Moldflow Summit 2017

Advances in Weld Line Strength Predication and As-Manufactured Structural Simulation For Plastics

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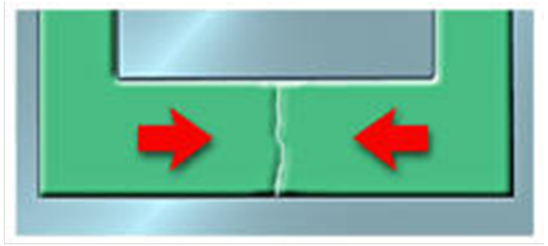
Weld Line Introduction

What Is A Weld Line or Knit Line?

- Regions where separated melt fronts recombine

- Separation due to:
  - Obstacle such as a core pin
  - Geometrical features of part
  - Multiple injection locations
  - Jetting



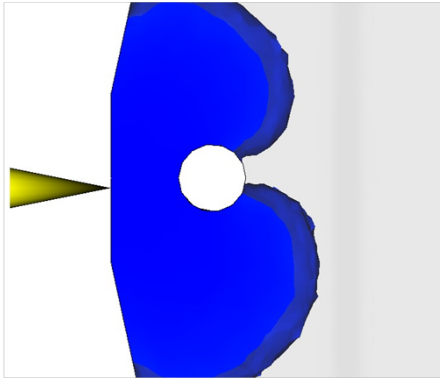


Image Source: PlasticsToday

Why Should We Care About Weld Lines?

- Product quality concerns
  - Weld lines can exhibit severe reductions in strength compared to bulk material
  - Insufficient polymer chain mixing
  - Fiber alignment

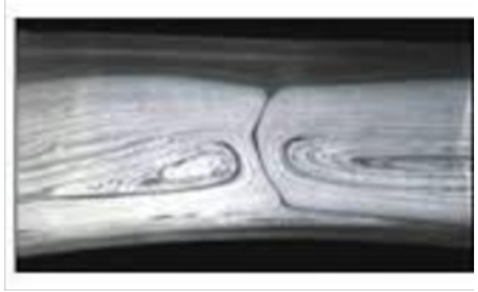
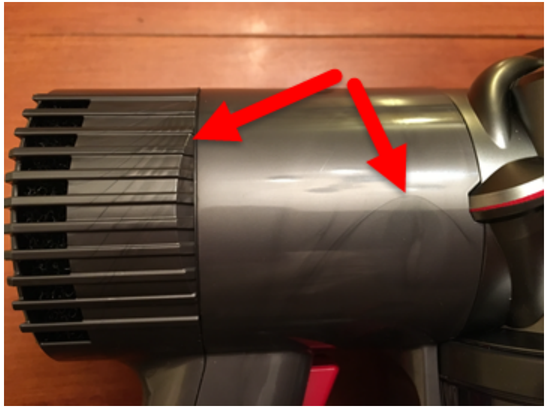


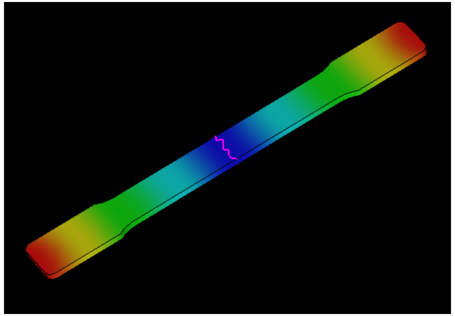
Image Source: PlasticsTechnology

- Aesthetic
  - Produces visible “line” on part surface
  - Perceived quality issue

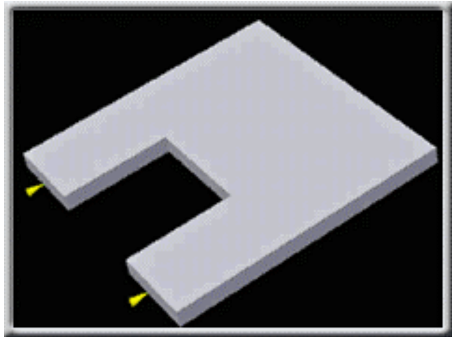


Classification of Weld Lines

- Class 1 (cold or butt) weld line:
  - Separated flow fronts traveling in opposite directions meet and rapidly immobilize
  - Weaker than Class 2 due to poor bonding at interface



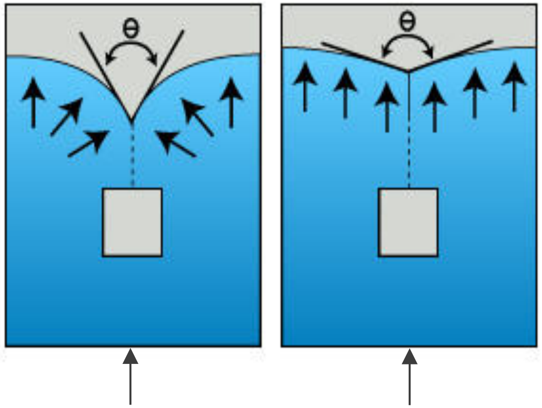
- Class 2 (hot, streaming or meld) weld line:
  - Flow front traveling in same direction separated by an obstacle or multiple gates and recombines



Meeting Angle Classification

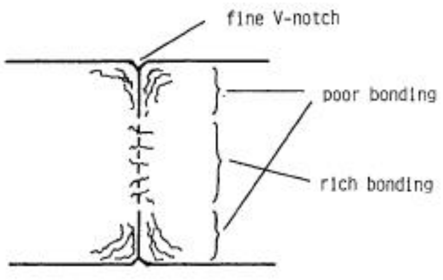
- Meeting angle – Plane included angle, θ, of meeting flow fronts

- Used in CAE software to determine severity and classification
  - θ < 135°= weld line (Class 1)
    - Dashed line in image
  - θ > 135°= meld line (Class 2)
    - Solid line in image

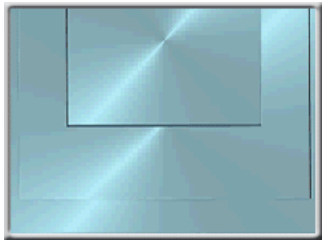


Primary Factors Effecting Weld Line Strength

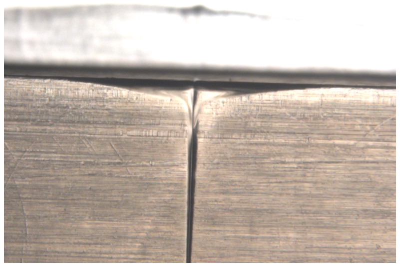
- Poor bonding at meeting interface:
  - Dependent on process and material
  - Varies across gap thickness
  - Weak secondary polar bonds at interface



- Orientation:
  - Fountain flow orients polymer chains or fillers (fiber) perpendicular to flow direction



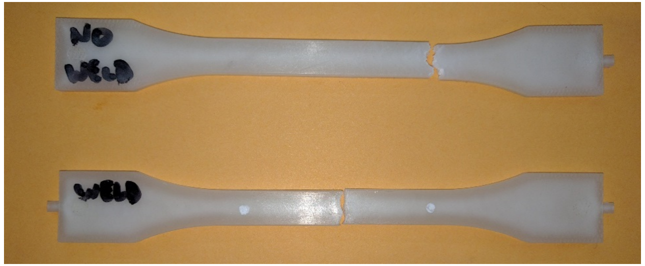
- V-notch (stress amplifier):
  - Compressed gases formed by meeting flow fronts
  - High viscosity or frozen skin

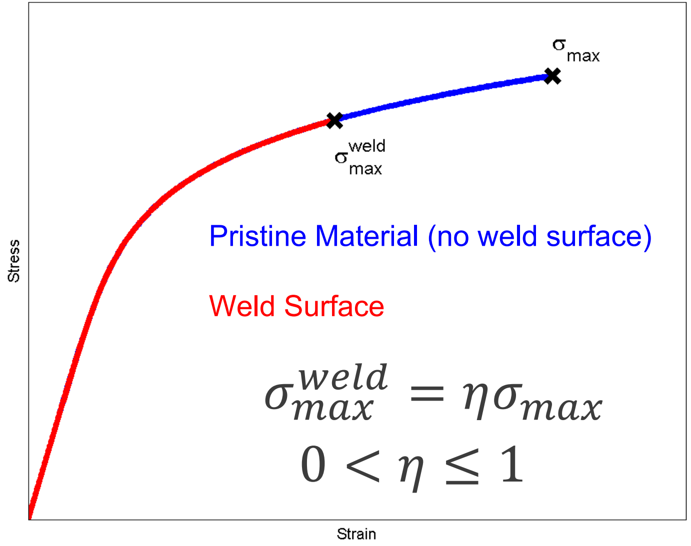


Top Image Source: Tomari et al. PES, 33, 1001 (1993)

Weld Line Strength Testing

- Weld line retention $$\eta = \frac{F_w}{F_b} or \frac{\sigma_w}{\sigma_b}$$
- Tensile Testing
  - ASTM-D647
  - Notch sensitive
  - Rate & temperature dependent





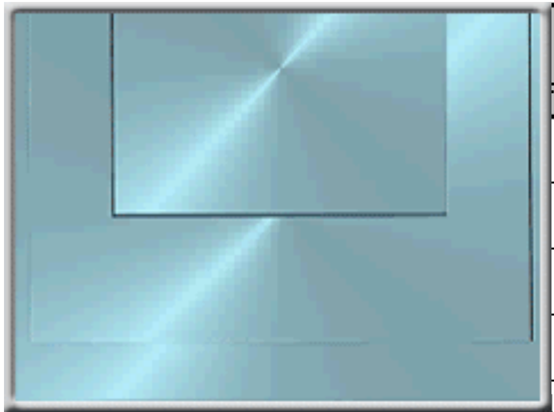
Example Weld Line Strength Retention Values

Amorphous Resin	Reinf.	%	Filler	%	η % (UTS)
PC	-	-	-	-	99
PC	GF	10	-	-	90
PC	GF	30	-	-	65
PC	GF	40	-	-	55
PC	-	-	Milled Gl	30	92
PC	GF	30	PTFE	15	60
SAN	-	-	-	-	80
SAN	GF	30	-	-	40
SAN	GF	30	Flame Ret	10	45
PSU	-	-	-	-	100
PSU	GF	30	-	-	62

Crystalline Resin	Reinf.	%	Filler	%	η % (UTS)
PA66	-	-	-	-	97
PA66	GF	10	-	-	93
PA66	GF	30	-	-	61
PA66	GF	40	-	-	52
PA66	LGF	30	-	-	58
PA66	CF	30	-	-	47
PA66	-	-	Glass Bd	30	95
PP	-	-	-	-	86
PP	GF	30	-	-	34
PPS	-	-	-	-	83
PPS	GF	40	-	-	20

Reference: Cloud et al., “Reinforced Thermoplastics: Understanding Weld-Line Integrity”, Plastics Technology, 22, 48, (1976).

Example Weld Line Strength Retention Values



[illegible]	[illegible]	[illegible]	Filler	%	η % (UTS)
[illegible]	[illegible]	[illegible]	-	-	99
[illegible]	[illegible]	[illegible]	-	-	90
[illegible]	[illegible]	[illegible]	-	-	65
[illegible]	[illegible]	[illegible]	-	-	55
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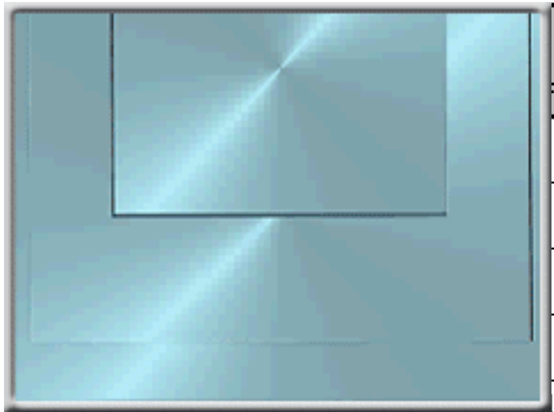

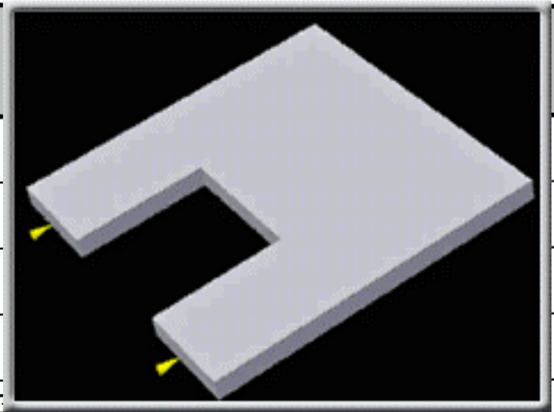

			Filler		
			-		
			-		
			-		
			-		
			…lled G…		
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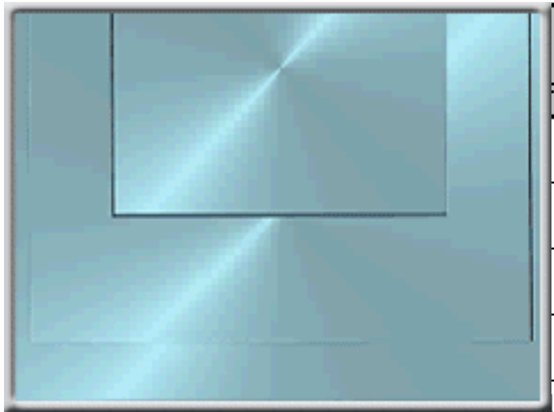
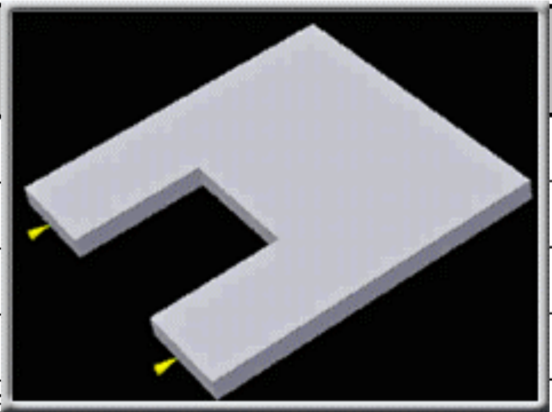
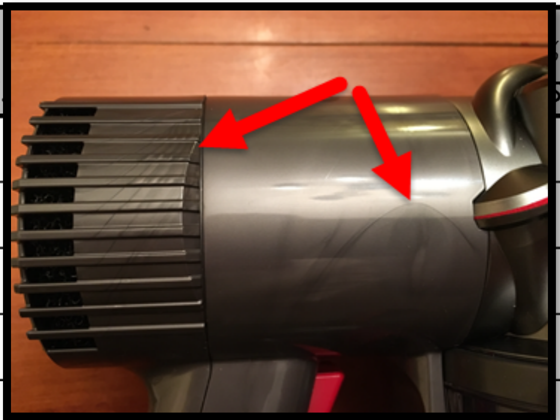
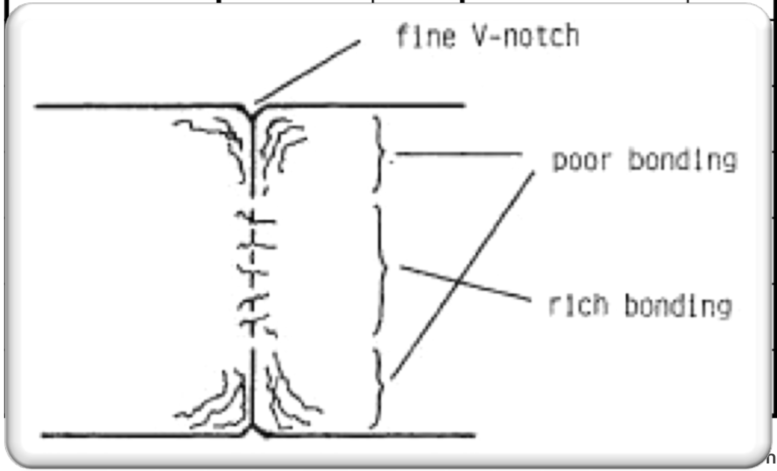


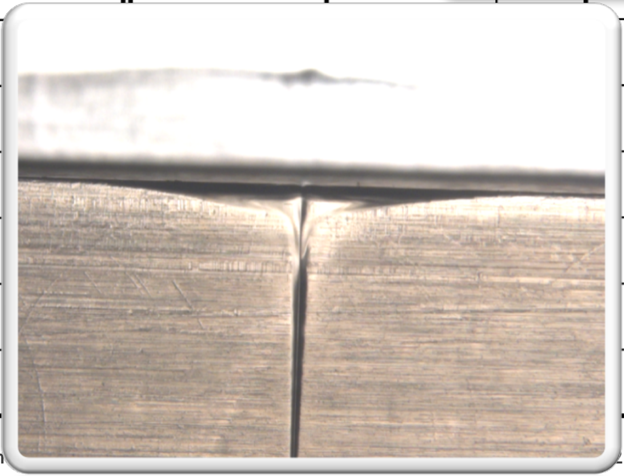




Filler	Reinf
-	-
-	GF
-	GF
-	GF
illed G	LGF

G





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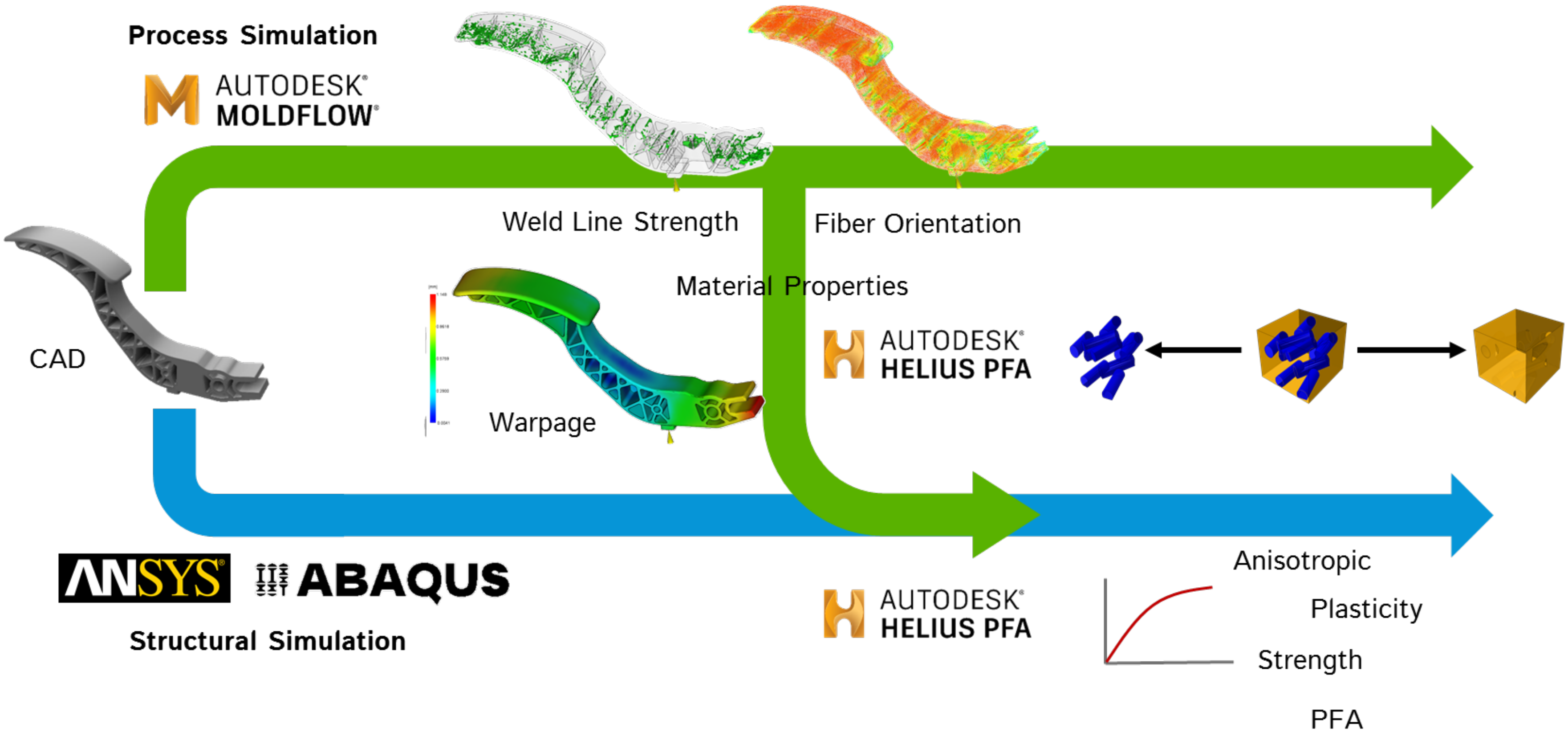
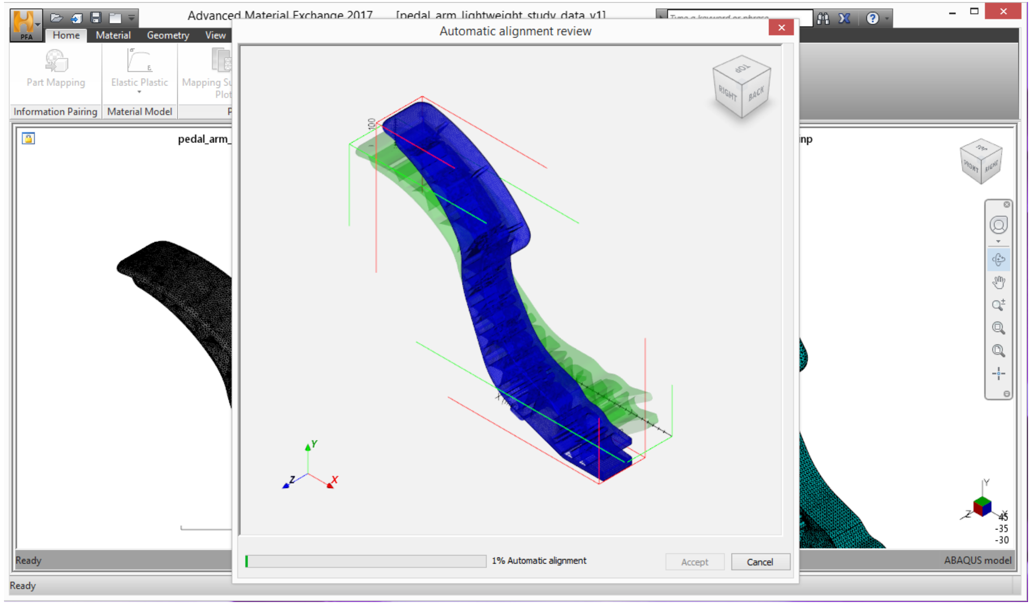
As-manufactured Simulation

As-Manufactured Simulation Workflow Overview



Helius PFA For Plastics Overview

- Dissimilar model support
  - Geometry
  - Mesh
  - Position



Helius PFA For Plastics Overview

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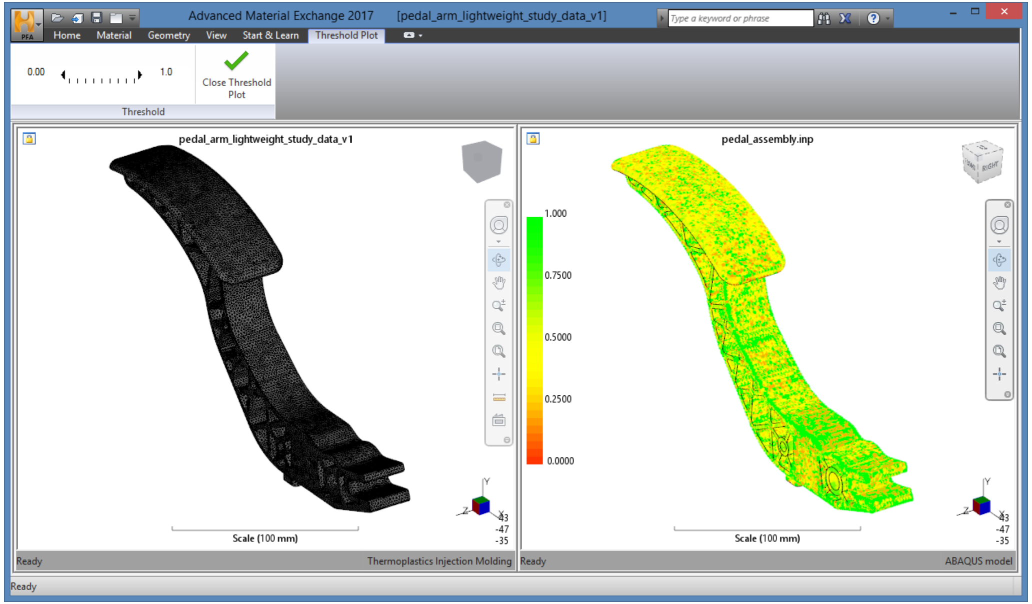
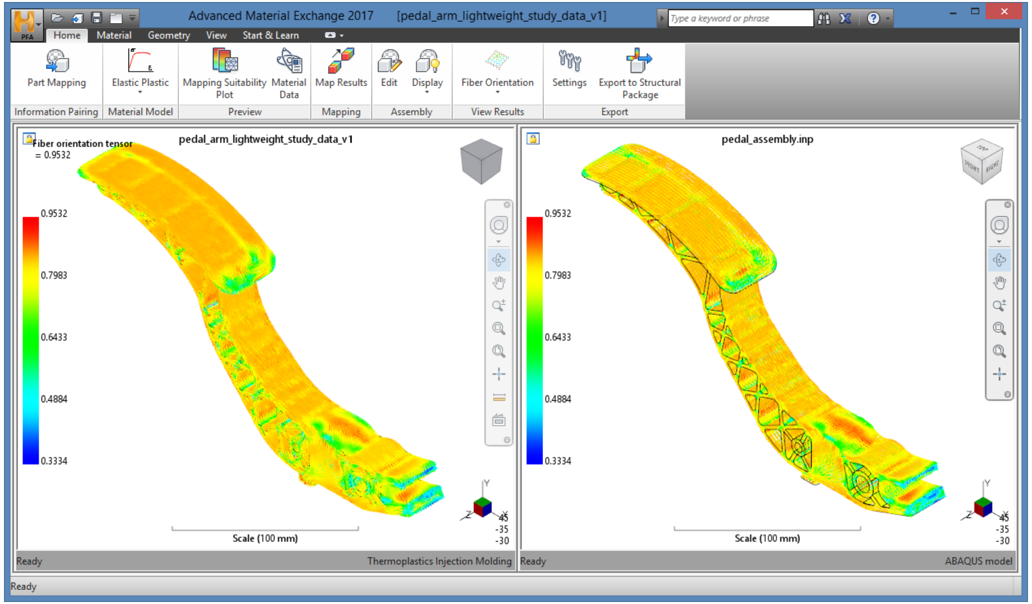
- Mapping
  - Solid to Solid
  - Shell to Shell
  - Mapping suitability
  - Assemblies



Helius PFA For Plastics Overview

- Dissimilar model support
  - Geometry
  - Mesh
  - Position
- Mapping
  - Solid to Solid
  - Shell to Shell
  - Mapping suitability
  - Assemblies
- Mapped data
  - Non-linear material properties
  - Fiber orientations
  - Strain (Warpage)
  - 3D weld surface strength

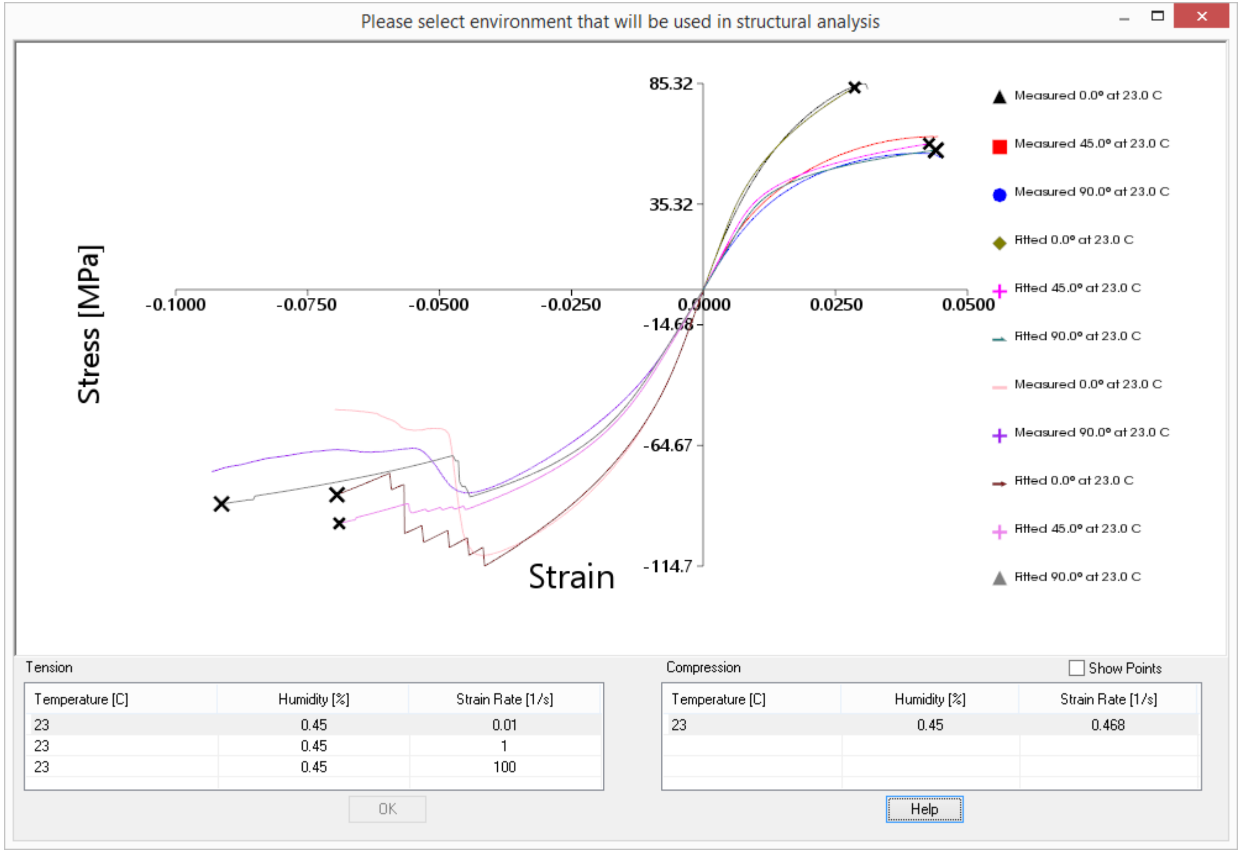


Moldflow **Structural**

Material Testing

Material Testing

- Testing offered through Autodesk Moldflow Labs and partners
- Parallel, perpendicular, 45º to flow direction
- Tension & compression data in MF database
- Many times compression data is not equivalent to inverse of tension



Tension

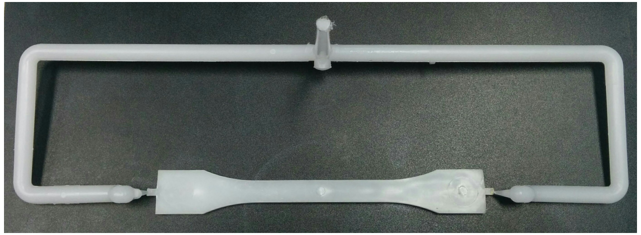
Temperature [C]	Humidity [%]	Strain Rate [1/s]
23	0.45	0.01
23	0.45	1
23	0.45	100

Compression

Temperature [C]	Humidity [%]	Strain Rate [1/s]
23	0.45	0.468

Material Testing – Weld Line Strength

- Soon to be added material test
- Dog bone specimens molded
  - Single and dual opposing gate configurations



- Two level Taguchi DOE sample:
  - Melt temperature
  - Mold temperature
  - Injection rate
  - Pack pressure
  - Pack time
  - Cooling time

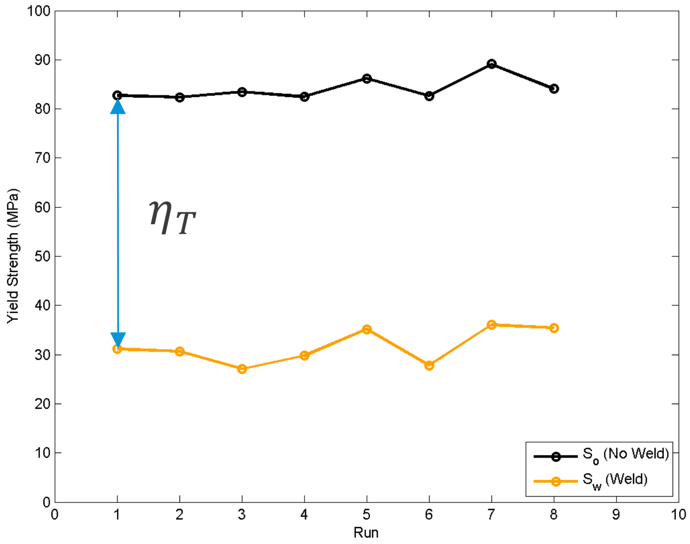
Run	Melt Temp (°C)	Mold Temp (°C)	Injection Rate (cm^3/s)	Pack Pressure (MPa)	Pack Time (s)	Cool Time (s)
1	200	20	40	40	2.5	35
2	200	20	40	70	6	45
3	200	40	80	40	2.5	45
4	200	40	80	70	6	35
5	220	20	80	40	6	35
6	220	20	80	70	2.5	45
7	220	40	40	40	6	45
8	220	40	40	70	2.5	35

- Multiple specimens from each process setup mechanically loaded in tension until ultimate failure
- Data generated used to determine weld line coefficients used in material file (Mech Prop)

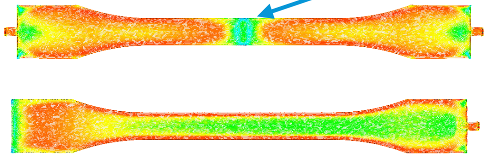
Weld Surface Strength Reduction Details

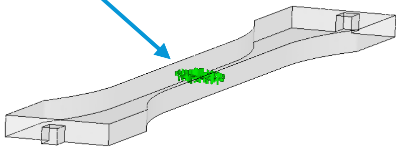
Weld Surface Strength Reduction Contributors

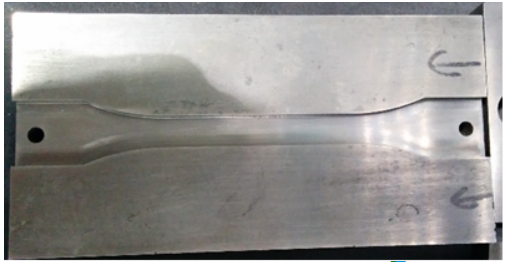
- Two contributors to strength reduction considered:
  - η_α – Fiber orientation
  - η_w – Weld surface



$$\eta_T = \frac{S_w}{S_o} = \eta_\alpha \eta_w$$

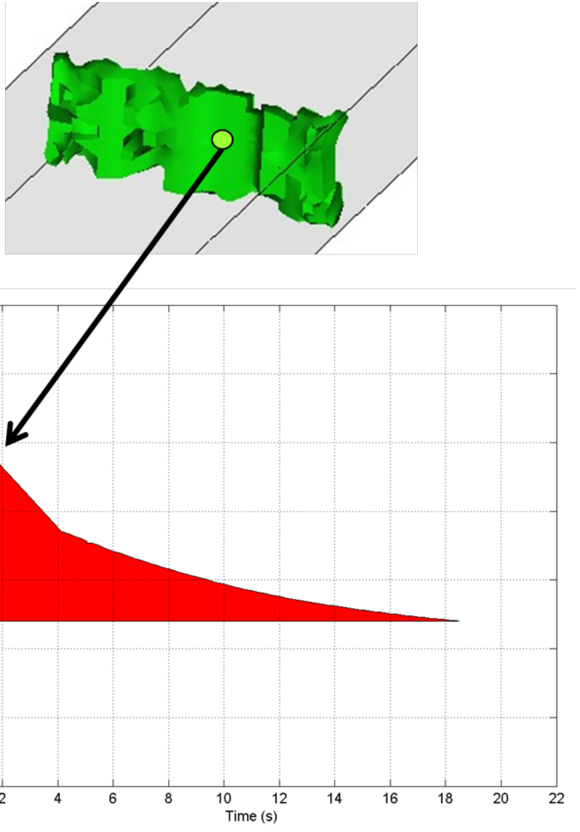






Weld Surface Reduction (Temp & Pressure)

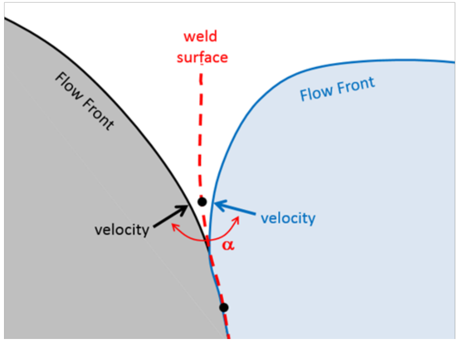
- Moldflow simulation yields detailed information for each point on the weld surface over time
  - Temperature and pressure history



$$d\beta = \beta_{(t)}\left(c_T\left(T_{(t)} - T_g\right) + c_P P_{(t)}\right)dt$$

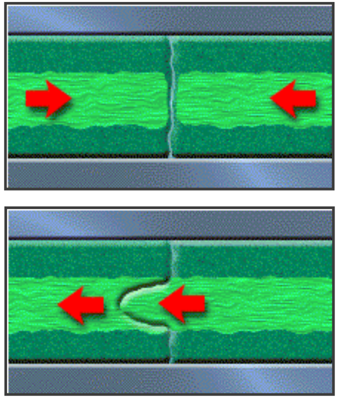
initial condition

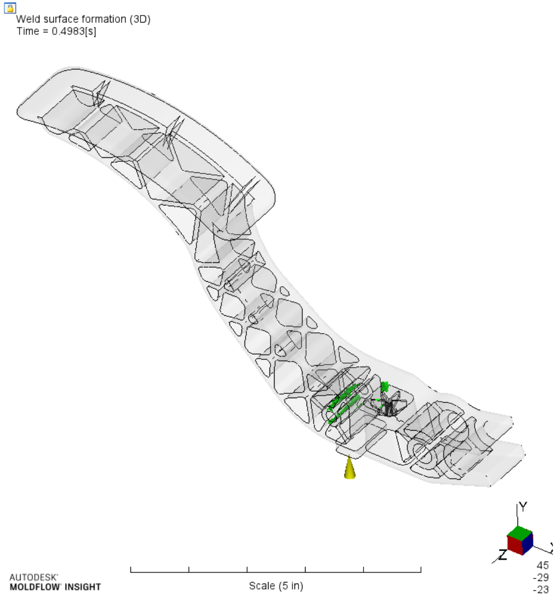
$$\beta(0) = \left\langle \frac{\alpha_{crit} - \alpha}{\alpha_{crit}} \right\rangle$$

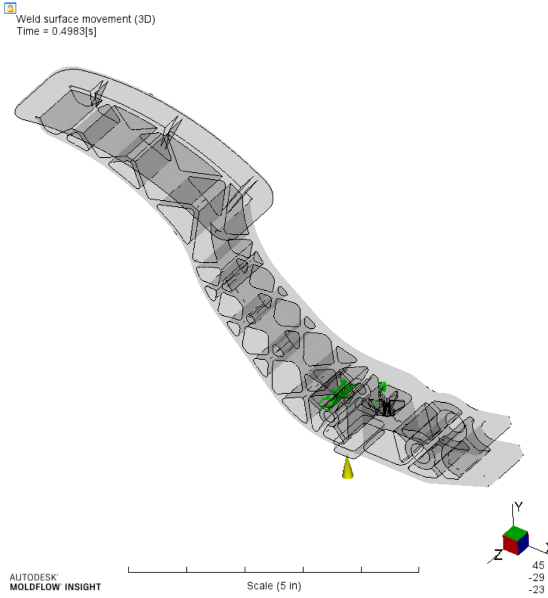


Weld Surface Reduction (Formation & Movement)

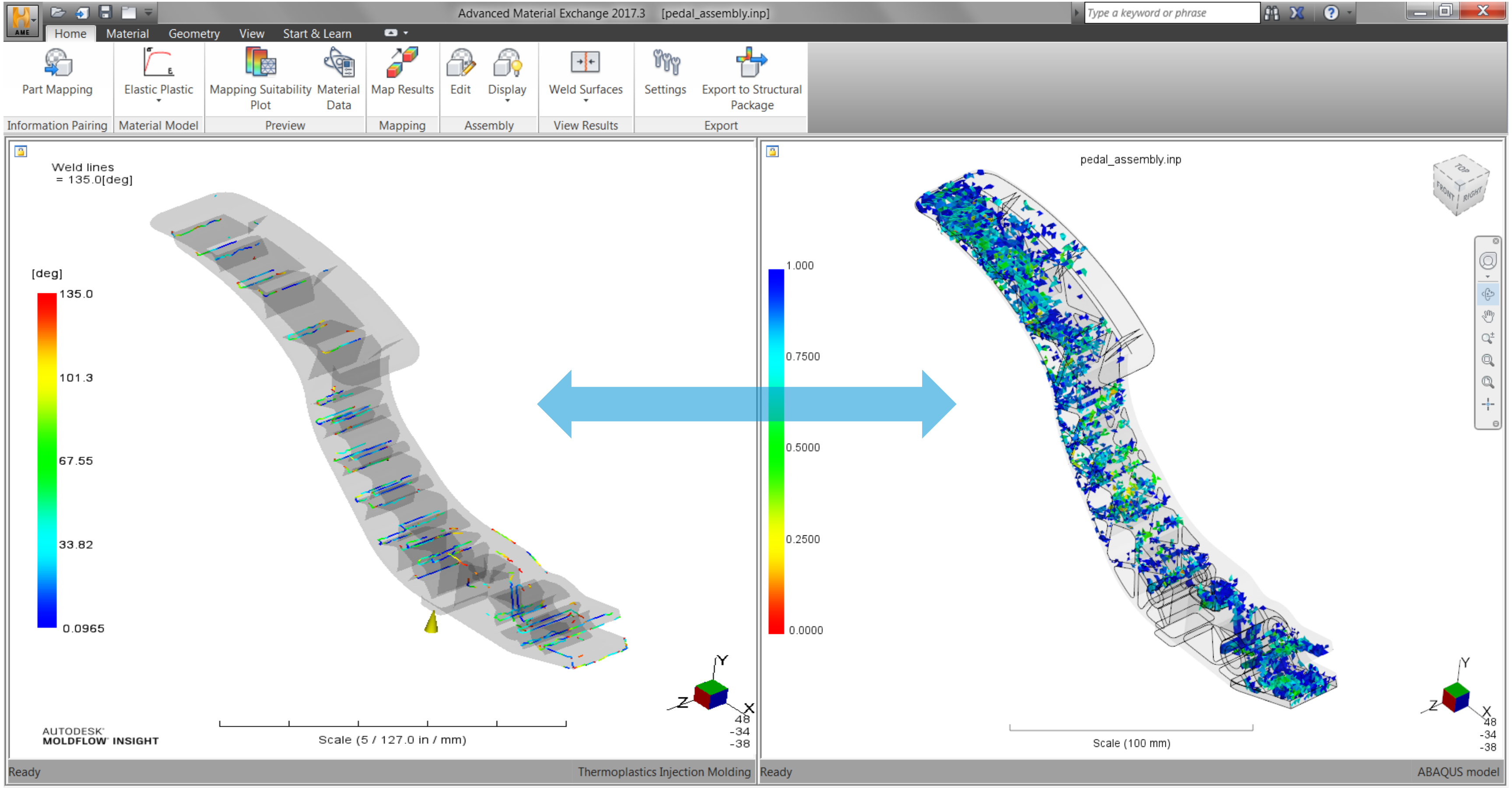
- Moldflow simulation yields detailed information for each point on the weld surface over time
  - Temperature and pressure history
  - Formation & Movement







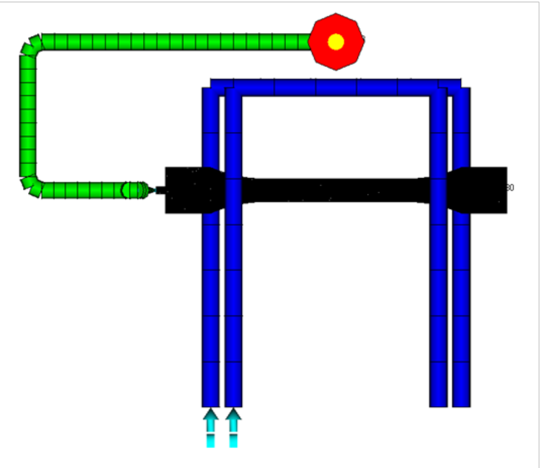
Weld Surface Strength Reduction In Helius PFA

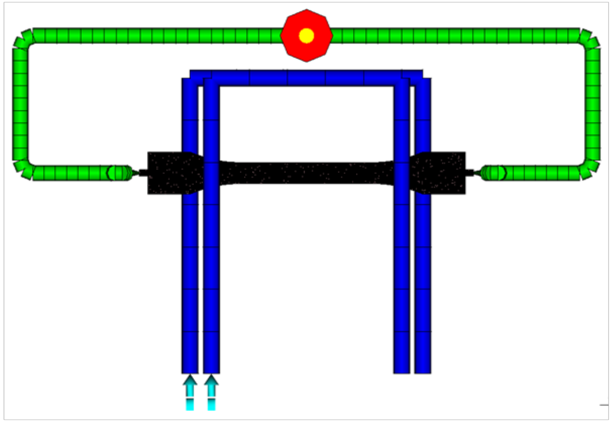


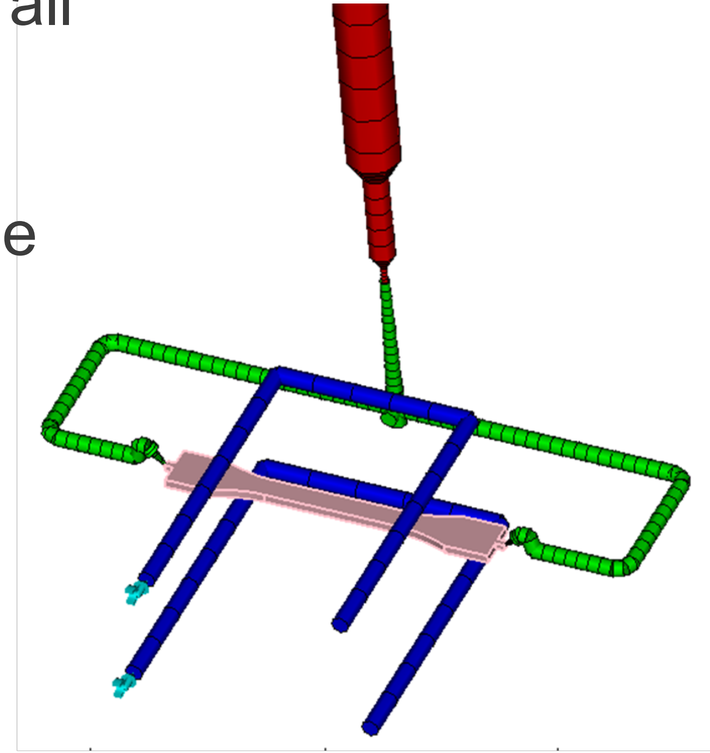
Validation Example

Dog Bone Moldflow Model

- Cool+Fill+Pack analysis performed for all eight process conditions (DOE)
- 1.5 million tetrahedral elements
- Extron 3019 HS 30% GF Polypropylene

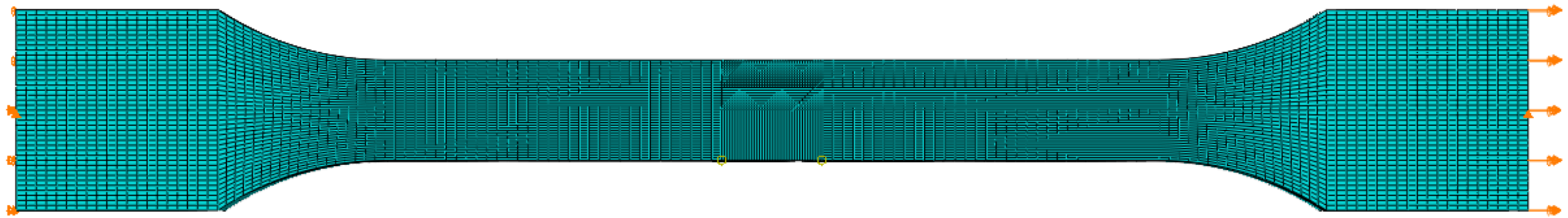






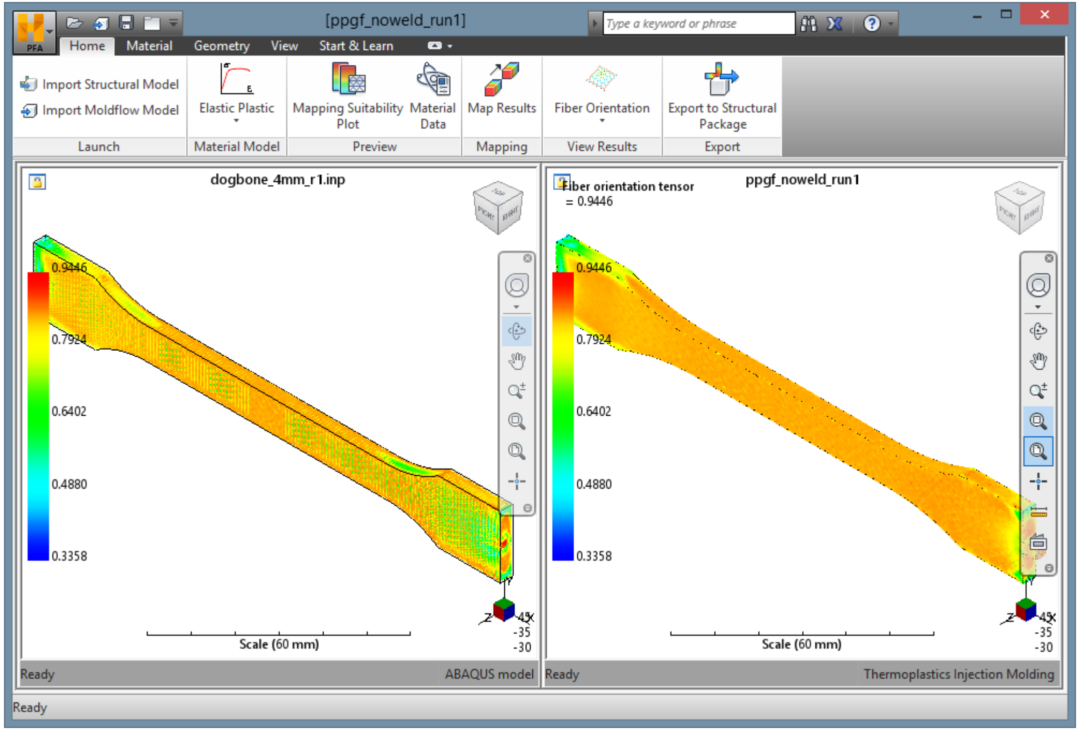
Dog Bone Structural Model

- Abaqus/Standard
- 116,000 hexahedral elements
- Displacement control loading



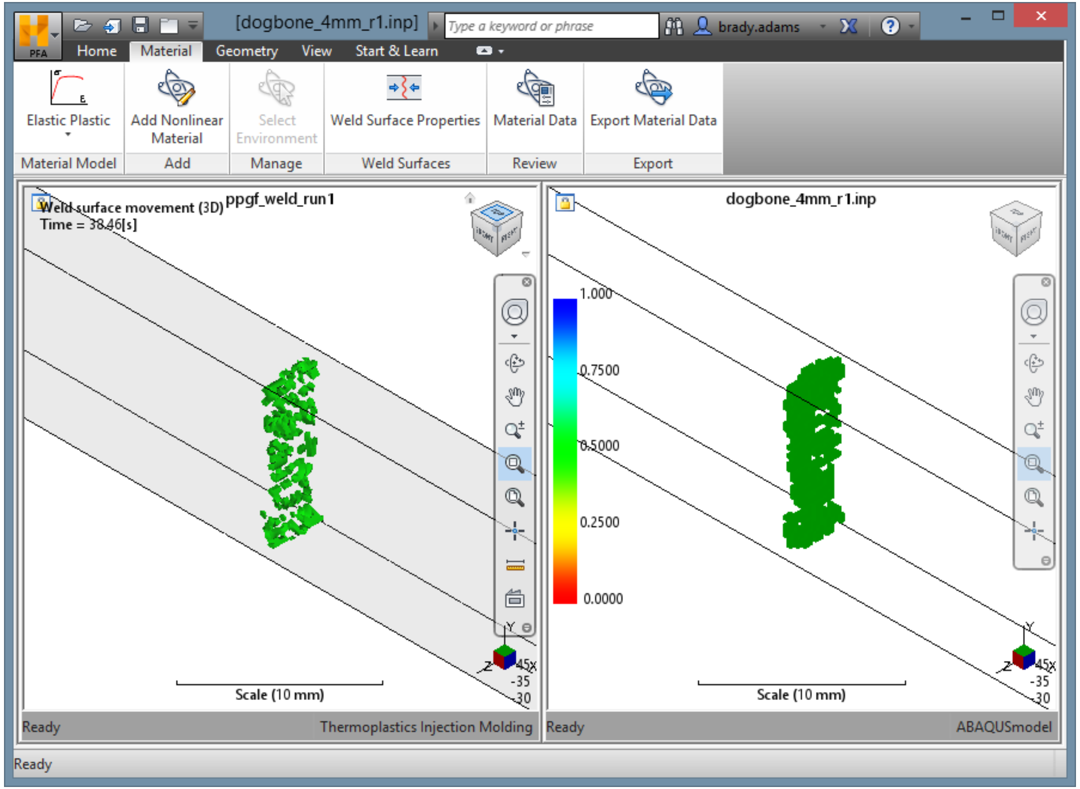
Mapping Moldflow Results to FEA using Helius PFA

- Transferred results to Abaqus FEA model for all eight processing conditions
- Fiber orientations transferred for single gate specimens

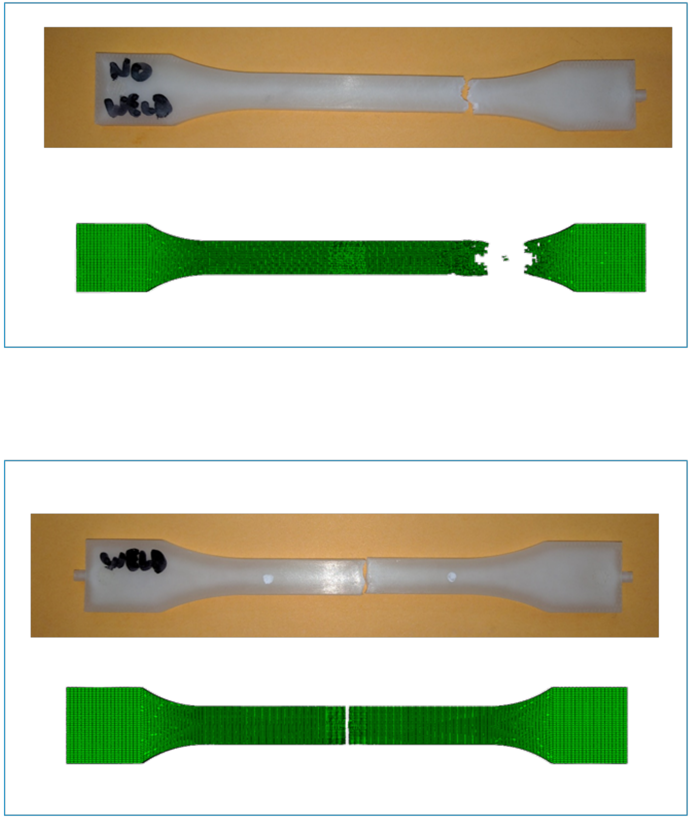


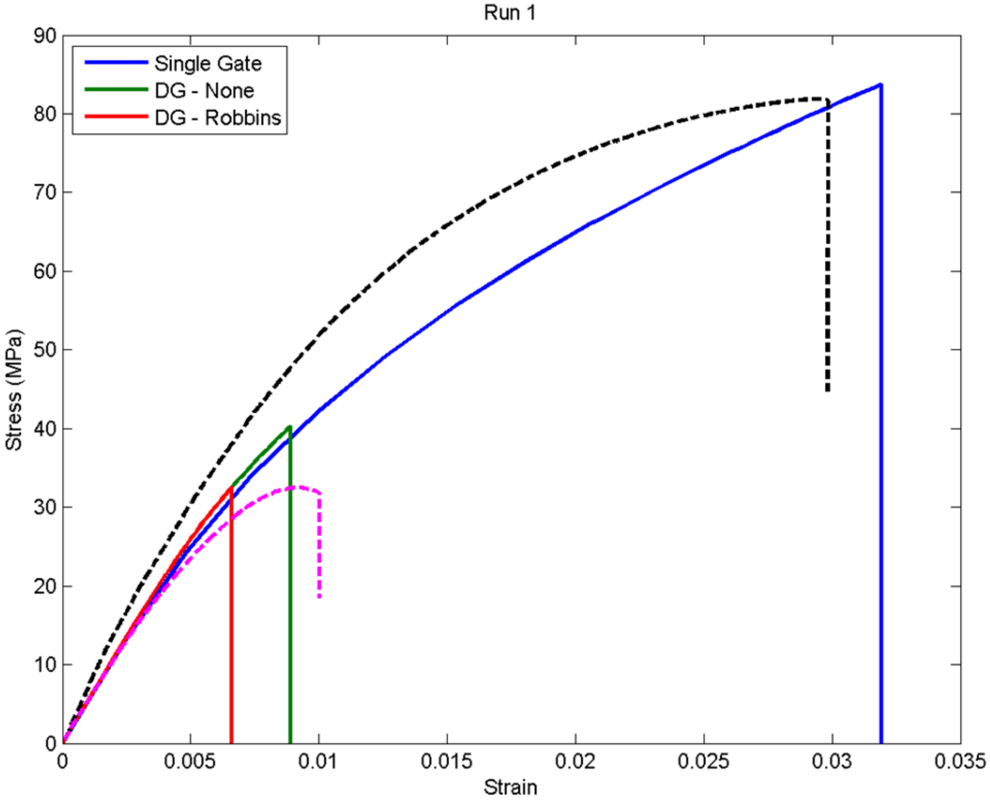
Mapping Moldflow Results to FEA using Helius PFA

- Double gate specimens ran twice:
- Without weld surface strength reduction (η_α only)
- With weld surface strength reduction (η_α and η_w)



Structural Simulation Results Comparison





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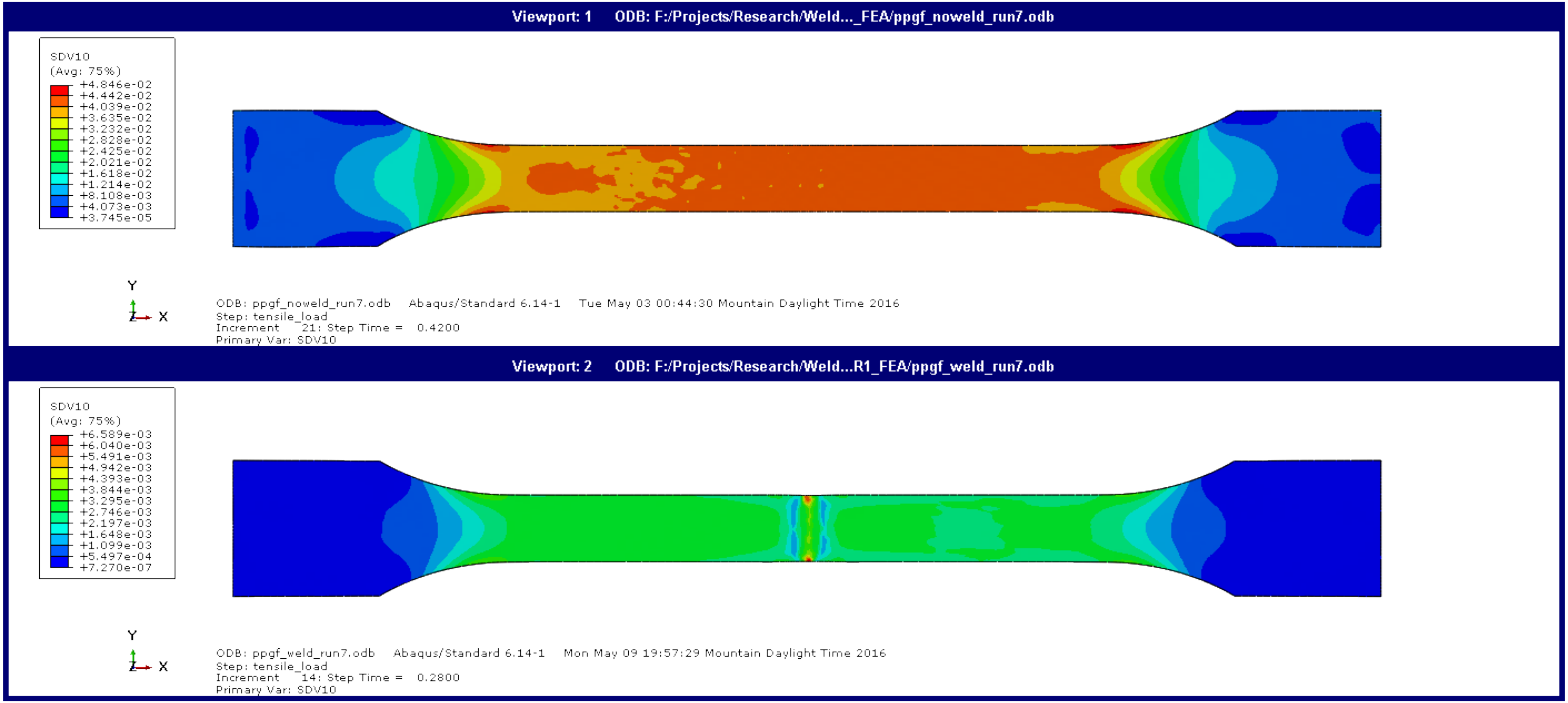
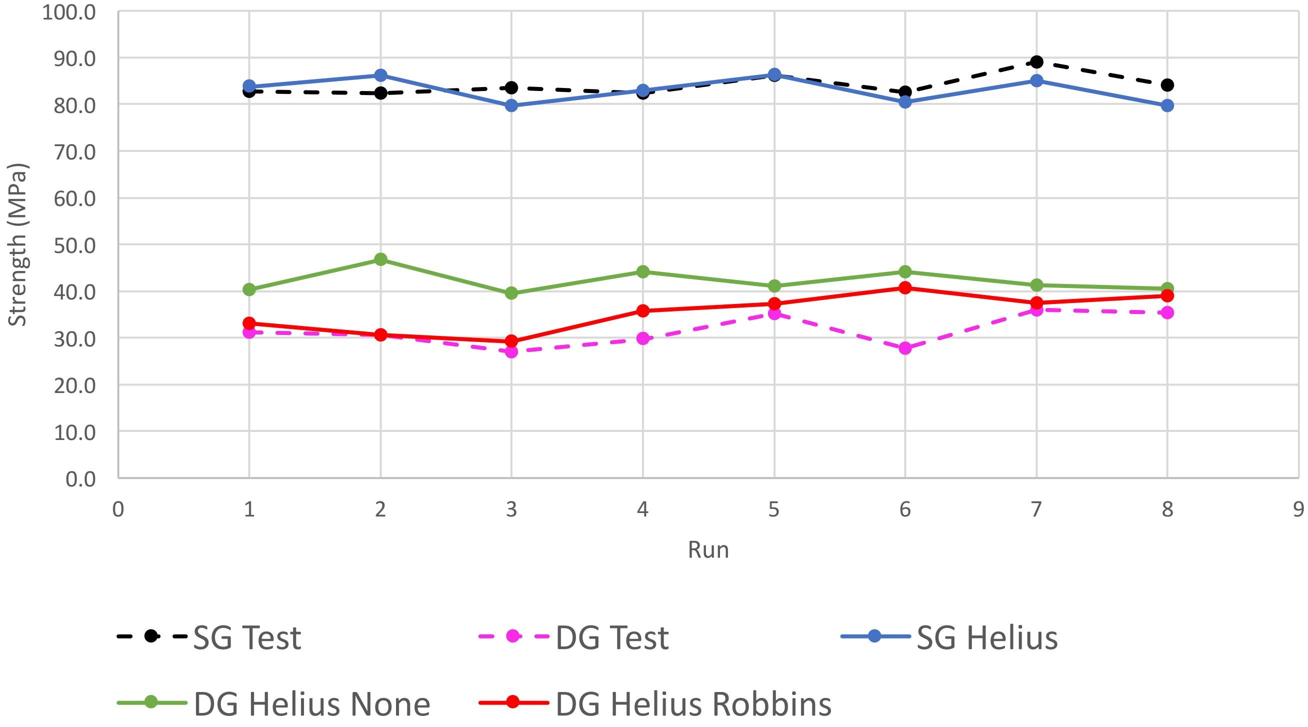


Plastic Strain

Summary Comparison to Experiment



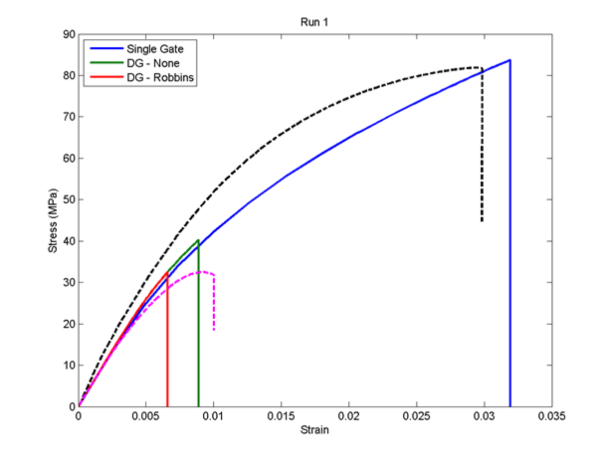
Summary

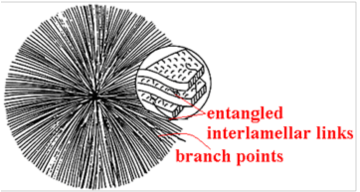
- Helius PFA for Plastics provides an integrated, simple approach to link the as-manufactured plastics simulation properties with structural simulation to increase FEA accuracy
  - Insight Ultimate 2018 **Subscription** customers have access to Helius PFA
  - Dissimilar mesh can be used (mapping suitability check)
  - Moldflow users can pass results to structural users
  - Simple interface for integration of both software packages
- Keys to increasing accuracy for structural simulation of plastics
  - Stiffness
    - Anisotropic
    - Nonlinear
  - Strength
    - Weld surface (meeting angle & movement, temp & pressure history)
    - Failure mode & load

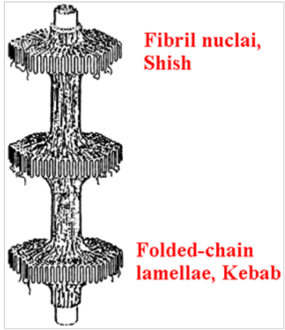
Future Work

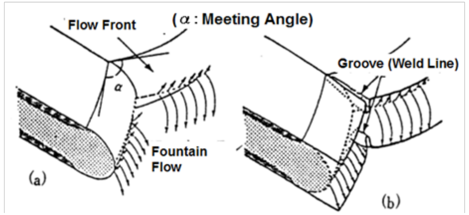
Future & Improvements

- Present validation with customer parts
- Improve prediction curve response
  - Include other effects into calculation:
    - Crystallinity
    - Polymer orientation
    - Polymer blends
    - Additives
    - More comprehensive approach to weld/meld lines





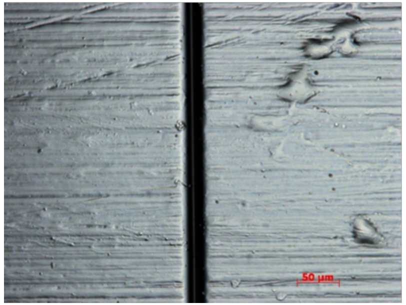


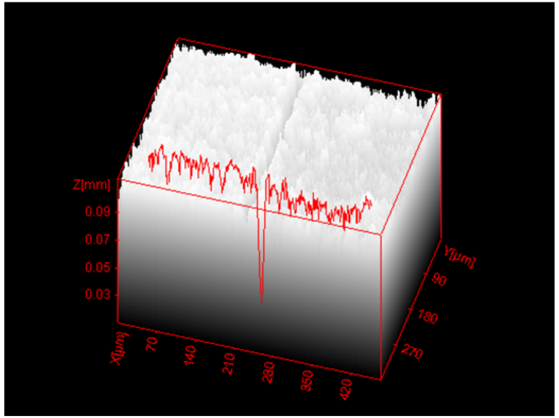


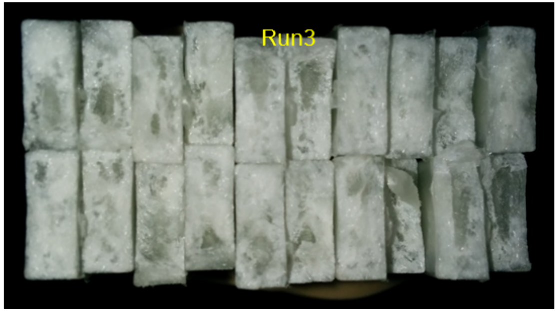
Future & Improvements

- Integrate venting analysis
  - Vnotch effects
  - Air traps
    - Specimens molded with high injection rate contained a large number of air traps

Run	Injection Rate (cm^3/s)	Air Traps
1	40	1
2	40	0
3	80	7
4	80	3
5	80	2
6	80	7
7	40	0
8	40	1







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