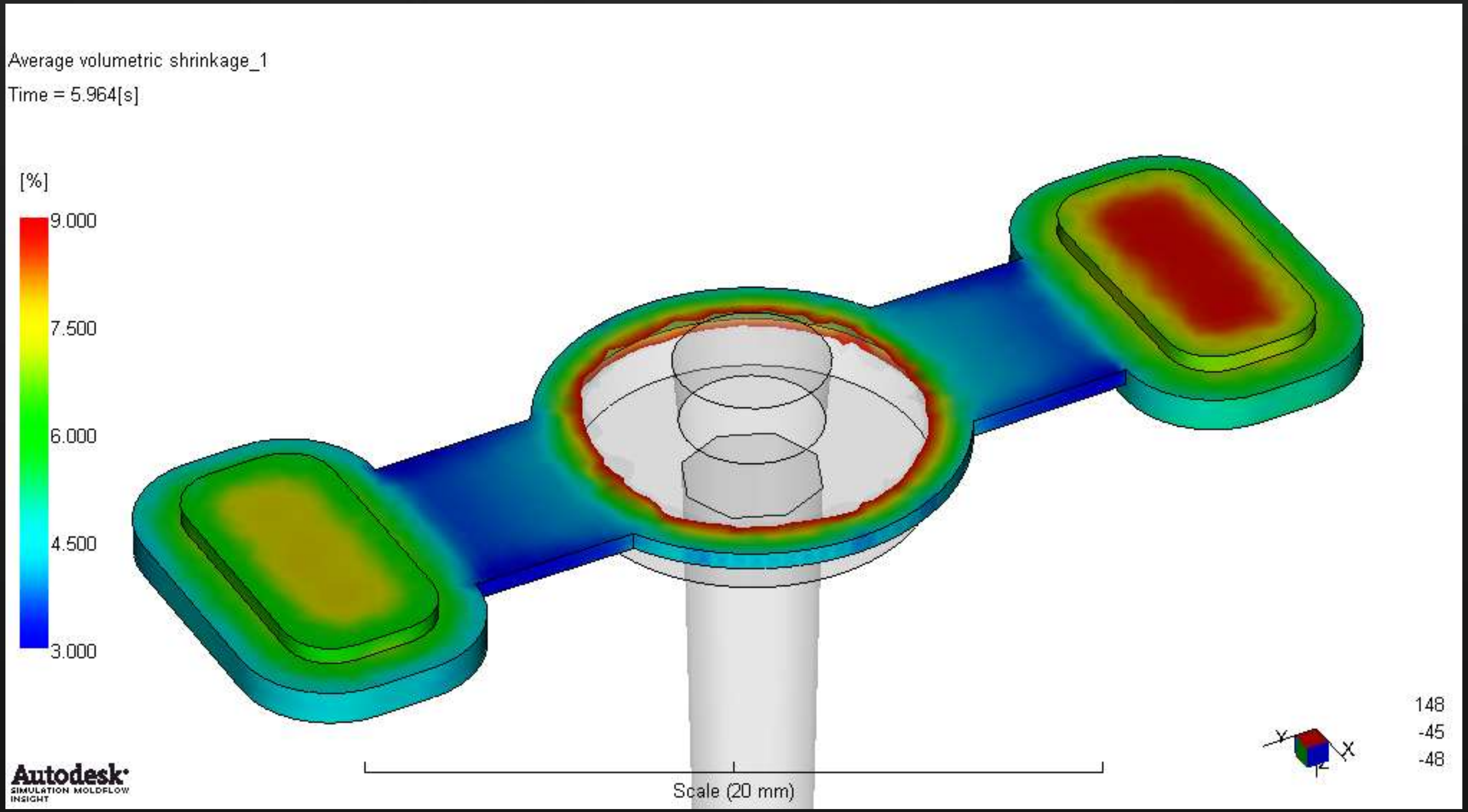


3D Inj-Compression Fill Pattern Visualization



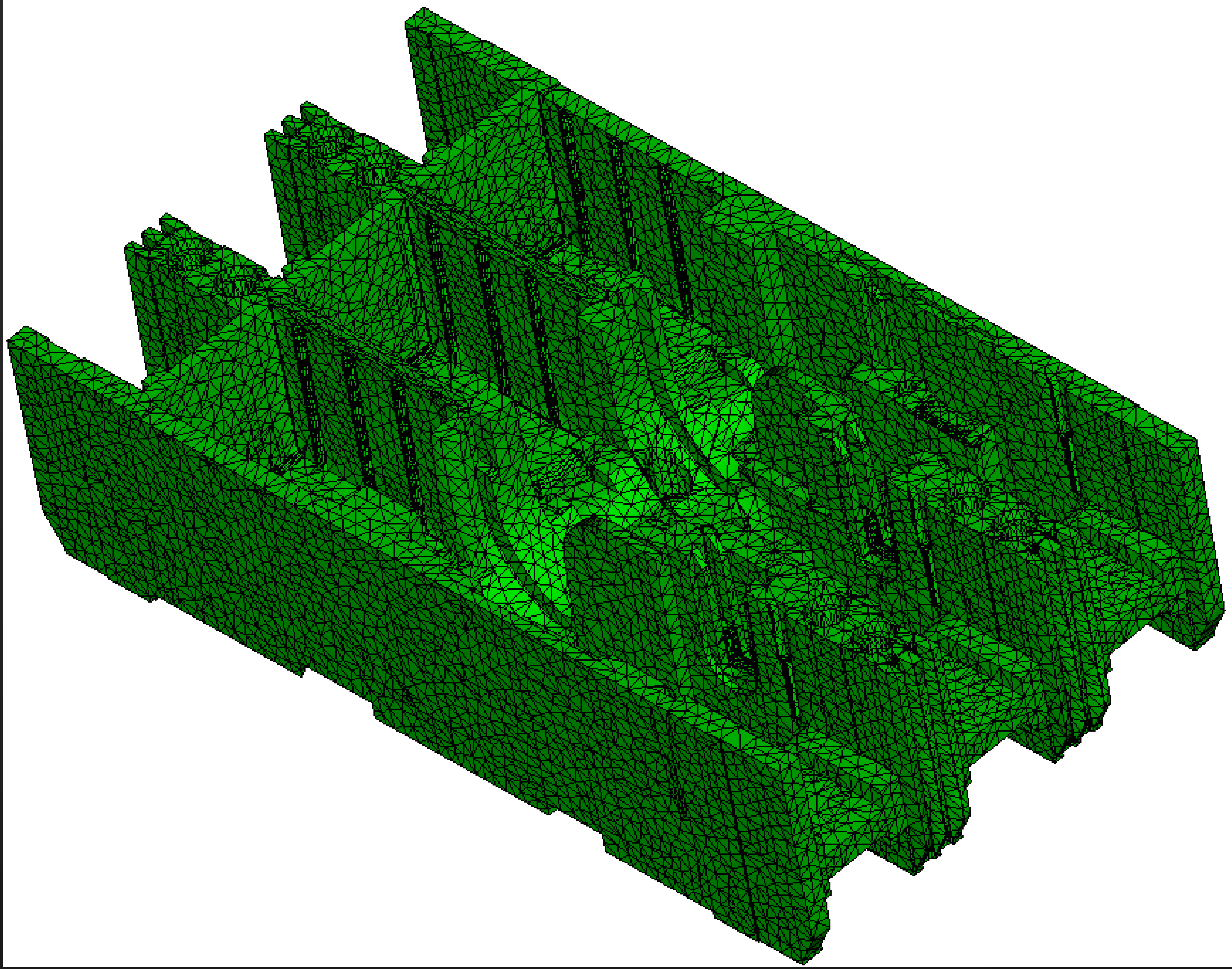
Only one cavity has compression

- Volumetric Shrinkage is lower in the cavity with compression



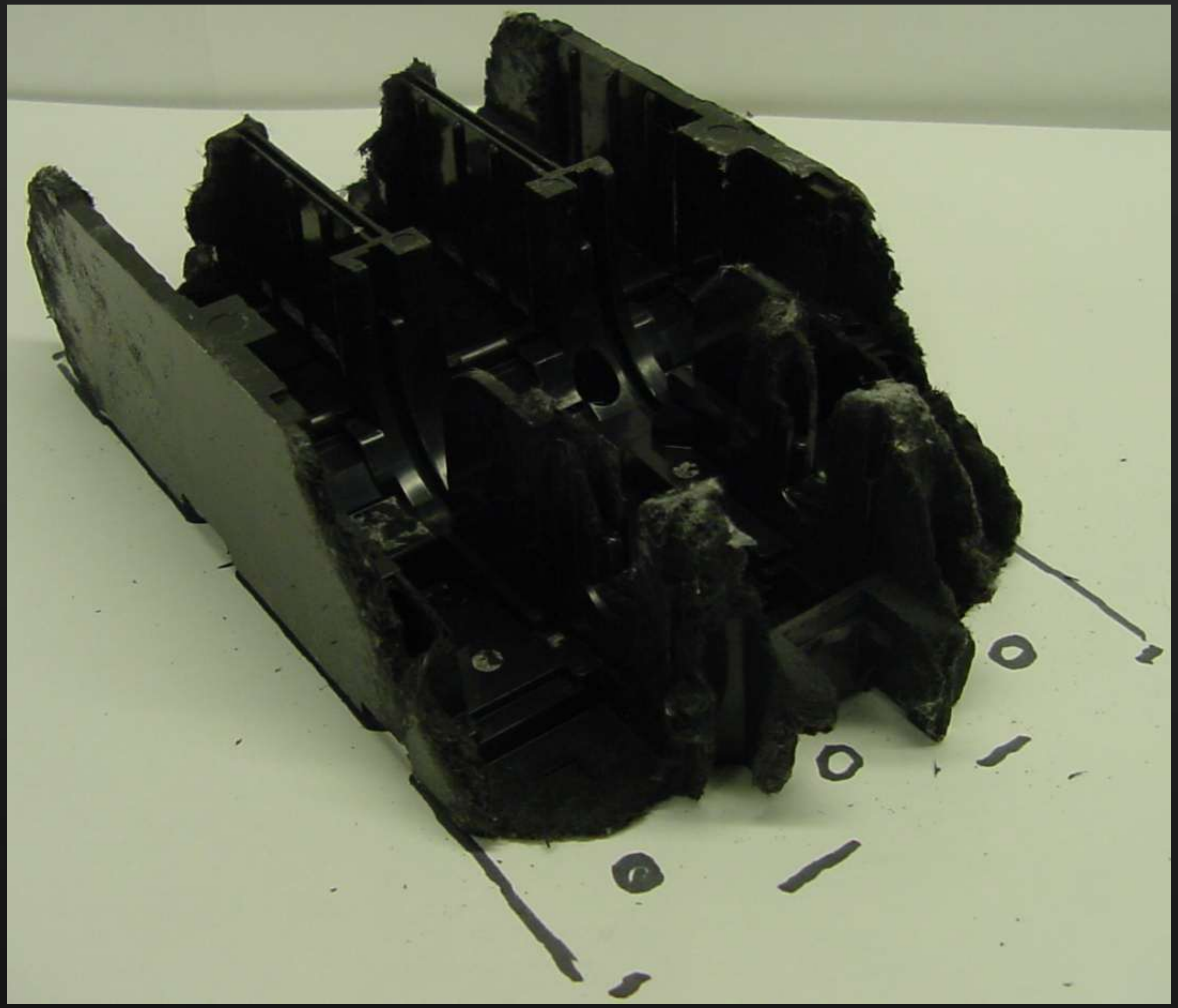
3D Injection Compression Molding

- Material: Thermoset
- Process conditions
  - Initial press open distance: 15 mm
- Approximate part size ~ 200 x 145 x 50 mm
- Typical part wall thickness ~ 6 mm
- Includes window area whose thickness becomes about 0.25 mm at the end of compression

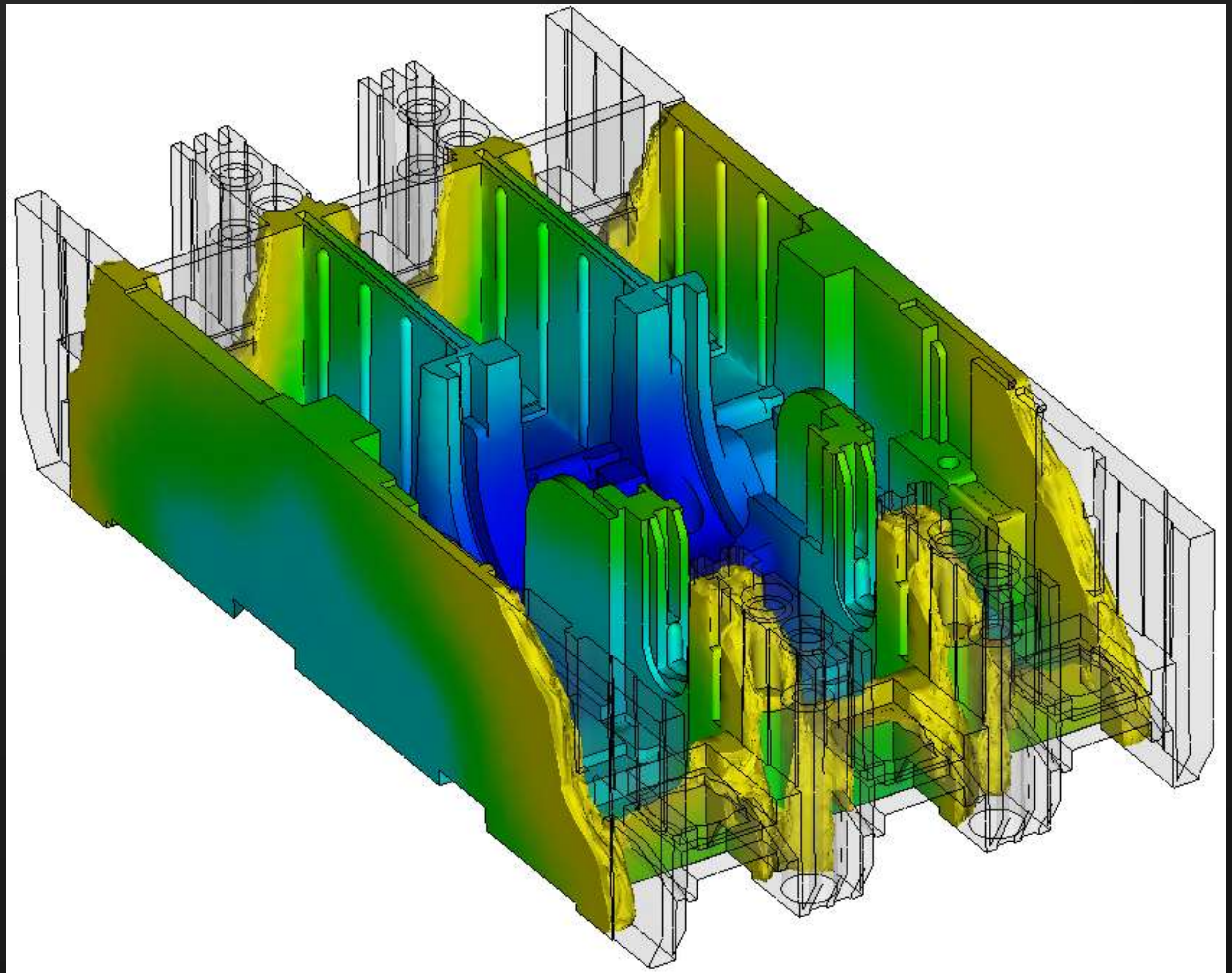


Case-study courtesy of Schneider Electric

3D Inj-Compression Fill Pattern Comparison

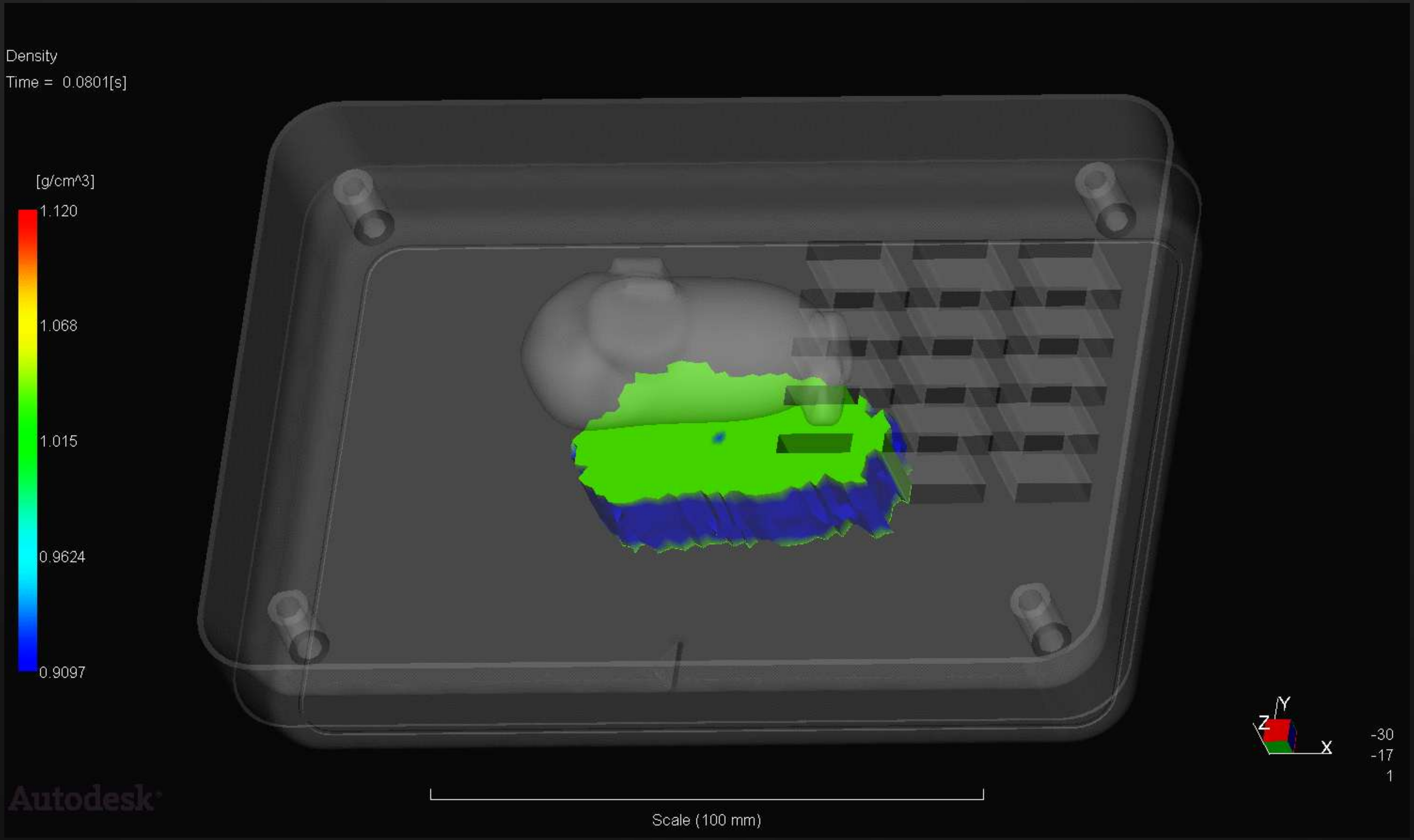


Experiment



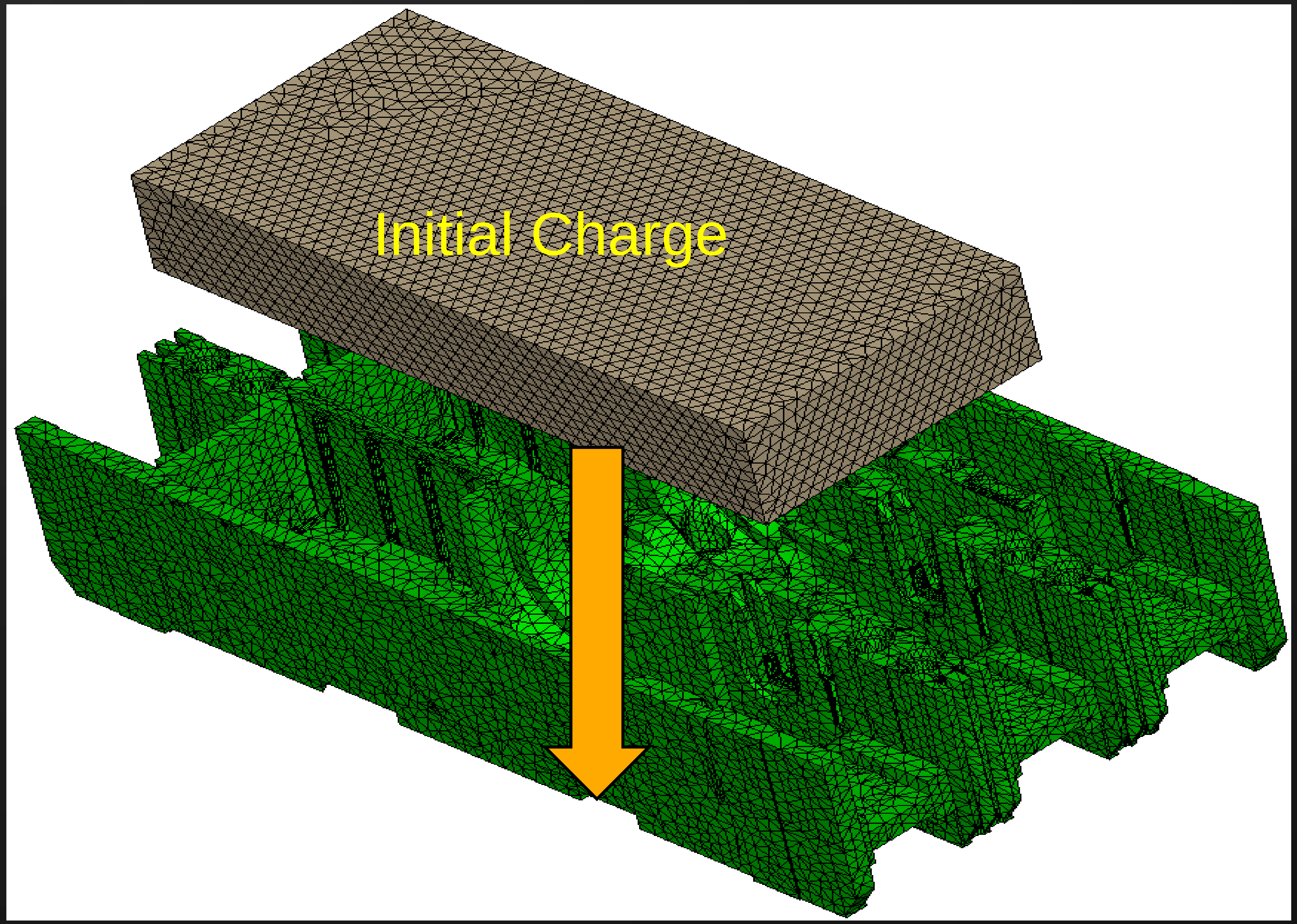
Simulation

3D Pure Compression Fill Pattern Visualization



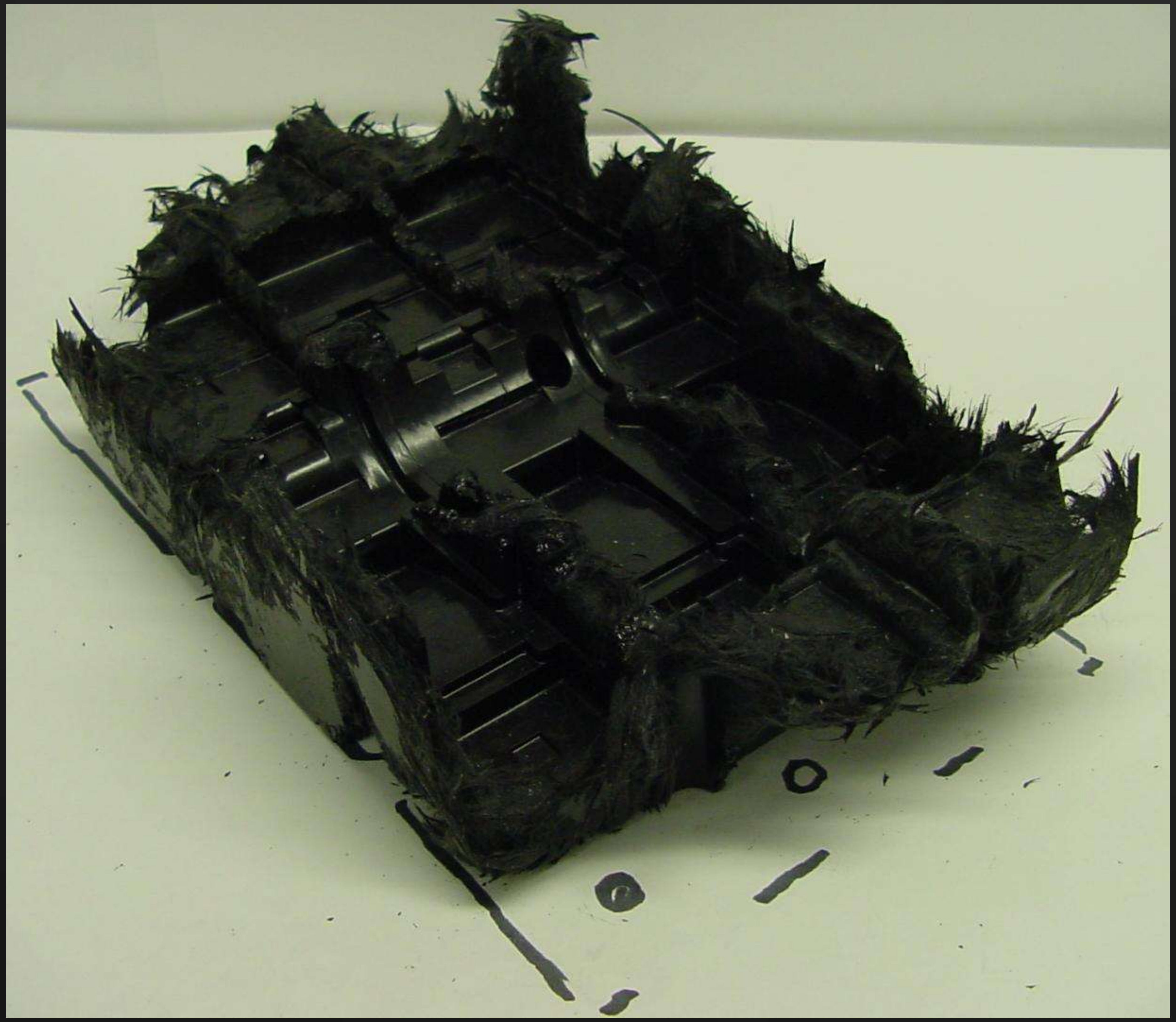
3D Pure Compression Molding

- Pure compression molding
- Material: Thermoset
- Process conditions
  - Press open distance at the start of compression: ~ 50 mm
- Initial charge: Rectangular plate shape (approximate size: 155 x 71 x 31 mm)



Case-study courtesy of Schneider Electric

3D Pure Compression Fill Pattern Comparison



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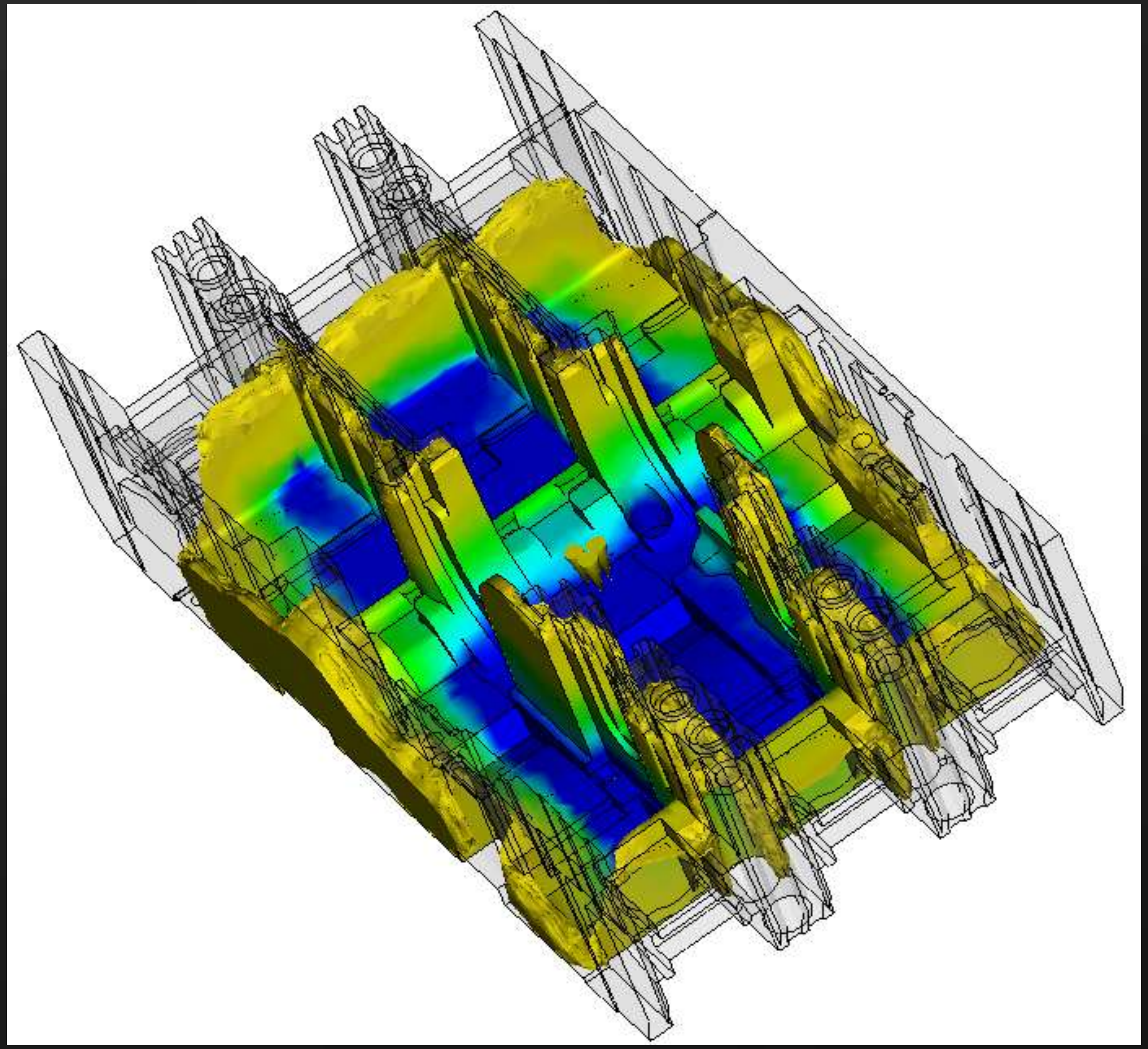
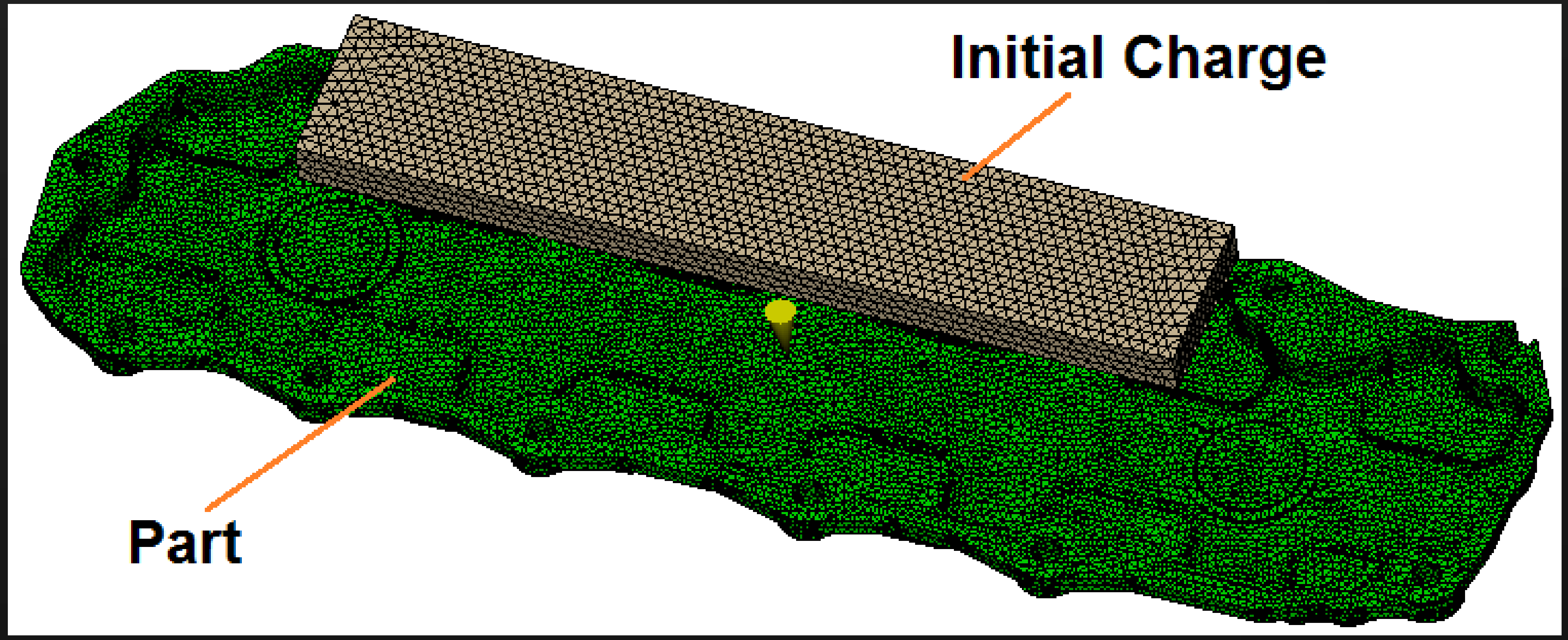


Simulation

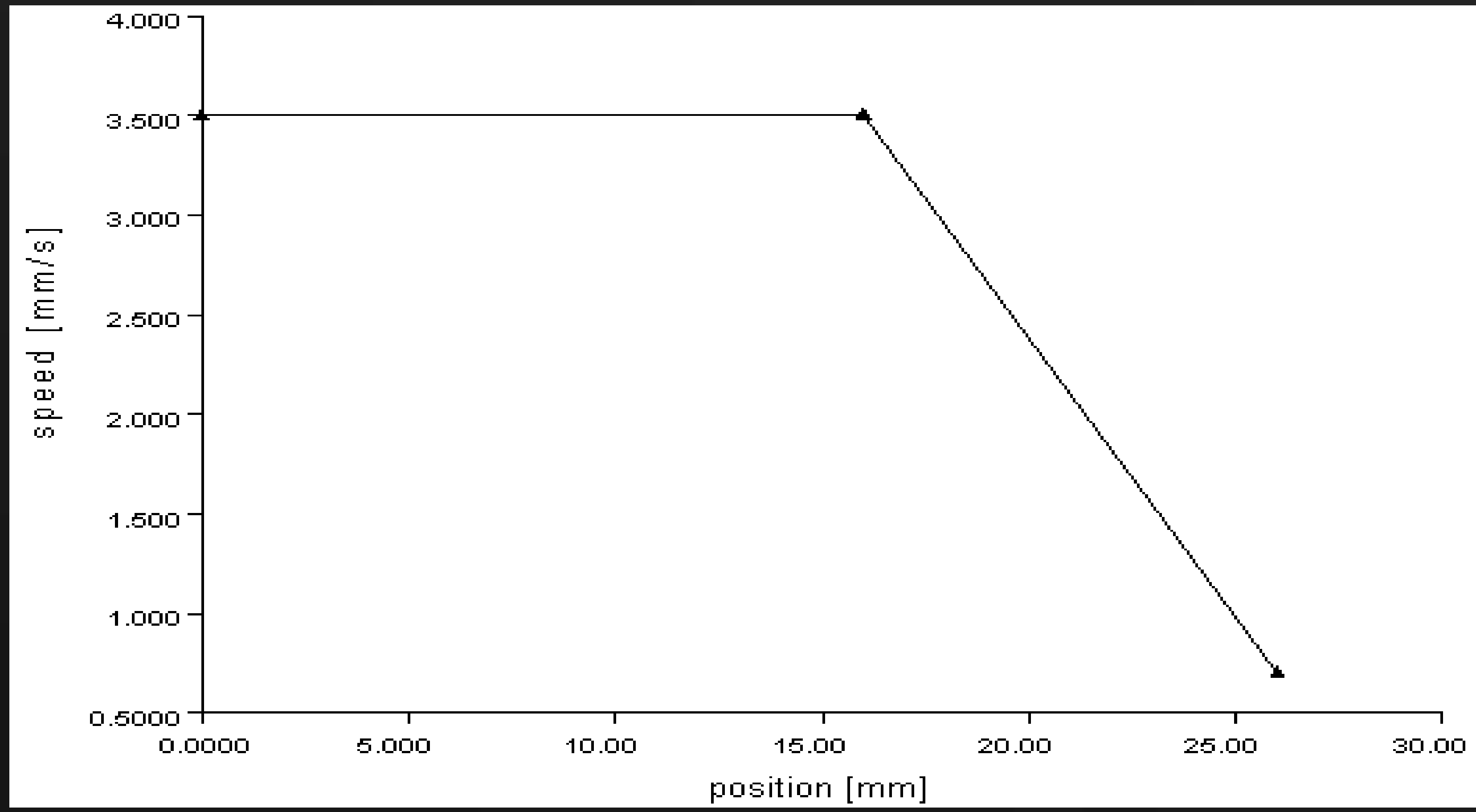
Compression Example 2

- Compression molding (Courtesy of Premix, Inc. USA)
- Length: 800 mm
- Width: 200 mm
- Typical thickness: 4 mm

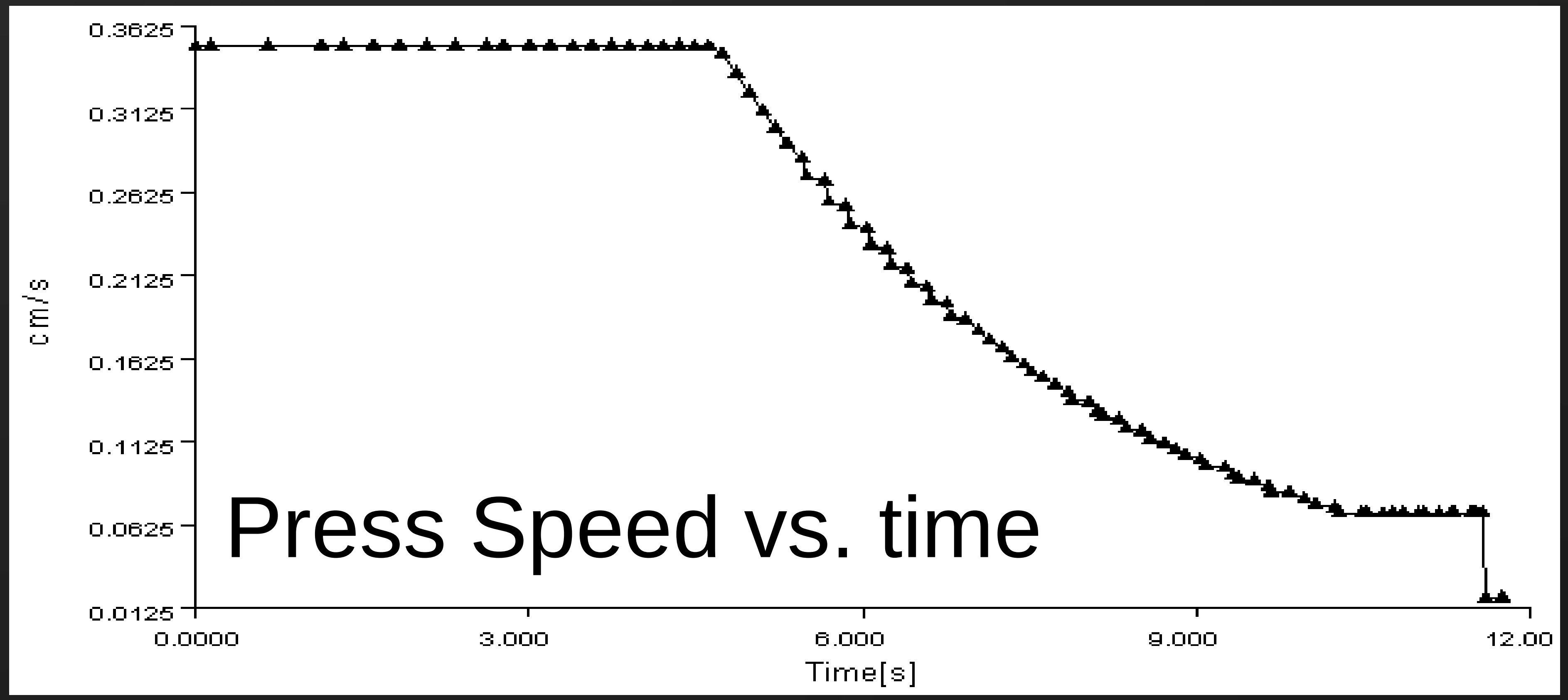


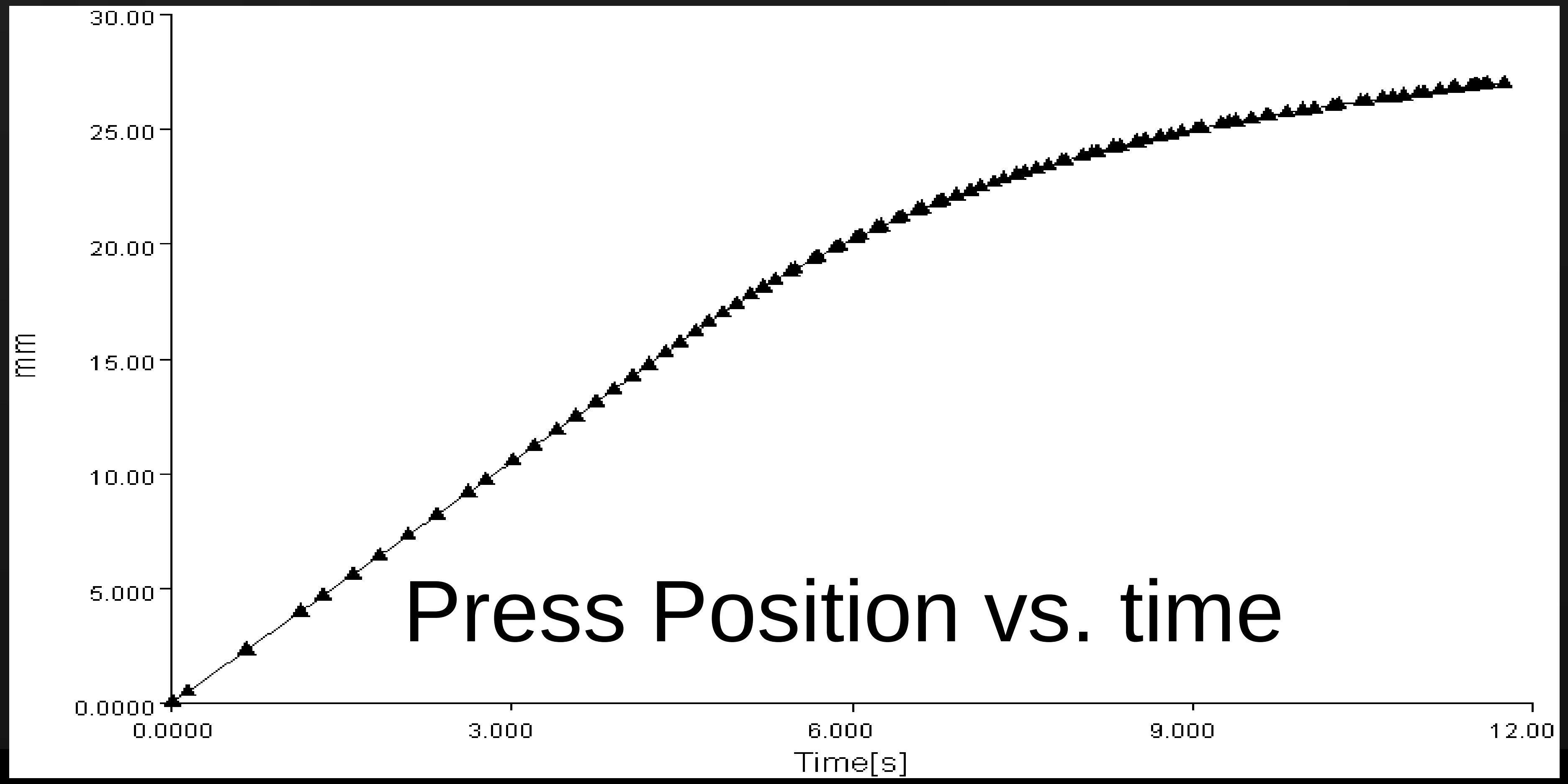
Compression Example 2

- Thermoset Sheet Molding Compound (Premi-Glas 1286: Premix)
- 34% glass fiber
- Initial fiber length: 12 mm

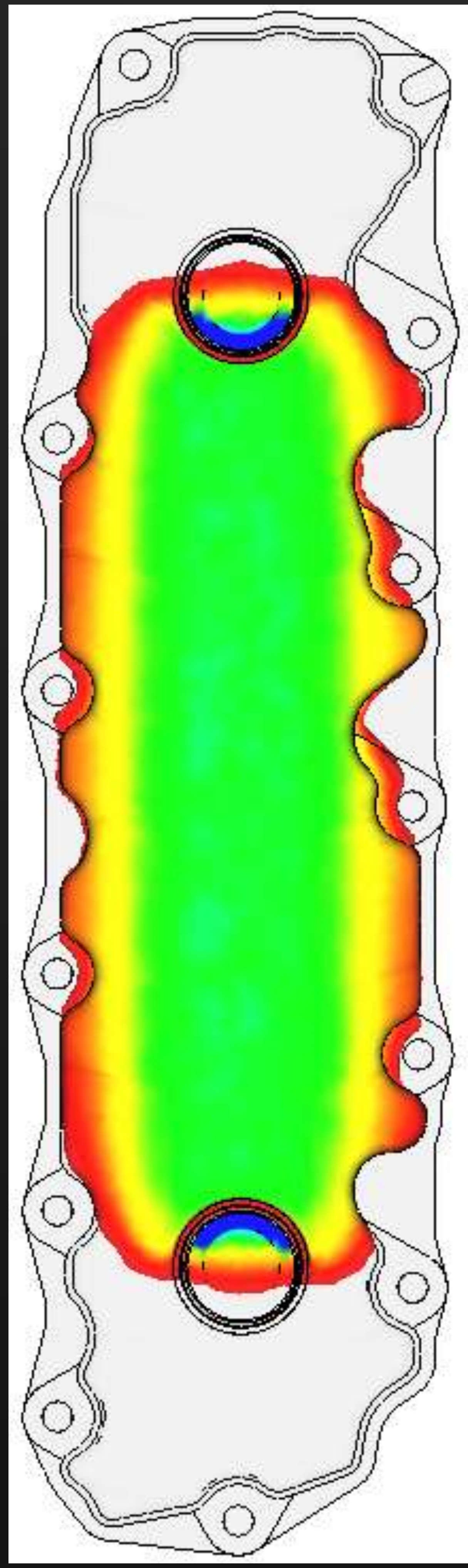


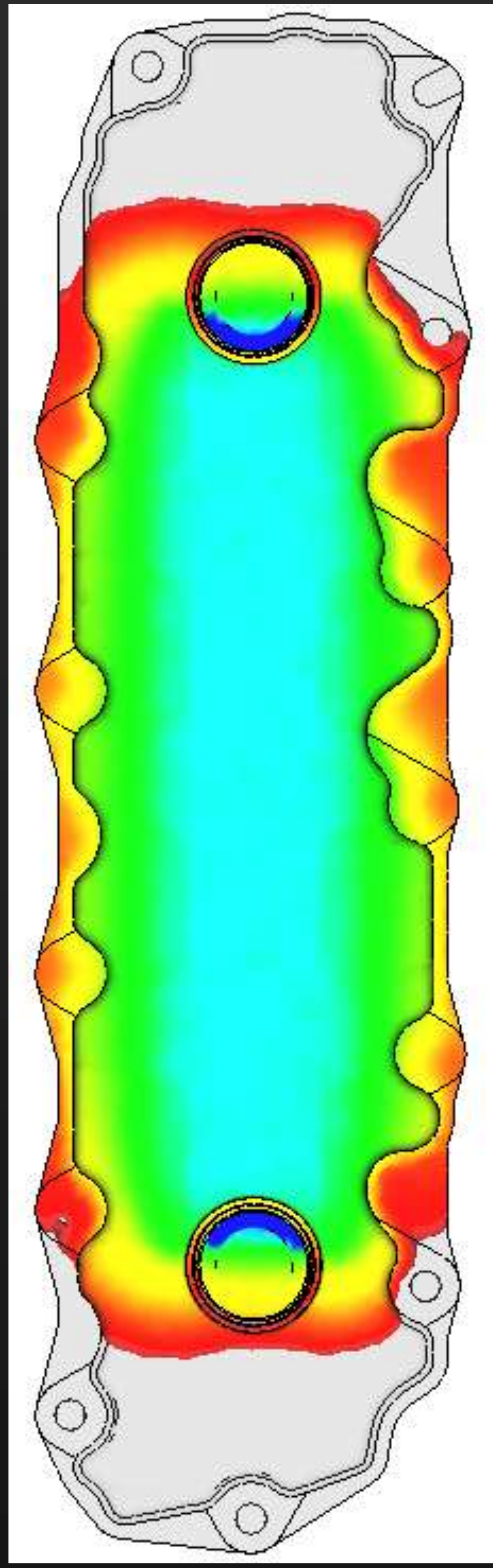
Input: Press Speed vs. Position

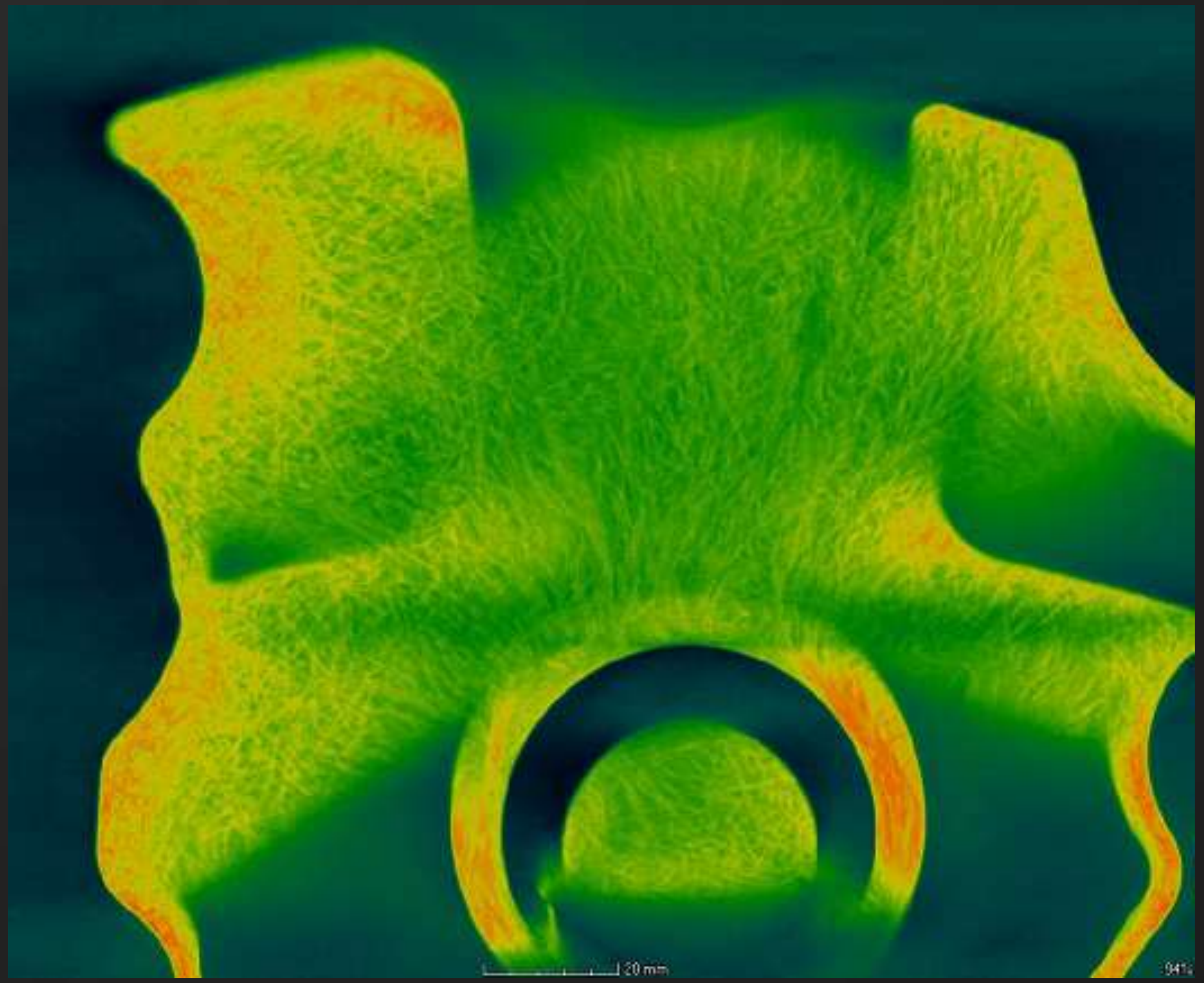




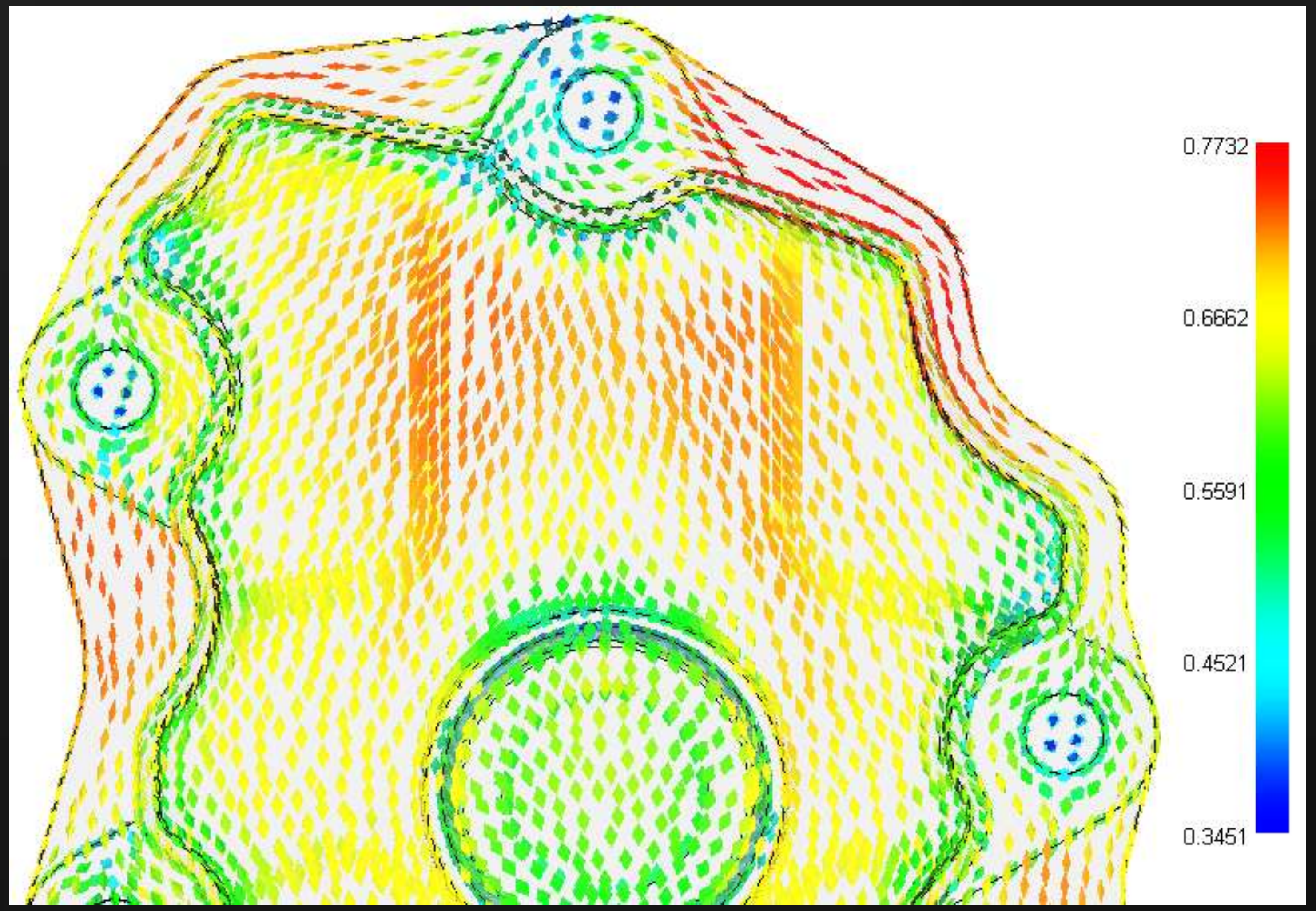
Fill Pattern & Fiber Orientation







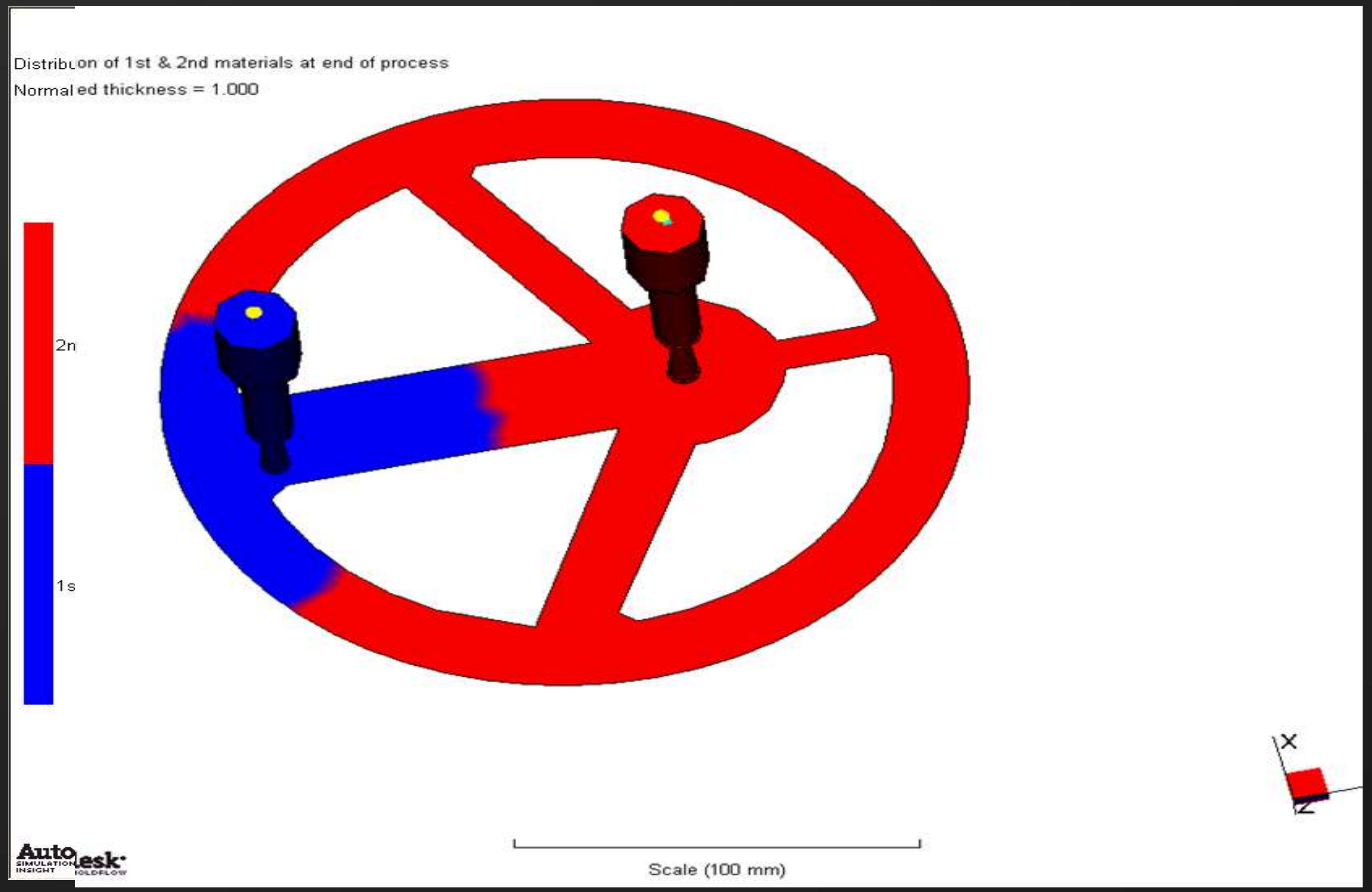
CT Scan

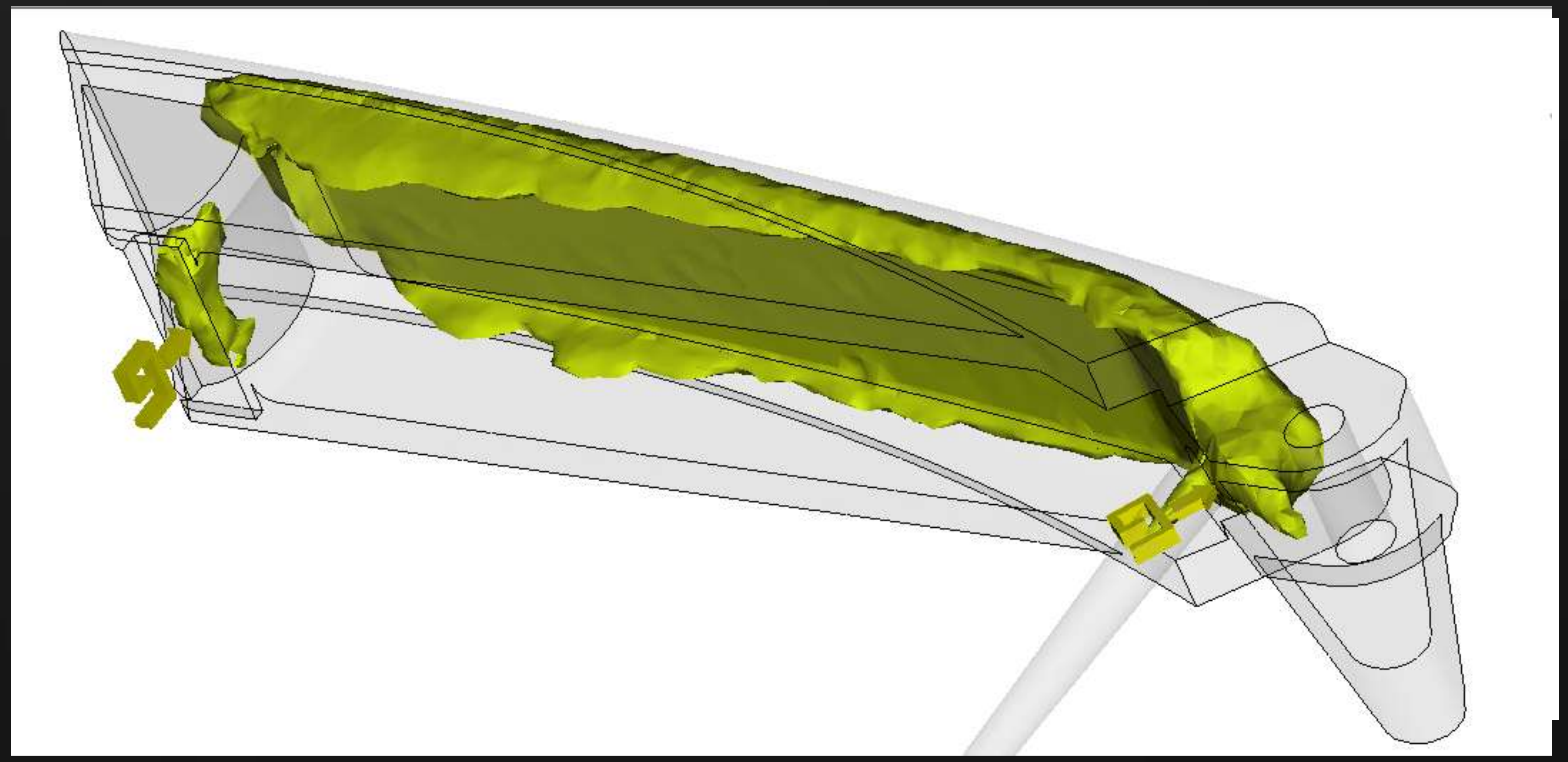


Numerical Simulation

Other Scandium Features

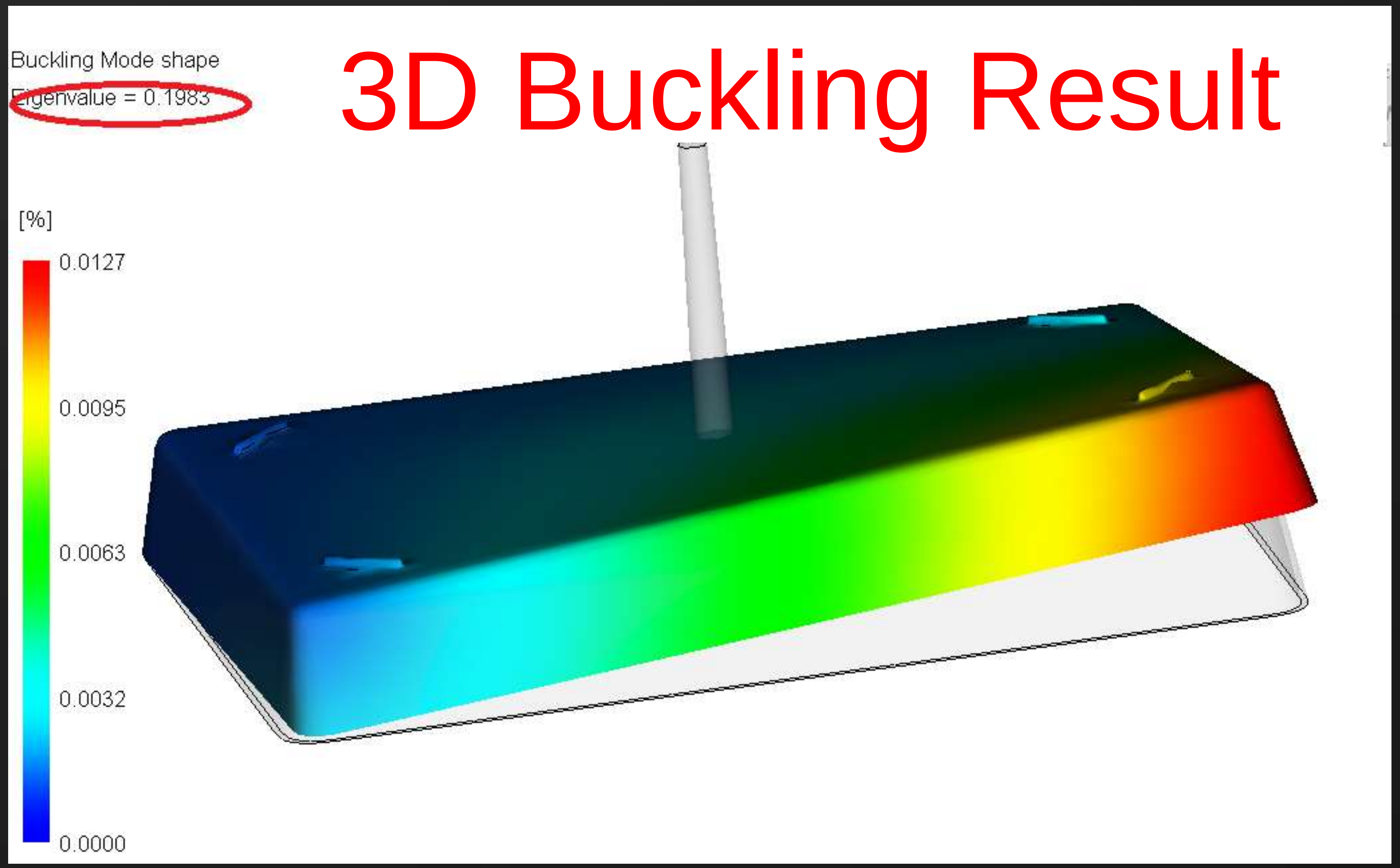
- Bi-Injection
  - Thermoplastics Bi-injection molding where 2 different materials are injected at different locations with independent process control
  - Midplane Only
- Multiple Gas Injection cylinders (3D)
  - Can have different pressure & delay
  - Was already available in Midplane

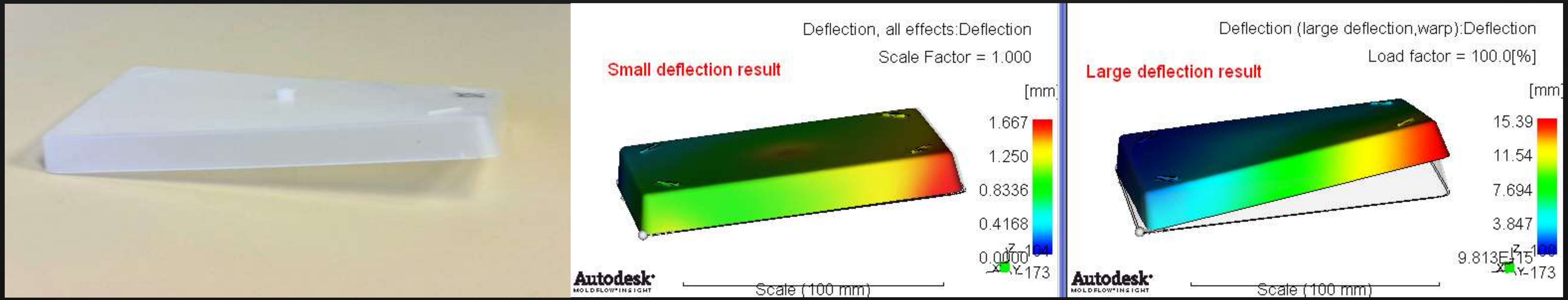




Buckling for 3D Warpage Analysis

- Depending on geometry, some parts may buckle during warpage
  - Similar to Buckling Option in Midplane
  - Extends the Large Deflection Analysis option released in Moldflow Insight 2012
  - Increases computation time
- Large Deflection for Microchip Encapsulation





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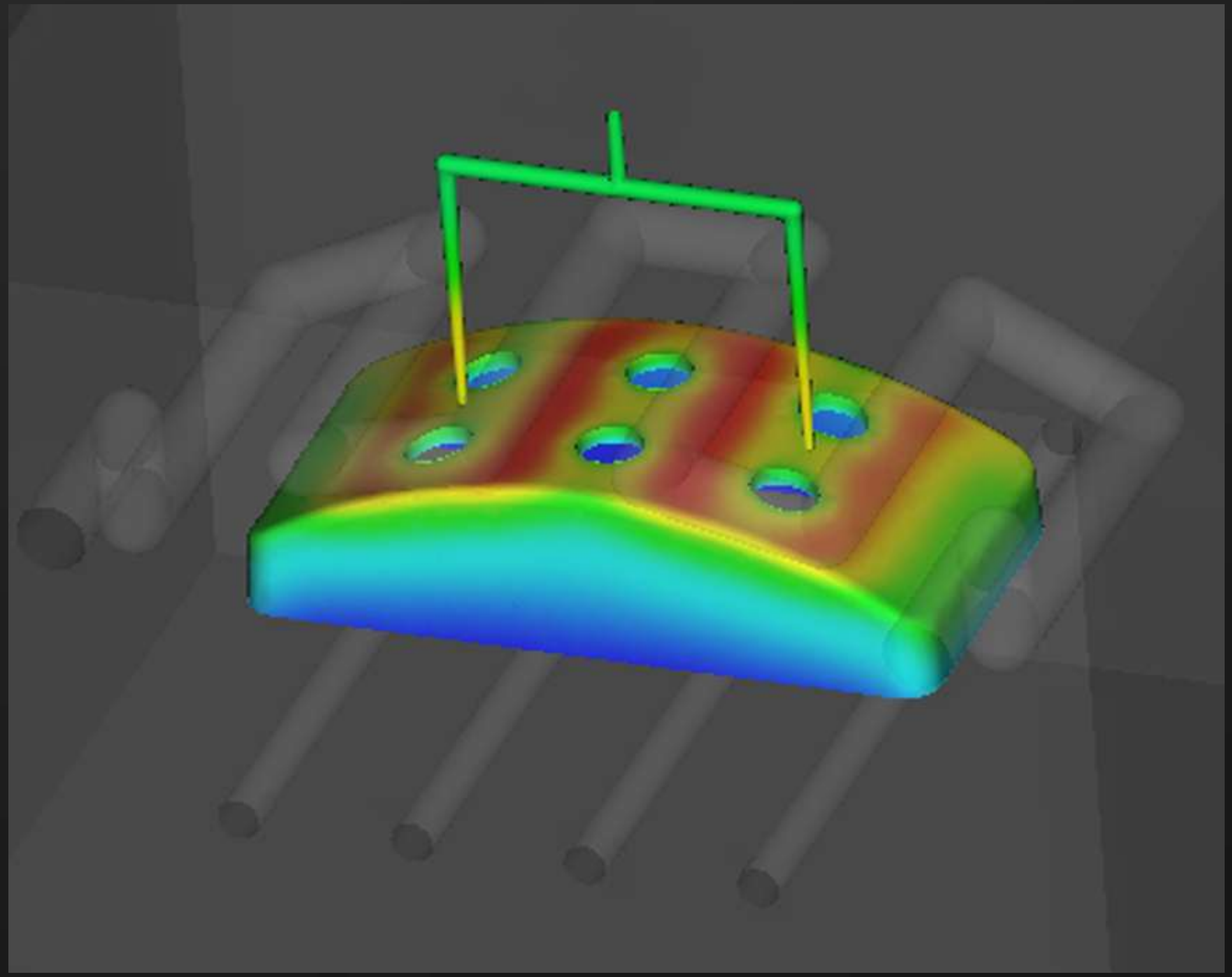
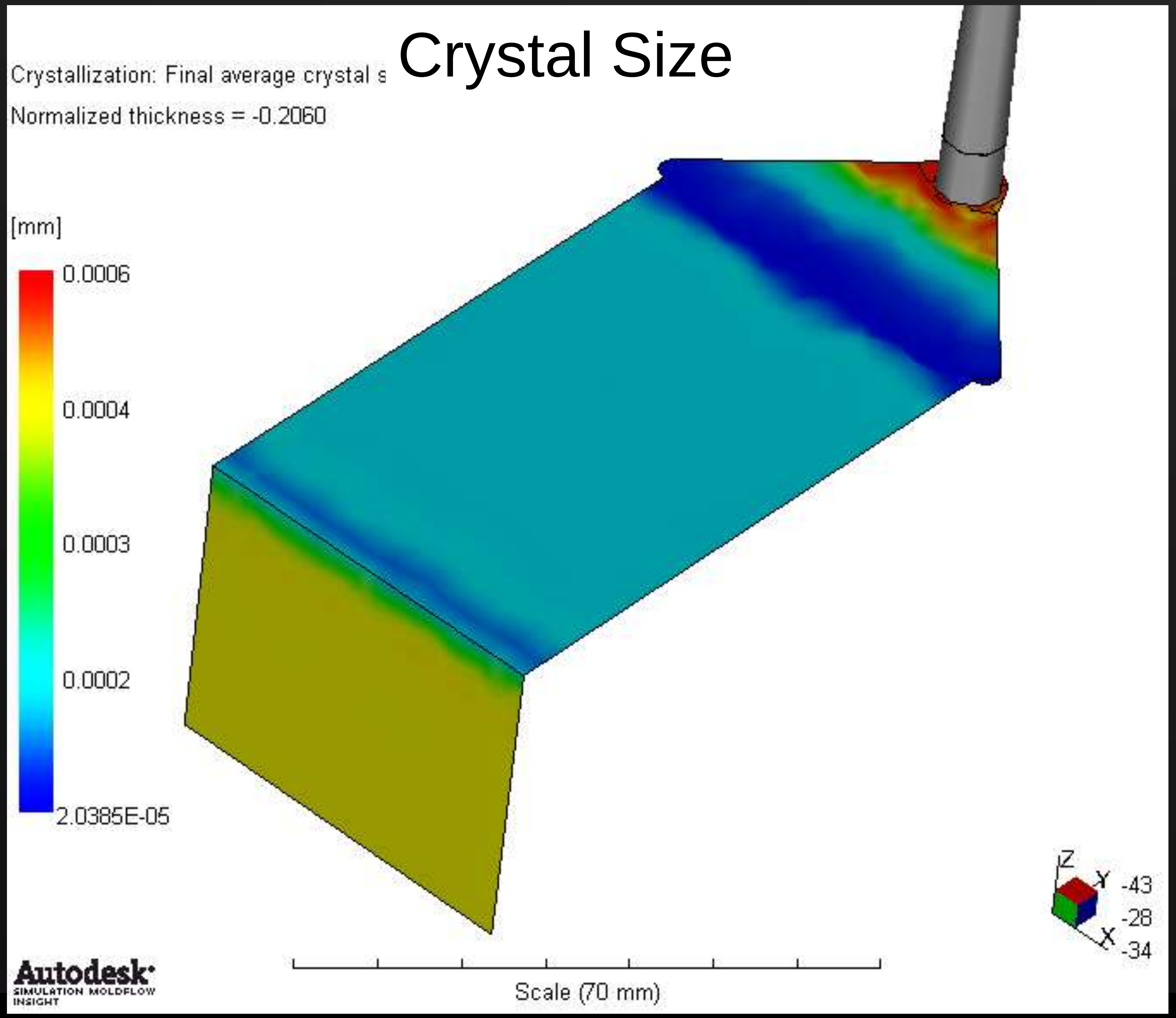
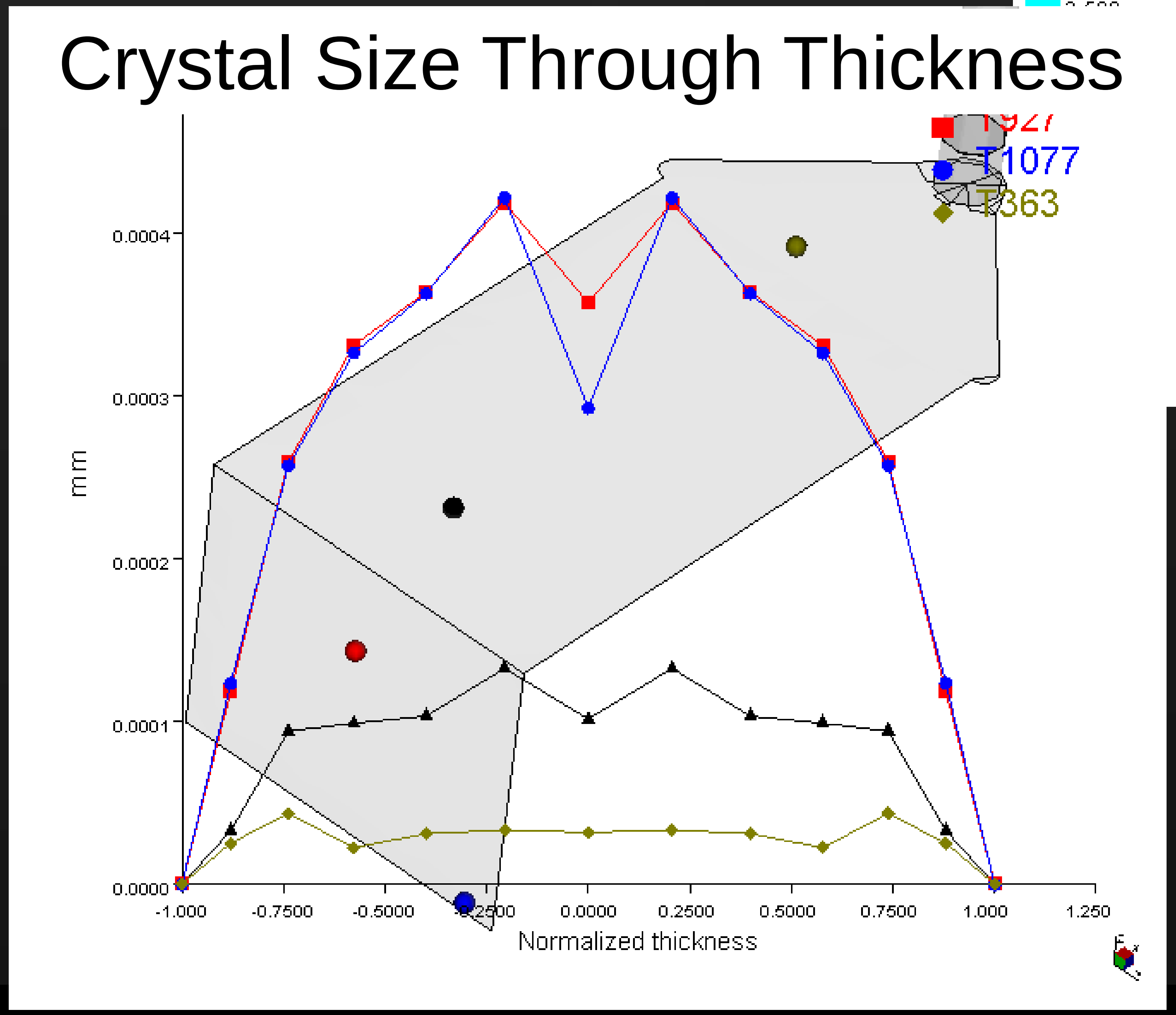
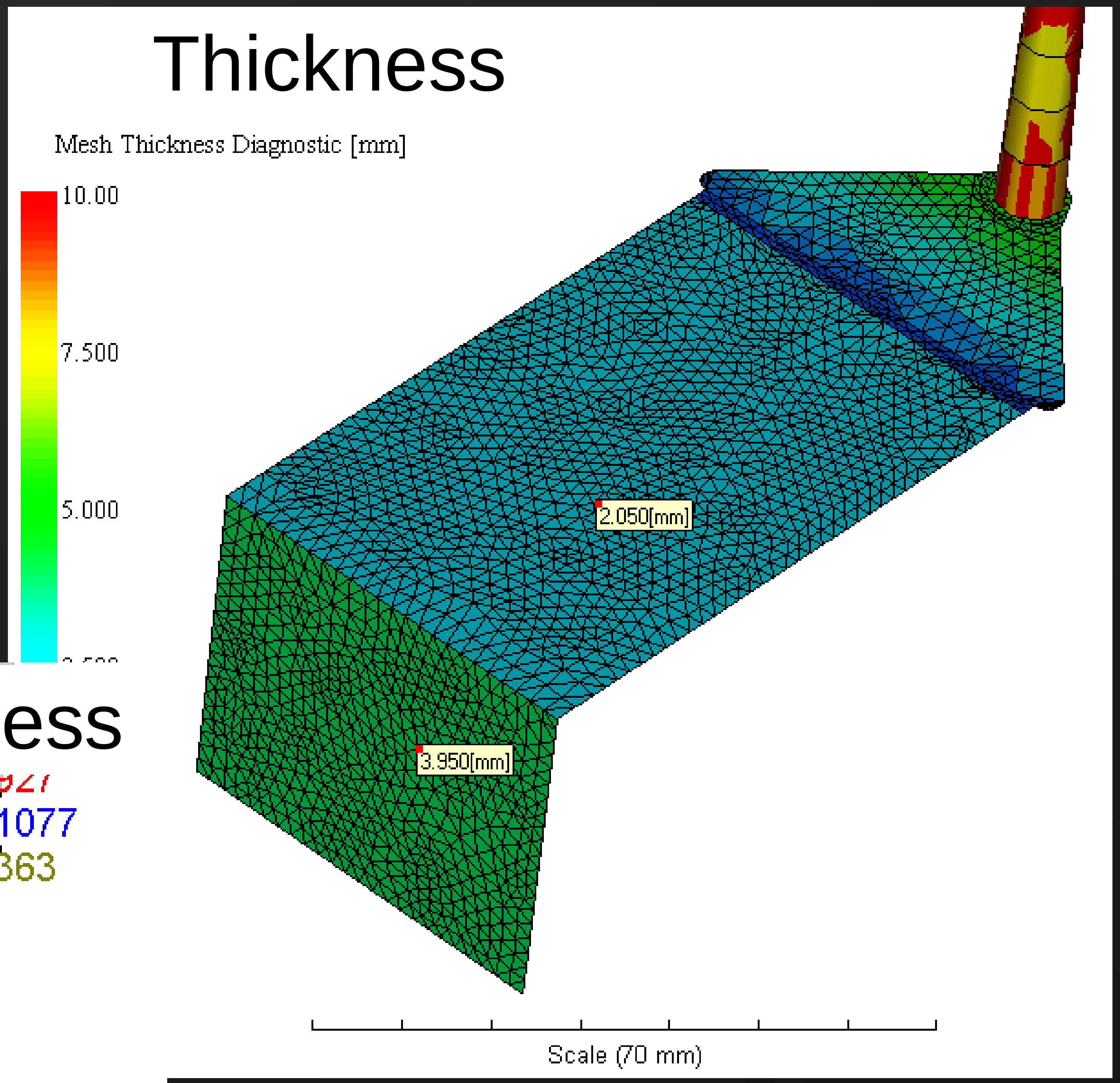


New Crystallization Result: Crystal Size

- Useful to understand effect of Mechanical Properties



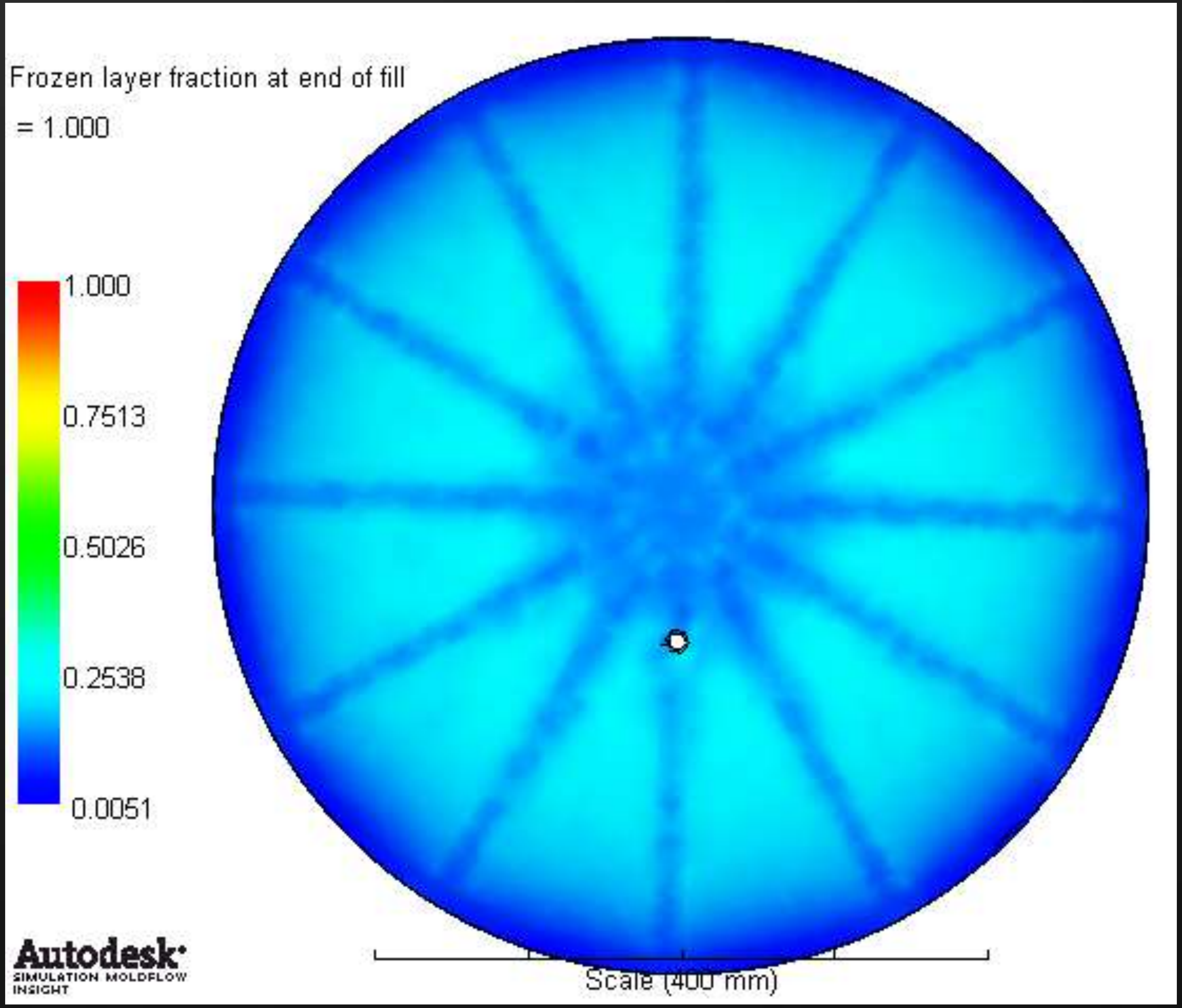




New 3D Grow From Result

New 3D Frozen Layer Fraction Result

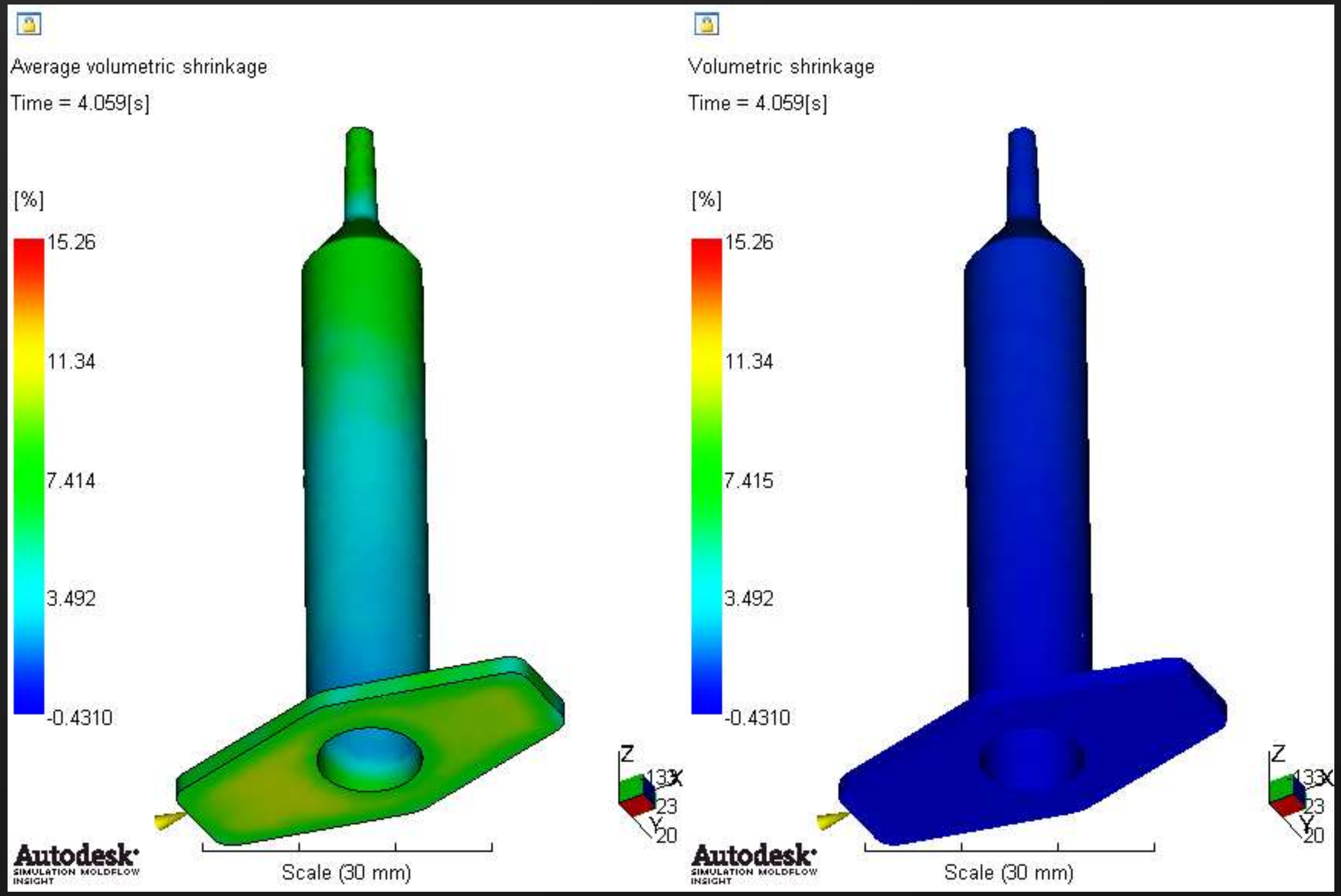
- Frozen Layer fraction over thickness
  - Equivalent to midplane/DD result
  - End of Fill and End of Pack/Cool
- Cured Layer Fraction result
  - Reactive (Thermoset)



Other Improvements

- Mucell: Reduced computation time by coding improvements
- 3D Flow: Reduced computation time for 3D Mapping to surface
- 3D Flow: Ram Position: XY Plot

- FBX export: Allows visualization in Autodesk Showcase, Maya, Inventor Publisher, MotionBuilder and other Autodesk products.



Average Volumetric Shrinkage through thickness

Volumetric Shrinkage on surface

Content

- **Autodesk Simulation Moldflow Insight 2013**
  - Crystallization
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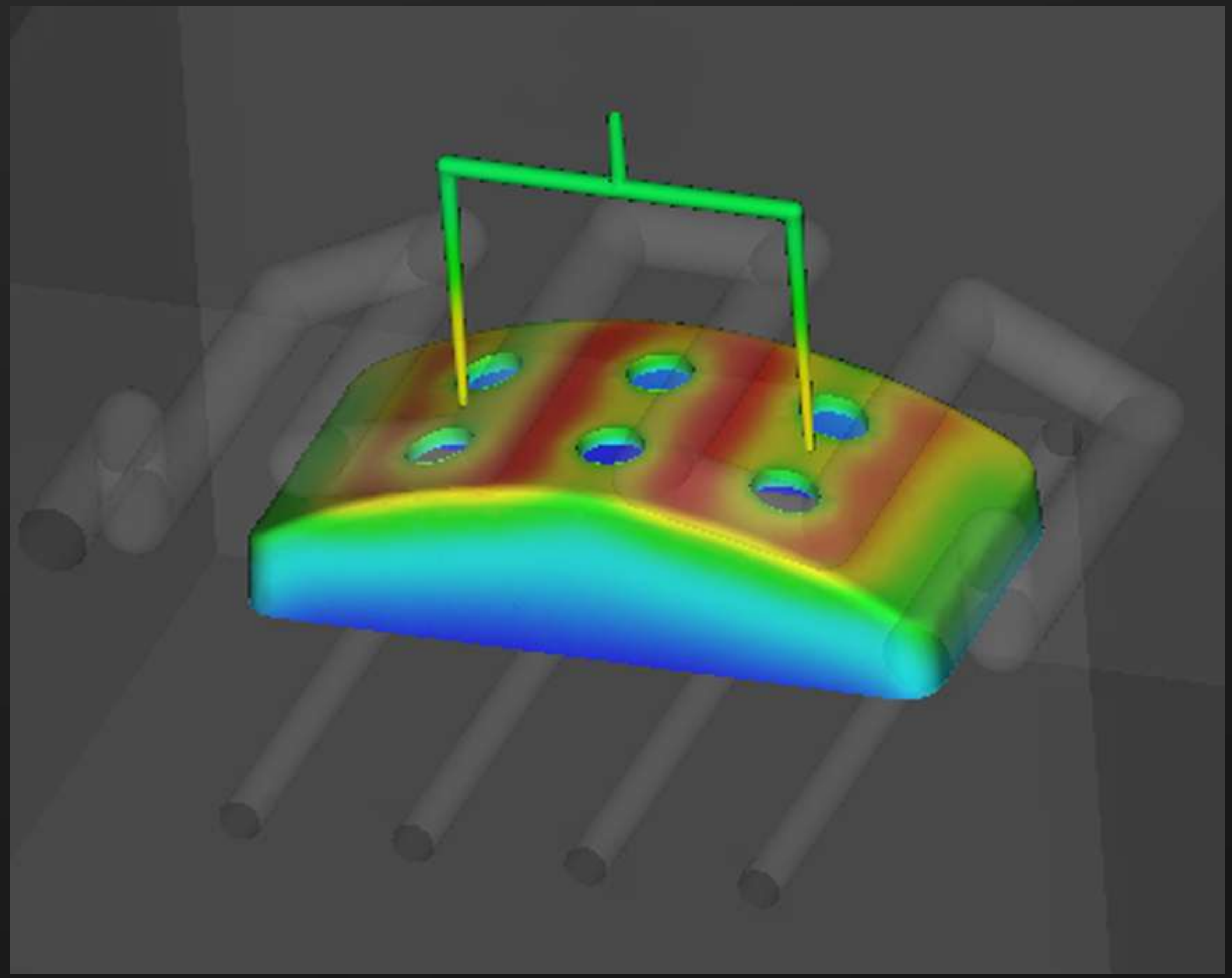
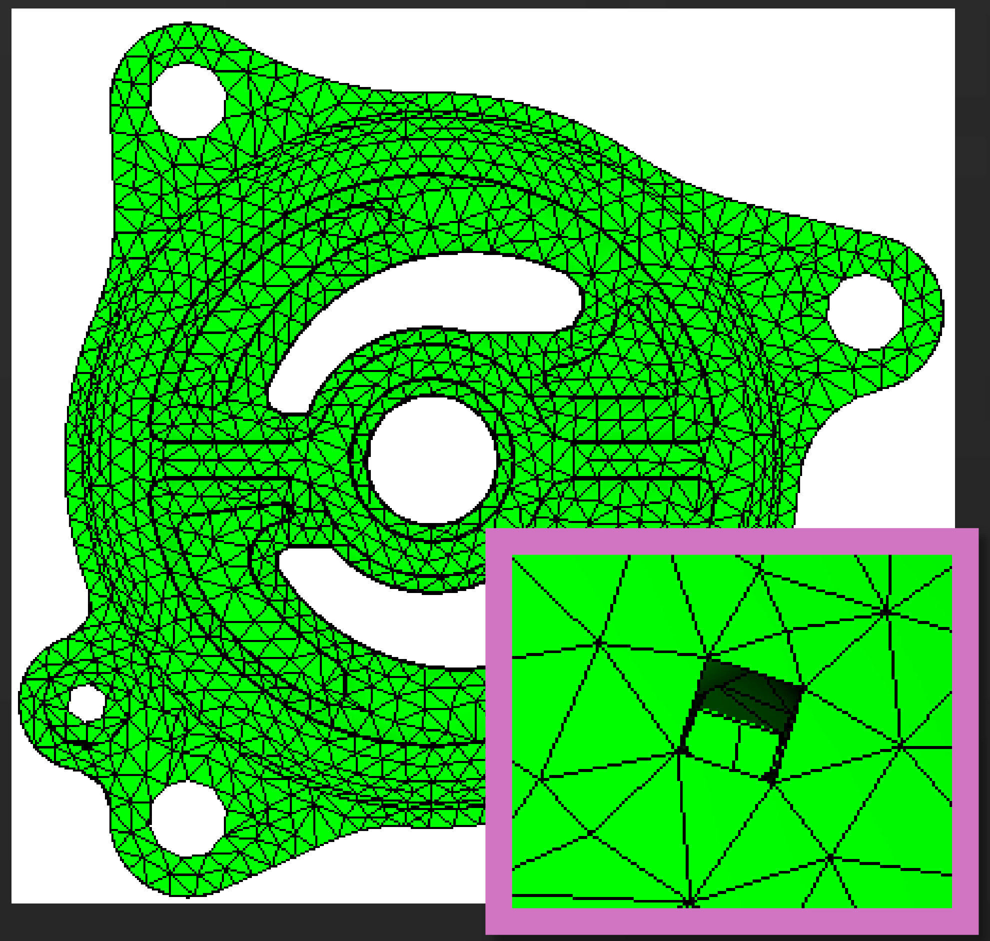
  - Viscoelasticity
  - Wall Slip
  - New analysis types
  - New result types
- **Some Research Topics**
  - New Integrations with Autodesk Mechanical Simulation

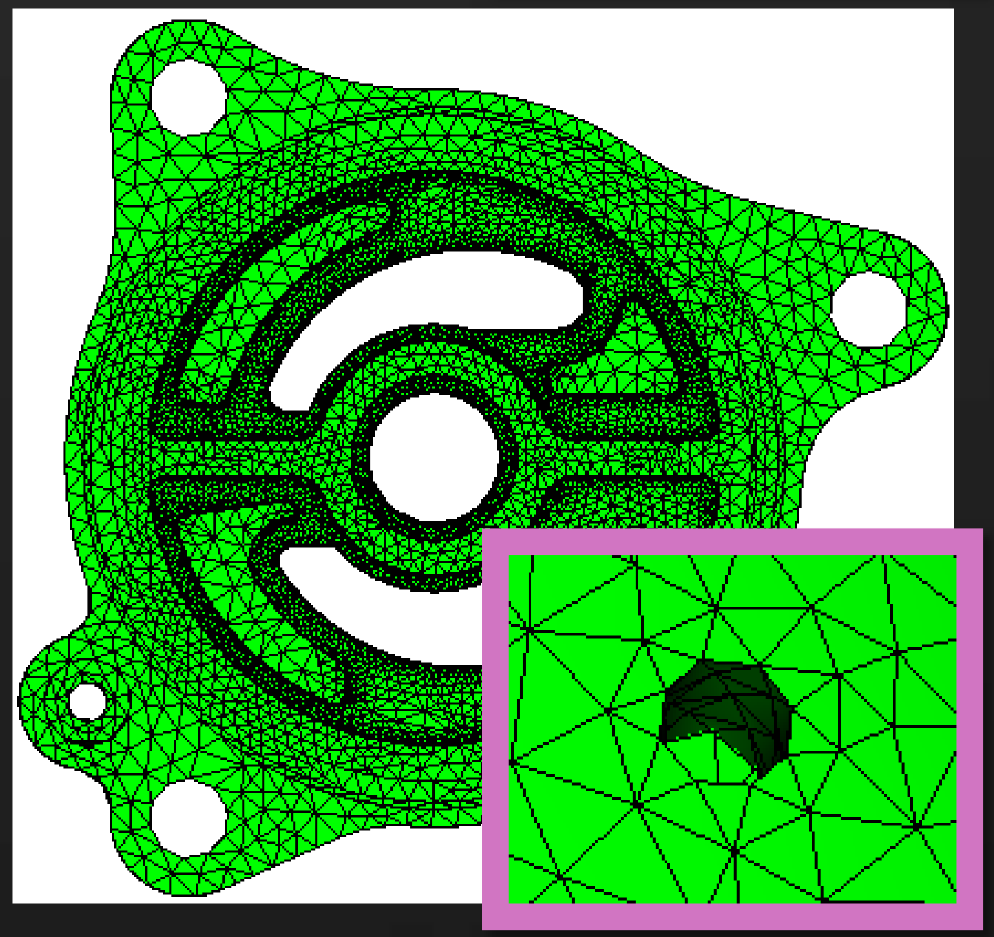


Meshing

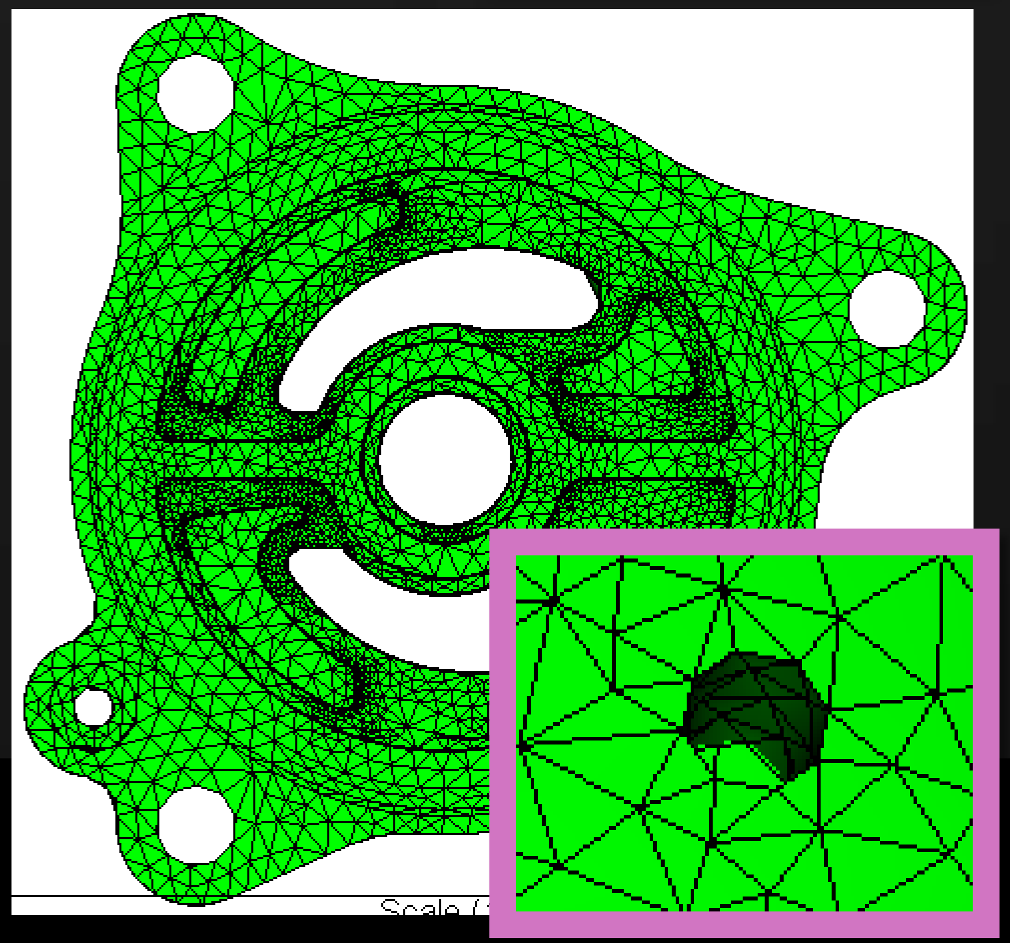
- Speed Improvements
  - During thickness calculation
  - By meshing multiple bodies in parallel
  - By 3D Meshing algorithm improvements (50% improvement on large models)
- Improve Chord Angle control
  - More efficient meshes with new fillet sizing control option



- No Chord Angle Control
- 15,000 triangles
- Poor definition around hole



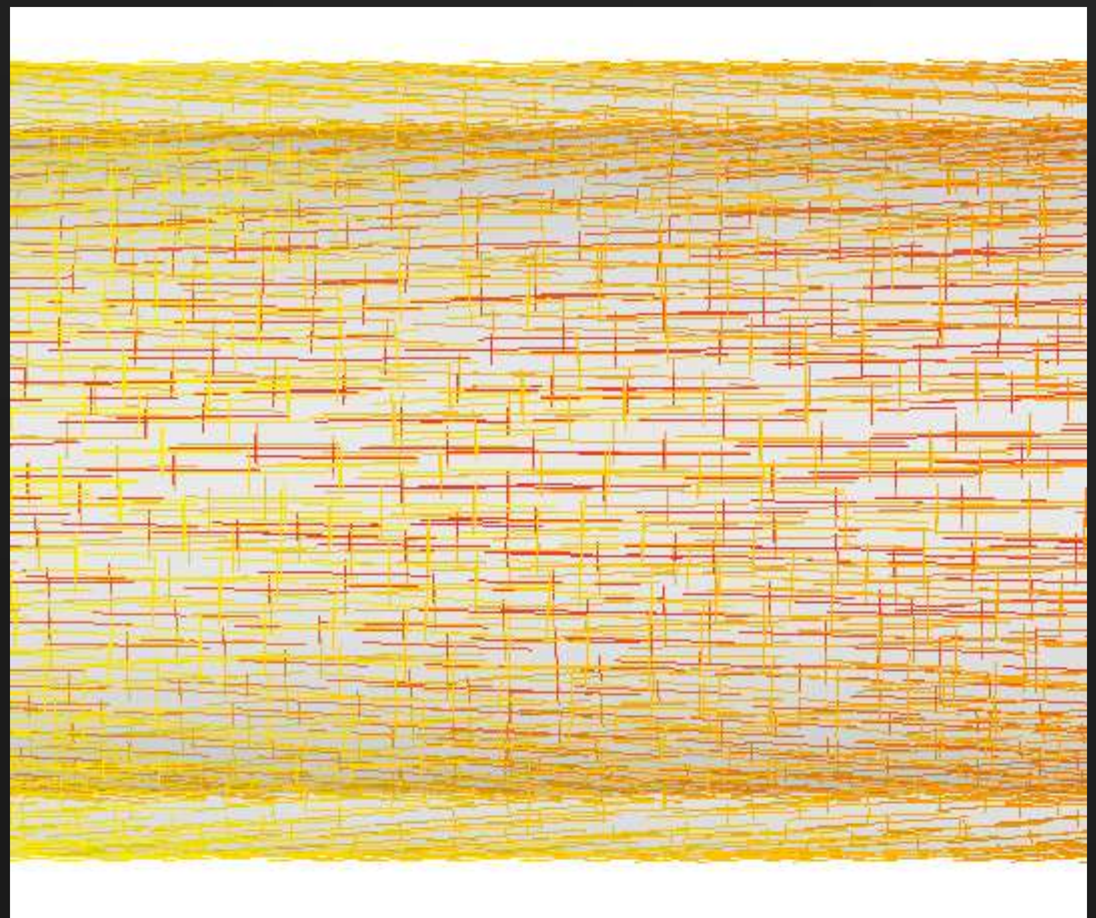
- Chord Angle Control
- 37,000 triangles
- Good definition around hole



- Chord Angle and Fillet Sizing Control
- 23,000 triangles
- Good definition around hole
- More efficient number of elements

Mechanical Properties of Long Fiber Composites

Long Fiber Orientation



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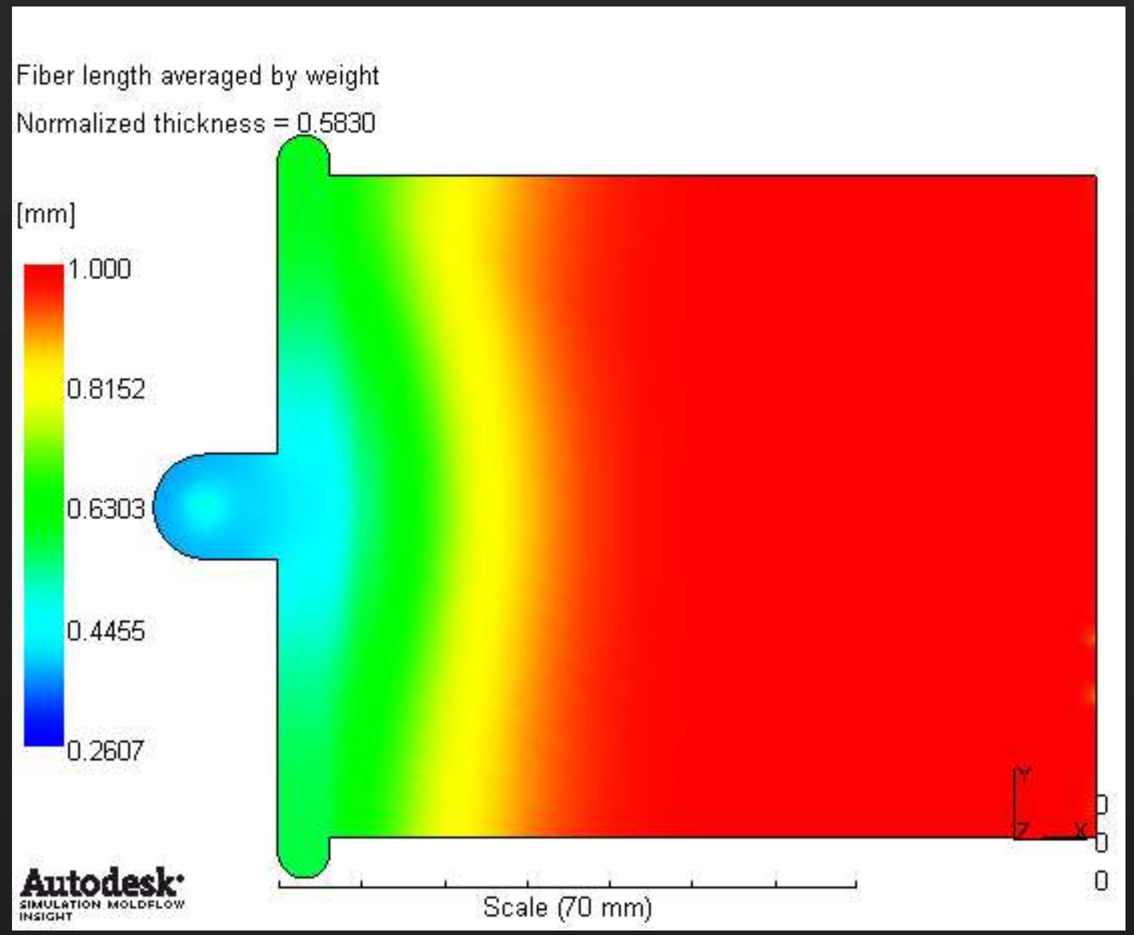
Fiber Length



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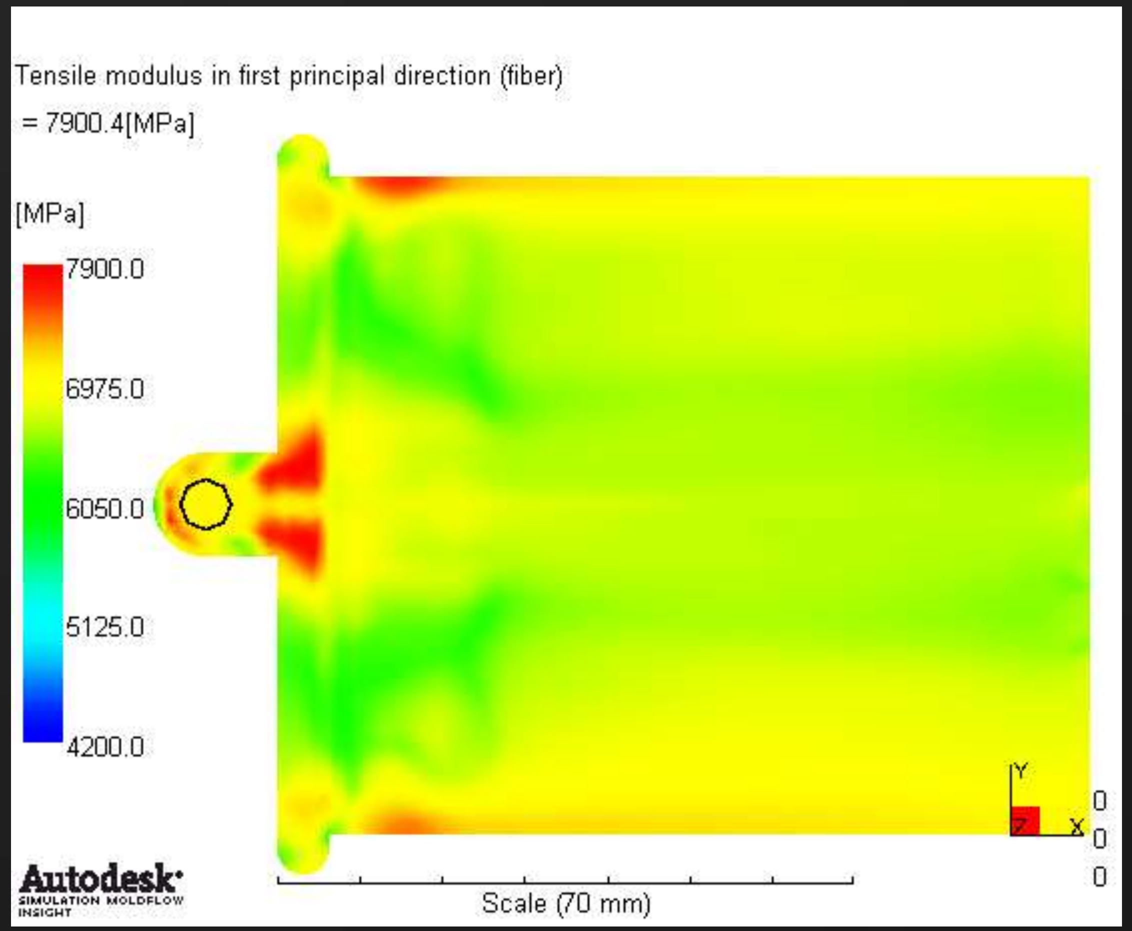
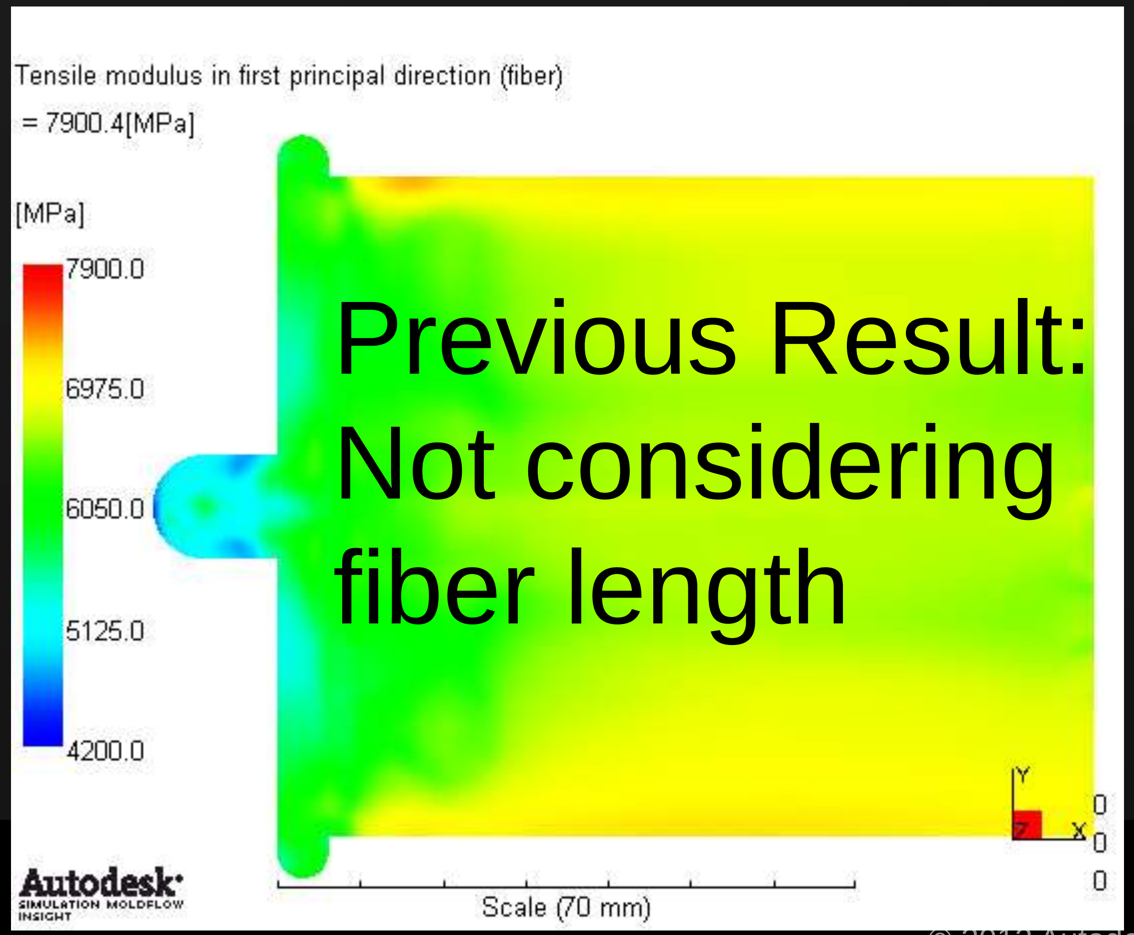
Mechanical Properties of Long Fiber Composites

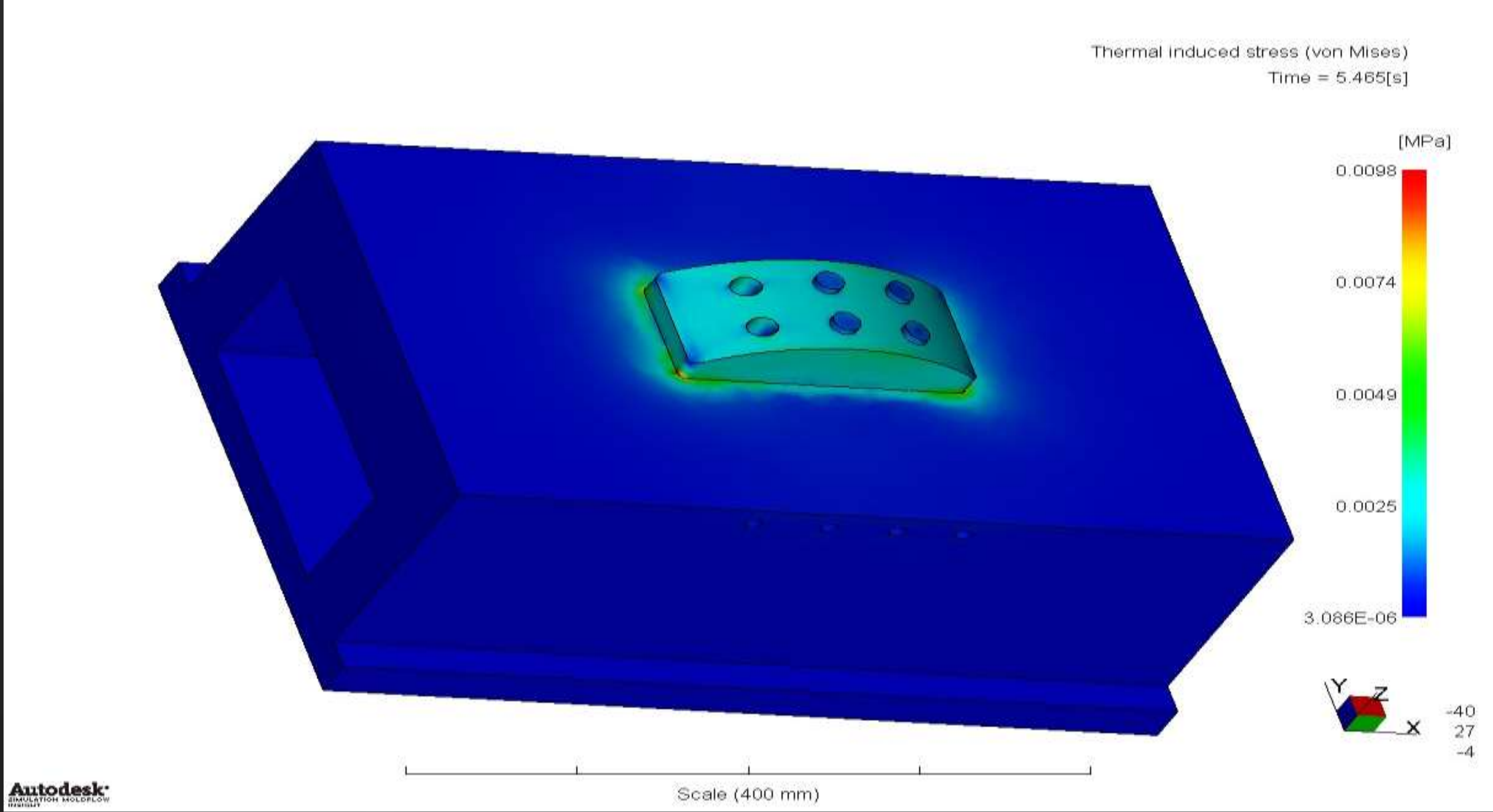


The model also considers debonding of the fibers from the matrix



Mold Fatigue Analysis with Autodesk Mechanical Simulation

- Mold Fatigue Analysis
  - Using temperature & stress history on mold from the Moldflow analysis
  - Use core-shift analysis
  - Use transient mold thermal analysis (Cool (FEM))
- Autodesk Mechanical
  - Thermal mold stress (cyclic)
  - Linear static stress
    - Polymer pressure
    - Clamp tonnage
  - Fatigue Wizard



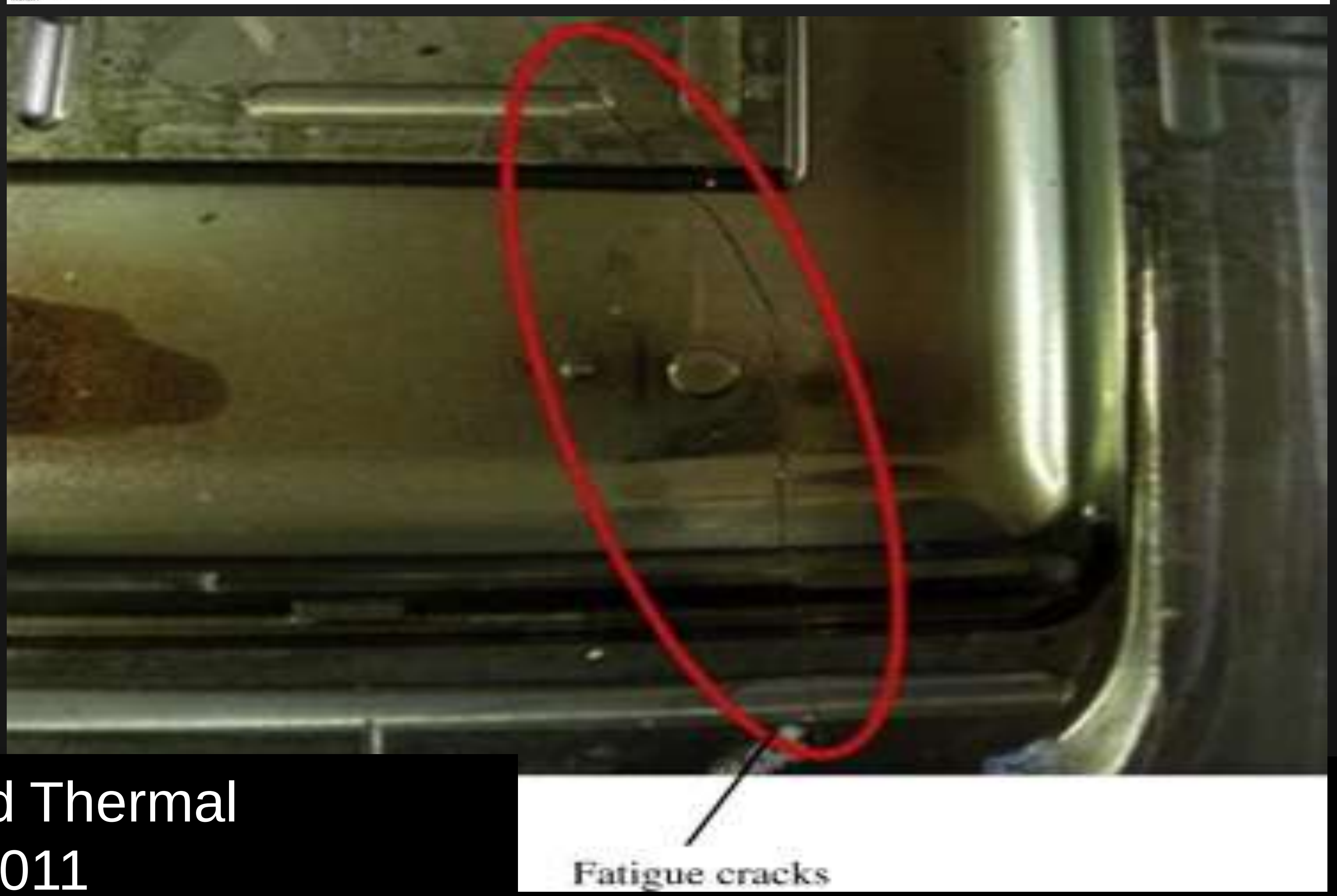
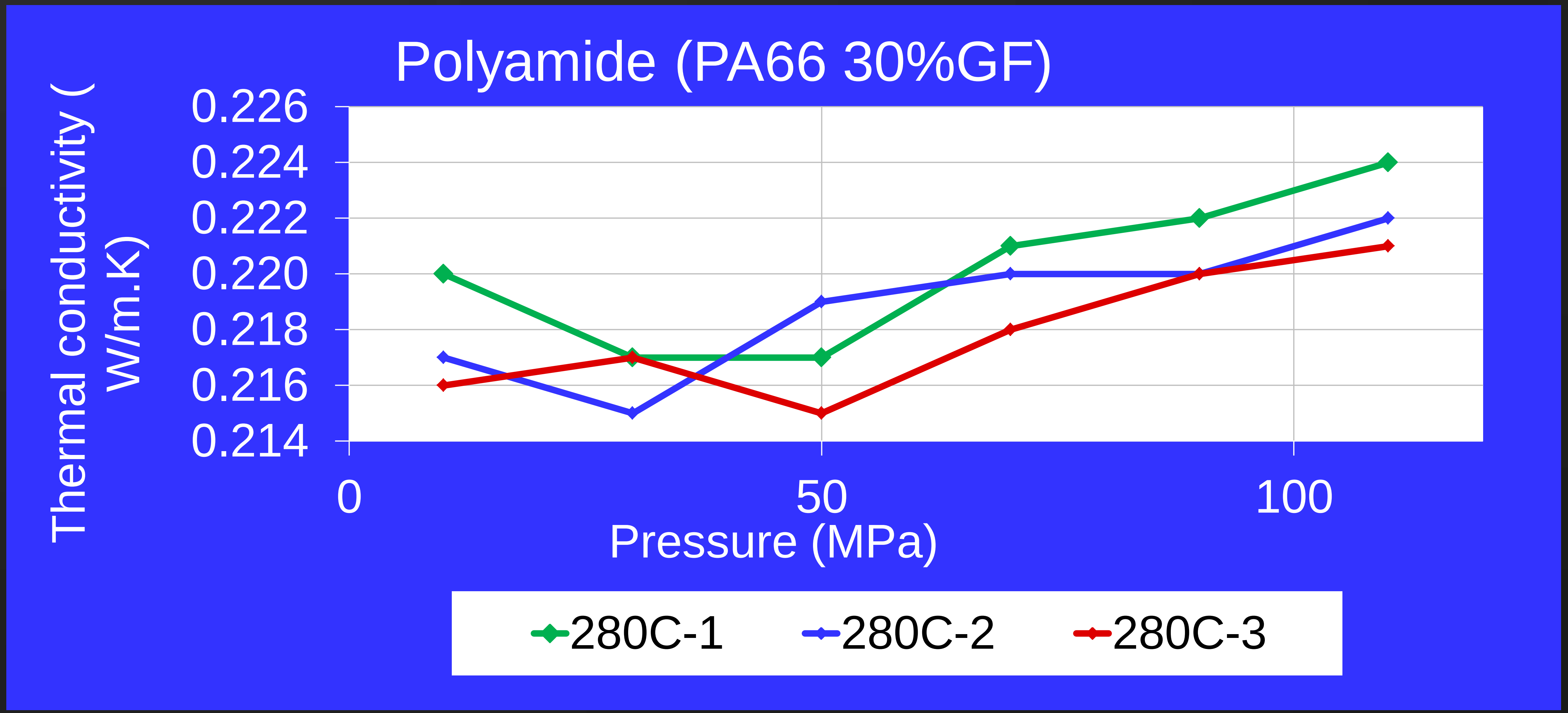
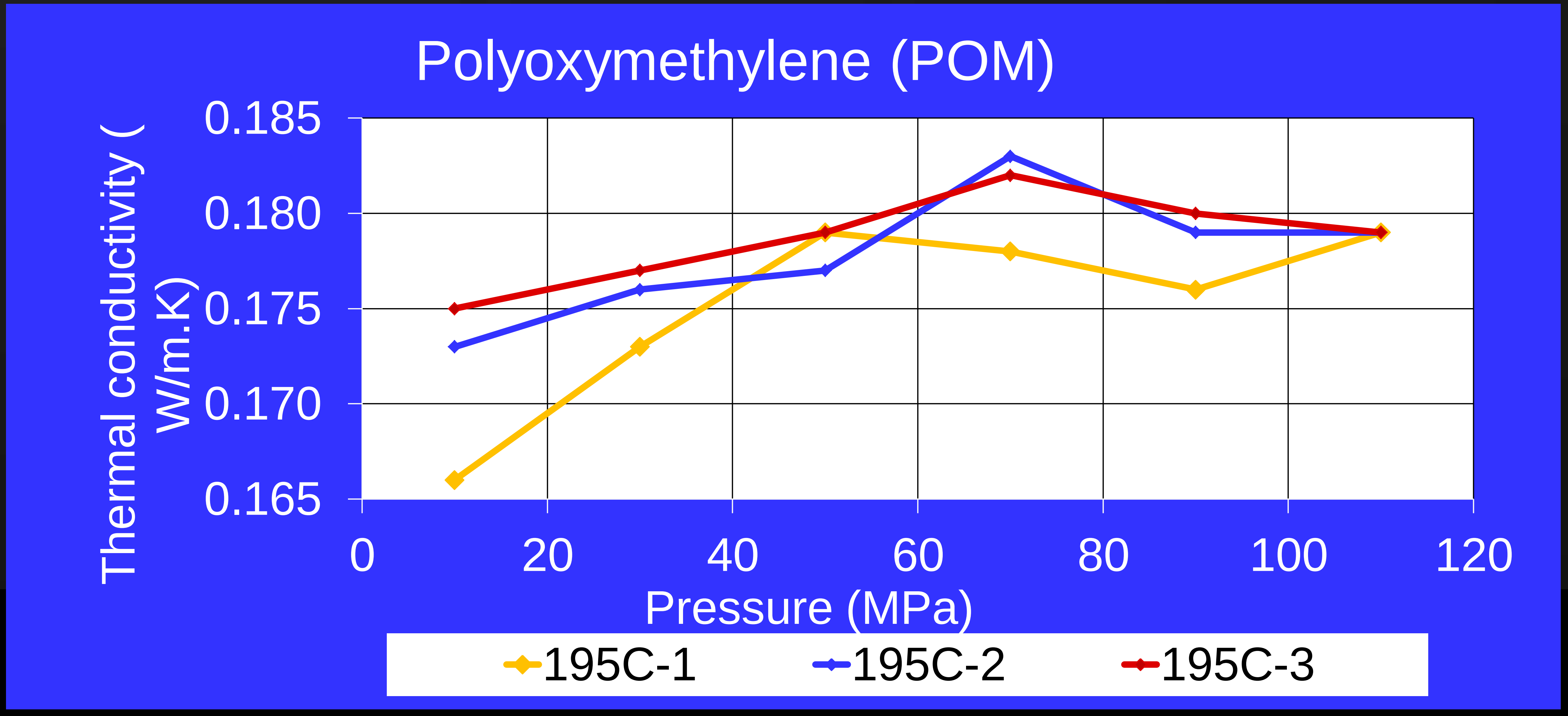


Image from Li *et al*: Applied Thermal Engineering, Vol 31, Dec 2011

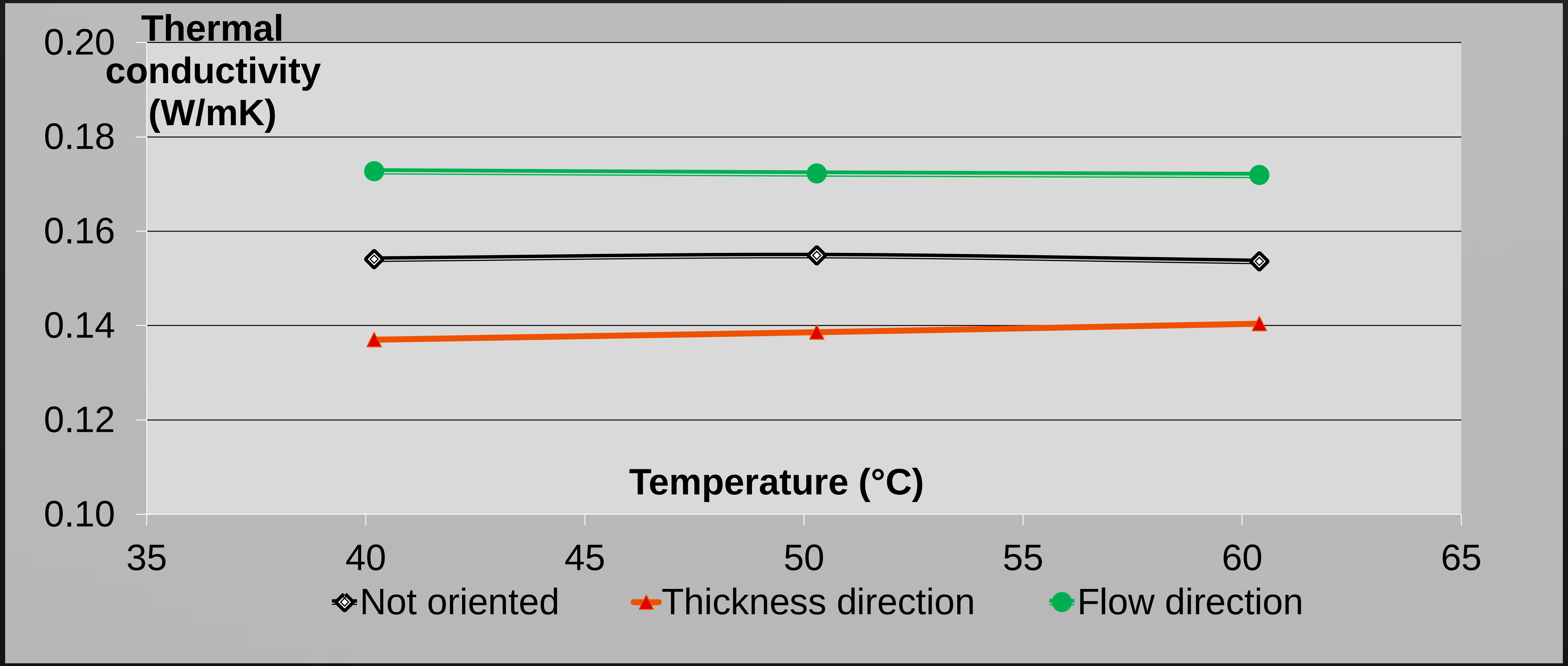
Research: Pressure Dependence of Thermal Conductivity

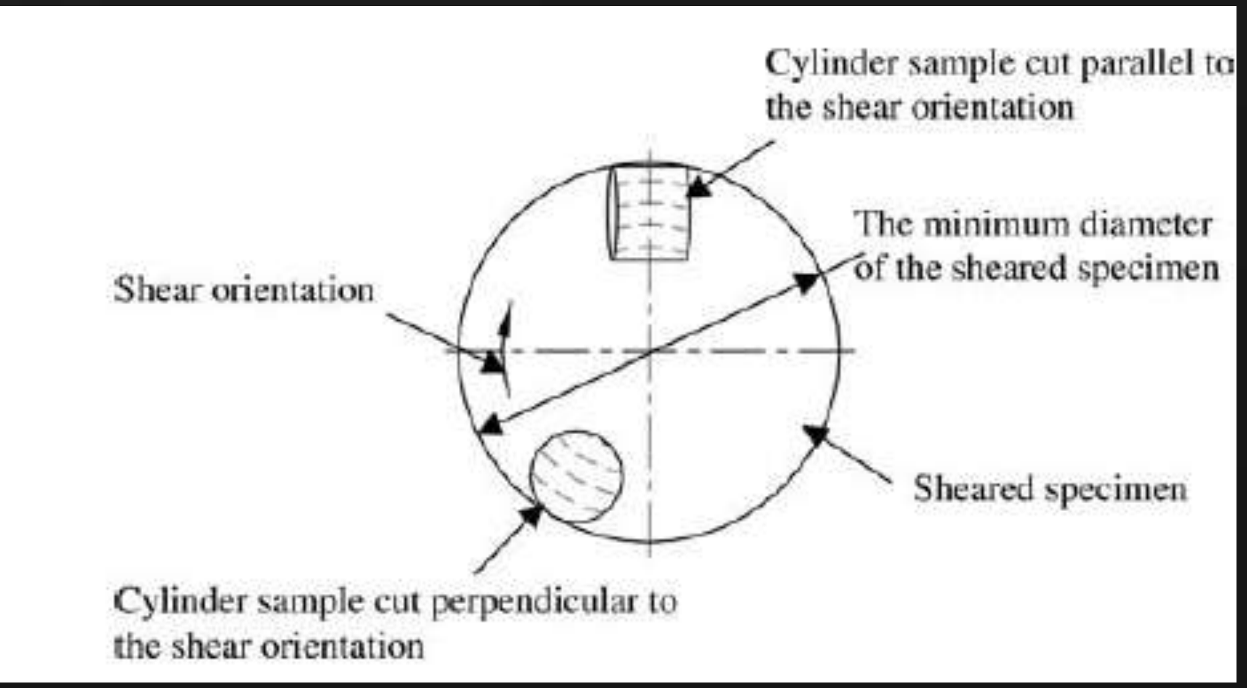




Anisotropic Thermal Conduction

- Research Study
  - Unfilled Polystyrene samples sheared in parallel-plate rheometer
  - Directional conductivity measured with Modulated DSC





Q & A

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