



Moldflow User Meeting Moldflow Research and Development Update

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Senior Research Leader



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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.

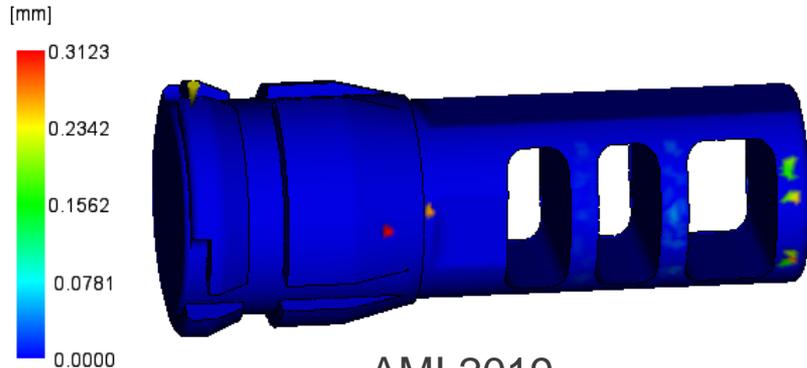
Sink Marks



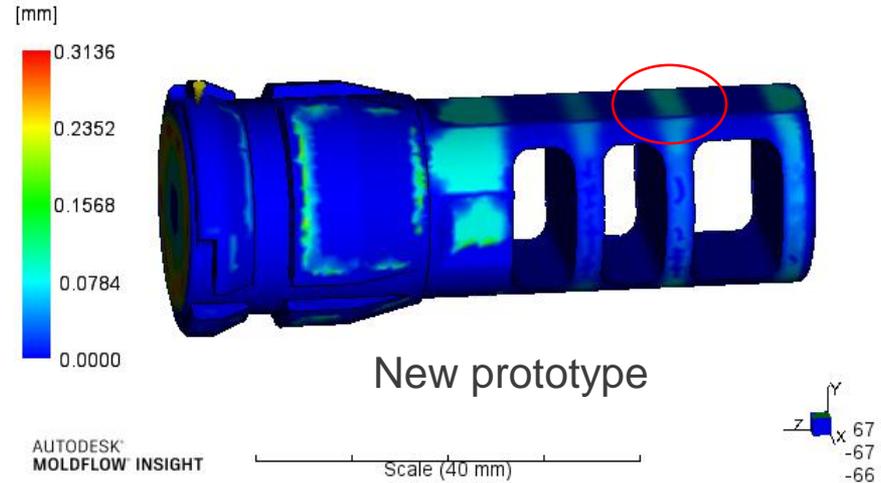
Sink Mark Predictions for General 3D Geometry

- Current method is limited to clearly defined ribs
- New method considers all geometry

Sink marks estimate
Scale Factor = 1.000



Sinkmark Estimate (New)
= 0.3136[mm]



Sink Mark Predictions for General 3D Geometry

- Current method is limited to clearly defined ribs
- New method considers all geometry

Sink marks estimate
Transition Temperature = 1.000

[mm]



AMI 2019

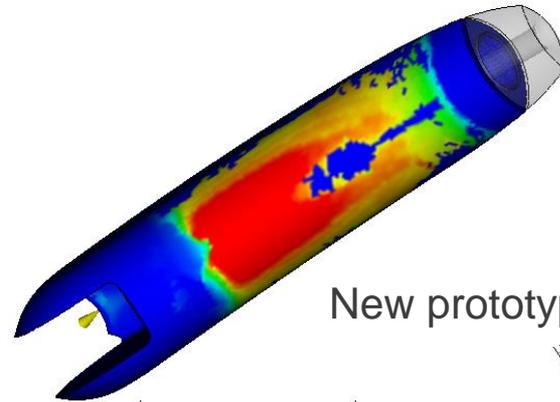
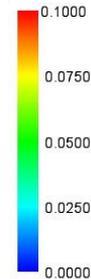


AUTODESK
MOLDFLOW INSIGHT

Scale (10 mm)

Sinkmark Estimate (New)
= 0.1000[mm]

[mm]

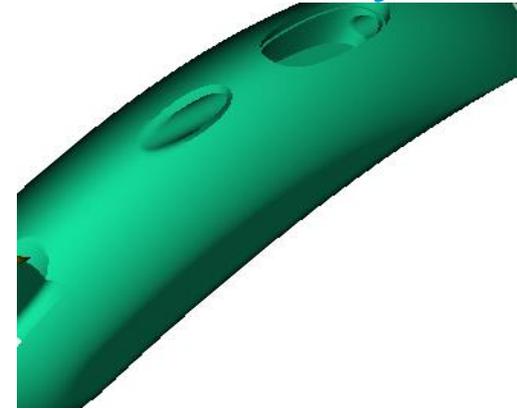


New prototype



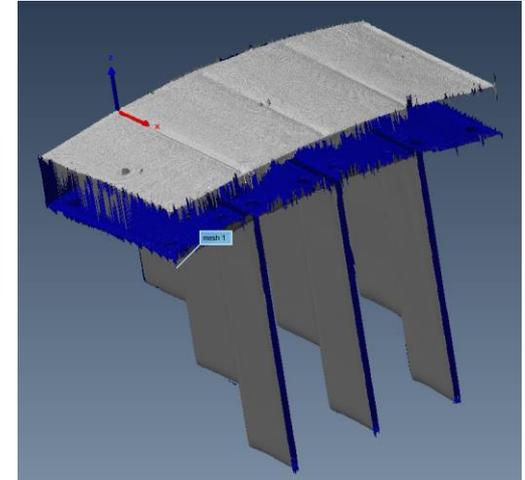
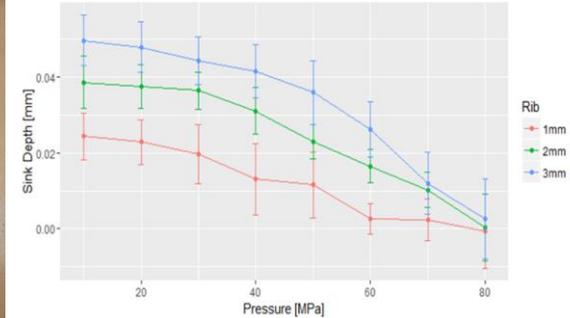
AUTODESK
MOLDFLOW INSIGHT

Scale (10 mm)



Sink Mark Validation

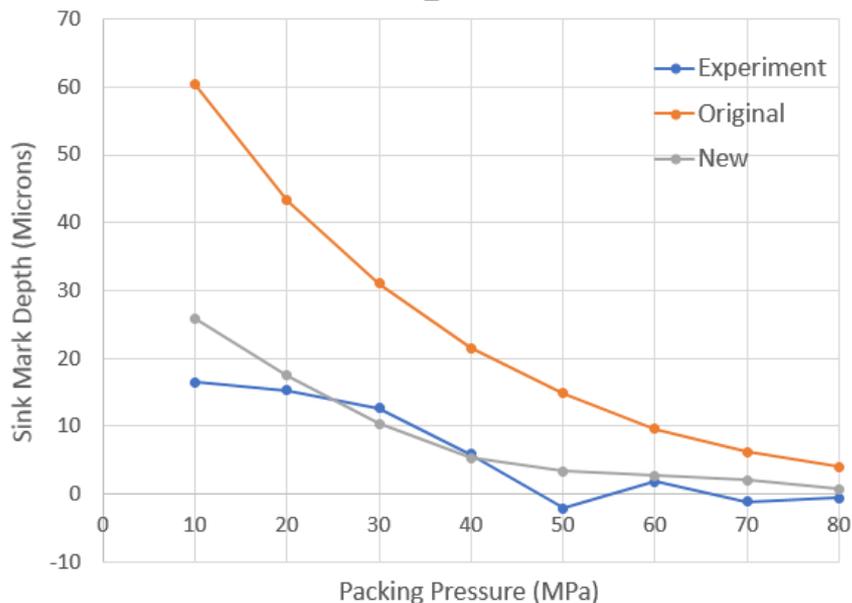
- Test Plaque with 1, 2 & 3mm thick ribs molded with different materials at various packing pressures
 - Example shown: ASA material
- Sink Mark Depth measured using laser scanner (exaggerated scan shown)
- Validation data:
 - Sink mark depth - pack pressure influence opposite each rib
 - Part cavity weight and volume measurements for solver validation



Sink Mark Validation Comparison

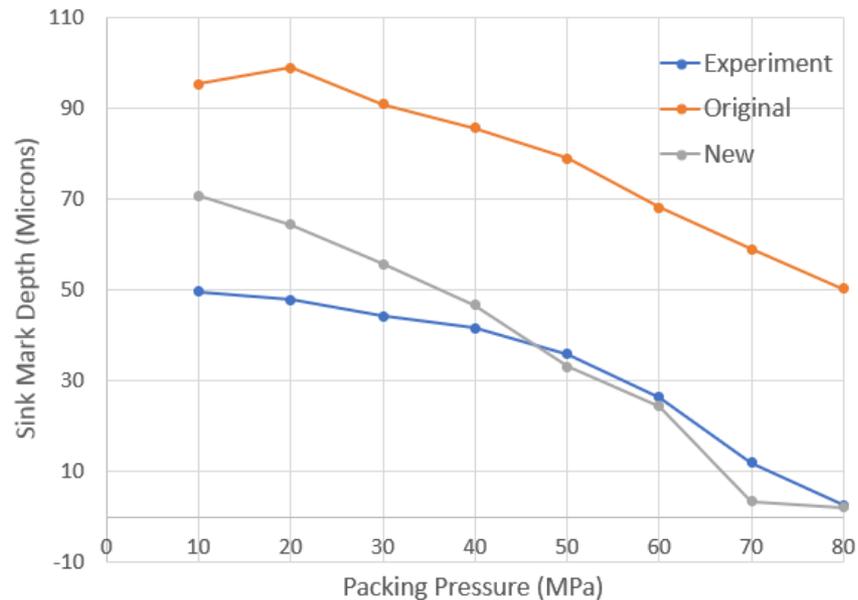
Narrow Rib (1 mm) Closest to the gate

Rib 1_Narrow



Wide Rib (3 mm) Furthest from the gate

Rib 3_Wide



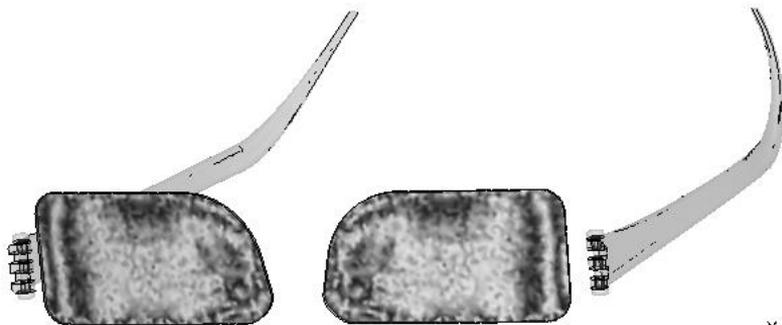
Other Visual Defects



Birefringence Fringe Plot

- New post-processing option to interpret birefringence results
 - Case-study shows the influence of overmolding stresses from the frame which changes the fringe (stress) pattern

Fringe pattern for light coming from +Z direction
= 180.0[deg]

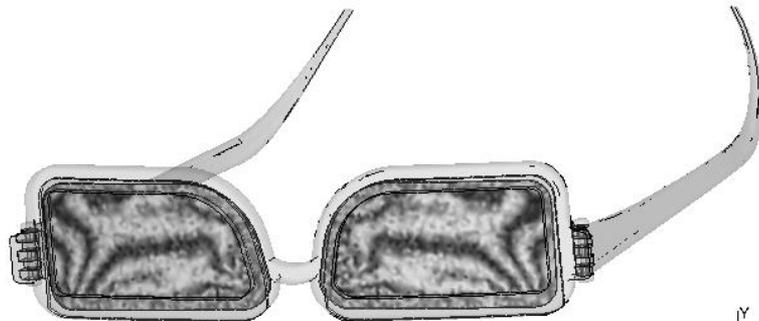


AUTODESK
MOLDFLOW INSIGHT

Scale (100 mm)

Single shot (no overmolding)

Fringe pattern for light coming from +Z direction
= 180.0[deg]



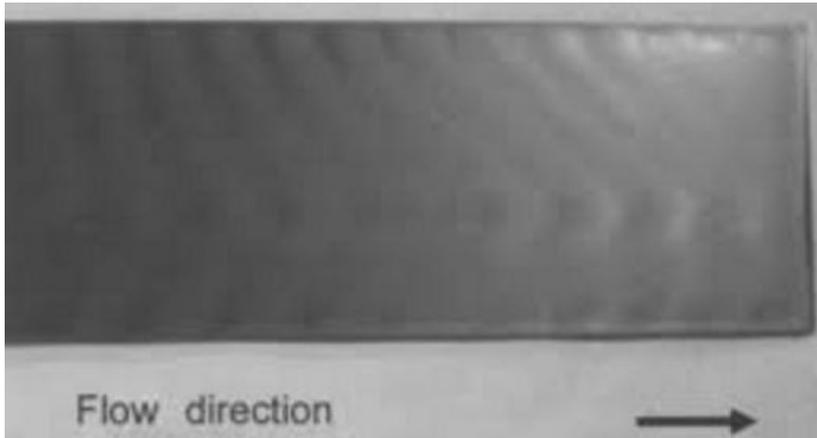
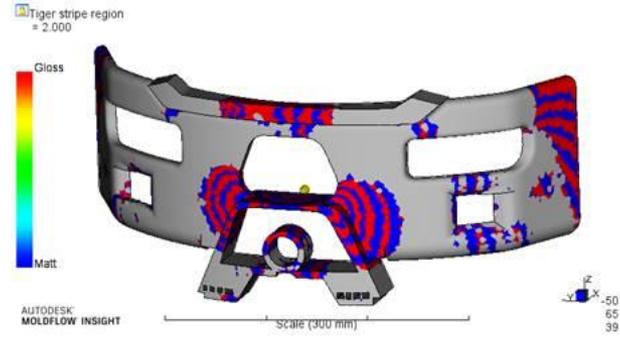
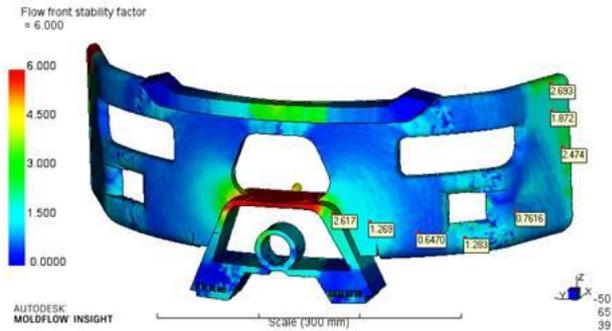
AUTODESK
MOLDFLOW INSIGHT

Scale (100 mm)

With Overmolded Frame

Prototype Tiger Stripes Prediction

3D; Collaborating on Validation Studies



Shrinkage Prediction

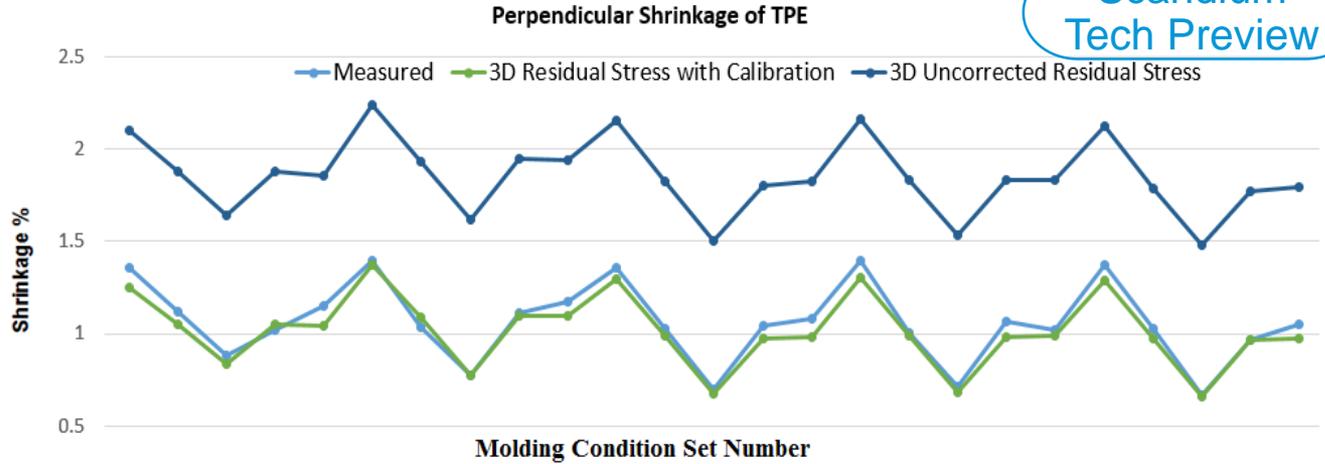


Shrinkage Calibrated Coefficient of Thermal Expansion

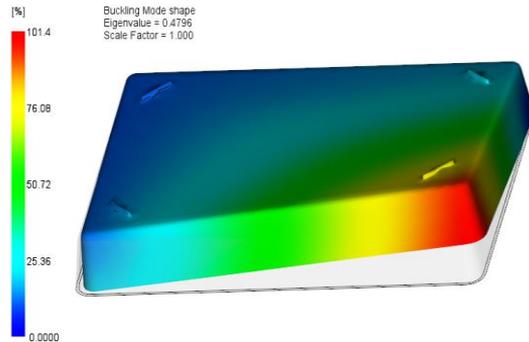
Scandium
Tech Preview

Moldflow's Shrinkage moldings

3D. For unfilled semi-crystalline materials with measured shrinkage data

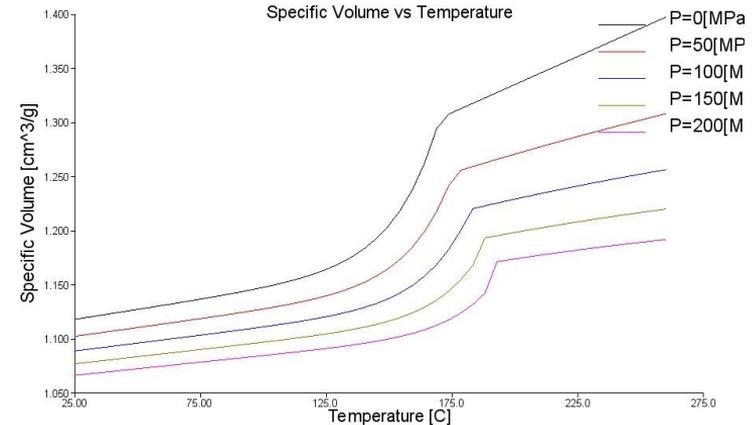


Warp Validation Molding



Consider Crystallization Effects on (3D) Shrinkage

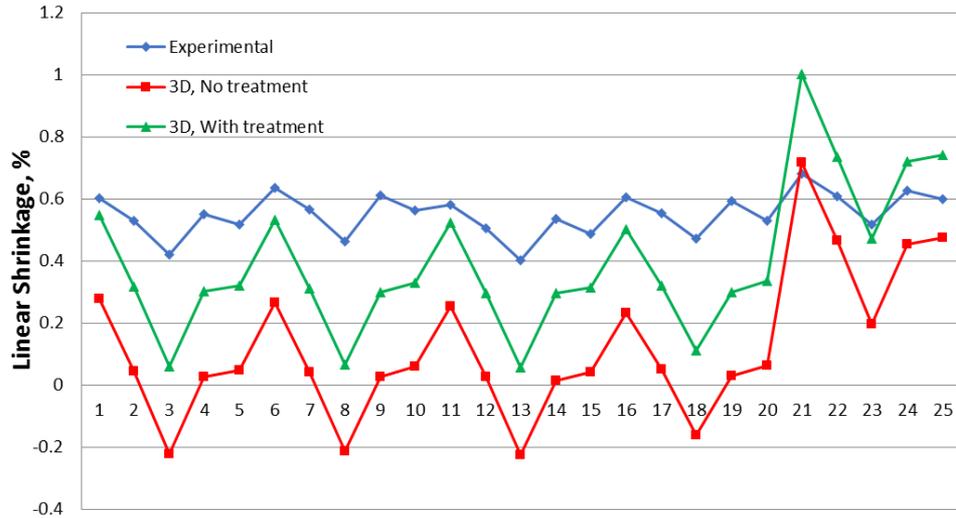
- Sharp drop in specific volume when a semi-crystalline material undergoes crystallization
- Proprietary treatment developed and implemented in Midplane and Dual Domain (DD) solvers in the past
- Same treatment has recently been implemented in 3D solvers
- Expected benefits:
 - More accurate shrinkage & warpage predictions from 3D solutions
 - Better consistency in shrinkage predictions between Midplane/DD and 3D solutions



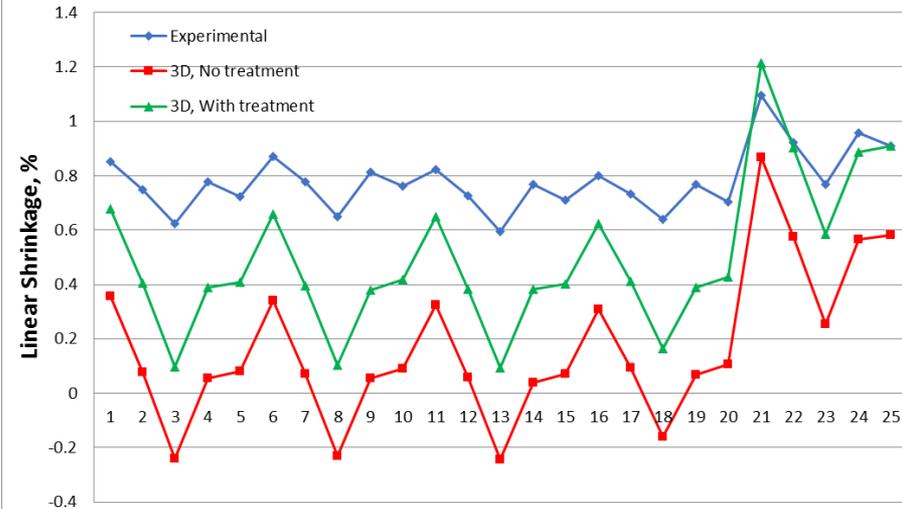
Consider Crystallization Effects on (3D) Shrinkage

- 3D Flow analyses for Shrinkage Tag Die / 25 processing conditions / uncorrected residual stress model)
- Comparison of linear shrinkage in parallel and perpendicular directions
- Level of predicted linear shrinkage improved after the treatment

Tag Die Shrinkage, Parallel (PP/Z6B01-37)

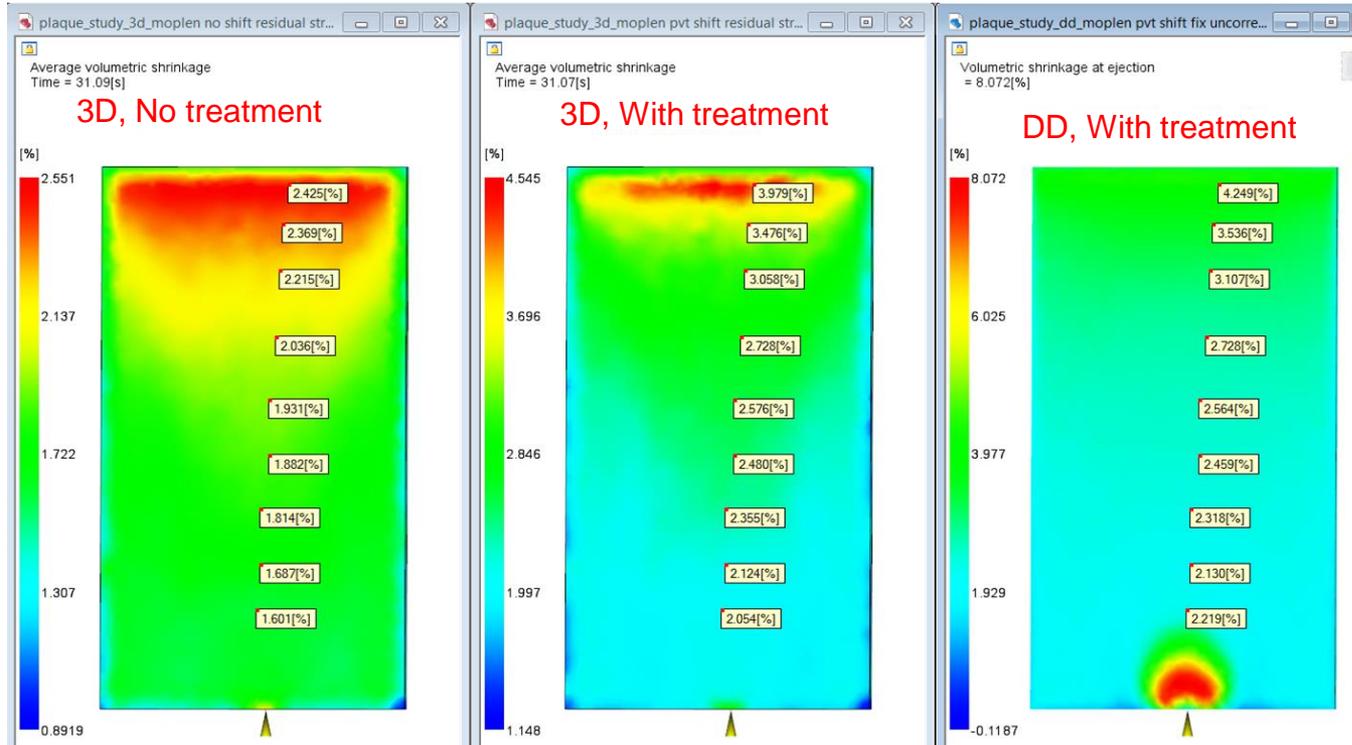


Tag Die Shrinkage, Perpendicular (PP/Z6B01-37)



Consider Crystallization Effects on (3D) Shrinkage

- More consistent volumetric shrinkage predictions between DD and 3D solvers with the treatment



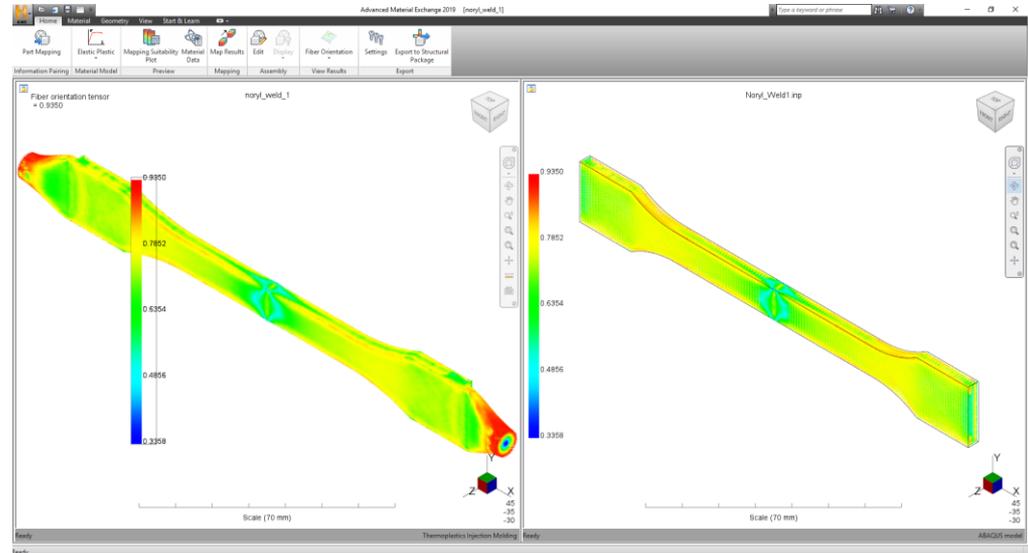
A 3D CAD model of a mechanical part, possibly a housing or bracket, is shown in a semi-transparent, cutaway view. The model is rendered in a light gray color. A large, semi-transparent white rectangular area is overlaid on the center of the model. Within this white area, there are several colored regions: a blue region at the top, a green region in the middle, and an orange region at the bottom. These colored regions represent different material layers or material exchange zones. The background is a light gray gradient.

Autodesk Material Exchange / Helius

Extend FEA Support for AME/Helius

FEA Support

FEA Platform for Helius (future)	Version
Abaqus	2018, 2019
ANSYS	19.x, 2019 R1
Autodesk Nastran/Nastran In-CAD	2019, 2020



Robust Weld Strength Failure Model in Helius

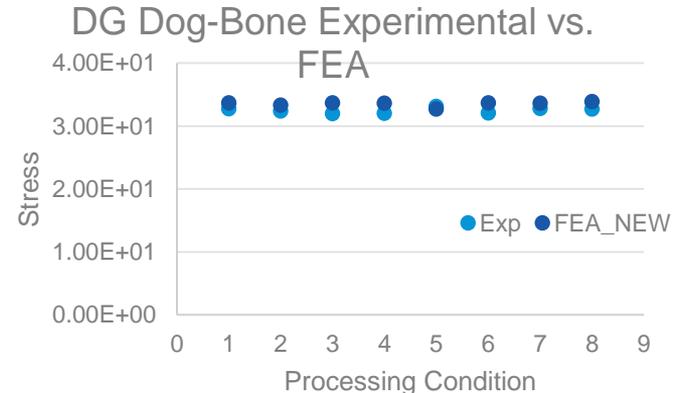
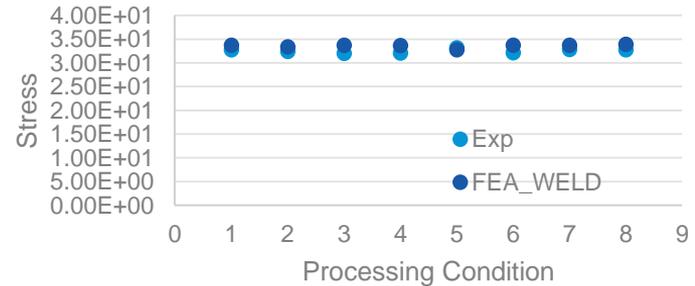
Helius / AME

- Maximum Distortion Energy Criterion i.e. Von Mises Stress measure.

$$\sqrt{\frac{(\tau_{11} - \tau_{22})^2 + (\tau_{22} - \tau_{33})^2 + (\tau_{33} - \tau_{11})^2 + 6(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)}{2}} = S_y$$

- Requires only one Double-gated tensile test to calibrate.

DG Dog-bone Tensile Test



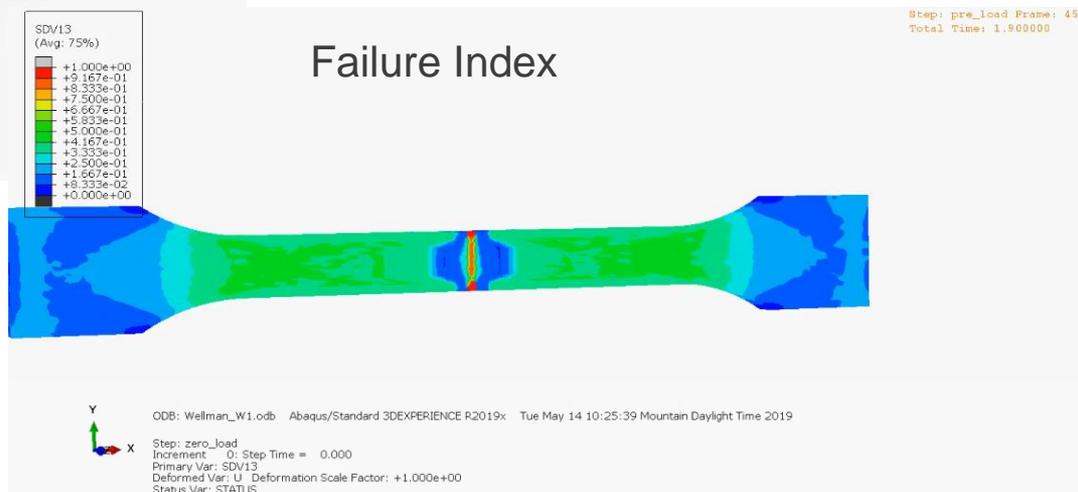
Robust Weld Strength Failure Model in Helius

Helius / AME

Von Mises Stress



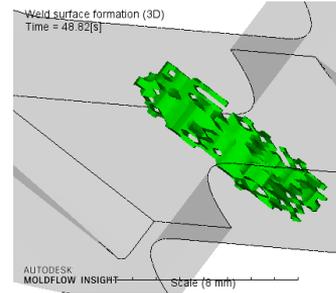
Failure Index



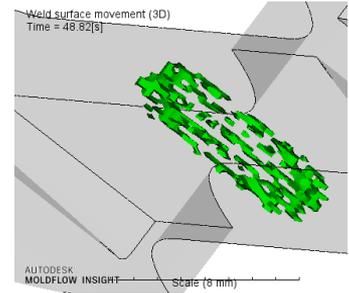
Weld Surface Prediction

- Broken weld surfaces predicted in Moldflow 2019:
 - Difficulty in weld surface strength characterization
 - Less accurate in structural FEA
- Improvement to obtain more continuous weld surface

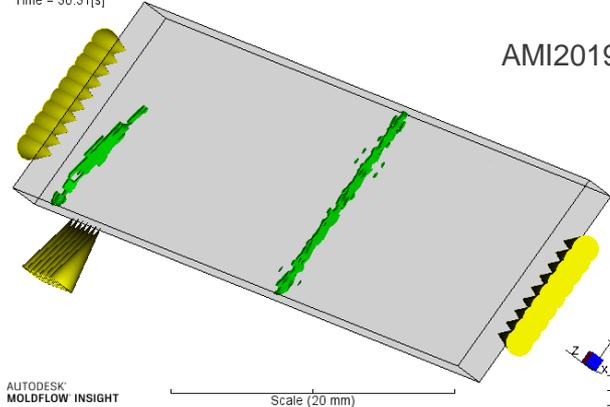
Initial Weld Surface position



Weld position after packing flow

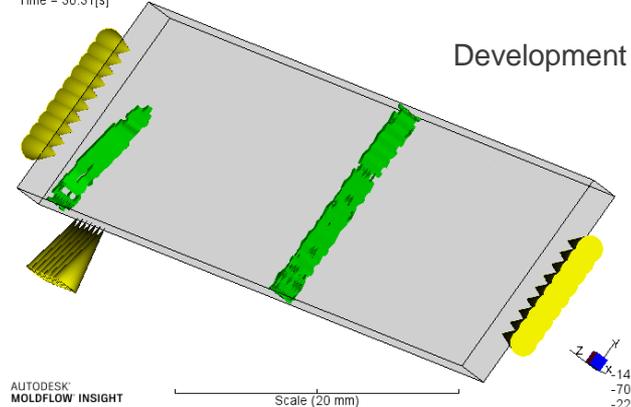


Weld surface formation (3D)
Time = 30.31[s]



AMI2019

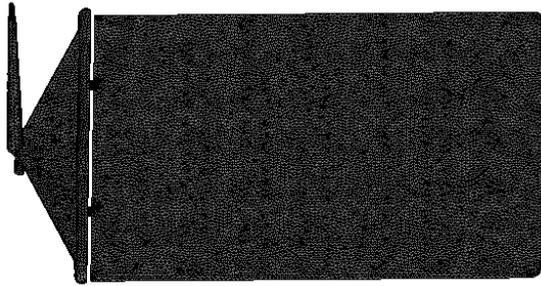
Weld surface formation (3D)
Time = 30.31[s]



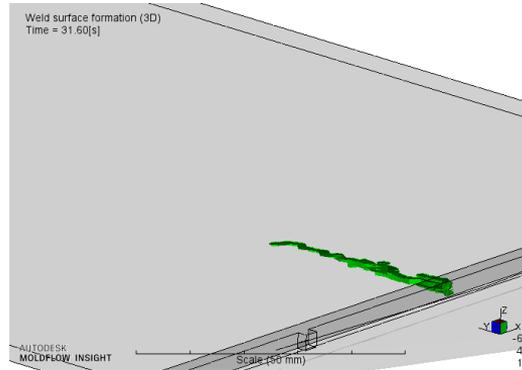
Development

Weld Surface Movement

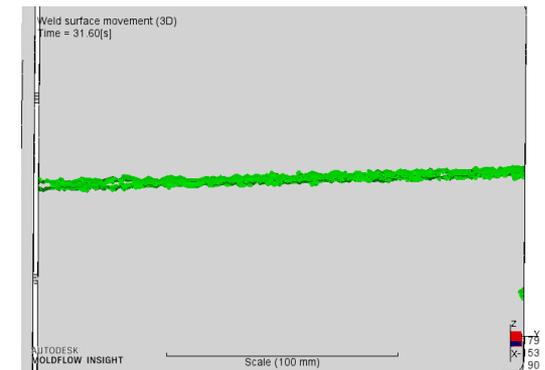
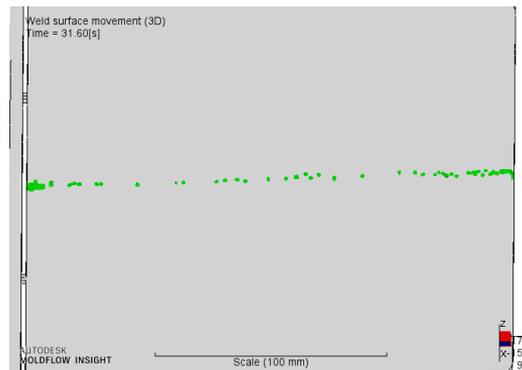
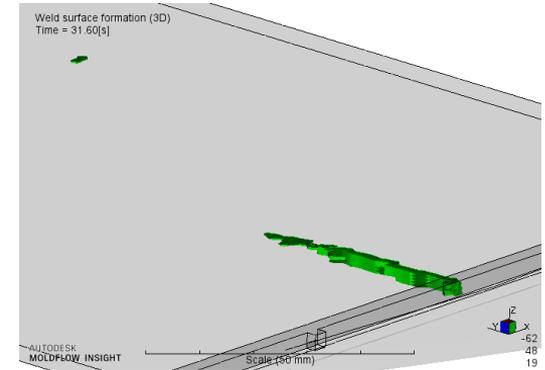
Two tab gate plaque



AMI2019



Development



A 3D CAD model of a mechanical part, possibly a housing or bracket, is shown in a semi-transparent white view. Overlaid on the model is a stress analysis visualization. The stress is represented by a color gradient: blue for low stress, green for medium stress, and orange for high stress. The highest stress (orange) is concentrated in the lower, thicker sections of the part, while the upper, thinner sections show lower stress levels (blue and green).

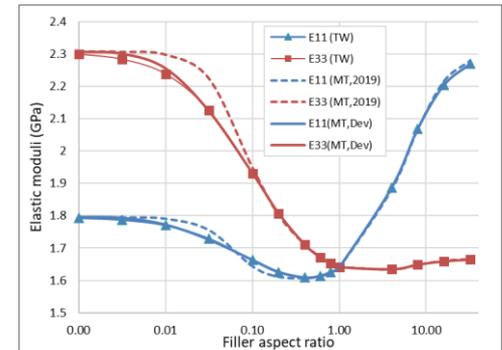
Mechanical Properties

Improvement and Bugfix in Property Calculation

Moldflow: Midplane, Dual-Domain & 3D

- Issue: non-physical composite properties predicted for some certain grades with *isotropic matrix*
 - Cause: wrong formula for one minor Poisson's ratio of composite in Tandon-Weng solution
 - Fix: re-derived and implemented the correct formula
 - Change: decomposed matrix properties and calculated composite properties
 - Changes are expected to be small for most grades, but might be large in decomposed matrix for some grades
- Issue: poor accuracy in Mori-Tanaka solution for some ranges of aspect ratio for *anisotropic matrix* (e.g. LCP)
 - Cause: poor accuracy in numerical integration for Mori-Tanaka solution
 - Fix: increased the accuracy and efficient of numerical solution
 - Change: Significant for disk-like fillers, not significant for fibers

Verification for uni-directional composite with isotropic matrix (TW and MT should be identical)

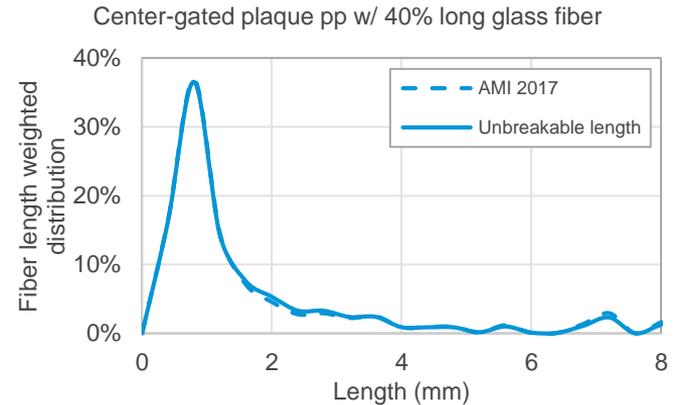
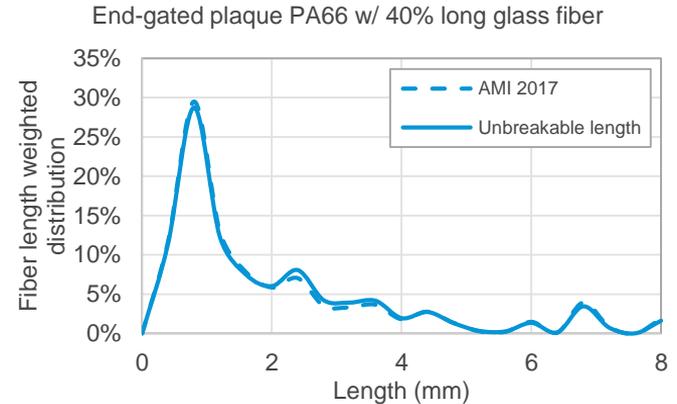


Fiber Breakage Model

Fiber Length Distribution

- Unbreakable length proposed by Phelps et al.*
 - More reasonable physical model
 - Already implemented in 3D in AMI 2017.3
 - To be implemented in Midplane and Dual Domain in next major AMI release
 - Very small change in length breakage is expected

* Phelps, J. H., Abd El-Rahman, A. I., Kunc, V., & Tucker, C. L. (2013). A model for fiber length attrition in injection-molded long-fiber composites. *Composites Part A: Applied Science and Manufacturing*, 51, 11–21. <https://doi.org/10.1016/j.compositesa.2013.04.002>



Foam Injection Molding

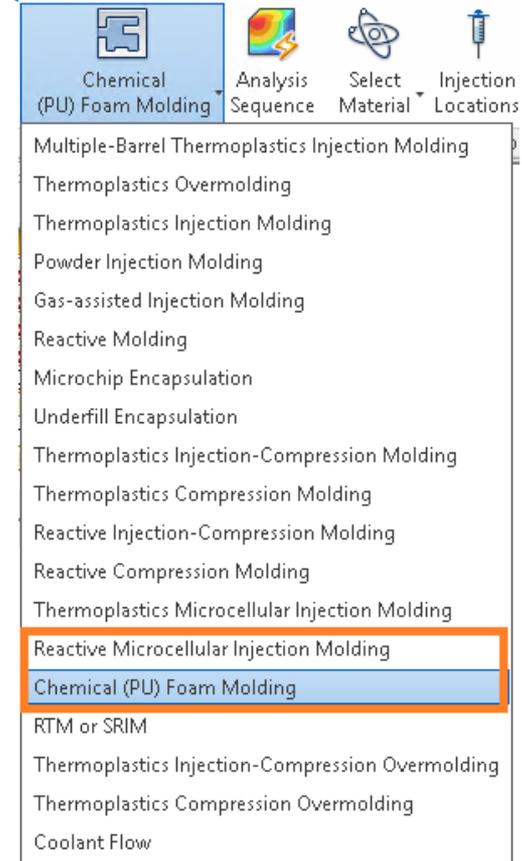


Reactive Microcellular Injection Molding & Chemical (PU) Foam Molding

Two New Processes:

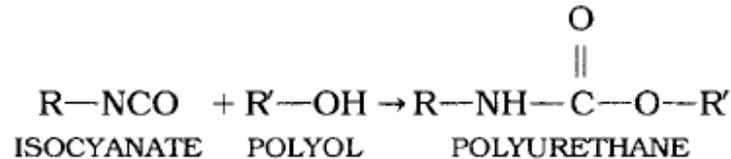
- Reactive Microcellular Injection Molding
 - Similar to “Thermoplastics Microcellular Injection Molding” process except that it is for thermoset materials

- Chemical (PU) Foam Molding
 - PU Foaming or General Chemical Blowing Agent Reaction
 - Foaming gas is generated during molding, so the reaction that generates a foaming gas is considered during the analysis
 - Still also have a separate reaction analysis for the curing of the resin

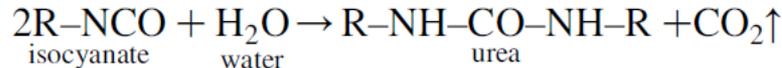


Chemical (PU) Foam Molding

- PU Foaming:
 - Considers gelling reaction and blowing reaction
 - Gelling reaction (thermoset curing)



- Blowing reaction



- General Chemical Blowing Agent Reaction
 - Blowing agent is generated by different chemical reaction from PU Foaming

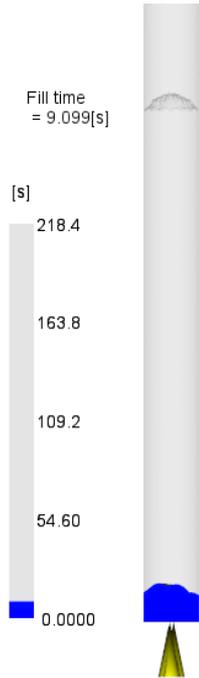
Kinetics data

Chemical blowing agent kinetics		
H	<input type="text" value="4.78e+06"/>	J/kg [0:1e+07]
m	<input type="text" value="0"/>	[0:100]
n	<input type="text" value="1"/>	[0:100]
A1	<input type="text" value="1.8507e+05"/>	1/s [0:]
A2	<input type="text" value="0"/>	1/s [0:]
E1	<input type="text" value="5306.7"/>	K [0:1e+08]
E2	<input type="text" value="0"/>	K [0:1e+08]

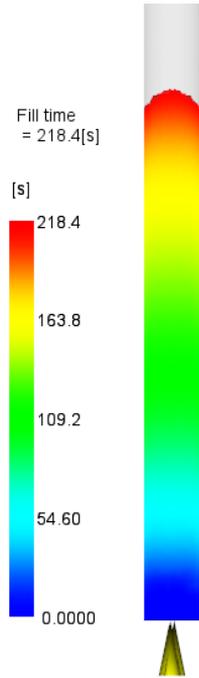
Chemical blowing agent kinetics

Chemical (PU) Foam Molding: Example 1

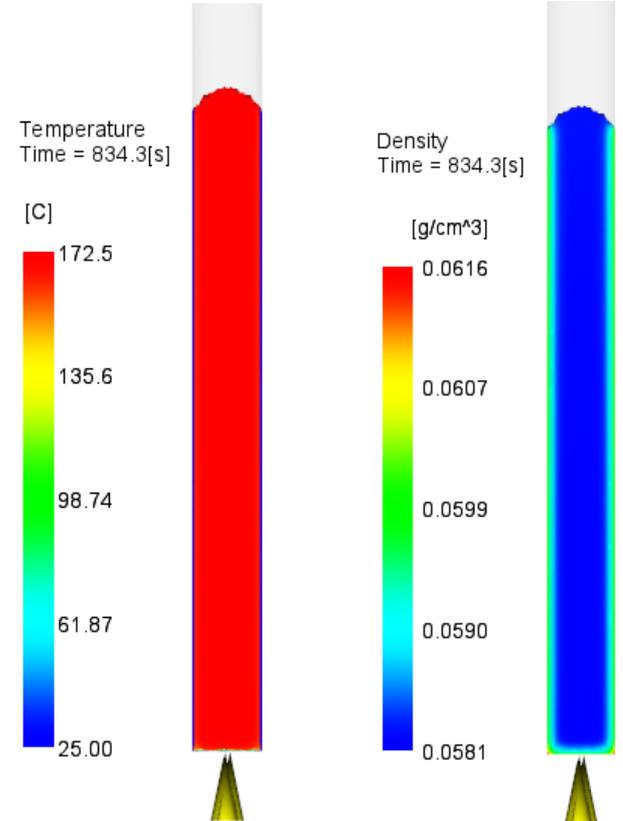
- Initial cavity filling by injection: 2.5% of total cavity volume
- After the end of injection: Cavity filling done by foaming
- Initial melt temperature: 34 C, mold temperature: 25C



Initial filling

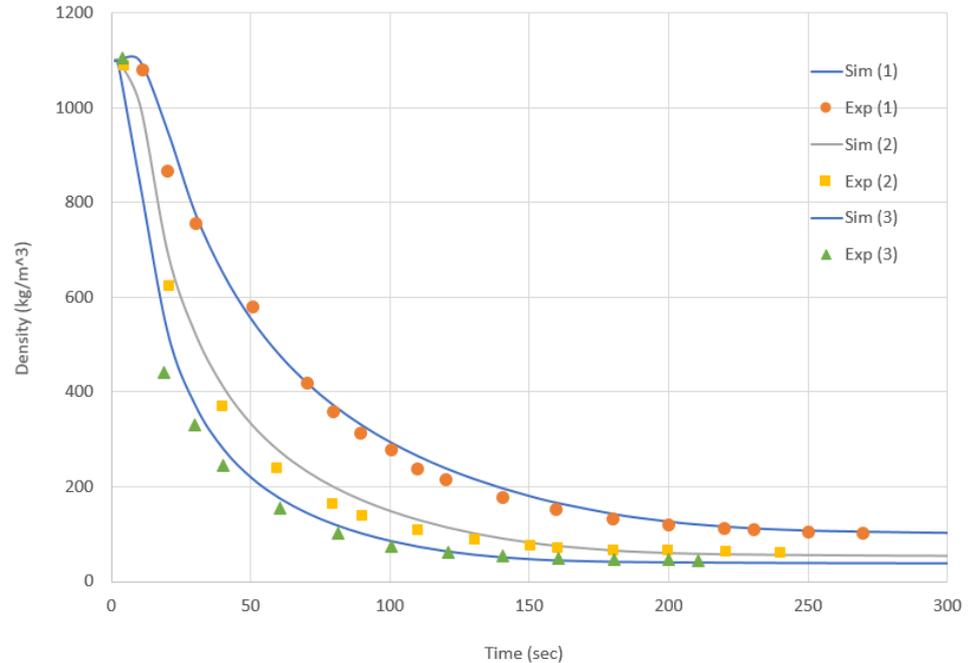
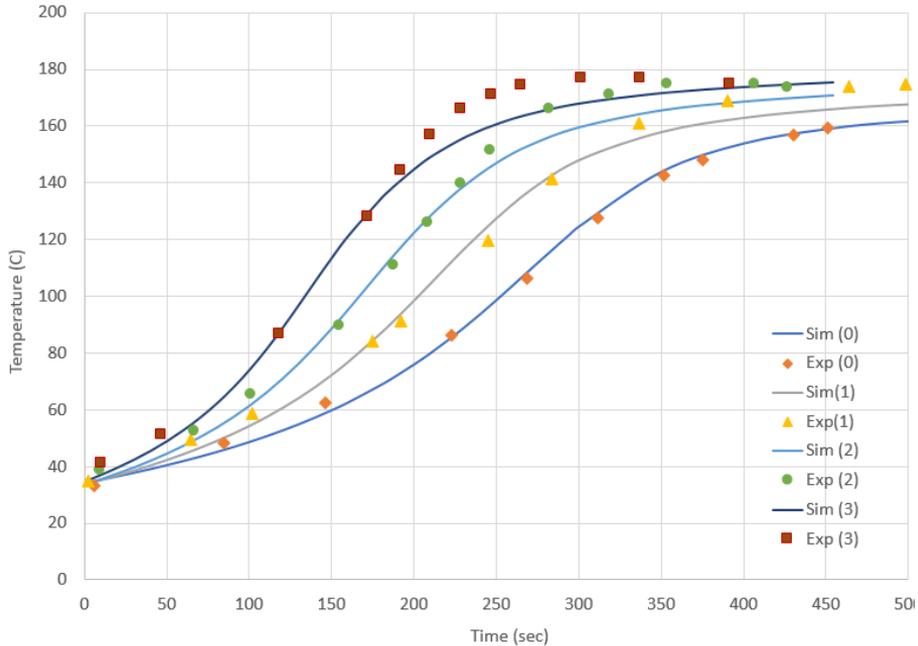


Filling by foaming



Chemical (PU) Foam Molding: Example 1

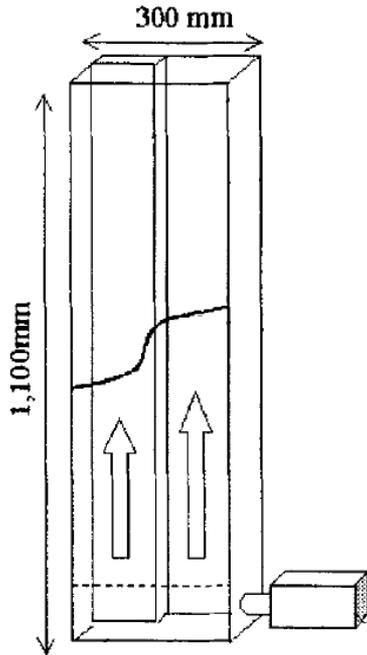
- Comparison of temperature and density history from experiment and simulation
- Water concentration: [0,] 1, 2, 3%



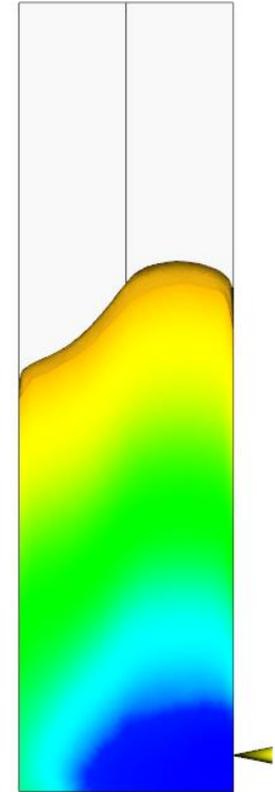
Experiment: Baser et al, 1994

Chemical (PU) Foam Molding: Example 2

- Comparison of flow front advancement between experiment and simulation
- Variable cavity thickness (35 mm: left, 65 mm: right)



Experiment: Mitani et al, 2003



Optimization

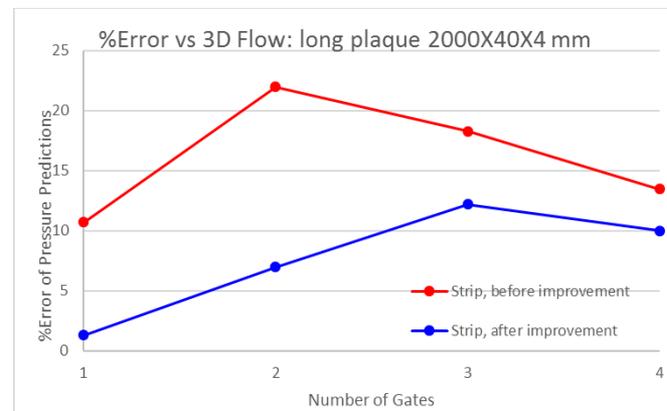
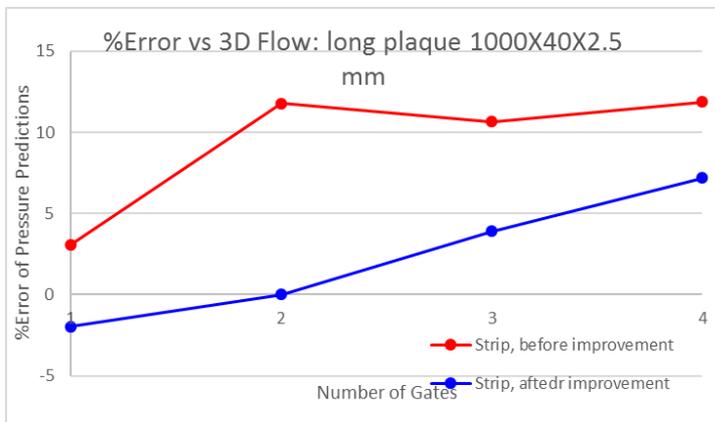
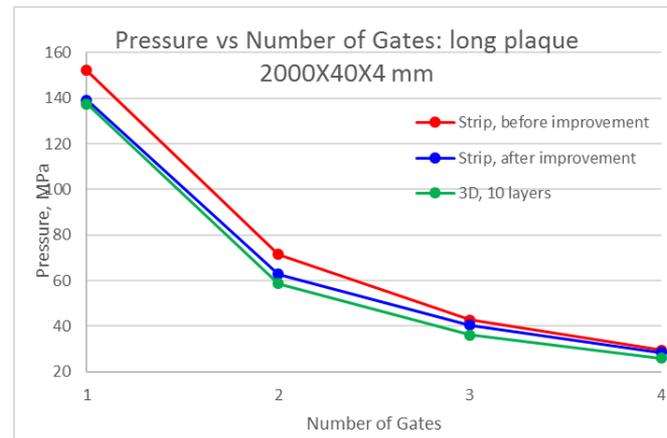
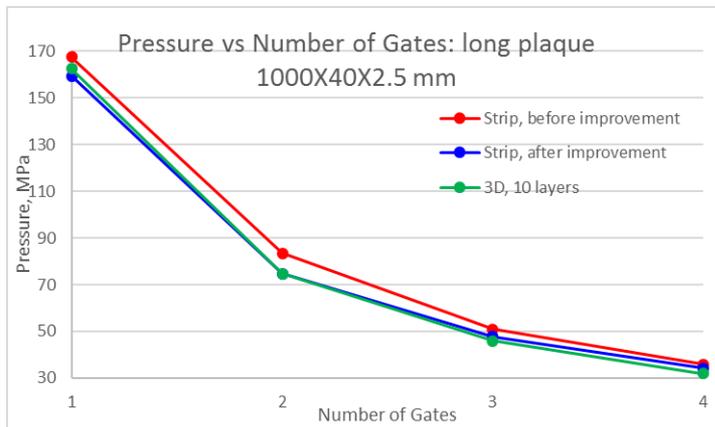


Improve Strip Solver Accuracy

Used by Midplane, Dual-Domain & 3D

- Accuracy is important as Strip Solver is a building block for Moldflow products such as Auto Injection Time (AIT), Runner Balancing, Molding Window, etc.
- Enhancements under implementation & testing
 - Include the effect of Mold-melt Heat Transfer Coefficient (HTC) – Consistent with the thermal boundary conditions used in other solvers (Midplane, DD, and 3D)
$$-k \frac{\partial T}{\partial n} = h[T - T_w]$$
 - Improve pressure drop calculation within a strip segment by including shear heating effect into the calculation of current segment
 - Preliminary test on a long plaque with material Xantar C CF407 (PC+ABS blend) showed accuracy improvement in pressure predictions (compared with 10 layer 3D Flow solutions)

Improve Strip Solver Accuracy: Test on Long Plaque



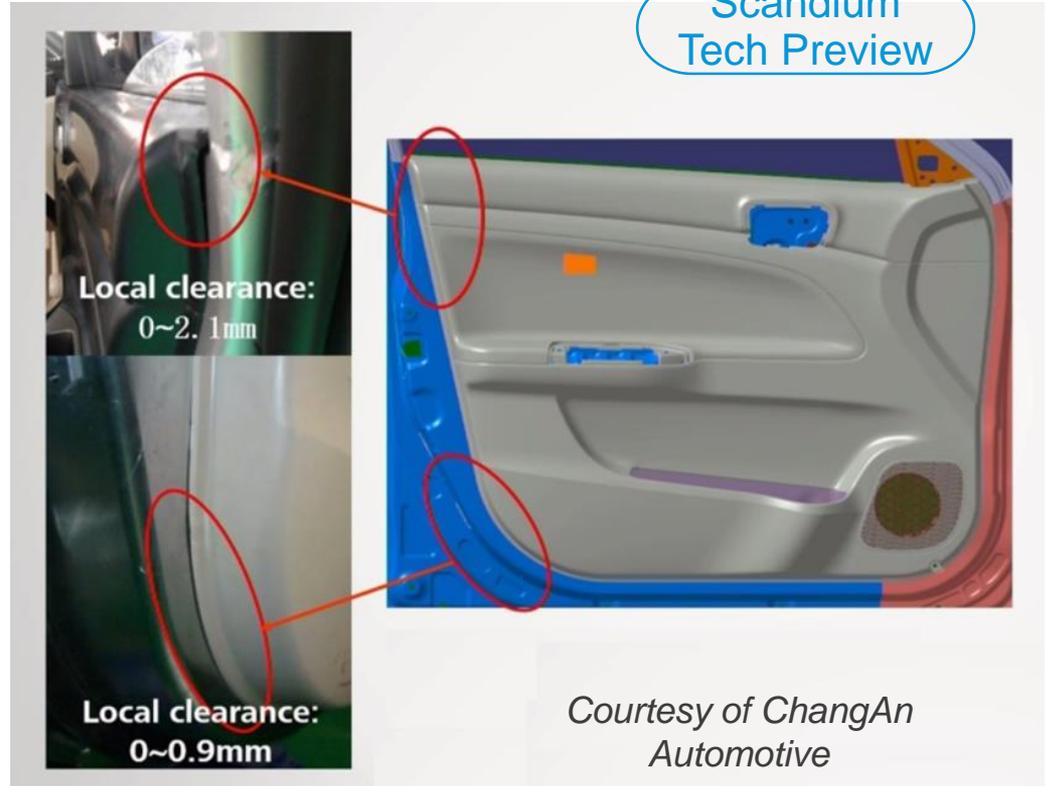
A 3D CAD model of a complex mechanical part, possibly a mold or a housing, shown in a semi-transparent view. The model is rendered in a light gray color. A semi-transparent overlay, colored in shades of blue, green, and orange, is applied to a portion of the model, highlighting specific internal features or sections. The overlay is divided into several distinct colored regions: a blue region at the top, a green region in the middle, and an orange region at the bottom. The text "Other Warp Enhancements / Prototypes" is overlaid on the image in a black, sans-serif font.

Other Warp Enhancements / Prototypes

Molded Component Assembly--Mounting Analysis

Scandium
Tech Preview

- Predicting the deformation and stress of injection molded components after being mounted into designed position
- Check if the assembly outcome can meet the tolerance requirement of geometric dimensioning and tolerancing.
 - Analysis using mold dimensions
 - Adjusts assembly constraints according to mold shrinkage allowance
- Top requested issue in Users' Group Meeting India and Europe



Molded Component Assembly--Mounting Analysis

Scandium
Tech Preview

Warping analysis type
Small deflection Use mesh aggregation

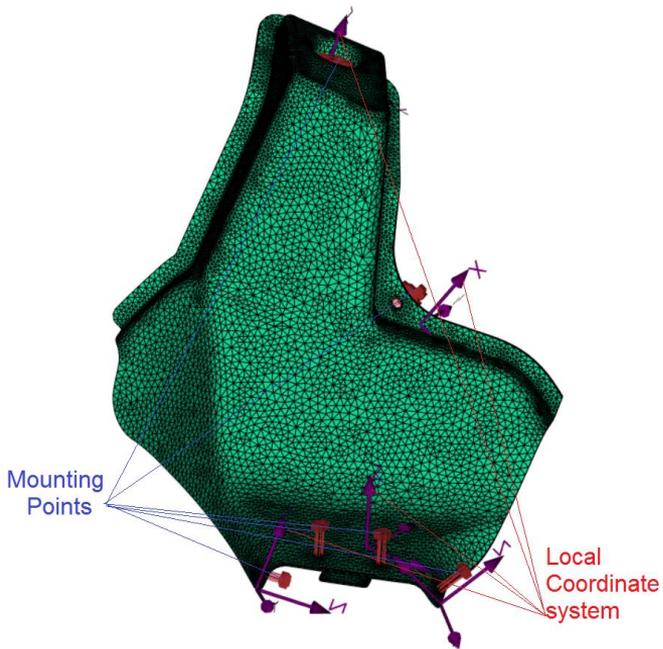
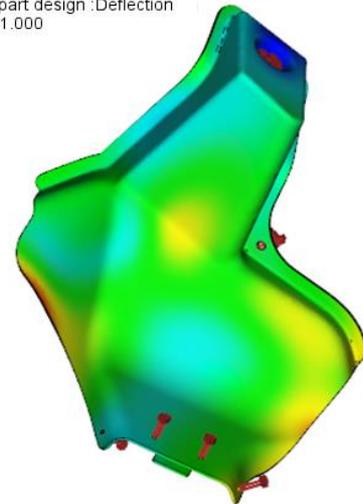
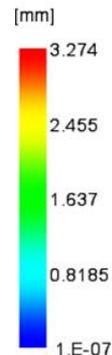
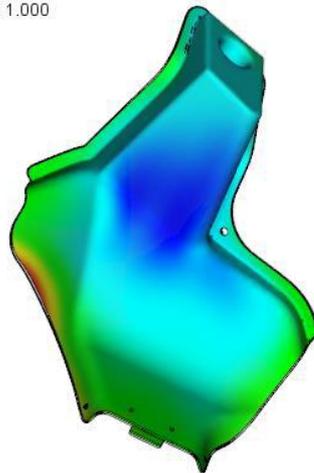
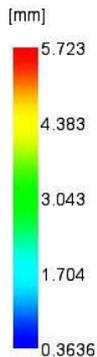
Isolate cause of warpage
Upgrade tetrahedral elements to second order All

Consider mold thermal expansion
 Calculate final deformation after assembly

Nominal shrinkage for mold making(percentage) 1

Deflection, all effects:Deflection
Scale Factor = 1.000

Deviation from part design :Deflection
Scale Factor = 1.000



Mounting details

Warped shape without considering assembly

Final geometric deviation from designed shape and size after assembly

Considering Stress Relaxation

3D Anisotropic Thermo-Viscoelastic Residual Stress Model

$$\sigma_{ij}(t) = \int_0^t C_{ijrs} (\xi_{(t)} - \xi_{(\tau)}) \left(\frac{\partial \varepsilon_{rs}}{\partial \tau} - \alpha_{rs} \frac{\partial T}{\partial \tau} \right) d\tau$$

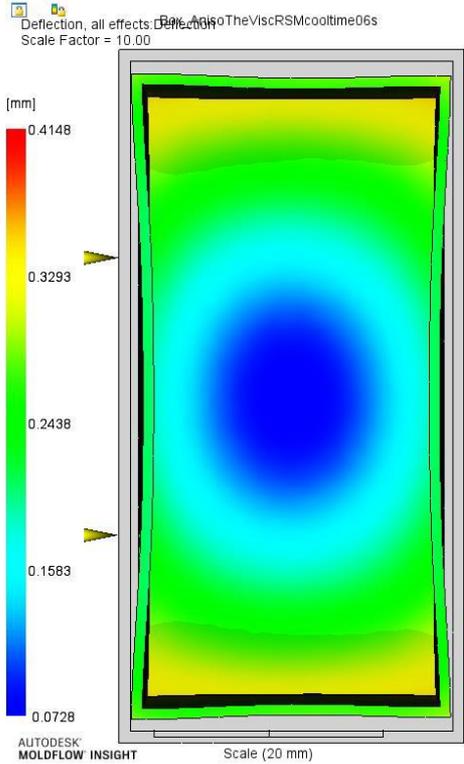
- Viscoelastic Material Modelling: Generalized Maxwell Model

- $G(t) = G(0)\varphi(t) = G(0)[g_\infty + \sum_{k=1}^N g_k \exp(-\frac{t}{\tau_k})]$

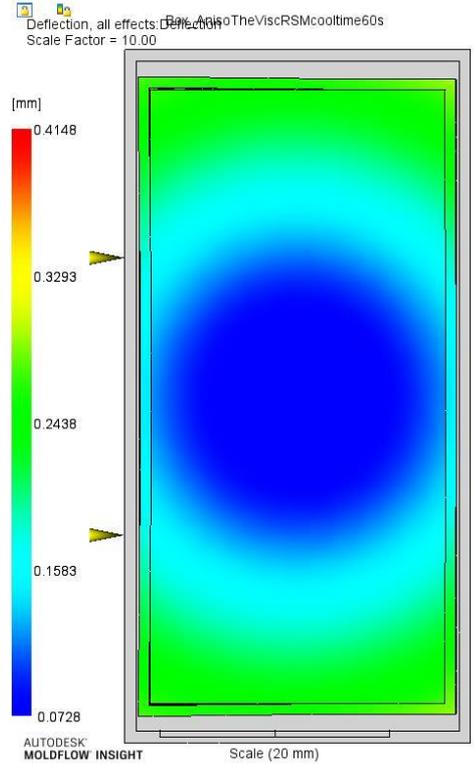
- Shift factor for Time-temperature Superposition
Tabulated shift Data, WLF equation, Arrhenius equation

Considering Stress Relaxation

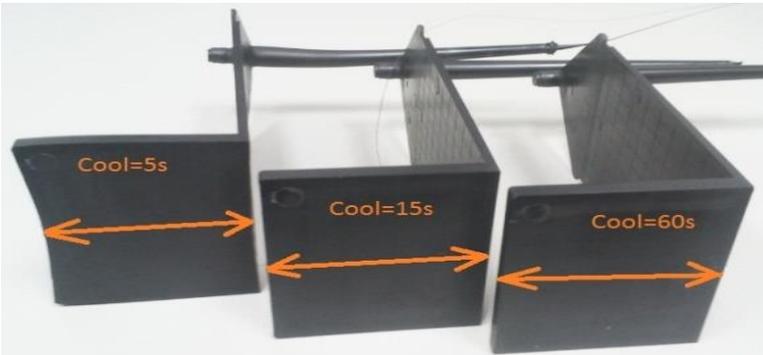
- 3D Anisotropic Thermo-Viscoelastic Residual Stress Model
 - Stress relaxation (viscoelastic)
 - Long cooling time effect: 6 sec (left) and 60 sec (right)
 - Liquid portion at ejection
 - Solidification sequence effect



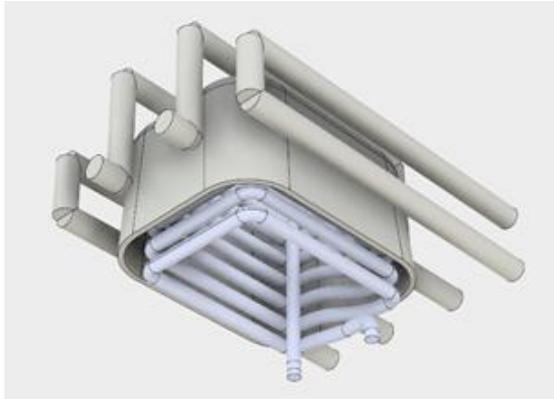
Cooling Time = 6 sec



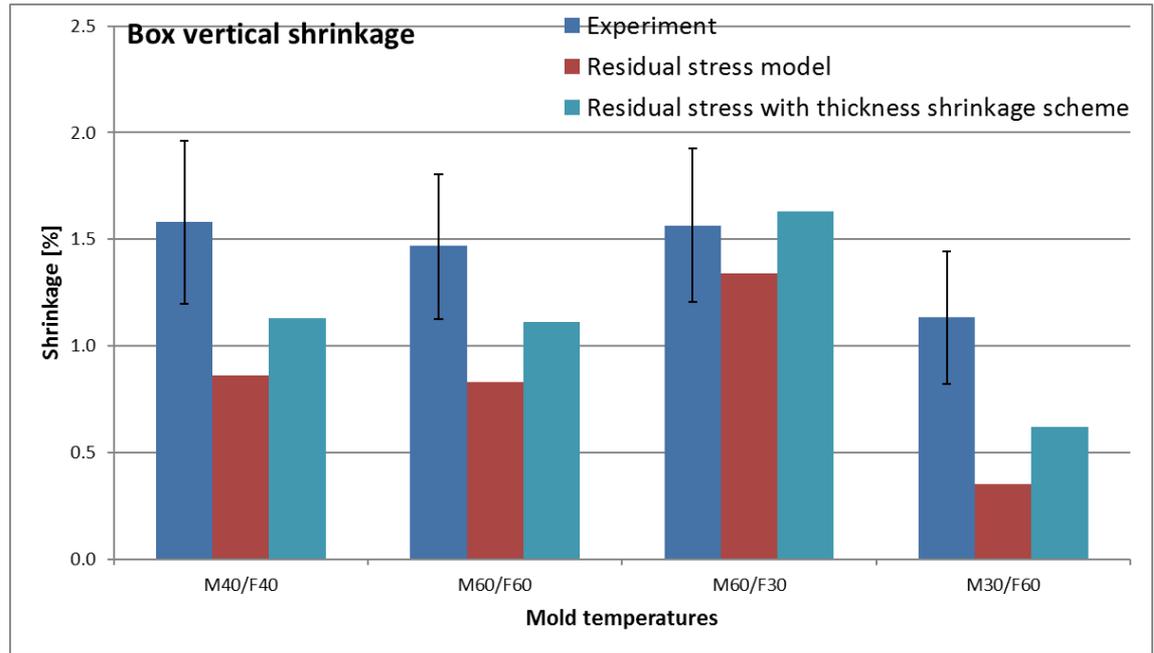
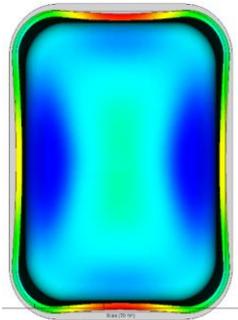
Cooling Time = 60 sec



Thickness Shrinkage Scheme

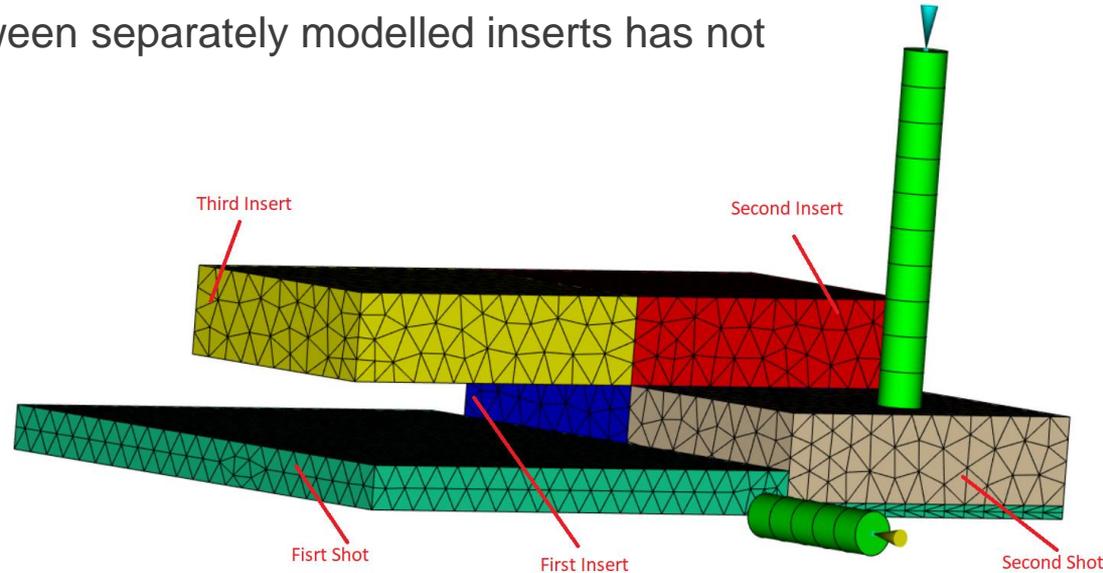


- Consider that shrinkage in thickness direction is higher than in-plane directions due to mold restraint effects



Handle Insert-insert Interface for Overmolded Parts

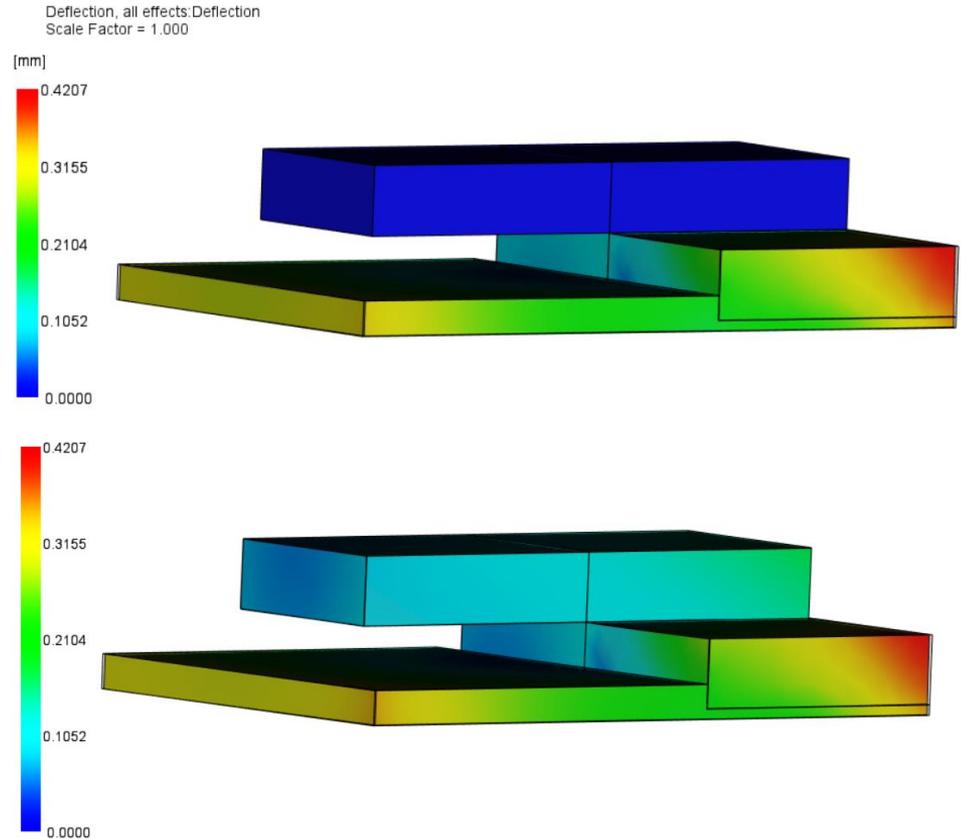
- AMI2019 warpage considers the bonded interface between
 - 1st Shot and Inserts
 - 2nd Shot and Inserts
 - 1st Shot and 2nd Shot
- Limitation: the bonded interface between separately modelled inserts has not been properly handled.
- The limitation has been eliminated!
 - Contact between all components is now handled

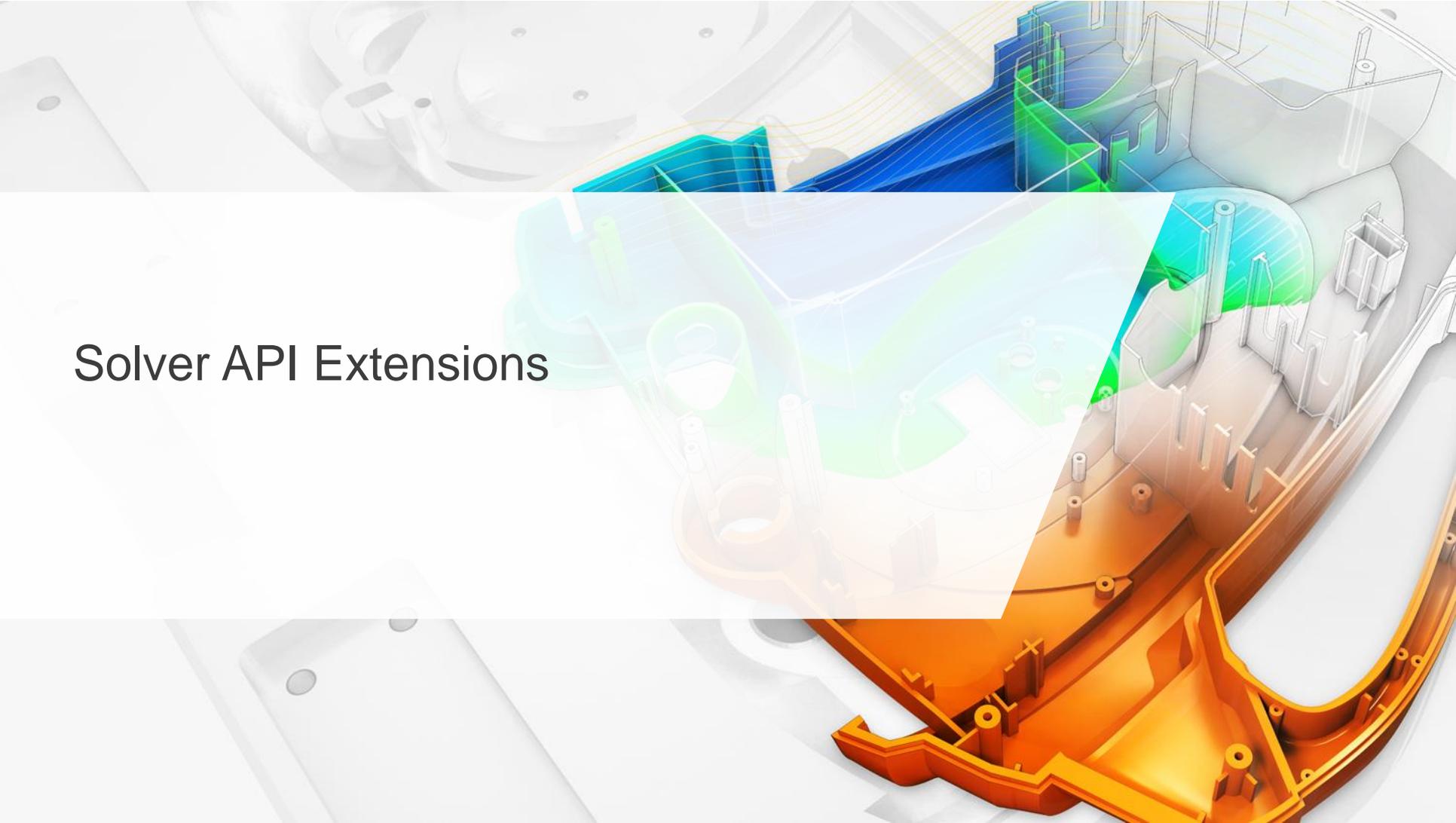


Handle Insert-insert Interface for Overmolded Parts

- AMI2019 Result:
 - 1st insert and 2nd insert are not involved in the warpage: no deformation at all

- After considering the bonded interface between inserts, 1st insert and 2nd insert are deformed together with other components!



A 3D CAD model of a mechanical part, possibly a housing or bracket, is shown in a cutaway view. The model is rendered in a light gray color. A semi-transparent, multi-colored overlay (blue, green, and orange) is applied to the model, representing a stress analysis or simulation results. The overlay shows varying intensities of color across the part, indicating different levels of stress or strain. The text "Solver API Extensions" is overlaid on the left side of the image.

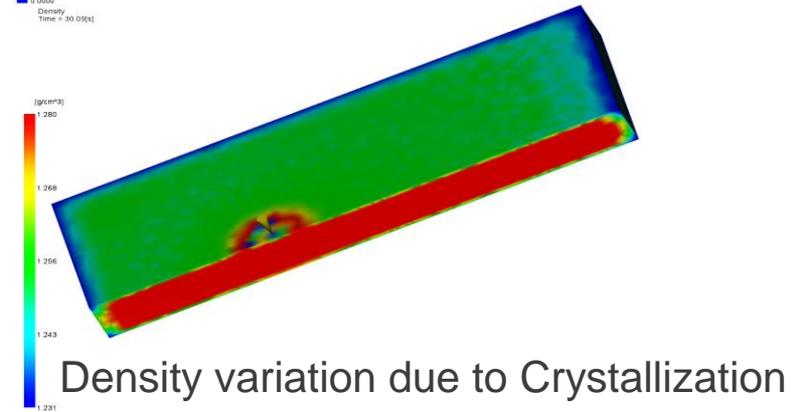
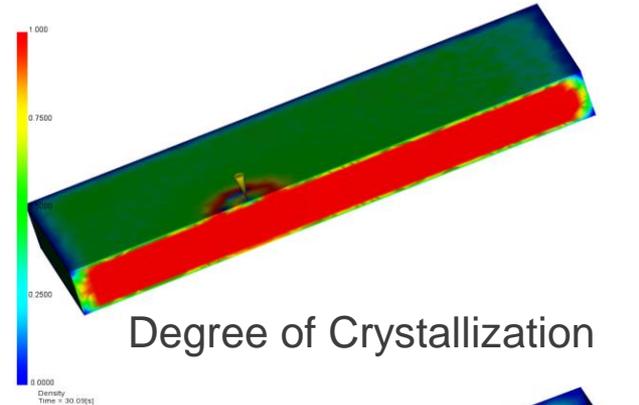
Solver API Extensions

Solver API Extensions

Open Framework for external researchers

- Existing functions allow user coded viscosity, PVT, Solidification & Core-shift
- Next major release:
 - Provide general purpose convection of any user calculated quantity.
 - E.g. Degree of crystallization
 - User calculation of Fiber Orientation
 - Will be used by Warp and Mechanical Properties
 - Access powder concentration result at each node
 - Access average fiber length result at each node
 - Access material identifiers
 - Proposed: Control time-step and injection speed/pressure

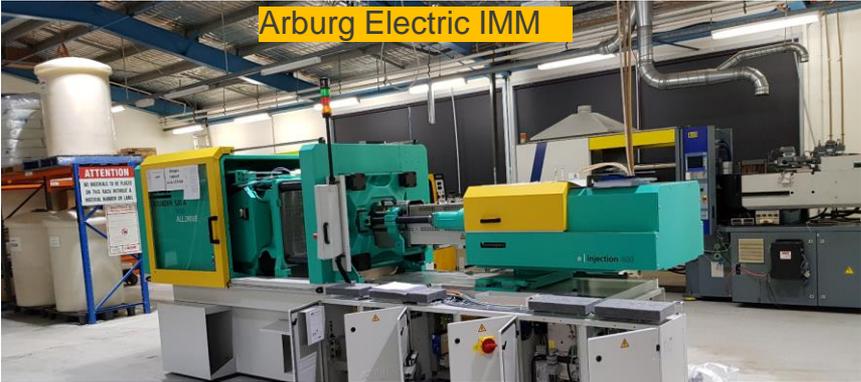
Example: Nakamura Crystallization model



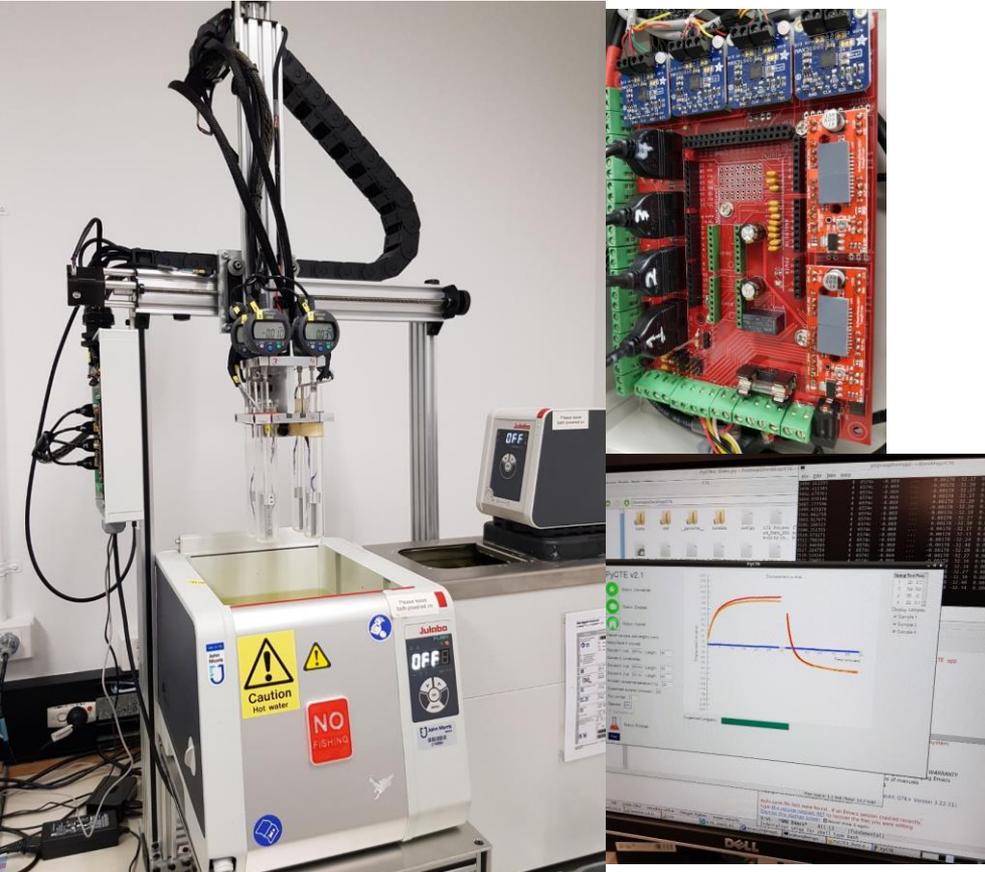
A 3D CAD model of a mechanical part, possibly a housing or a bracket, shown in a semi-transparent cutaway view. The model is rendered in a light gray color. The cutaway reveals internal features, including a central circular opening, various slots, and a complex internal structure. The cutaway is colored with a gradient from blue at the top to orange at the bottom. The text "Autodesk Plastics Lab" is overlaid on the left side of the image.

Autodesk Plastics Lab

Lab Refurbishment



New Device: Coefficient of Thermal Expansion



OBJECTIVE

- Increased capacity
- Up to 3 materials per day
- Flow & transverse (x4)

STATUS

- Mechatronics designed and built
- Software drafted
- Usability and performance testing in progress

Viscosity & PVT

New Slit Die Injection Molding Rheometer

- New Slit Die Injection Molding Rheometer
 - Multiple pressure sensors for pressure dependency measurement
 - Suitable for long fiber material
- Building a 3rd PVT Device
 - Allow greater throughput of testing
 - Indirect dilatometry – Similar to existing Gnomix devices

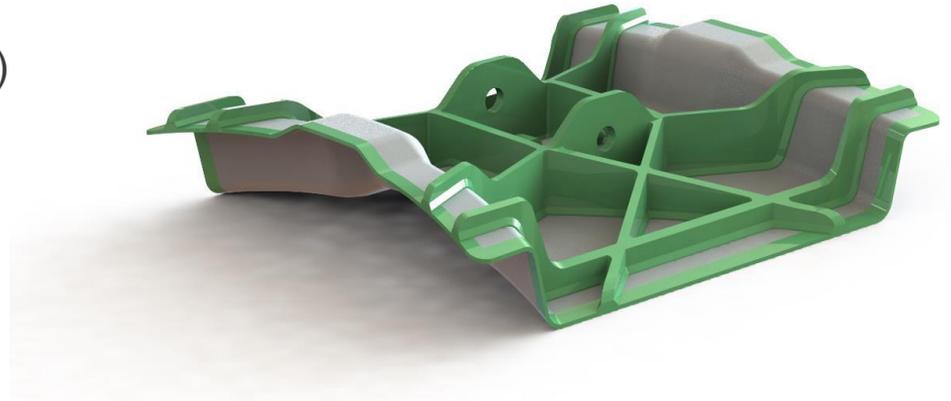


A 3D CAD model of a complex mechanical assembly, possibly a turbine or engine component. The model is shown in a semi-transparent cutaway view, revealing internal features. The top portion is colored blue and green, while the bottom portion is orange. The background is a light gray, showing other parts of the assembly.

External Research Collaborations

External Research Collaborations

- Composite Injection Overmolding (TPRC)
- Fiber breakage in Barrel (U of Bradford)
- Microcellular Foam Injection Molding (U of Toronto)
- Fiber Effect on Viscosity (RMIT, Australia)
- Microchip Panel Encapsulation (iNEMI)
- Wall Slip & Fiber breakage (U of Tokyo)





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