Moldflow Research & Development

Dr. Jin Wang
Sr. Research Engineer

AUTODESK

Research & Development

- In-house Research
  - 25 Ph.D. employees in Moldflow development
  - Lab with state-of-the-art equipment
- External Research Collaboration
  - Sponsorship for five Ph.D. students and six universities
  - Partnership with over 20 companies and institutions

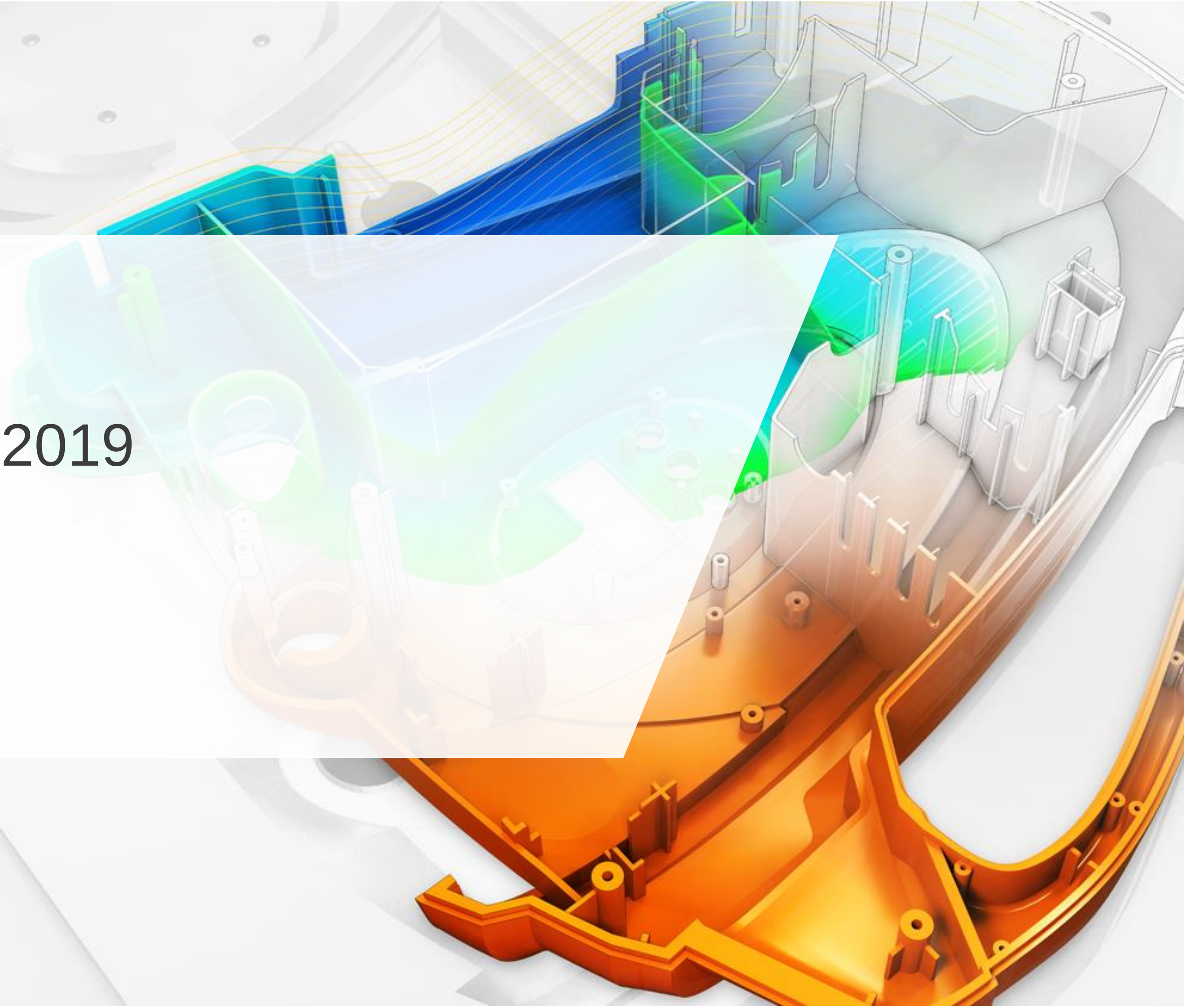
R&D Passion Project

- Developers work on their very own projects or ideas they are passionate about
- Generally, 10% to 20 % of their time is devoted for this Project
- Developers do not have to tell anyone about the project until they are comfortable to talk about or have a prototype

Contents

- Highlights of Moldflow Solver 2019
- Under Development
- Material Laboratory
- External Research Collaborations

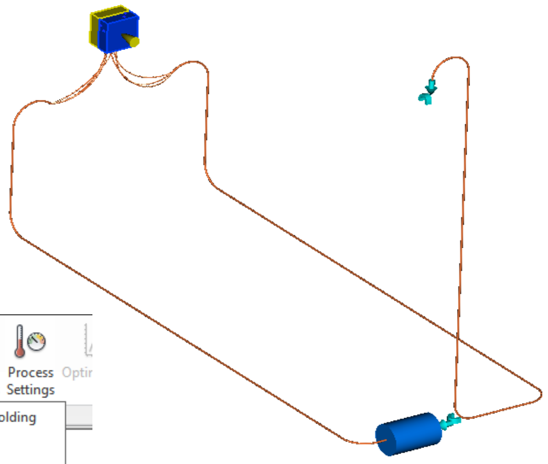
Autodesk Moldflow 2019

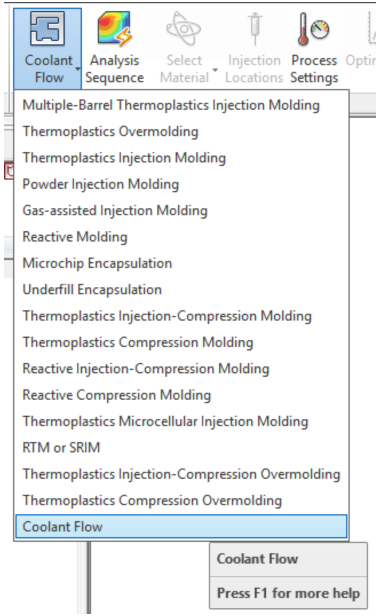


Coolant Flow Analysis

Passion Project
Dr. Clinton Kietzmann

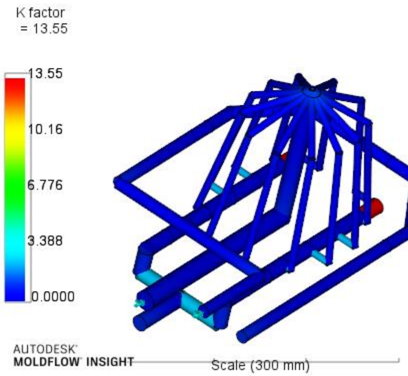
- Optimize the flow balance in the cooling circuit design
  - Without running the full mold temperature solution
  - Check for turbulence – avoid dead zones
  - Option to calculate coolant temperature change
  - Include gravity, pump performance, friction losses at bends and junctions
  - Familiar Moldflow environment – easy to switch to full mold thermal analysis
  - 3rd party multi-physics simulation package is not necessary

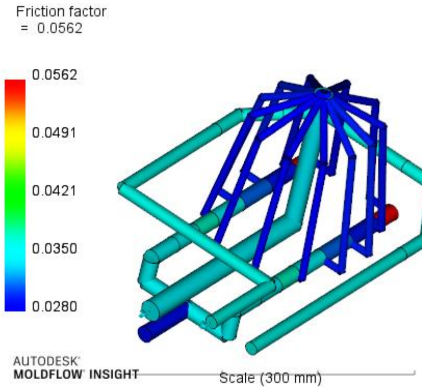


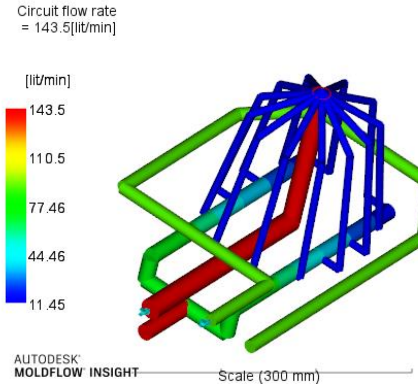


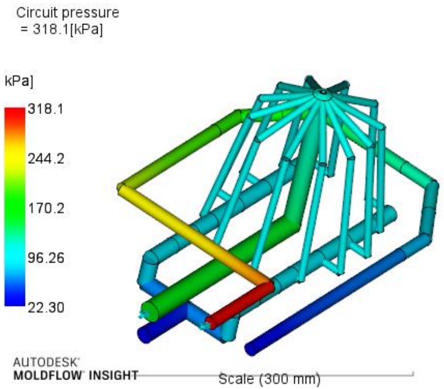
Coolant Flow Analysis (cont'd)

- New Results
  - Friction Factor, depends on flow rate and temperature in straight channel
  - K-Factor, add minor pressure losses at changes in diameter, bends and junctions



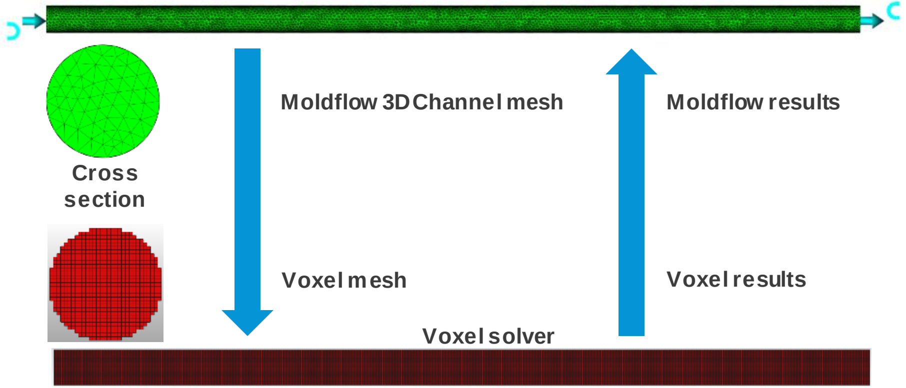


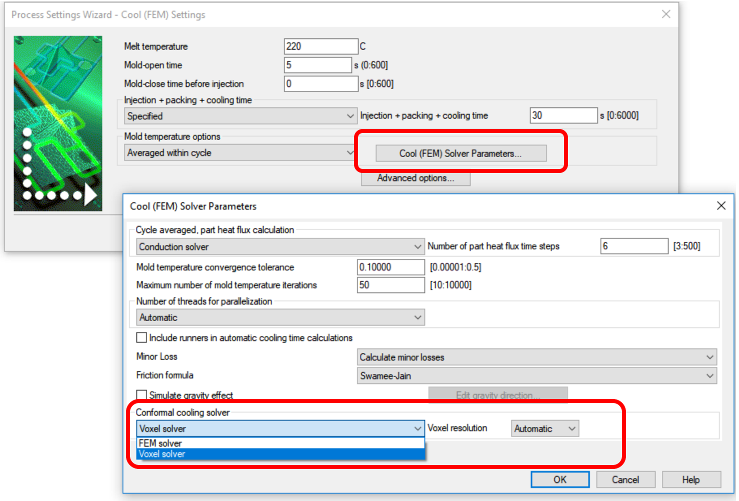


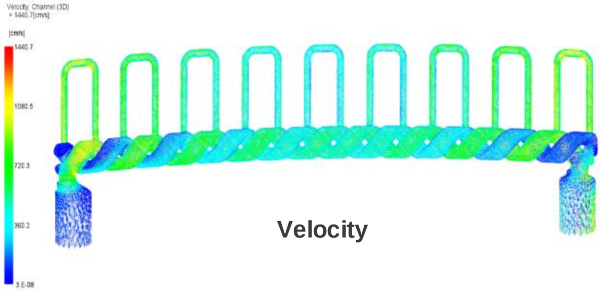


Faster Conformal Coolant Flow 3D Solver

- Support Linux and Parallelization
- Voxel based coolant flow calculation
- Default is still FEM (CFD) solver
- Option to control grid resolution
  - Automatic is recommended



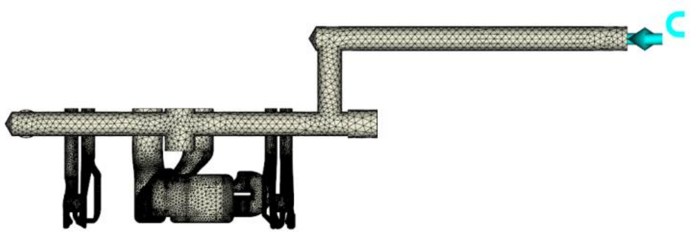




Model courtesy of http://www.hofmann-innovation.com

Faster Conformal Coolant Flow 3D Solver (cont'd)

Analysis time			
Fine Voxel (1024)	Coarse Voxel (512)	AMI 2018.2 (FEM CFD)	Automatic
1 hr, 52 min	27 min	4 hr, 39 min	11 min



Analysis time			
Fine Voxel (1024)	Coarse Voxel (512)	AMI 2018.2 (FEM CFD)	Automatic
6 hr, 18 min	1hr, 15 min	18 hr, 15 min	1hr, 35 min

- Using automatic Voxel size determination, accuracy remains equivalent:
  - Cavity Surface Temperature – Average: 32.1°C (Voxel) vs. 32.3°C (FEM)
  - Mold Exterior Temperature – Average: 29.15°C (Voxel) vs. 29.18°C (FEM)

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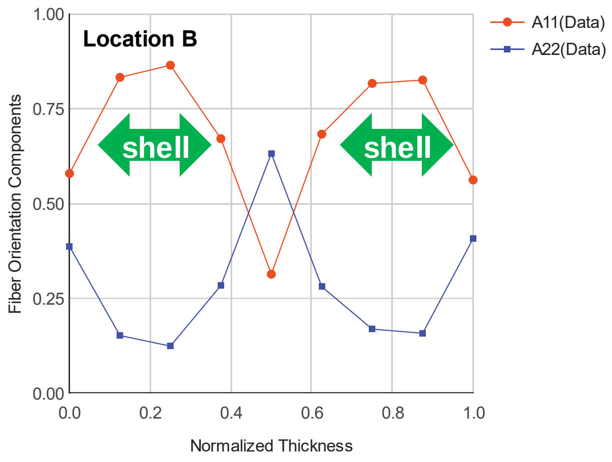
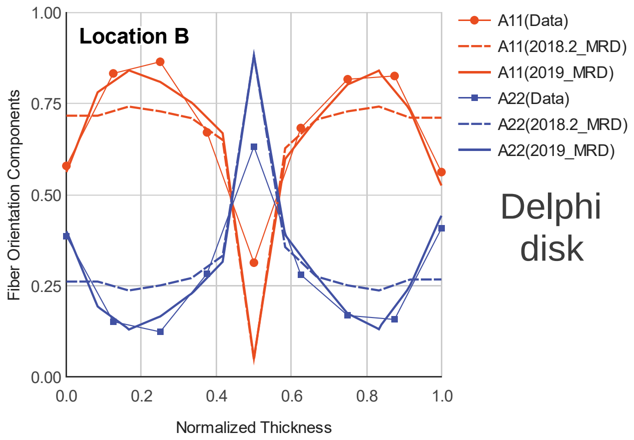
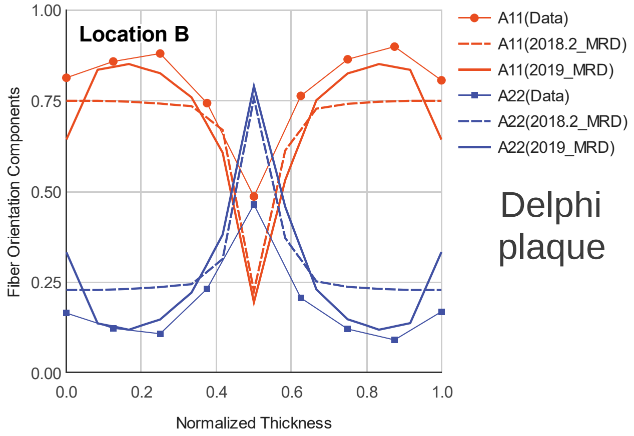
Fiber Solver Improvement – Shell Orientation

- Strong alignment in shell layers are controlled by fiber interactions
- Automatic MRD model parameters are improved





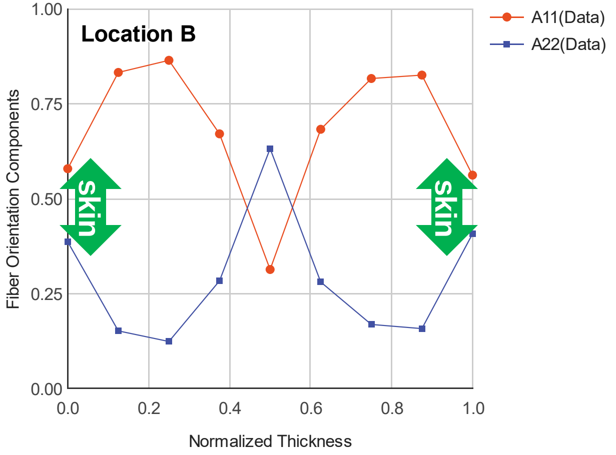
Delphi disk

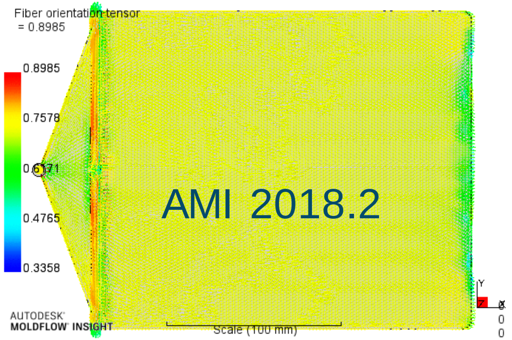


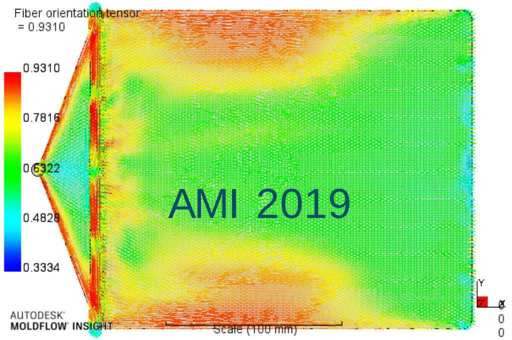
Delphi plaque

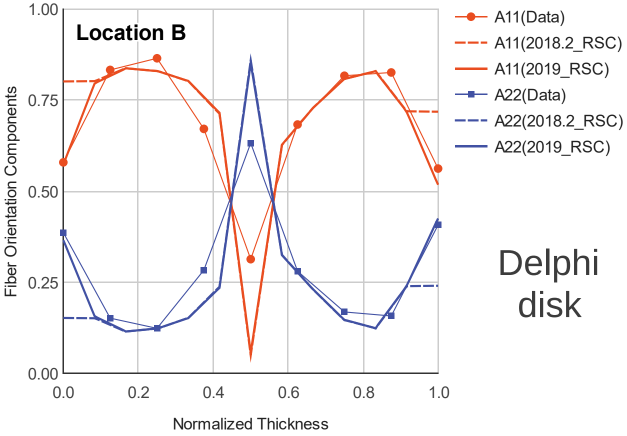
Fiber Solver Improvement – Skin Orientation

- Weak alignment in skin layers is due to fountain flow effect
- Fountain flow effect now considered for all 3D orientation models





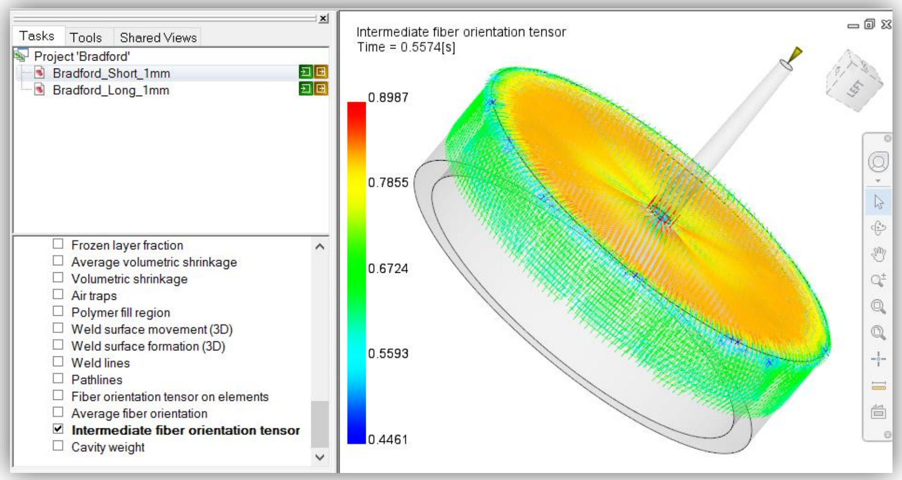


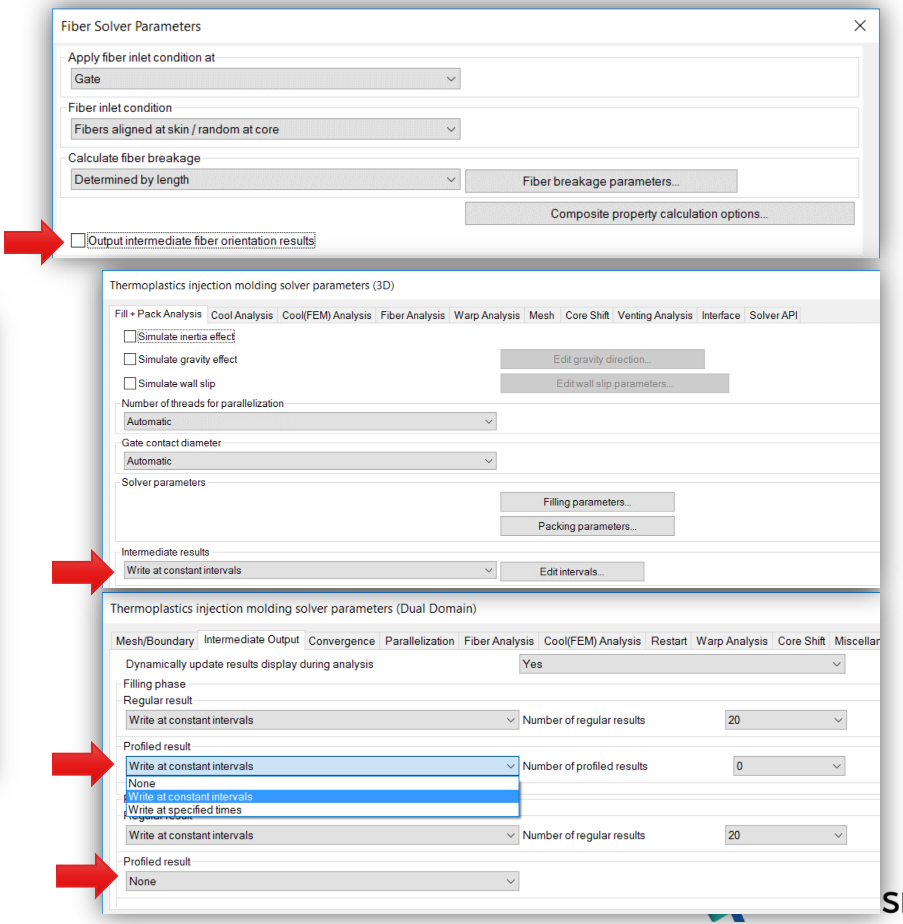


Delphi disk

Intermediate Fiber Orientation Result

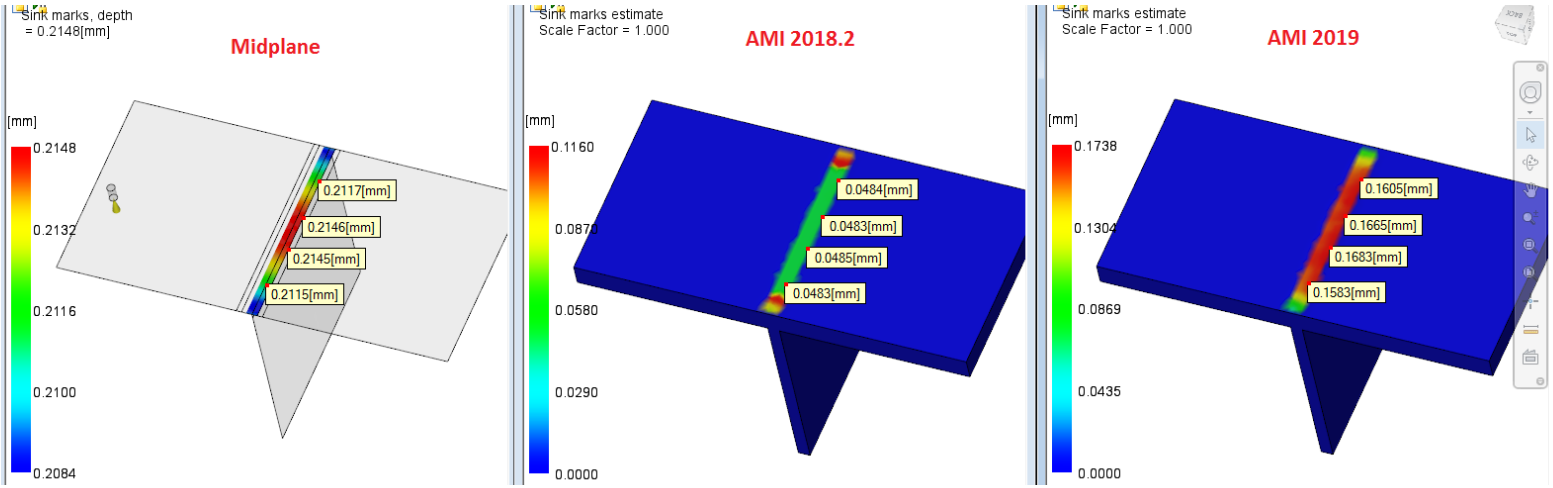
- Frequent request by advanced users
- Useful to better understand the evolution of fiber orientation





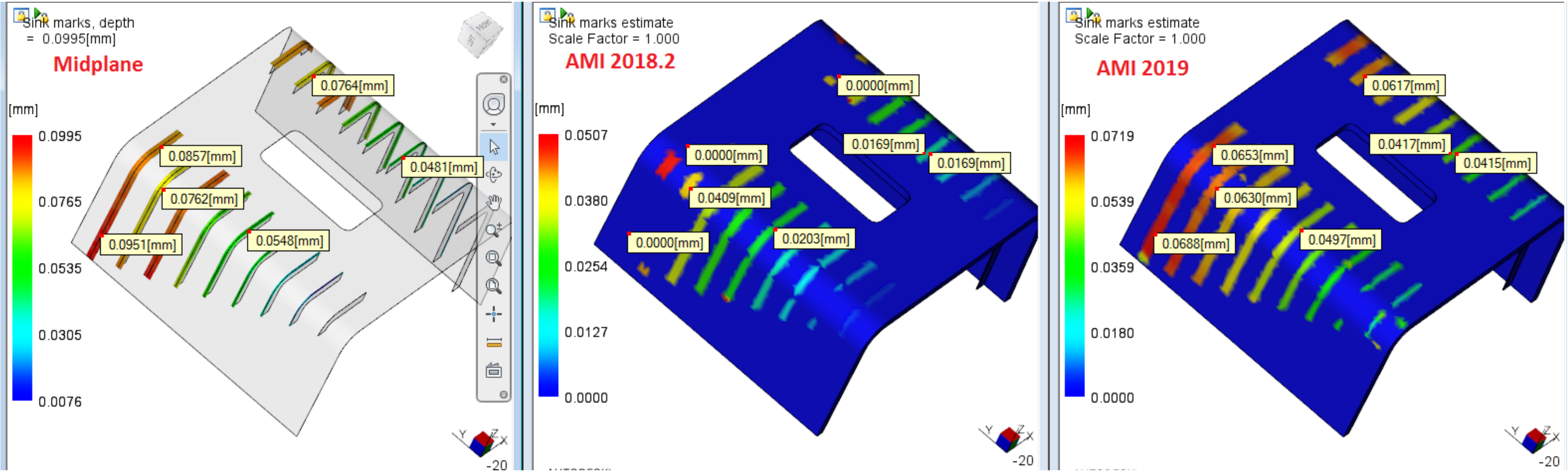
Sink Marks – Consistency Improvement

- Changed 3D and DD solvers to use the same formula as in Midplane solver for sink depth calculation
- Improved consistency in sink depth values between Midplane and 3D and between AMA and AMI
- Added sink mark analysis for 2-shot overmolding



Sink Marks – Robustness Improvement

- Fixed the issue of missing sink marks in 3D in prior releases



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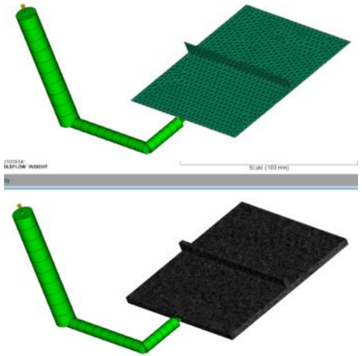
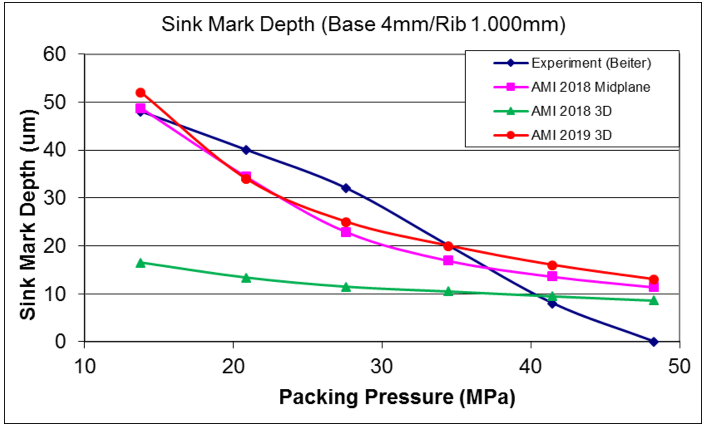
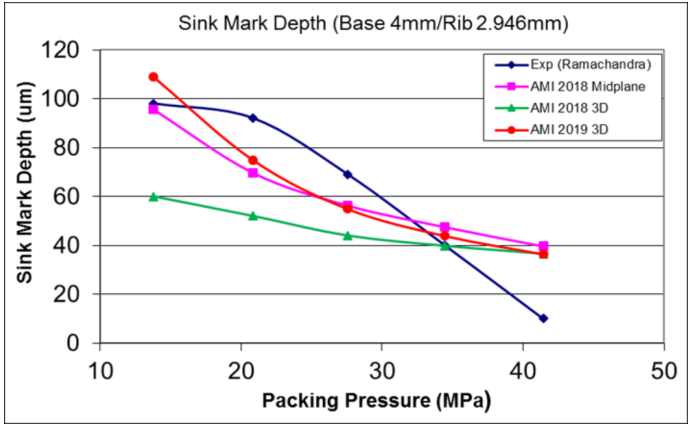
Sink Marks – Validation

- In 2018 and prior releases, 3D solver predicted lower sink mark values than Midplane and experiment, especially for low packing pressures
- After the improvements in 2019, 3D predictions matched experiment and Midplane solutions much better







Source: "Geometry-Based Index for Predicting Sink Mark in Plastic Parts", K. Beiter, M. S. Thesis, Ohio State University, Columbus (1991).

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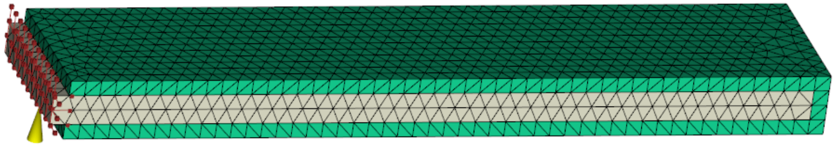
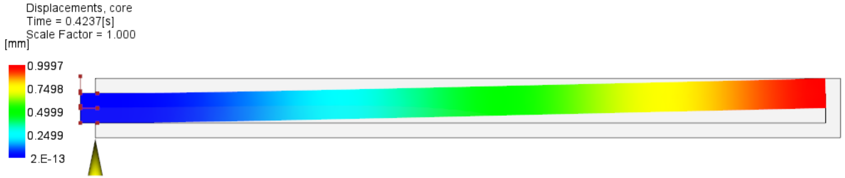
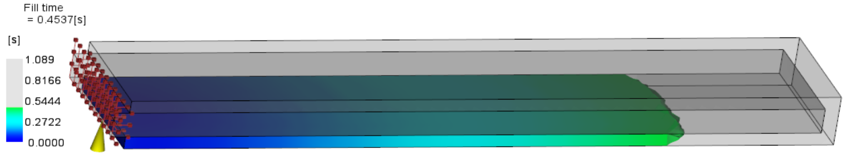
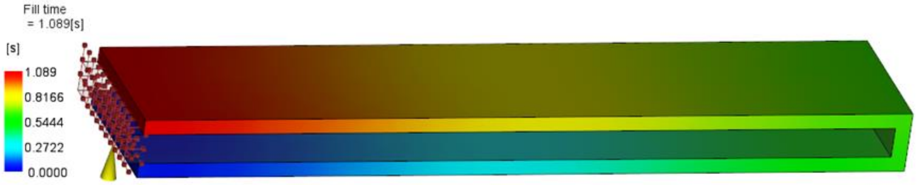
3D Core-Shift Analysis Improvements

- Better handling the effects on flow of large core-shifts

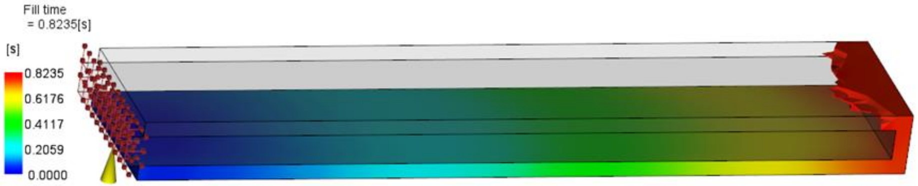








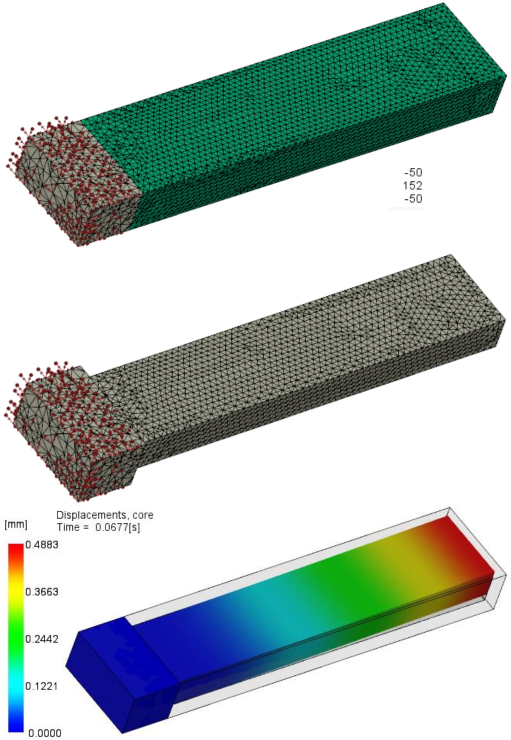
2018 Release

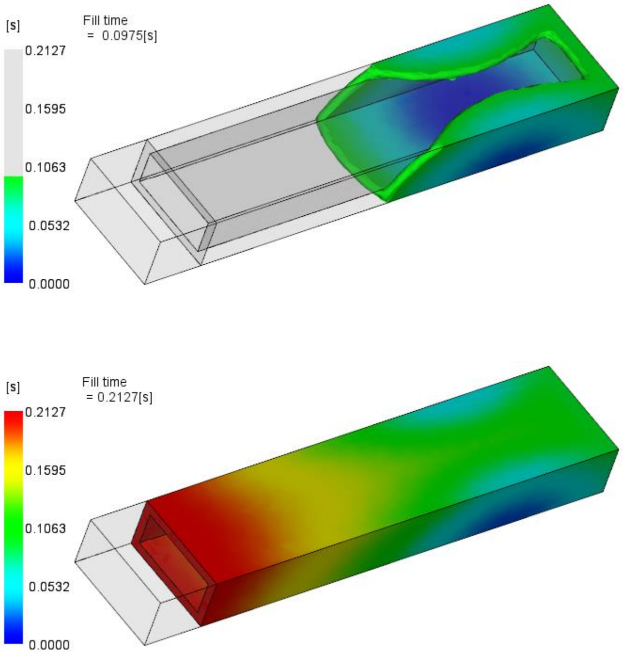


2019 Release

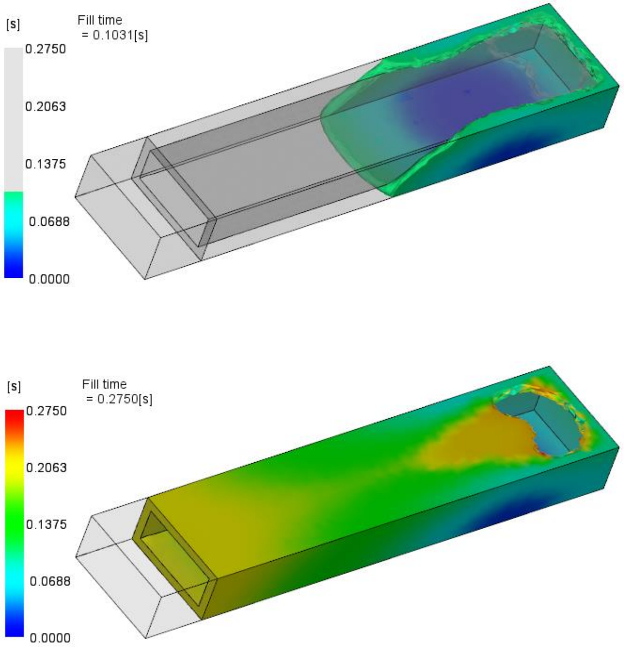
3D Core-Shift Analysis Improvements (cont'd)

- Large core-shift case





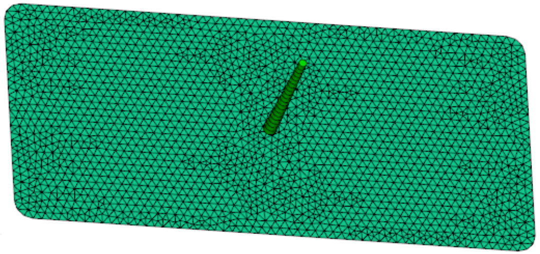
2018 Release

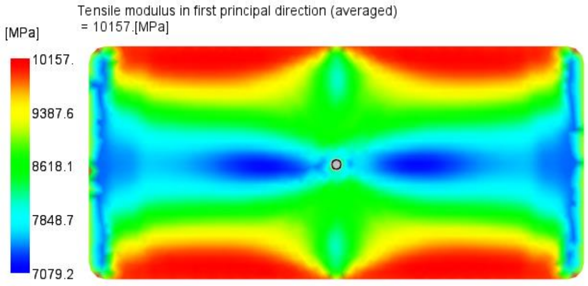


2019 Release

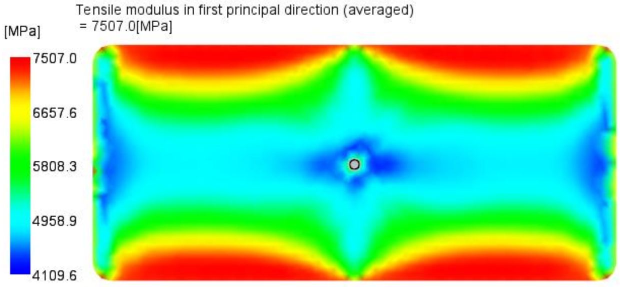
Microcellular Injection Molding

- Fixed the problems in calculating mechanical properties in 2018 release:
  - Tensile modulus was higher than for conventional injection molding

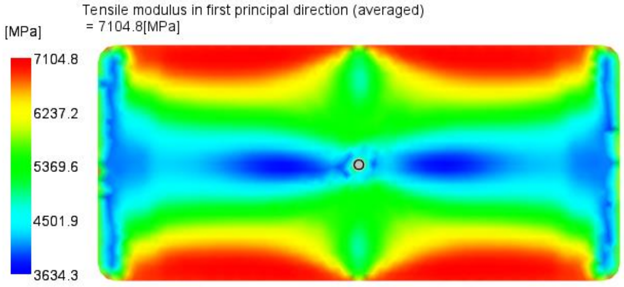




2018 Release
(10157 MPa)

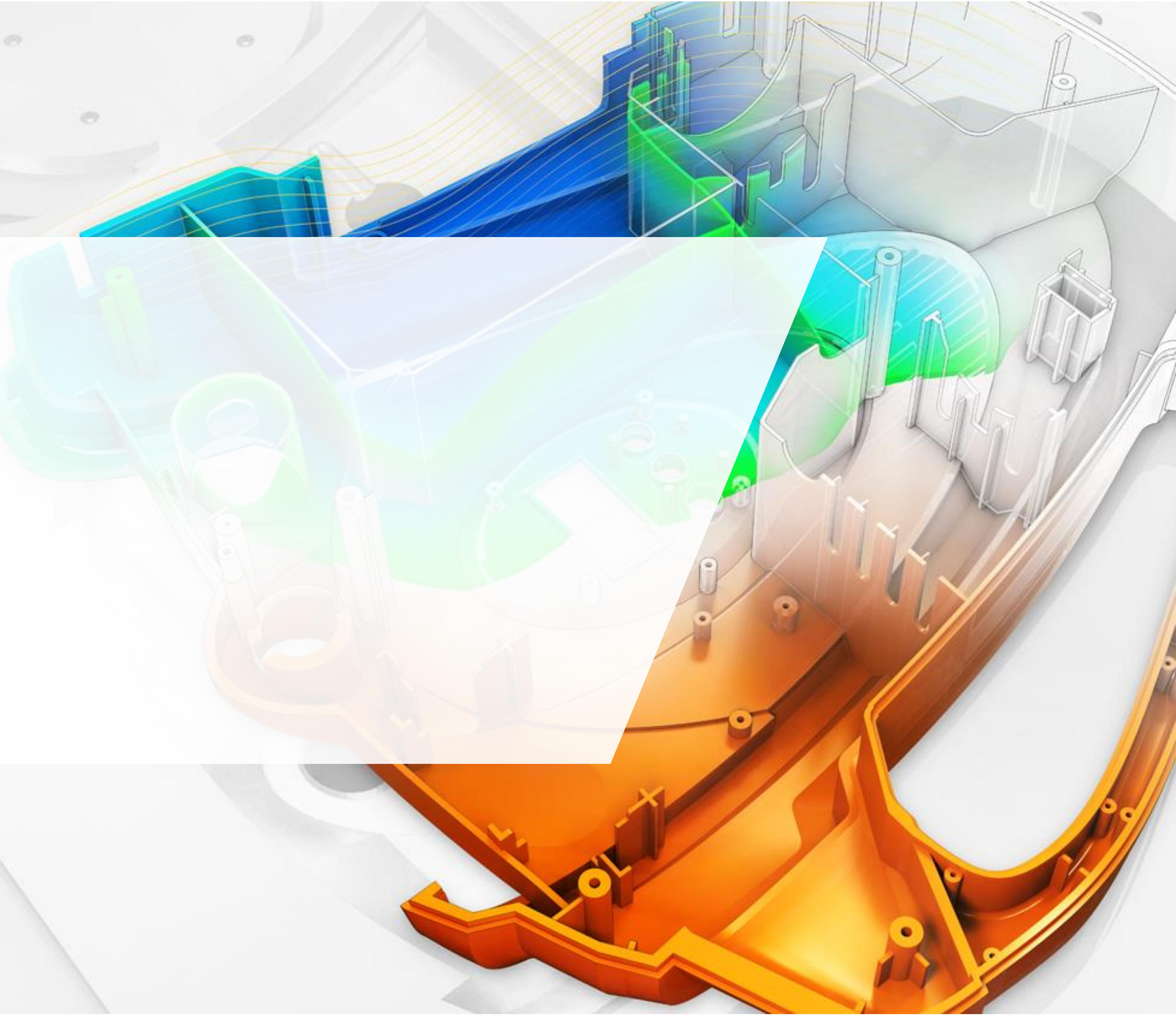


Regular injection molding
(7507 MPa)



2019 Release
(7105 MPa)

Under Development



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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.

Mesh Type – Automatic selection

Passion Project
Dr. Shoudong Xu

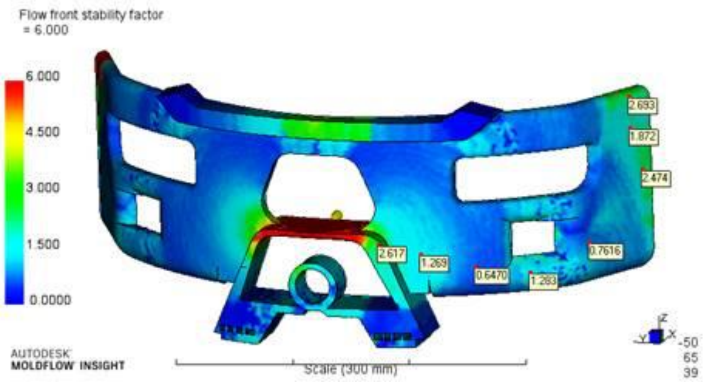
- Set mesh types (DD or 3D) automatically by an automatic classification
  - Current classification is by % of matched elements
- Examined a suite of models:
  - Manually classified by expert users
  - Compare with automatic classification by matched elements
  - Accuracy of automatic classification improved from 75% ➜ 93% with new classification.

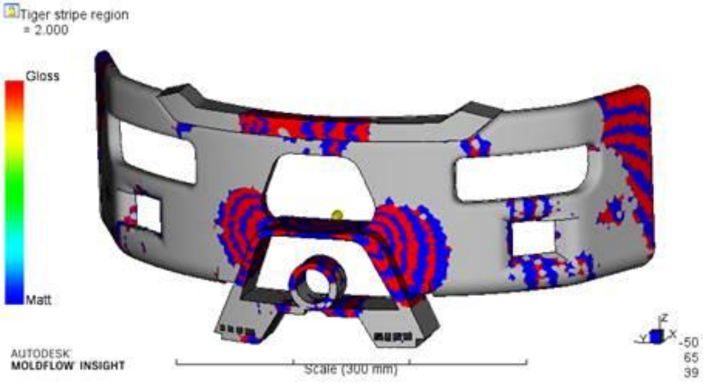
% of matched elements says this is suitable for Dual-Domain

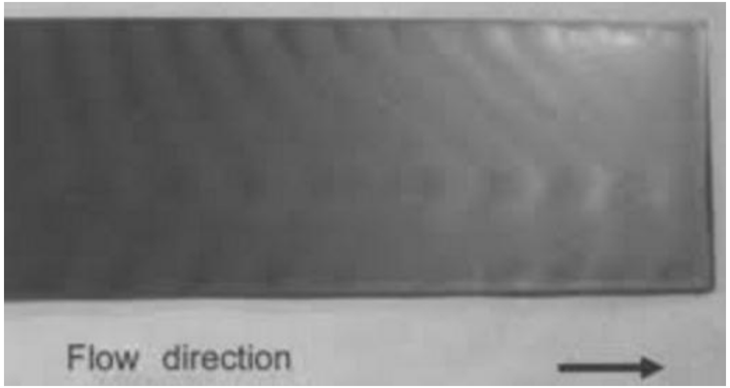
experts and new classification recommend 3D

Prototype Tiger Stripes Prediction

- Collaborating with some automotive customers on validation







2-Parameter ARD Model for Long Fiber

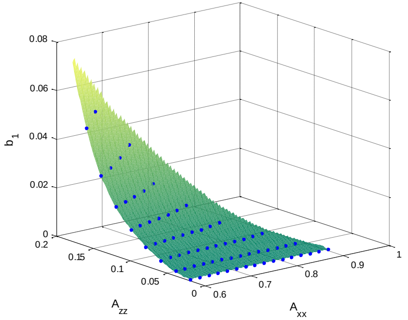
Passion Project
Dr. Jin Wang

- Original ARD model has five bi parameters

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

Target Steady-State Orientation				ARD bi Parameters				
A11	A22	A33	A13	b1	b2	b3	b4	b5
0.72	0.26	0.02	0.02					
0.72	0.26	0.02	0.04	0.000622	0.011186	0.02	0.000412	0
0.72	0.26	0.02	0.06	0.000472	0.011689	0.04	-0.003874	0
0.72	0.26	0.02	0.08	0.000110	-0.029160	0.13	-0.009655	0
0.72	0.24	0.04	0.02					
0.72	0.24	0.04	0.04	0.003094	-0.029774	0.08	0.005233	0
0.72	0.24	0.04	0.06	0.002068	0.018617	0.02	0.000388	0
0.72	0.24	0.04	0.08	0.001716	0.019289	0.04	-0.006146	0

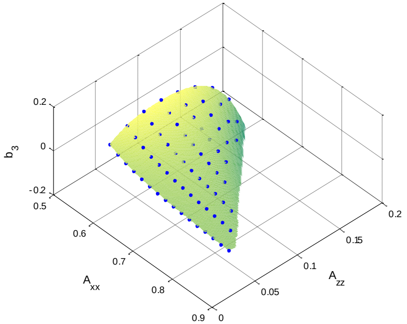
- b5 is normally zero
- b4 is normally small
- b1 is small, but it is the isotropic term



- Rotary diffusion tensor is simplified as

$$\mathbf{C} = b_1\mathbf{I} + b_3\mathbf{A}^2$$

  - b_1 and b_3 are determined by fitting to target orientation (A_{xx}, A_{zz})
  - Less parameters ➔ more practical in applications
  - Independent on flow ➔ easier to obtain stable solutions
  - No change of terms ➔ easy to implement in existing program



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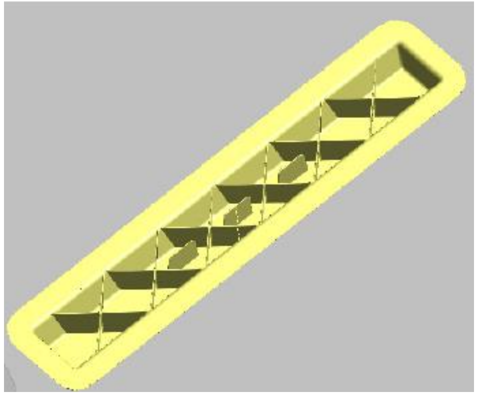
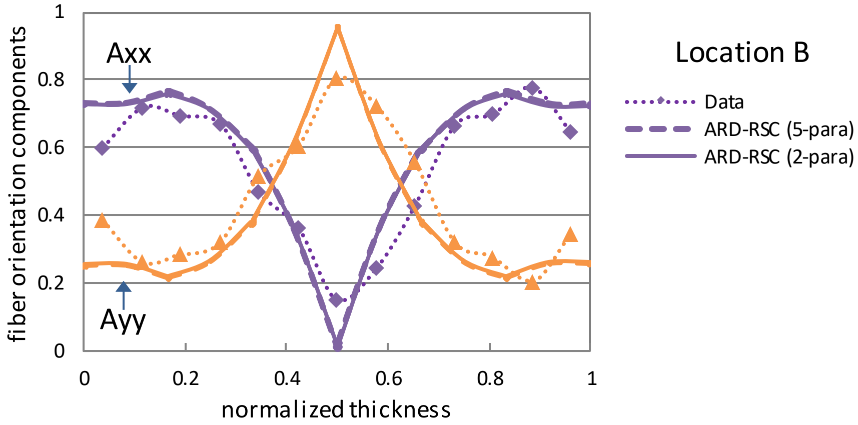
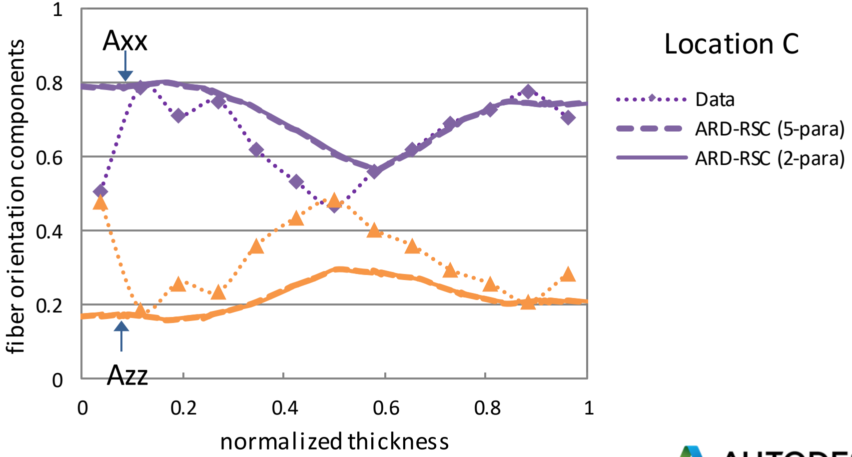
2-Parameter ARD Model for Long Fiber (cont'd)







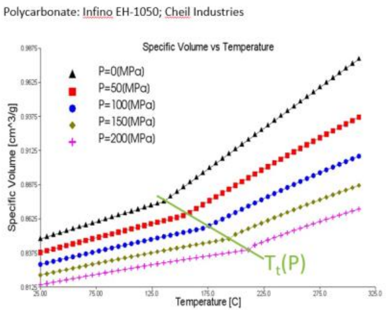
Solver API – User Defined Scalar or Tensor

- Currently allows user coded routines for:
  - Viscosity
  - PVT
  - Solidification
  - Core-Shift

- New routines for user-defined variable

$$\frac{\partial \boldsymbol{X}}{\partial t} = -\boldsymbol{v} \cdot \nabla \boldsymbol{X} + \boldsymbol{E}(\boldsymbol{X}, \ldots)$$

  - Residence time
  - Fiber orientation
  - Crystallization
  - and more



$T_t(P) = b_5 + b_6 P$

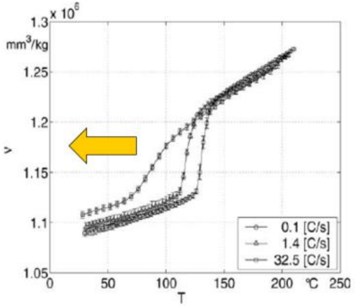
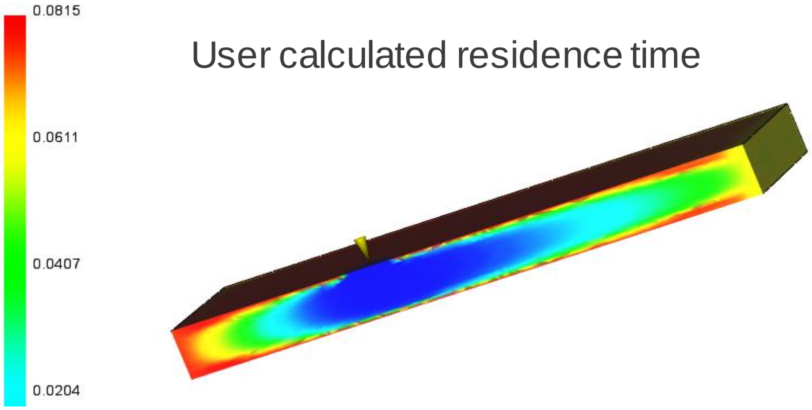


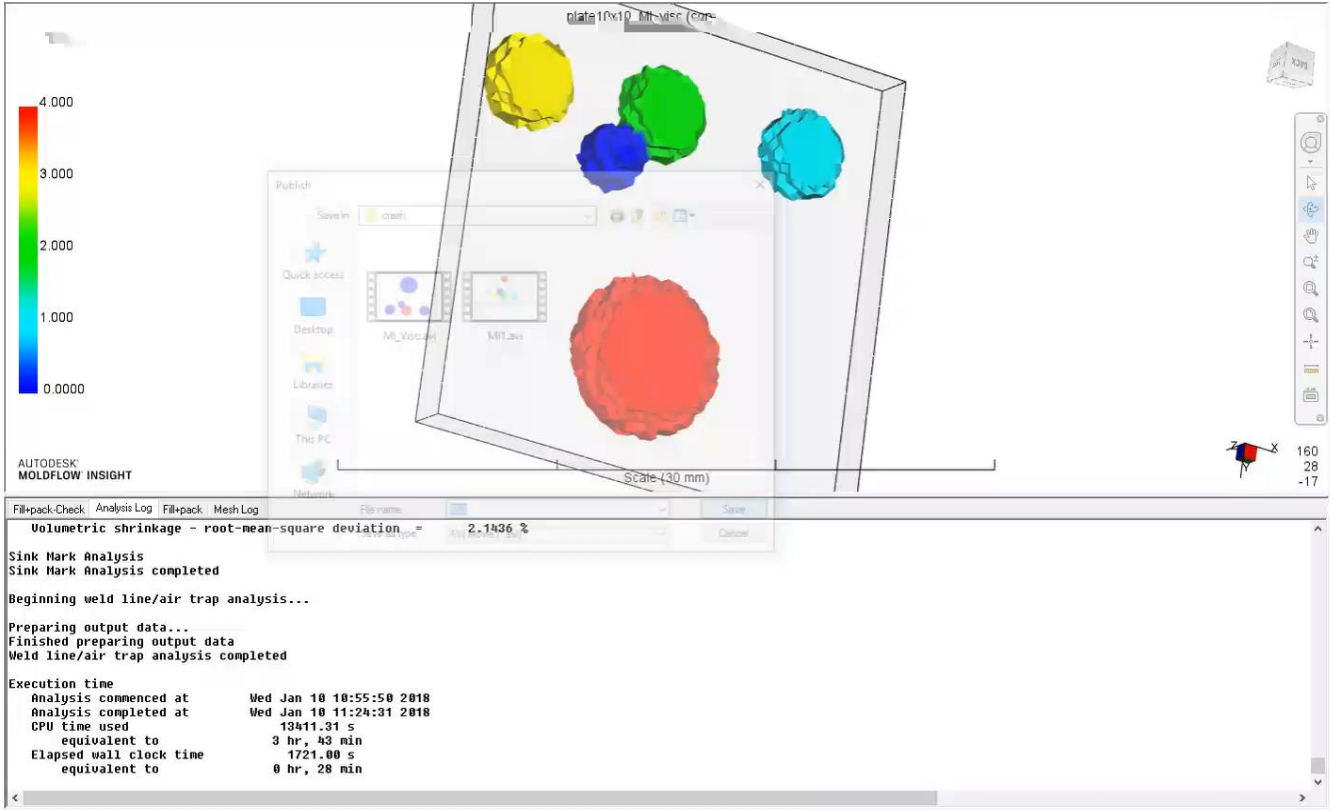
Fig. 9. Influence of cooling rate on the specific volume of i-PP at a pressure of 40 MPa. Average cooling rates during crystallization are given in the figure

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



Solver API – User Defined Scalar or Tensor (cont'd)

Tracking injection from multiple gates



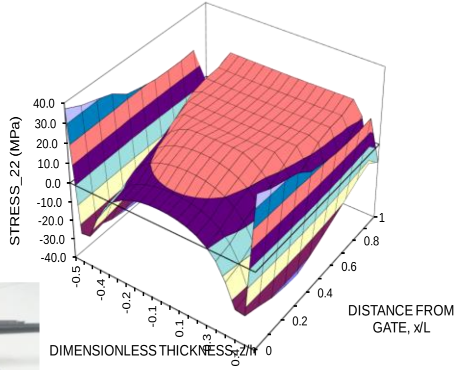
Molded Component Assembly-Mounting Analysis

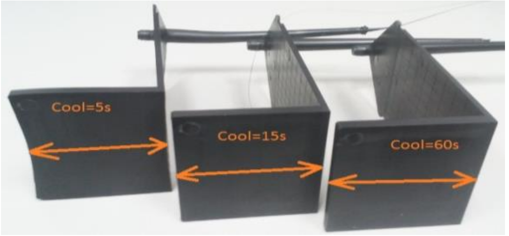
- Predicts final part deformation and residual stresses after assembly
- Top requested issue in Users' Group Meetings India and Europe

Courtesy of ChangAn Automotive

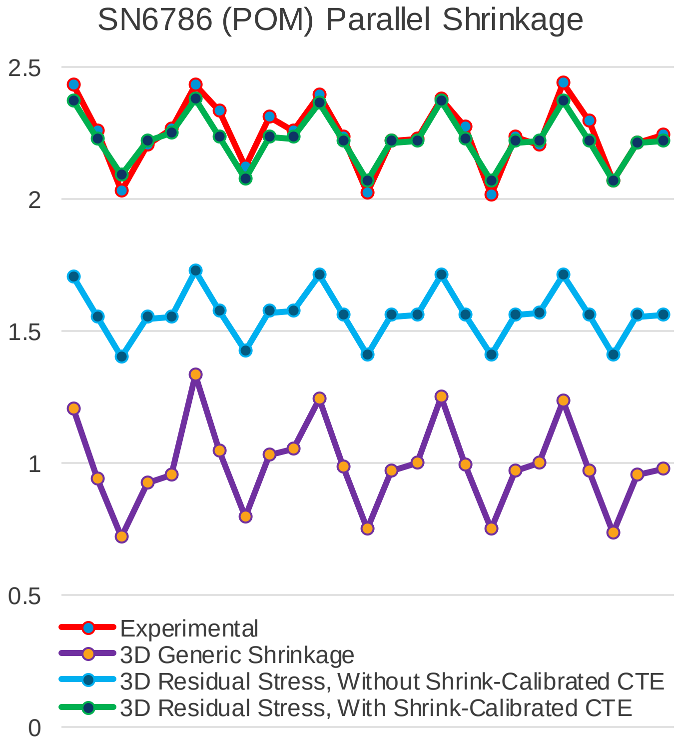
Warp Accuracy Improvements

- Anisotropic Thermo-Viscoelastic Stress Model
  - Stress relaxation (viscoelastic)
  - Long cooling time effect
  - In-mold shrinkage
  - Liquid portion at ejection
  - Solidification sequence effect





- 3D Shrinkage Correction by Calibrated CTE



Polyurethane Foaming Prototype

Passion Project
Dr. Sejin Han

Initial filling: By Injection or Initial Charge

Mold surface temperature	30	C
Melt temperature	30	C
Filling method	By injection	Edit data...
	By injection	
	By initial charge	
Curing time	900	s [0:]

PU Foaming Process Data

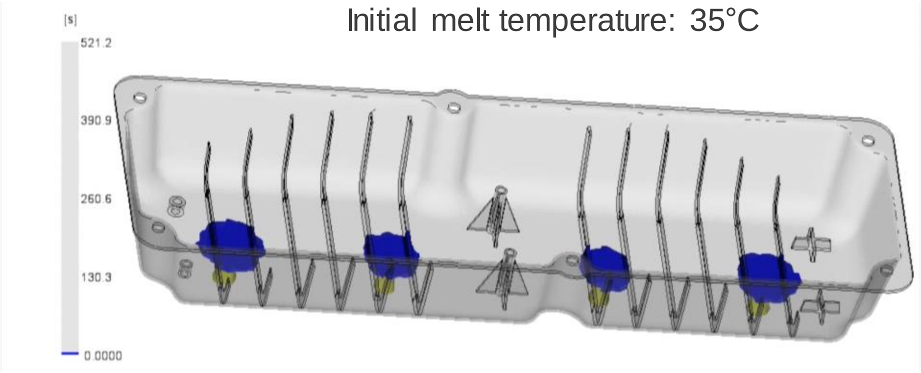
Blowing reaction kinetics data

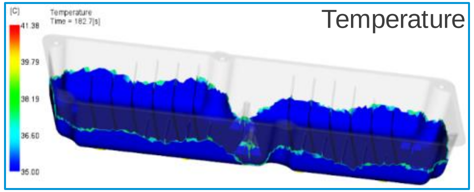
PBA (Physical blowing agent) data: Optional

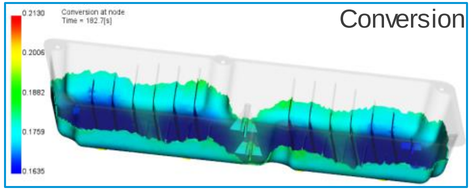
Initial water concentration	1.276	% [0:10]
Initial OH concentration	42.25	% [0.1:99]
Initial NCO concentration	56.48	% [0.1:99]
Initial dissolved CO2 concentration	0.044	% [0:1]
Equivalent weight of OH	153.7	[1:10000]
Equivalent weight of NCO	135	[1:10000]
Chemical blowing agent kinetics		
H	4.78e+06	J/kg [0:1e+07]
m	0	[0:100)
n	1	[0:100)

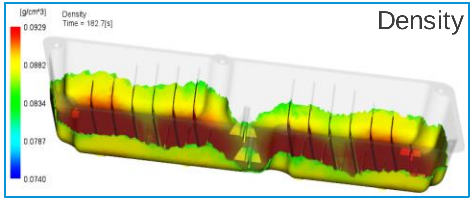
5% initial filled by injection, then filled by foaming

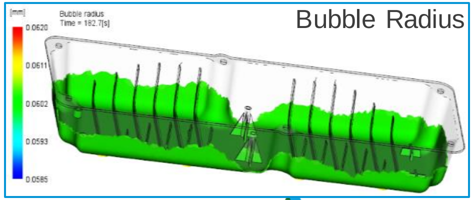
Initial melt temperature: 35°C











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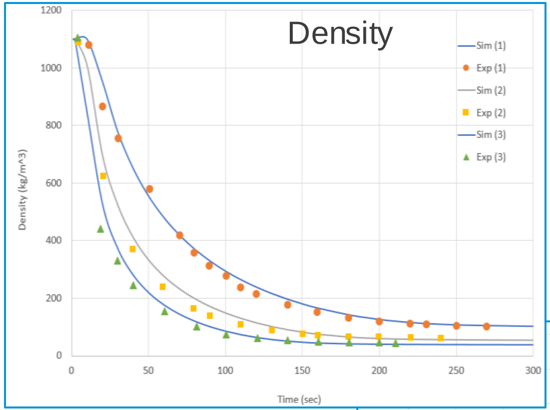
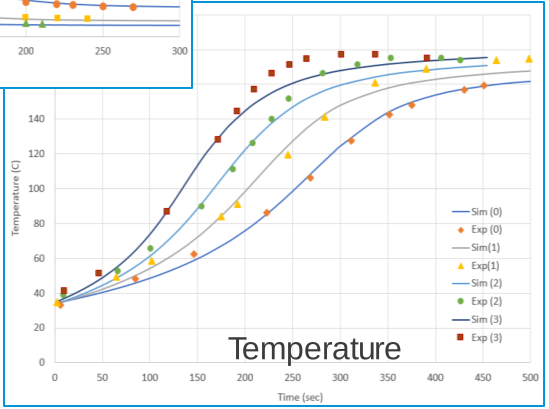
Polyurethane Foaming Prototype (cont'd)

Density and Temperature vs. Time

With different water concentration: 0, 1, 2, 3%

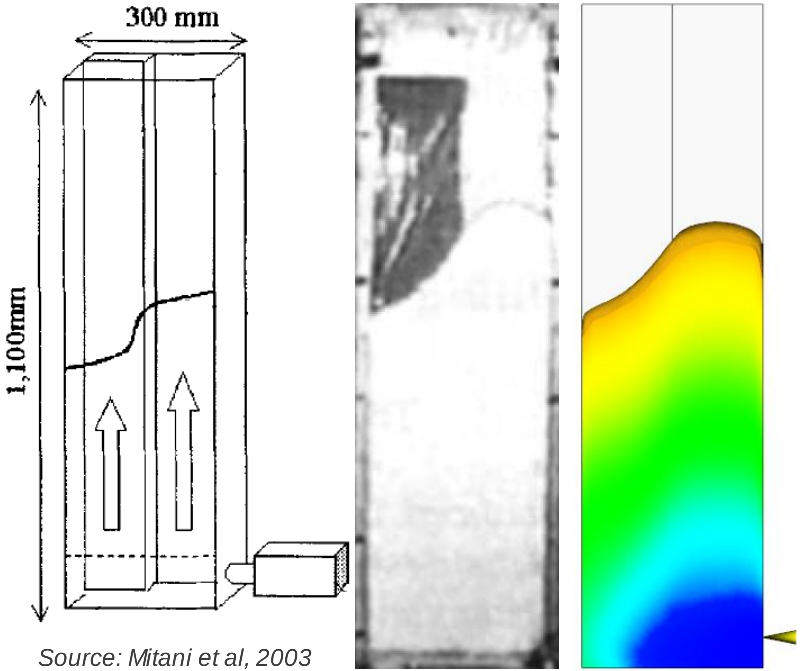




Source: Baser et al, 1994

Variable Cavity thickness

Left side: 35 mm, right side: 65 mm



Source: Mitani et al, 2003

AUTODESK.

Moldflow & Helius End-to-End Solution

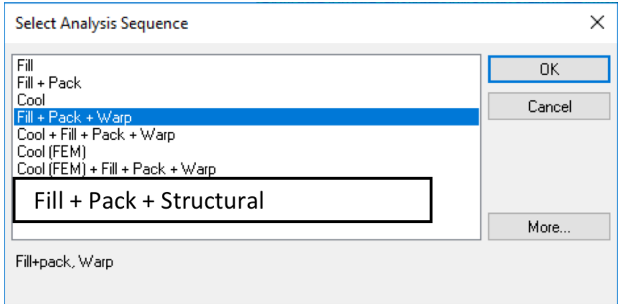
Cool

Fill

Pack

Warp

Structure



Material Testing Laboratory

Recent Investments in Materials Lab

- Hotdisk (Plane Source) Thermal Conductivity
  - Multi-sample
  - Range: 0.005 – 1500 W/(m•K)
- DHR (Discovery Hybrid Rheometer)
  - Viscoelasticity, Thermosets
- Tormach 3-axis CNC
  - Tensile bar insert, conductivity sample cells, weld line strength jigs, CTE
- Stepcraft CNC router
  - Specimen milling for mechanical, CTE, conductivity, rheometry

Recent Investments in Materials Lab (cont'd)

- Compressor
  - 24/7 operation provides overnight and weekend material drying
- PVT
  - Upgrades, PVT #2
- Mechanical testing
  - Jigs and fixtures
  - Temperature cabinet
    - -40°C to 100°C
- Gloss meter
  - Tiger-stripe project

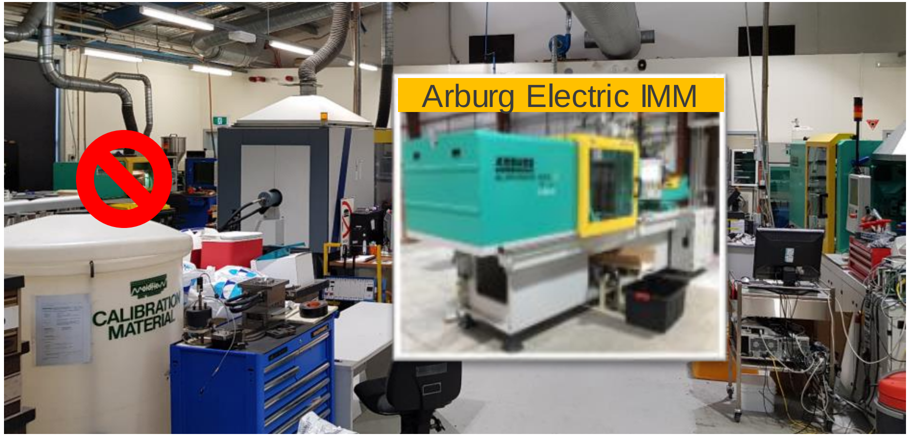
AUTODESK.

In Progress Enhancements in Materials Laboratory

- CLTE
  - Enabling 4 materials a day
- PVT #3
  - Complete build from scratch
- Slit die
  - Detailed pressure distribution for viscosity in one test
- Battenfeld IMM upgrade
  - New barrel and screw

Planned Investments in Materials Laboratory

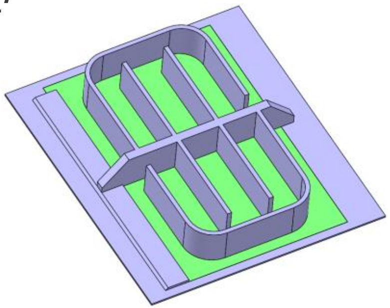
- New Arburg Injection Molding Machine (Electric)
  - July 2018
- New Injection Molding Rheometer

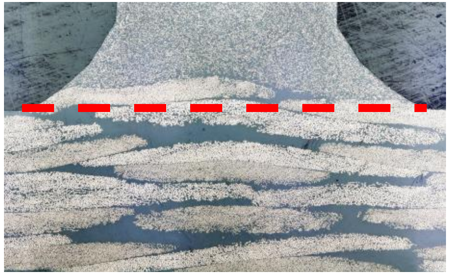


External Research Collaborations

Injection Overmolding of Continuous Fibers Thermoplastic Composites

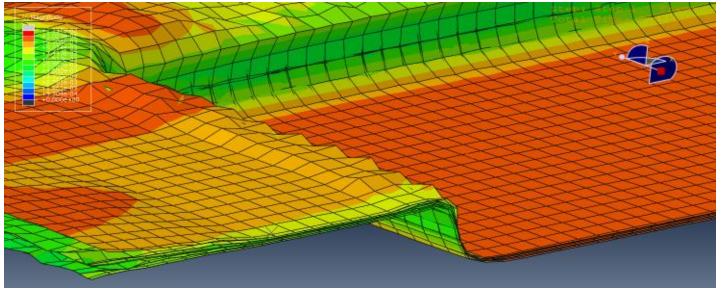
- High strength plus functional features
- Outcomes:
  - Demonstrator / Validation Data
  - Support anisotropic part inserts with strain loadings – interface to forming simulation
  - Understanding of bonding mechanisms
- Renewed for 2nd Phase
  - Interface to Structural FEA (including Helius)
  - Bond Strength dependence on flow length

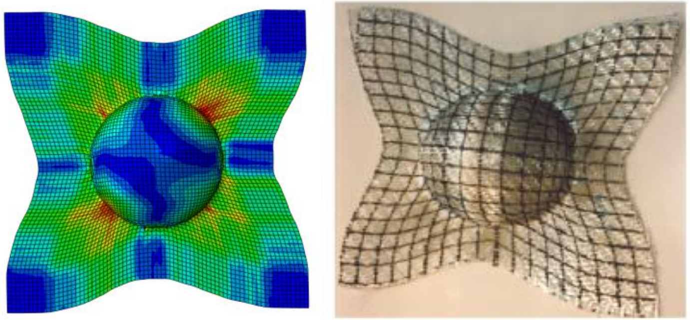




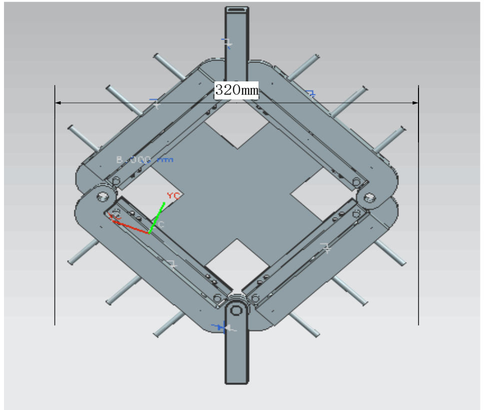
Composite Overmolding

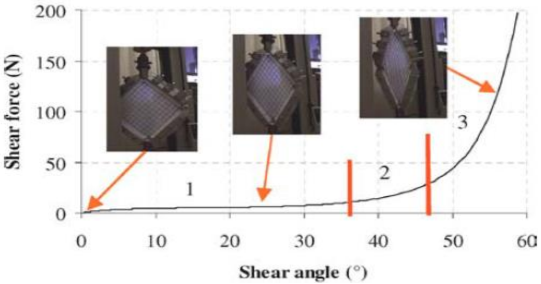
- Model non-recoverable deformation and resistance of a continuous fiber composite (pre-preg) being compression overmolded

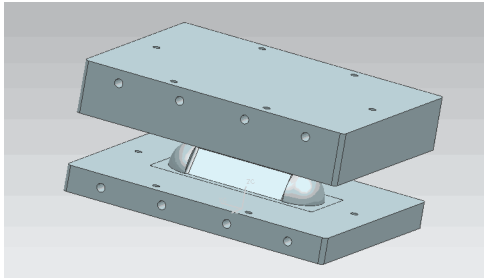




90° fiber orientation on hemisphere forming test

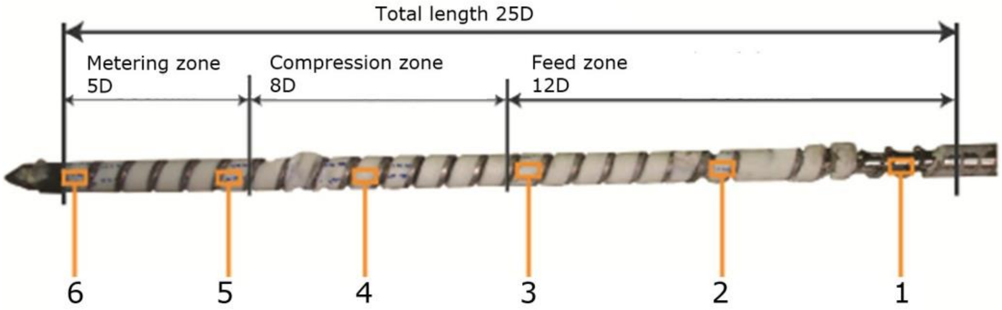


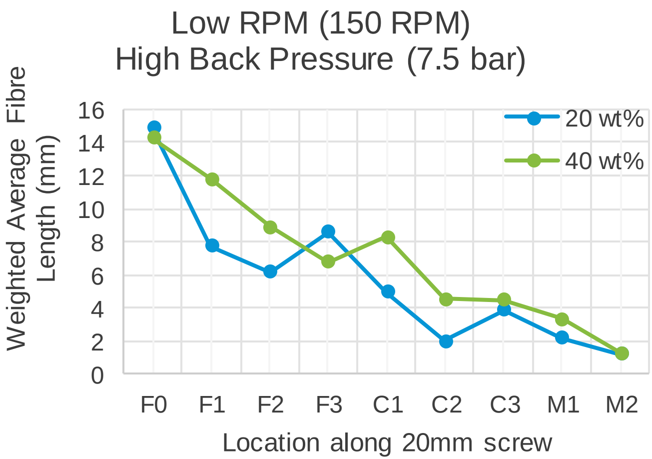




Fiber Breakage in Barrel

- Prediction of long fiber breakage during melting in injection barrel – as input for flow analysis in mold

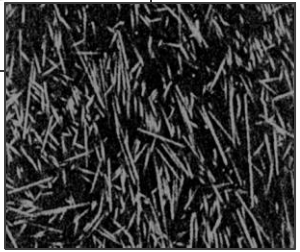


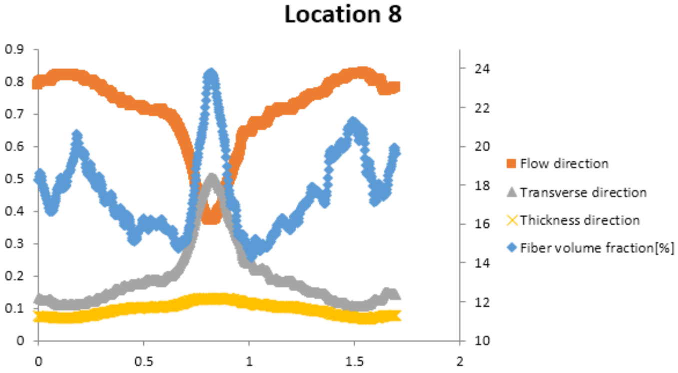


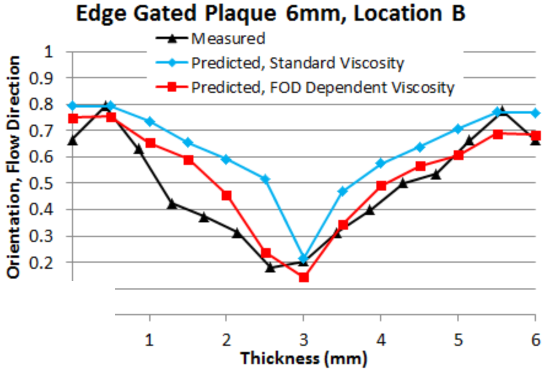
- Outcomes:
  - Fiber length data along barrel
  - May use this to build a model for fiber breakage in the barrel

Coupling Fiber Orientation and Viscosity

- Measure orientation in samples by X-Ray CT
- Develop a model for fiber orientation effect on viscosity
  - Enables prediction of plug flow in core
  - Predict a wider fiber orientation core

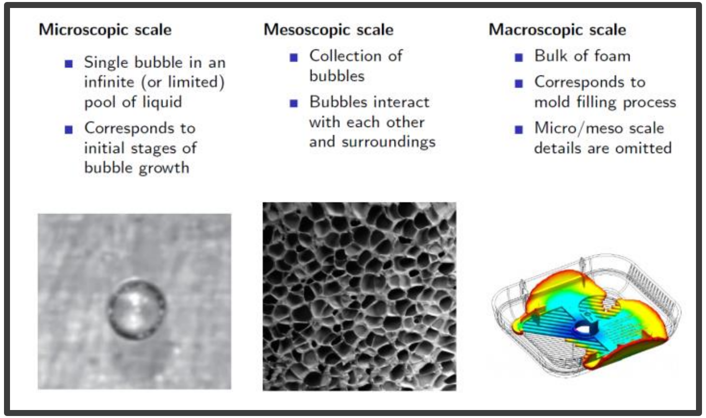


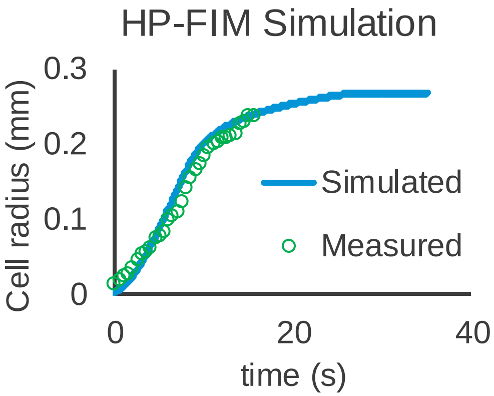


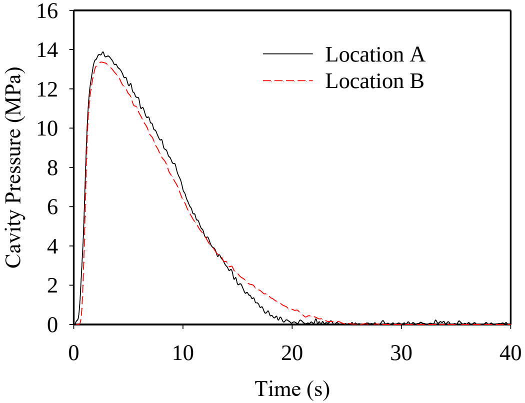


Foam Injection Molding

- Measurement and Modelling of Bubble Nucleation
- Outcomes:
  - Data on bubble growth
  - Potentially new modelling approaches

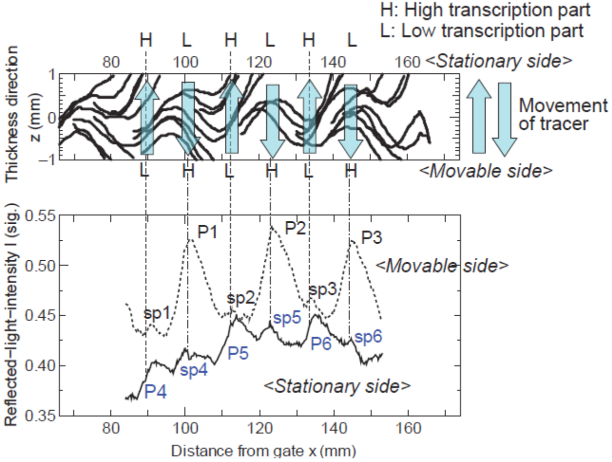


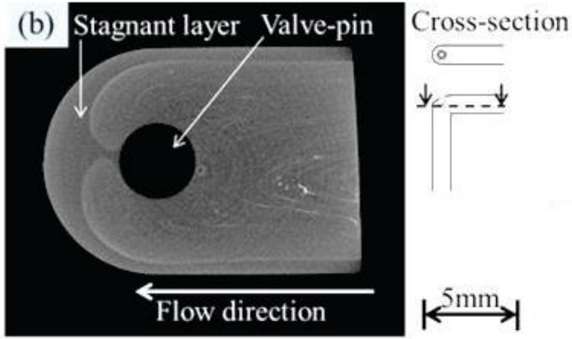


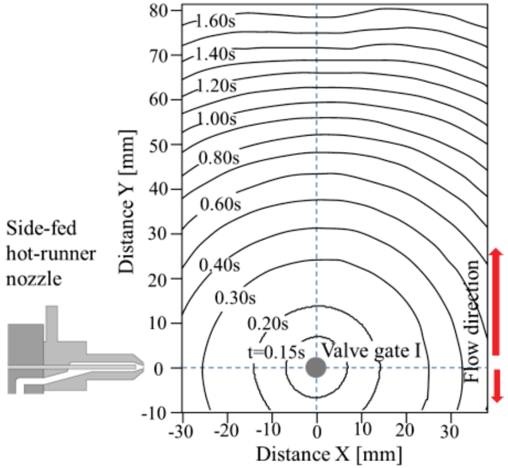


Yokoi Injection Molding Consortium

- Observing Fountain Flow Oscillation (Tiger Stripe)
- Flow Imbalance (Race-Track)
- Fiber breakage in barrel



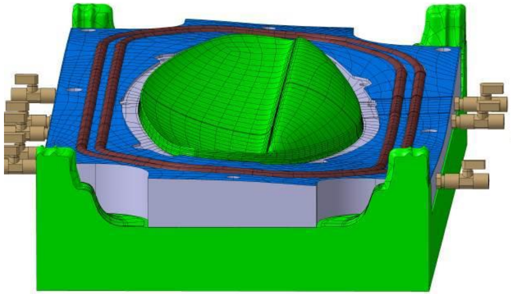


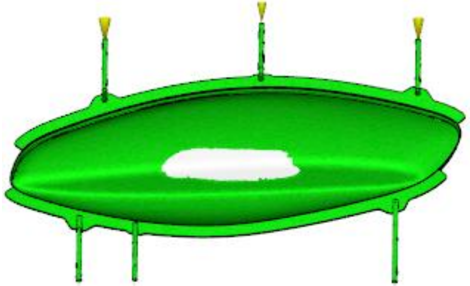


Source: Yokoi et al. PPS-31, 144-148 & 350-354

Resin Transfer Molding Validation

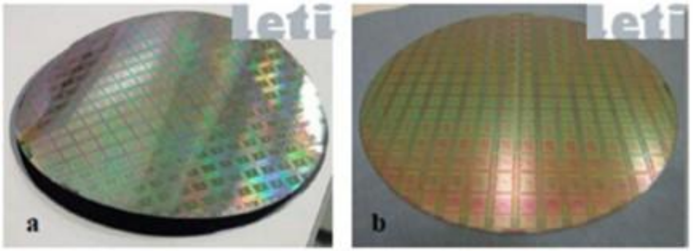
- Commissioned RTM moldings to obtain detailed process data for validation



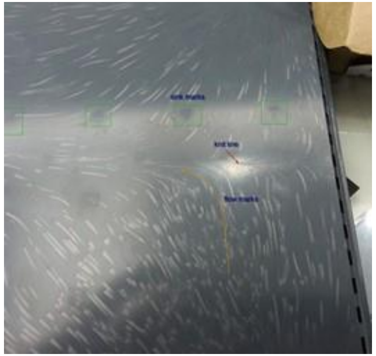


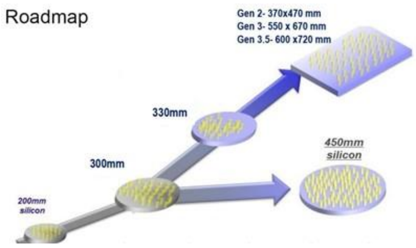
iNEMI Wafer/Panel Electronics Encapsulation

- Study of Flowability and Warp of Microelectronics Panels or Wafers



Polymer 1 Polymer 2





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