Simulating Compression Molding of LFT

Patrick Mabry, Erik Foltz

The Madison Group

AUTODESK.

The Madison Group

- Independent plastics consulting firm located in Madison, WI
  - Founded in 1993
  - Originally began with development of CADPRESS software for compression molding of SMC
- Patrick Mabry, M.S.
  - B.S. Composite Materials Engineering – Winona State University
  - M.S. Mechanical Engineering – University of Wisconsin – Madison
    - Focus in polymers processing at the Polymer Engineering Center
  - Composites manufacturing engineer for Trek Bicycle Corp.
  - Plastics engineer with The Madison Group

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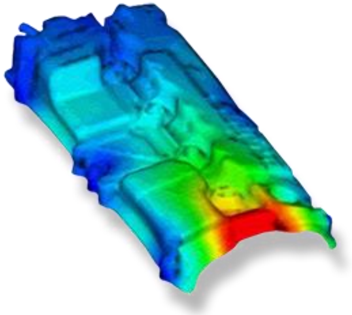
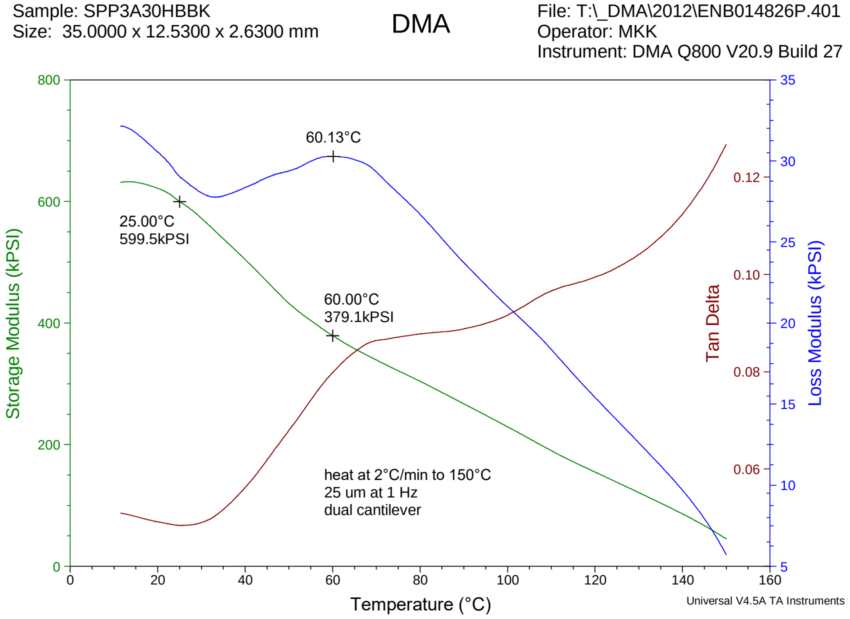
The Madison Group

- Materials Engineering
  - Materials Selection
  - Part Design Review
  - Structural FEA
  - Mechanical and Thermal Characterization of Materials
  - Aging and Compatability Studies
  - Product and Life Time Analysis





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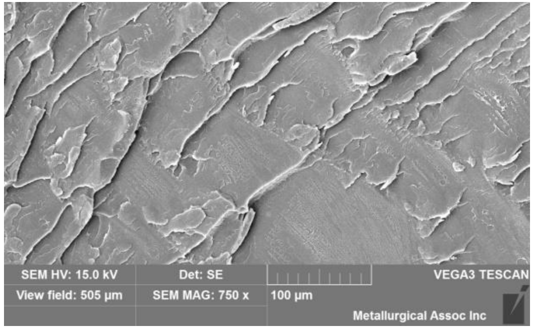
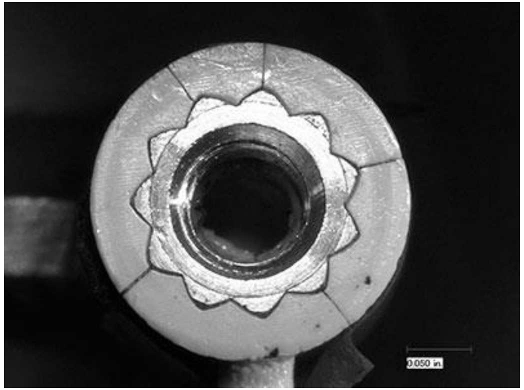
- Failure Analysis
  - Determination of Root Cause
  - Failure Type Assessment
  - Fractography
  - Destructive and Non-Destructive
  - On-site Support





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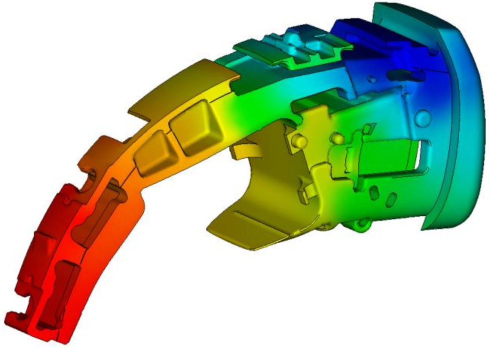
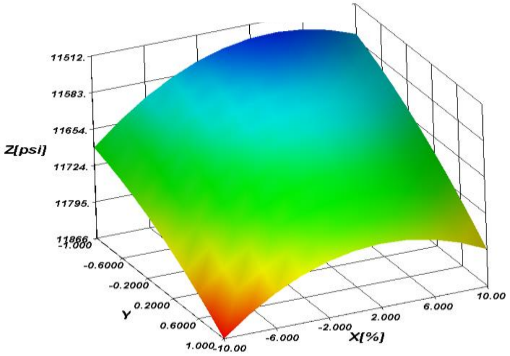
The Madison Group

- Manufacturing Solutions:
  - Moldflow Analysis
    - Injection Molding
    - Compression Molding
    - Thermosets and Thermoplastics
  - Physical DOE Set Up and Analysis
    - Process Capability
    - Product Qualification





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Why Compression Molding?

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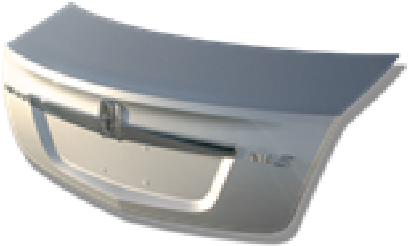
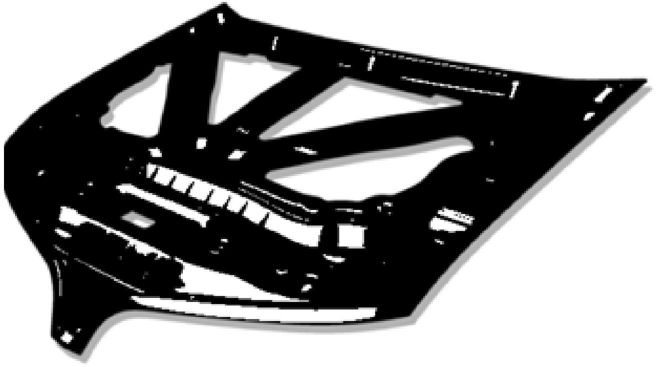
Why Compression Molding?

- As pressures increase to reduce weight and costs, non-metallic materials are being utilized in more performance demanding applications
- Thermoplastic composites can present easier processing and faster cycle times relative to thermoset composites





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Performance vs. Cycle Time

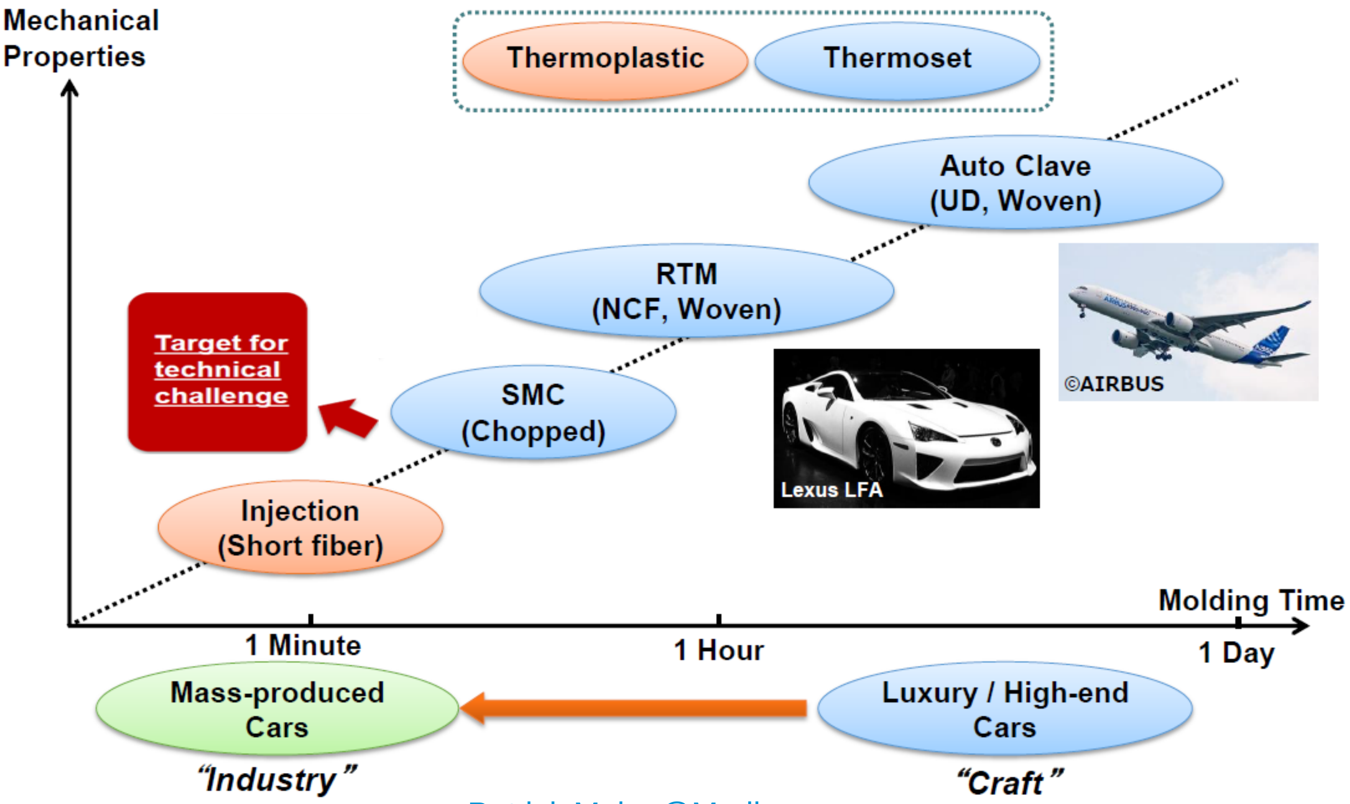

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Image Source: Teijin

Thermoplastic Composites

- Discontinuously reinforced thermoplastic composites offer the ability to mass-produce higher performance components on conventional equipment

- Matrix

- PP
- PA6
- PA66
- TPU

- Reinforcement

- Glass Fiber
- Carbon Fiber

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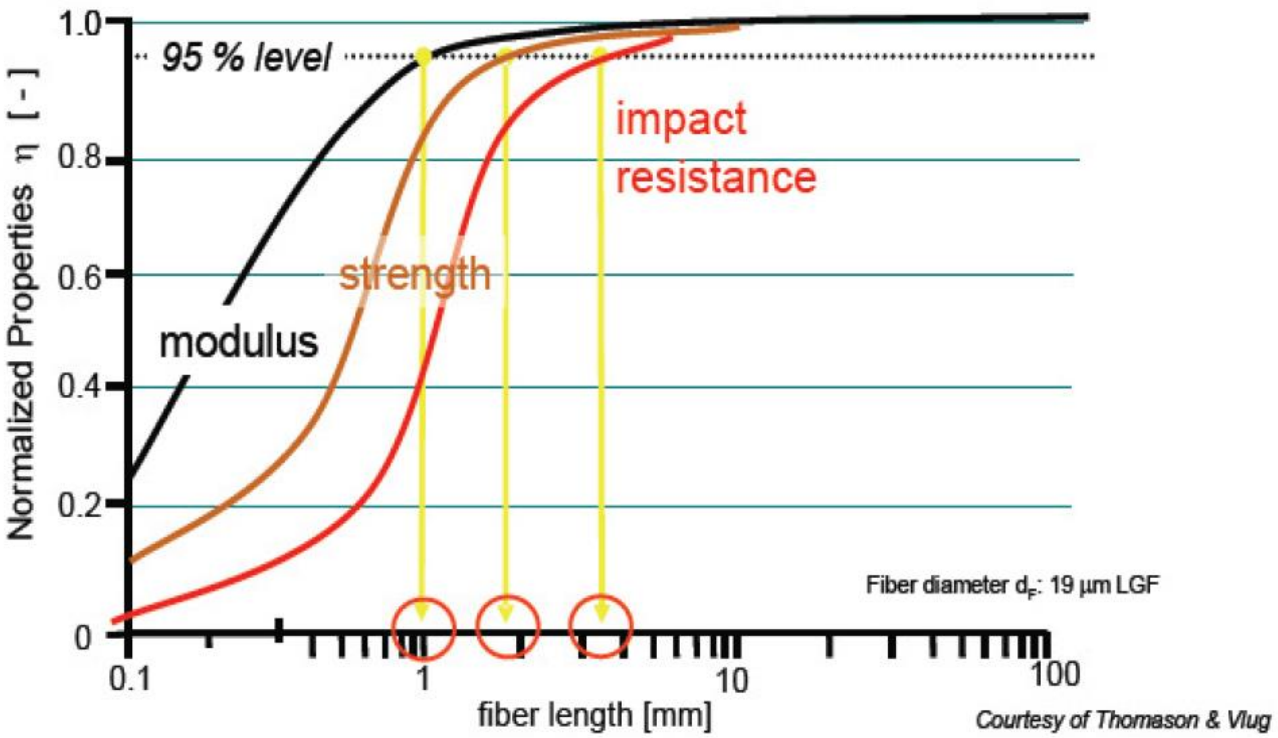
Effect of Fiber Length



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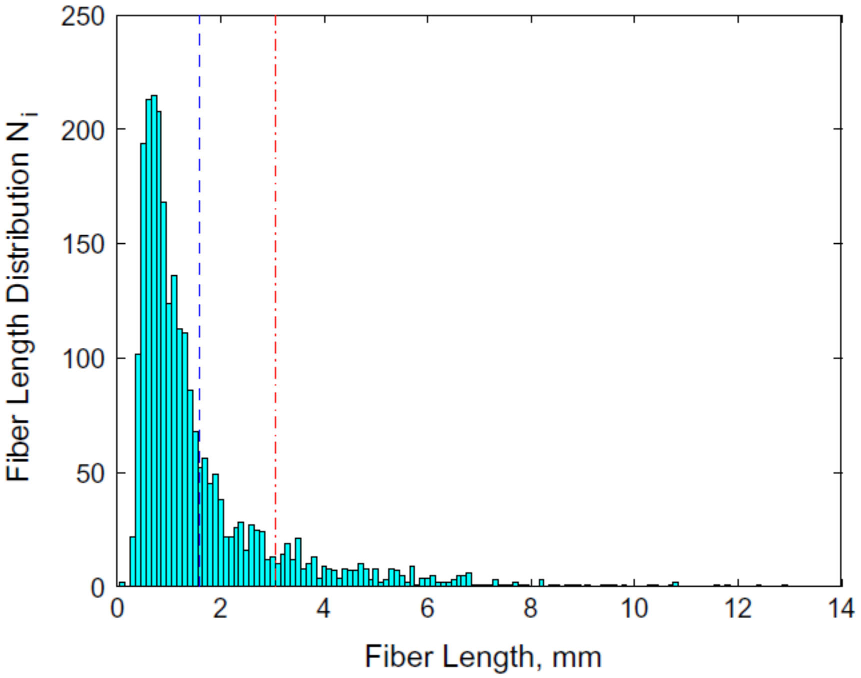
Fiber Length Distribution – Injection Molding

- The initial fiber length in this study was 12 mm
  - The resulting fiber length in the molded part is significantly shorter than this
- These shorter fibers can primarily be a result of conditions during injection and high shear rates
- Processing conditions associated with compression molding can help maintain these longer fiber lengths



Phelps et al Composites: Part A 51 (2013) 11-21

Influence of Fiber and Matrix

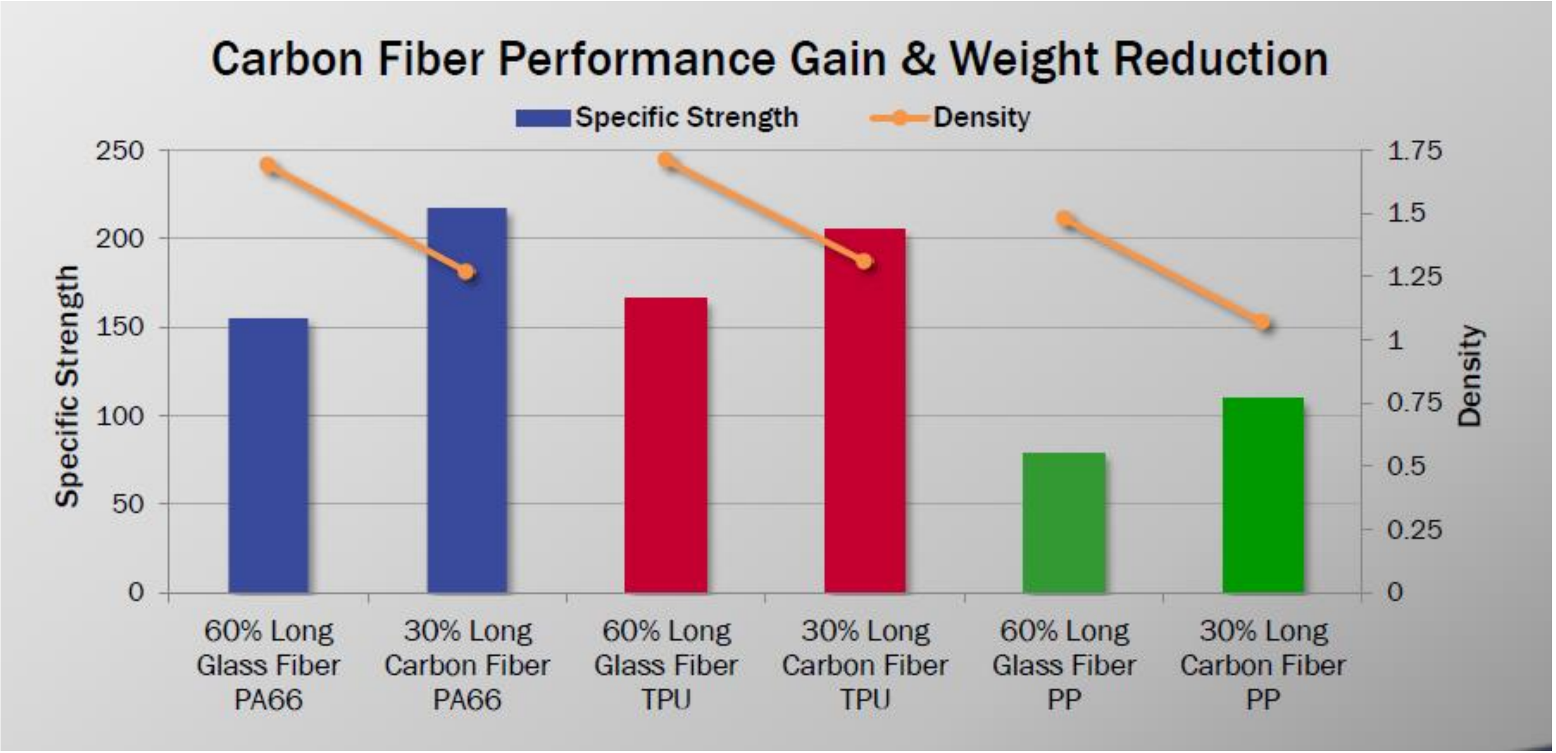


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Image Source: Plasticomp

Influence of Fiber and Matrix

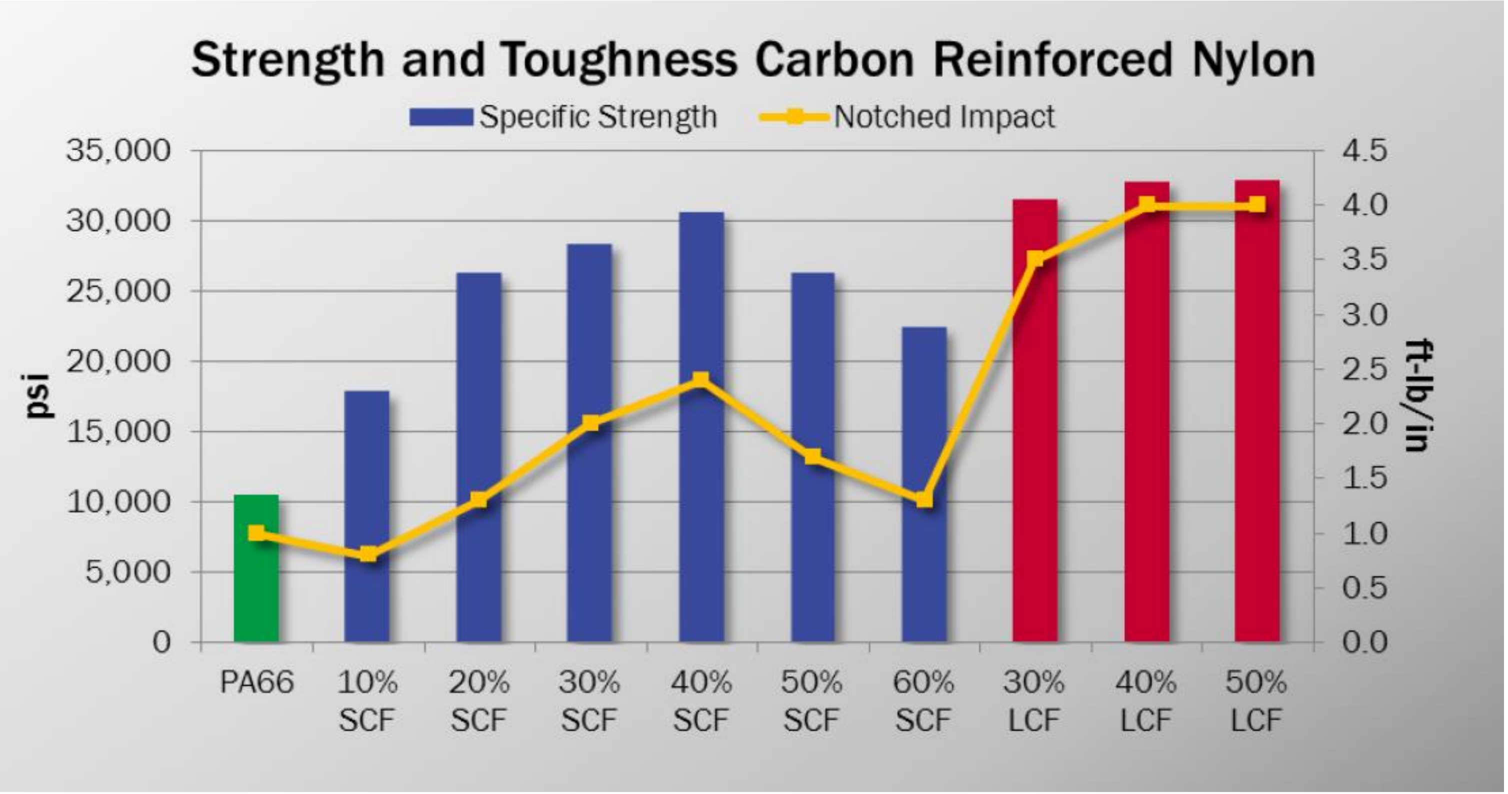

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Image Source: Plasticomp

Effect of Fiber Bridging

- Greater fiber lengths in molded parts can result in fiber bridging

Image Source: RTP

Long vs. Short Fiber

- Determining whether a material is short or long fiber is sometimes subjective
- The aspect ratio (L/D) of the fiber in composites can be a good metric for classifying a fiber as either short or long

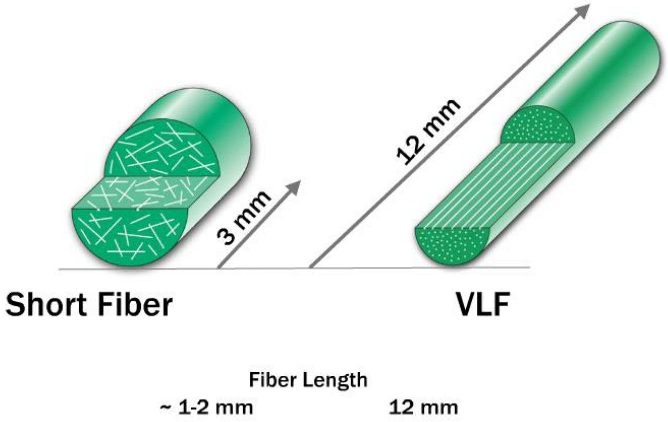
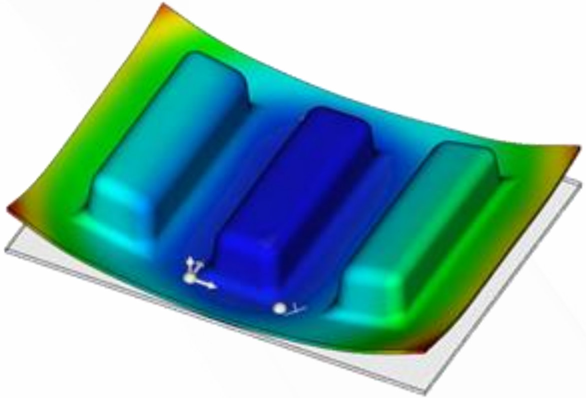
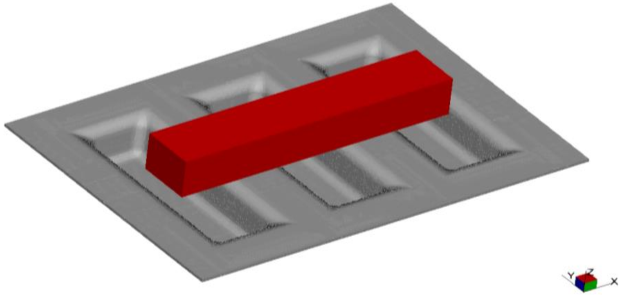


Image Source: RTP

Study 1: Compression Molding Simulations





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Fiber Prediction Models

- Moldflow Fiber Prediction Models:
  - **Folgar-Tucker** – Based on Jeffrey's equation, single rigid fiber in newtonian fluid, isotropic rotary diffusion
  - **RSC** – Reduced strain closure, focus on slow fiber kinetics that can be over-predicted in Folgar-Tucker model
  - **RSC-ARD –** reduced strain closure with anisotropic rotary diffusion, focus on capturing the fiber-fiber interaction of long fibers

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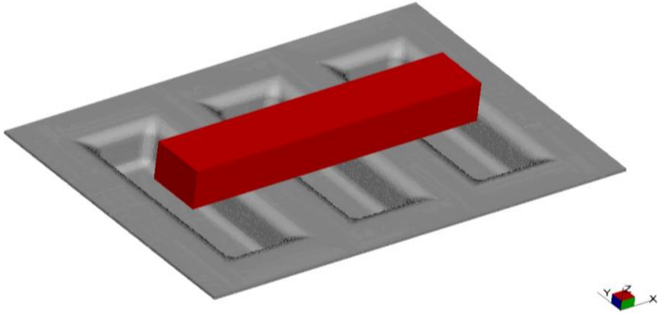
Study 1: Compression Molding Simulations

- Each simulation used the same charge pattern as shown
- Each case used a 35% CF PA6 resin model from Plasticomp inc.
- This study focuses on the result of the following cases:
  - Case 1 – Folgar-Tucker Model, C_i =0.01, planar random initial fiber orientation
  - Case 2 – RSC/ARD-RSC Model, planar random initial fiber orientation
  - Case 3 - RSC/ARD-RSC Model, 3D initial fiber orientation



Simulates Plasticomp CF35 PA6

Charge size:138 mm, 27.8 mm, 27.5 mm

Initial Charge Fiber Orientation Assumptions

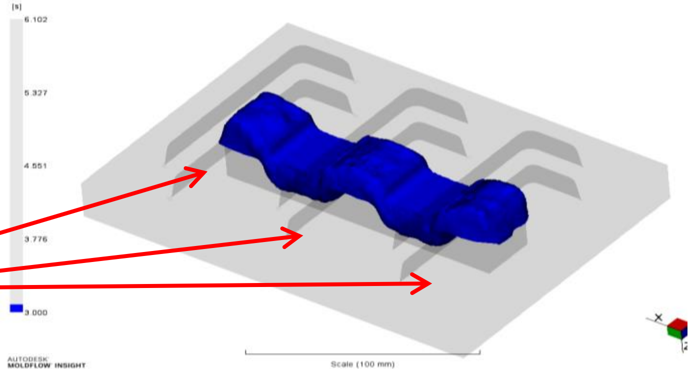
- These simulations were performed to identify trends between the initial fiber orientation of the charge, and the final fiber orientation in the part, as well as part warpage
- The initial charges for Cases 1 and 2 were modeled such that the fiber orientation tensor represented a random orientation in the material

Fiber Orientation Tensor

$$A_{ijk} = \begin{vmatrix} 0.5 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 0 \end{vmatrix}$$

Case 1: Fill Pattern

- The fill pattern is shown when filled with the modeled random charge
- The change in the compression surface drastically changes the filling pattern of the cavity
  - There appears to be a sharp convergent flow on the short ends of the troughs
- Due to variable gap distance, the flow front accelerates at the end-of-fill

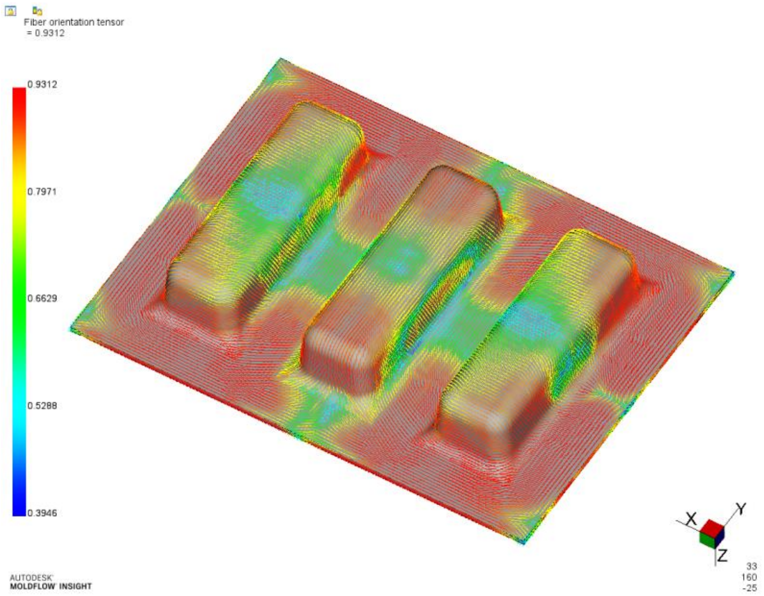


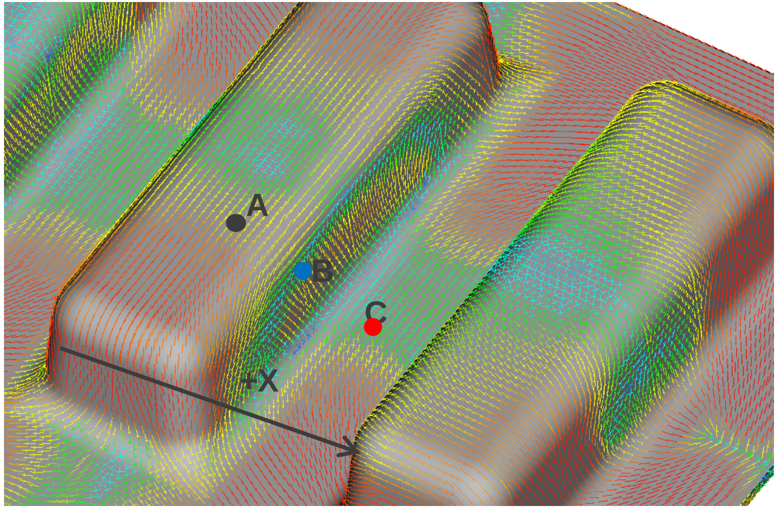
Convergent Flow Occurs at Both Ends

Simulates Plasticomp CF35 PA6

Case 1: Fiber Orientation; Folgar-Tucker

- The predicted principal fiber orientation throughout the part is shown when filled with the random initial charge pattern





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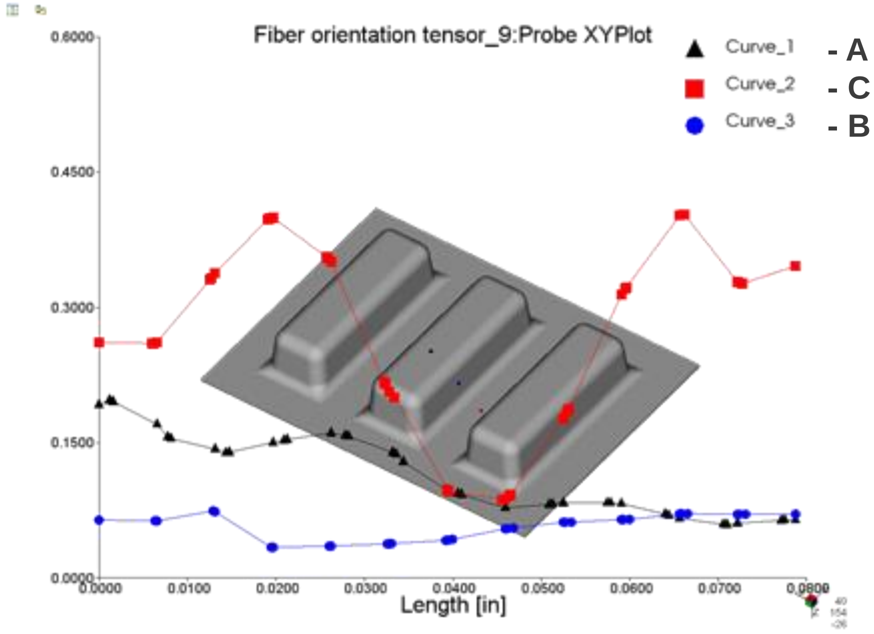
Case 1: Fiber Orientation; Folgar-Tucker

- The predicted fiber orientation in the A11 direction (X-direction) for the Plasticomp compound is shown at the three points



- A (Black)
- C (Red)
- B (Blue)

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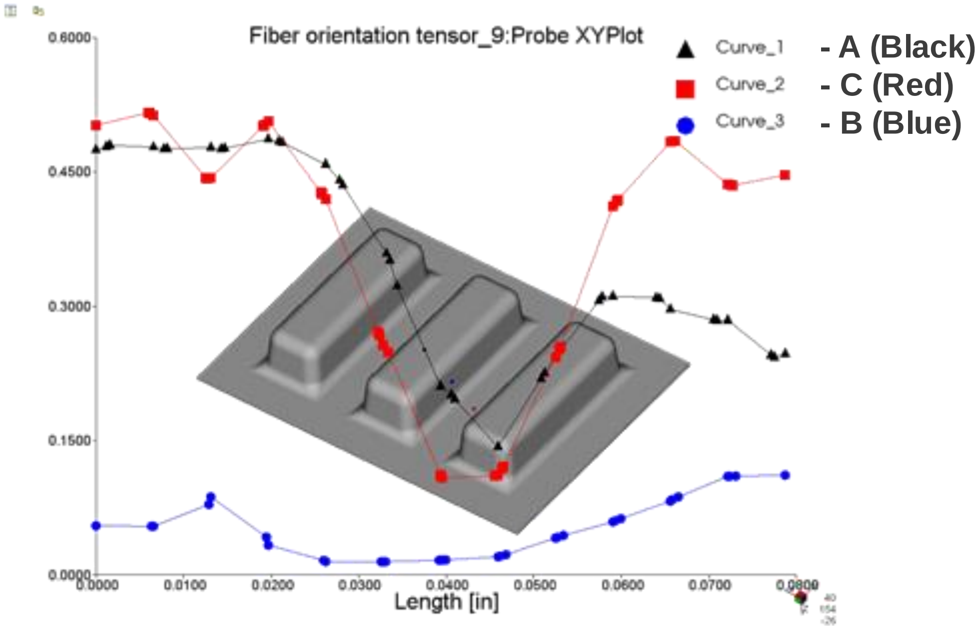
Case 2: Fiber Orientation; RSC/ARD-RSC Model

- The predicted fiber orientation in the A11 direction (X-direction) for the Plasticomp compound is shown at the three points



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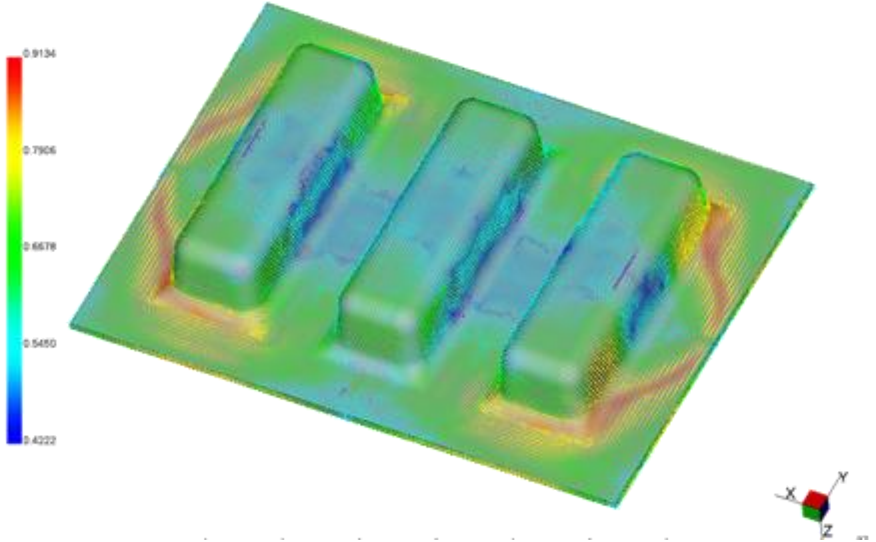
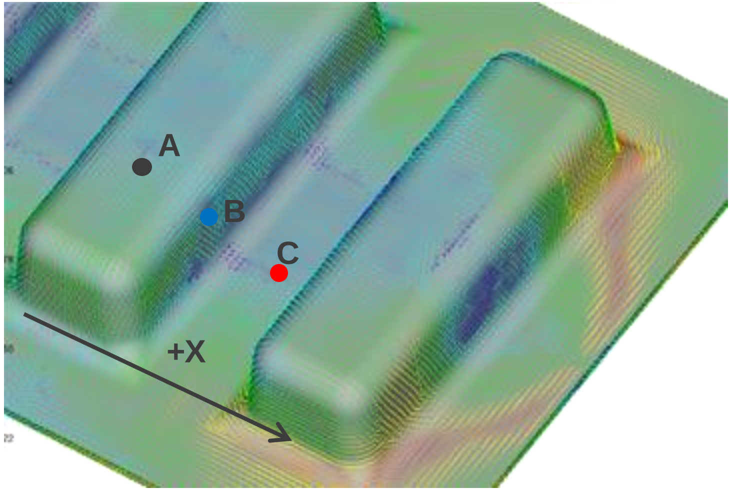
Case 2: Fiber Orientation; RSC/ARD-RSC Model

- The predicted principal fiber orientation throughout the part is shown when filled with the random initial charge pattern

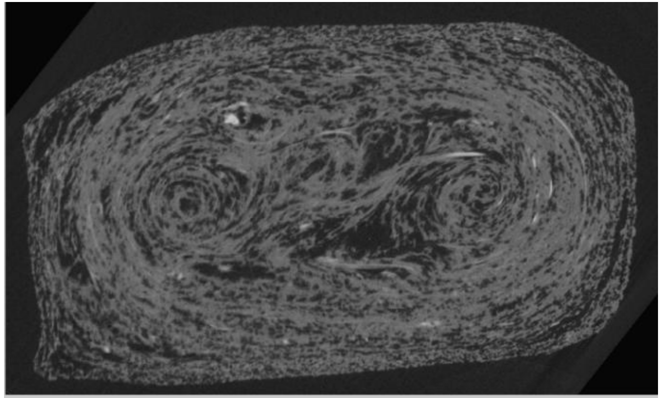




Initial Charge Fiber Orientation Assumptions

- The next case changed the initial fiber orientation direction to a circular pattern, as shown, to better represent the initial fiber orientation in the charge
  - Case 3 simulates the process in Autodesk Moldflow 2017

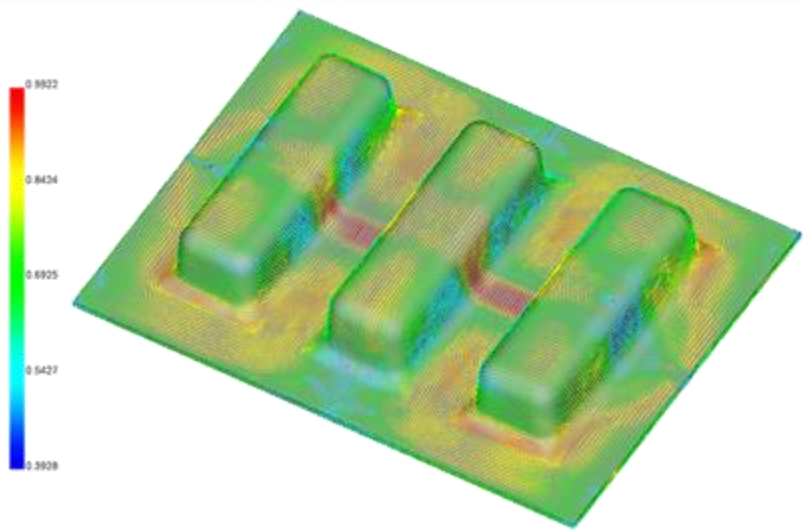
Circular Pattern Throughout the Charge

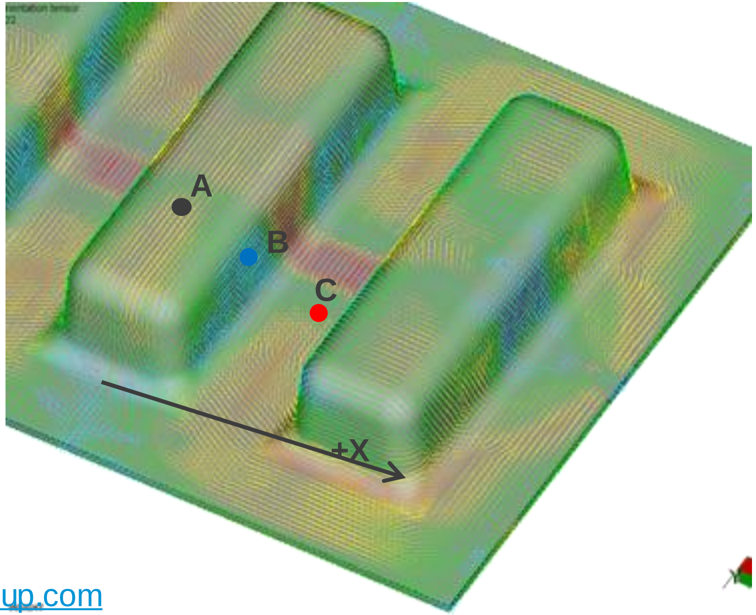


[Perez, Osswald]

Case 3: Fiber Orientation; RSC/ARD-RSC Model

- The predicted principal fiber orientation throughout the part is shown when filled using the Plasticomp compound





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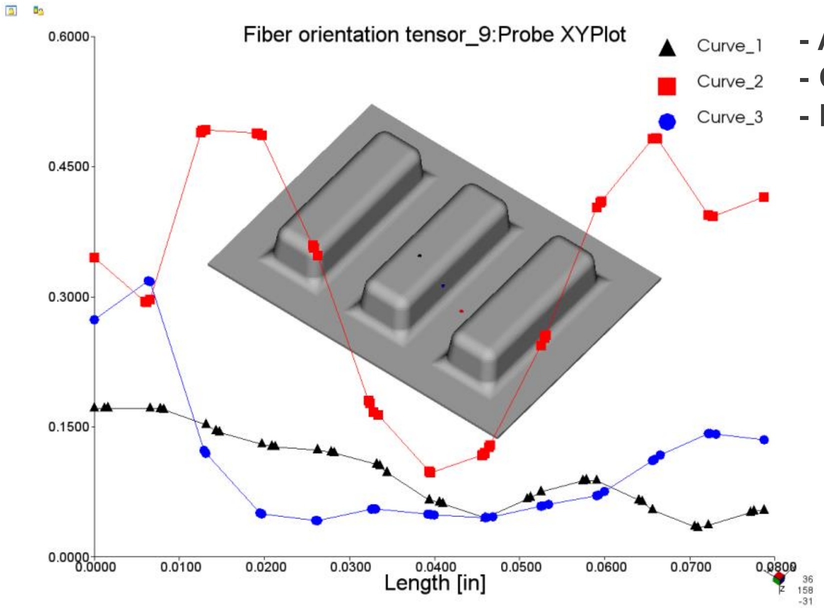
Case 3: A11 Fiber Orientation; RSC/ARD-RSC Model

- The predicted fiber orientation in the A11 direction (X-direction) for the Plasticomp compound is shown at the three points with the modified charge orientation



- A (Black)
- C (Red)
- B (Blue)

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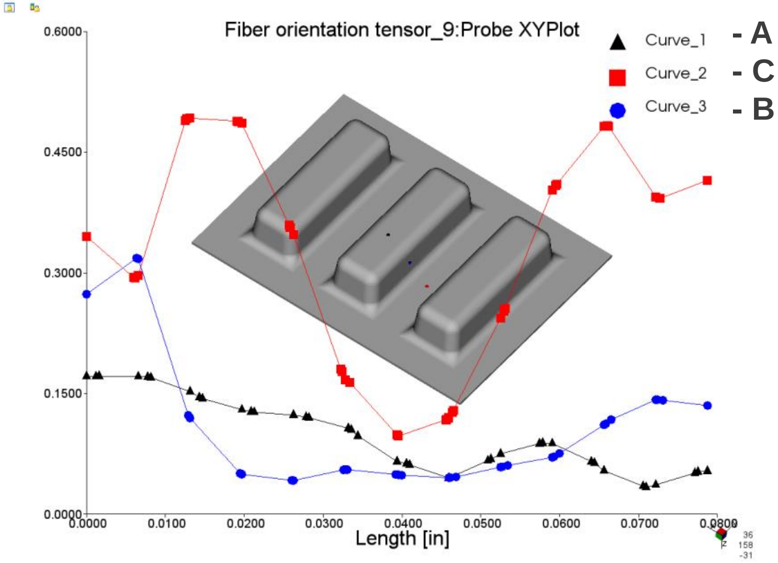
A11 Fiber Orientation Comparison; Cases 2 and 3

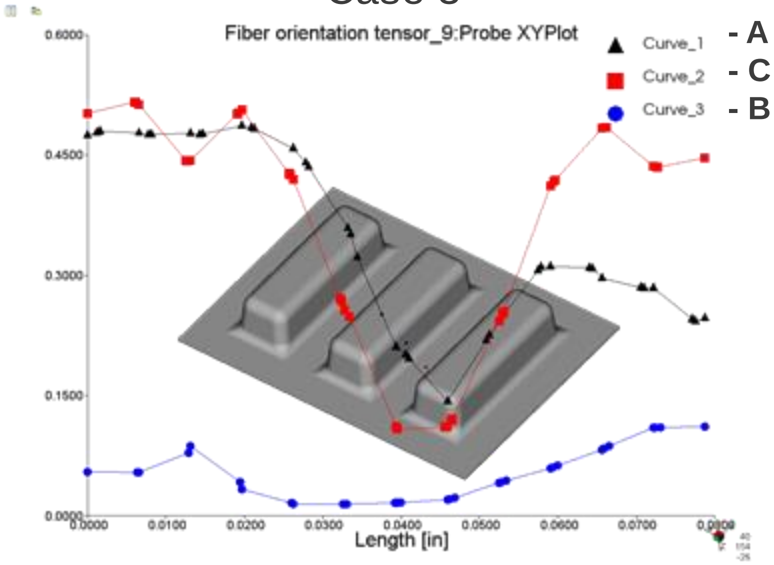
- A comparison of the predicted fiber orientation in the A11 direction (X-direction) for the Plasticomp compound is shown

Case 2



- A (Black)
- C (Red)
- B (Blue)

Case 3



- A (Black)
- C (Red)
- B (Blue)

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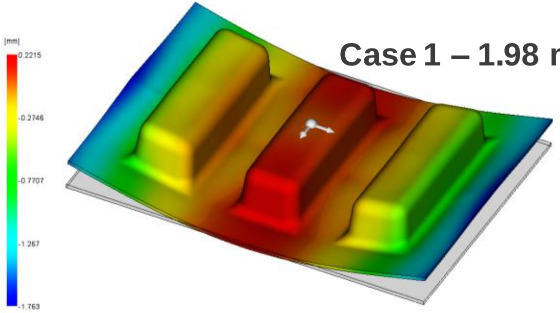
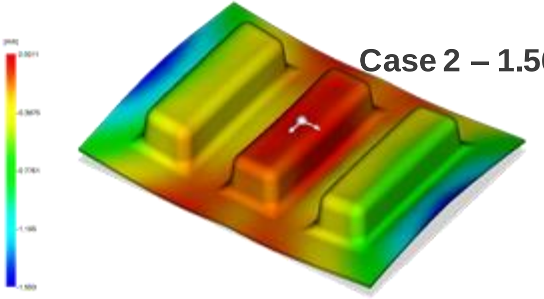
Predicted Warpage Comparison

- The predicted part out-of-plane deformation of each case is shown, along with the actual measured deflection

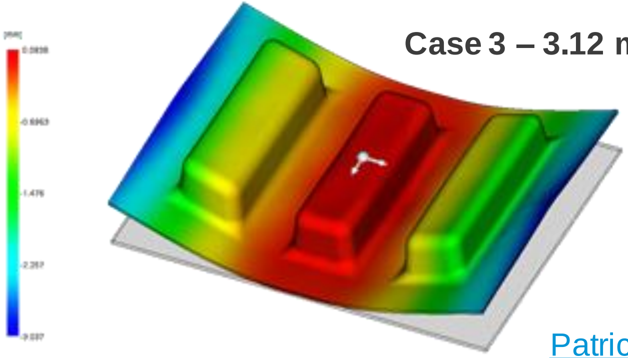
Case 1 – 1.98 mm



Case 2 – 1.56 mm



Case 3 – 3.12 mm



Actual Deflection – 3.6 mm

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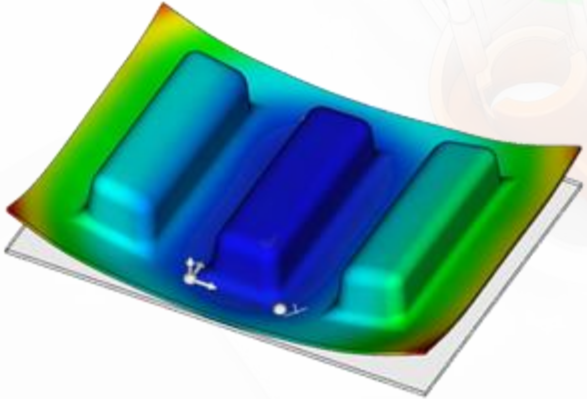
Study 2: Compression Molding Simulations – Charge Placement



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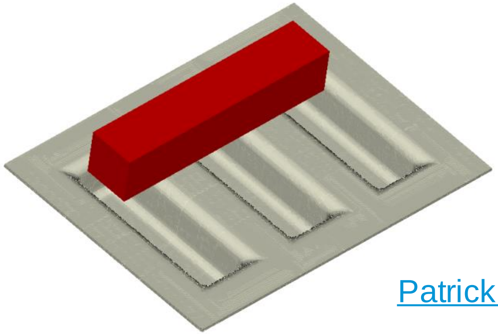
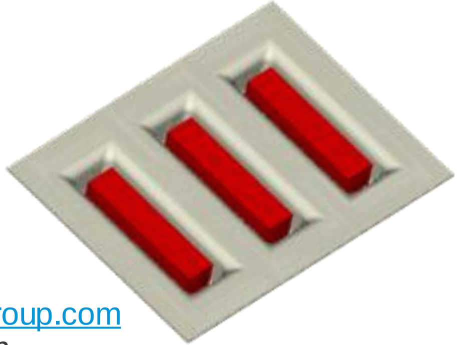
Study 2: Compression Molding Simulations – Charge Placement

- Objective: Determine sensitivity of part warpage and final fiber orientation as a result of changing the initial charge placement
- Each simulation used the same 3D initial fiber orientation, and used the RSC/ARD-RSC fiber code
- This report focuses on the result of the following cases:
  - Case 1 –Simulates an Offset Charge
  - Case 2 – Simulates Three Charges

Offset Charge



Three Charges



Simulates Plasticomp CF35 PA6

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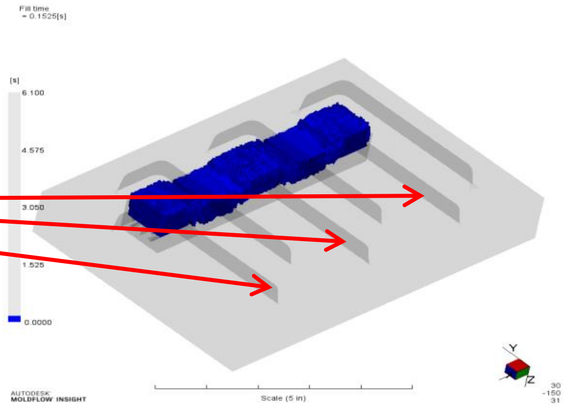
Case 1: Fill Pattern; Offset Charge

- The fill pattern is shown when filled with the Offset Charge
- The change in the compression surface drastically changes the filling pattern of the cavity
- The filling pattern is unbalanced, and the strong convergent flow still exists at the far edge of the trough with the offset charge

Convergent Flow Occurs at These Ends



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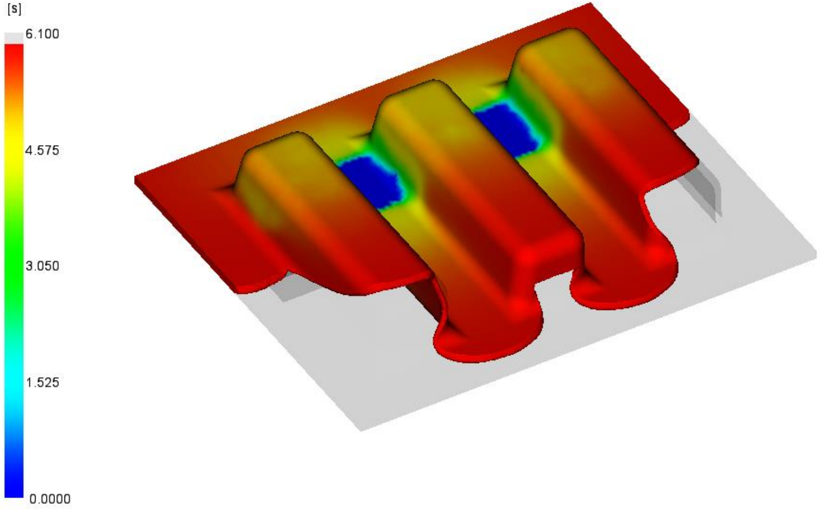
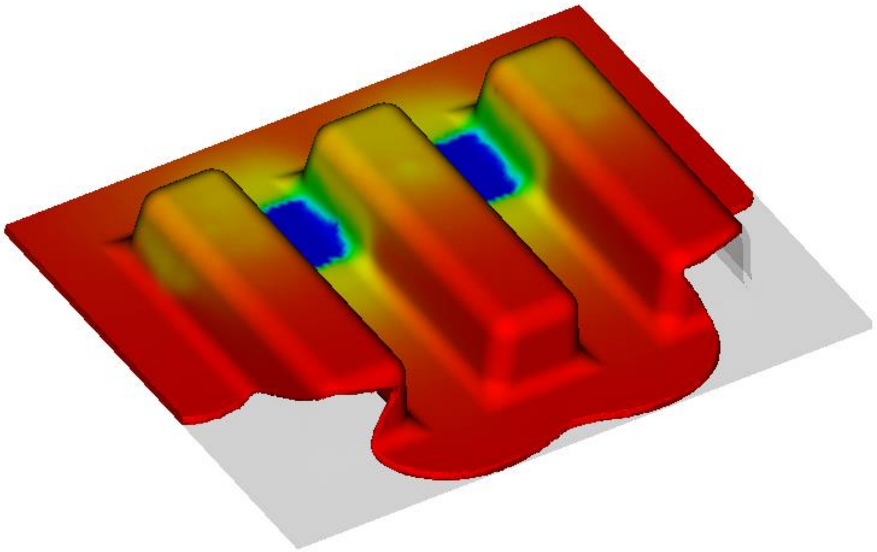
Case 1: Fill Pattern; Offset Charge

- These images show how the material flows at the end of the troughs

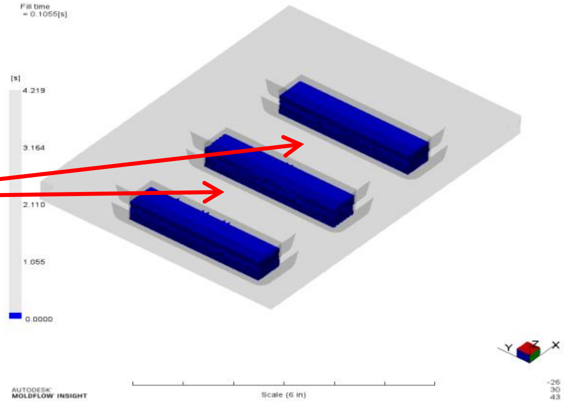




Case 2: Fill Pattern; Three Charges

- The fill pattern is shown when filled with the Three Charges
- The fill time is reduced to 4.22 seconds
  - The fill time difference is due to the placement of the charge near the compression surface
- With the multiple charges, the filling pattern is balanced, but large knit lines form between the troughs

Knit Lines Formed Between Charges



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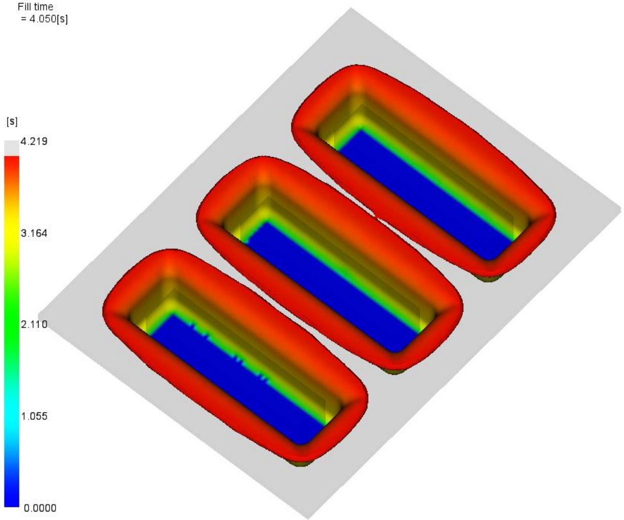
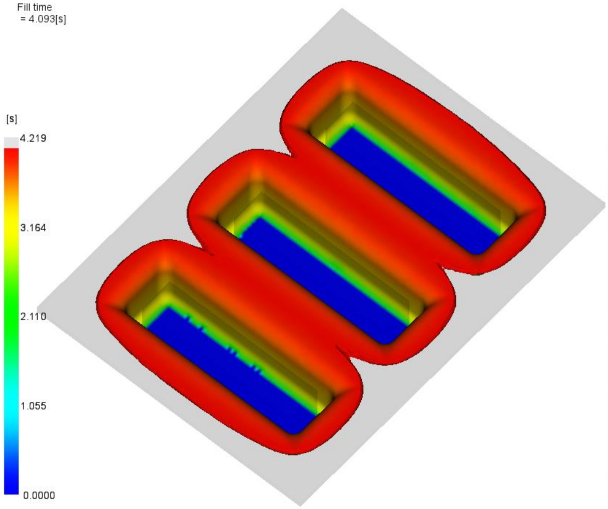
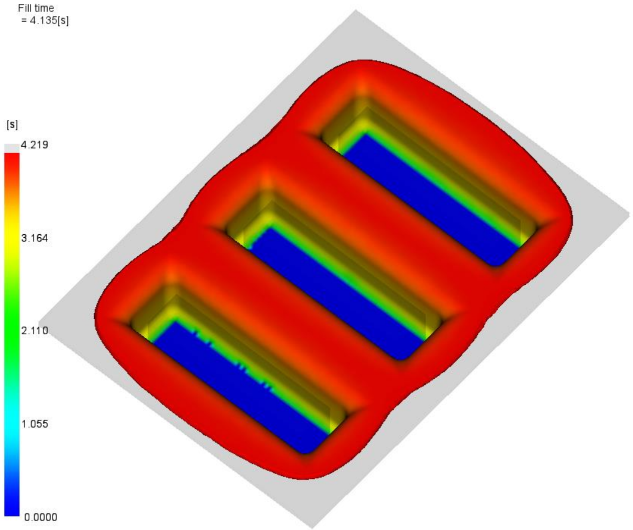
Case 2: Fill Pattern; Three Charges

- These images show how the material meets between the troughs with the Three Charge configuration







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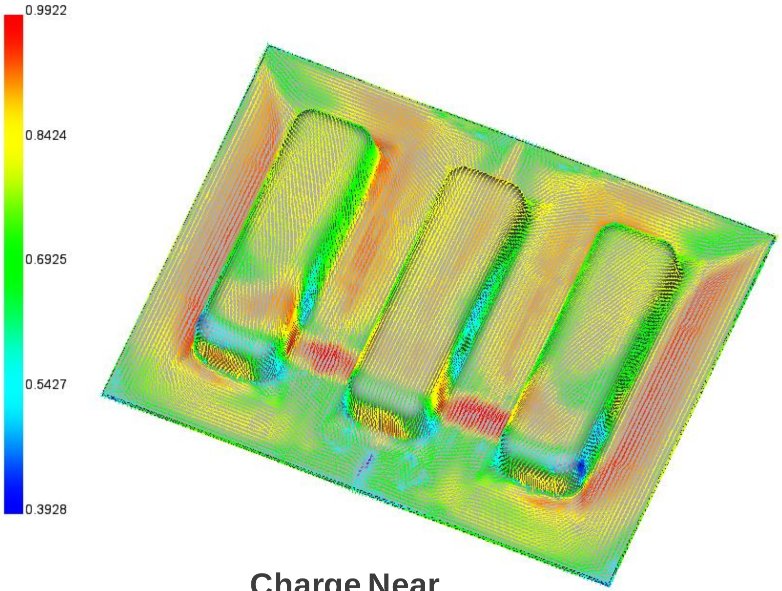
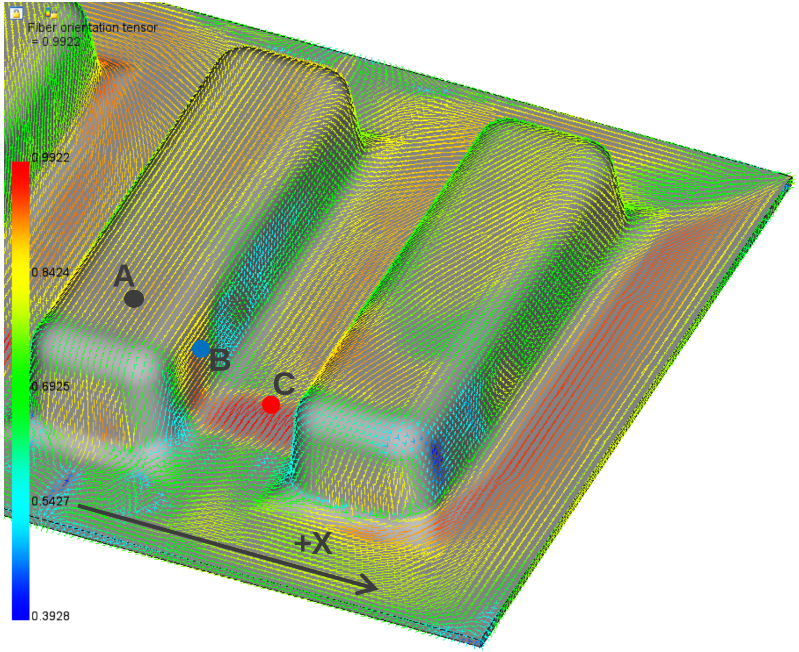
Case 1: Fiber Orientation; Offset Charge

- The predicted principal fiber orientation throughout the part is shown when filled using the offset charge



Charge Near This End



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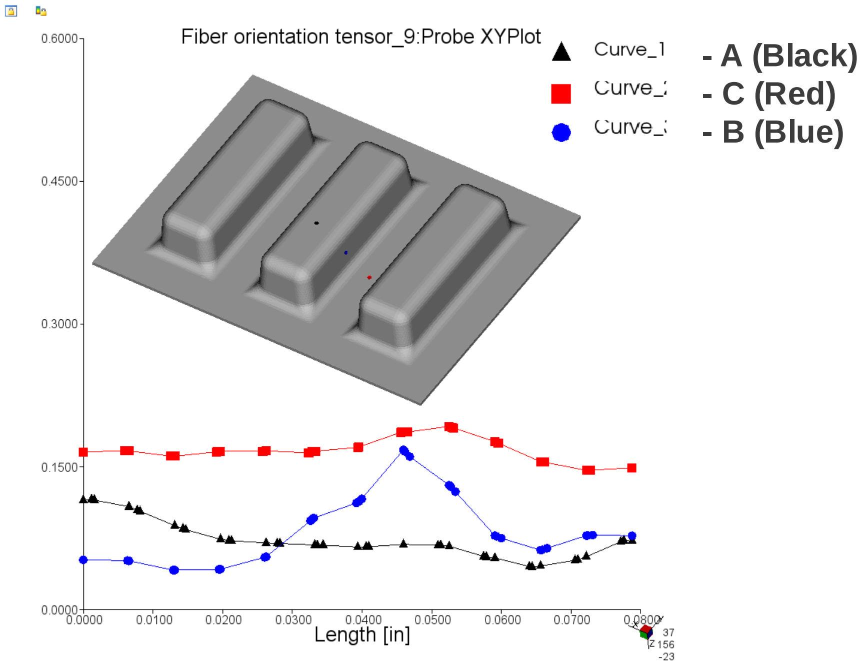
Case 1: Offset Charge; A11 Fiber Orientation; RSC/ARD-RSC Model

- The predicted fiber orientation in the A11 direction (X-direction) for the Plasticomp compound is shown at the three points with the offset charge position



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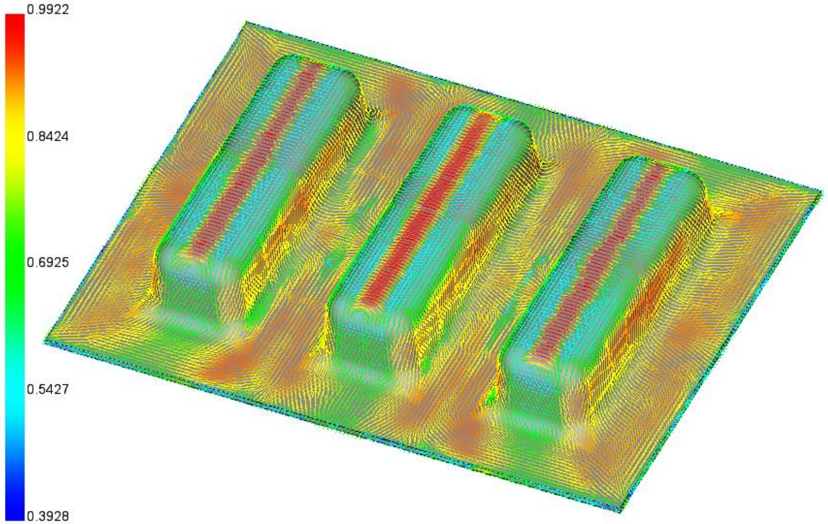
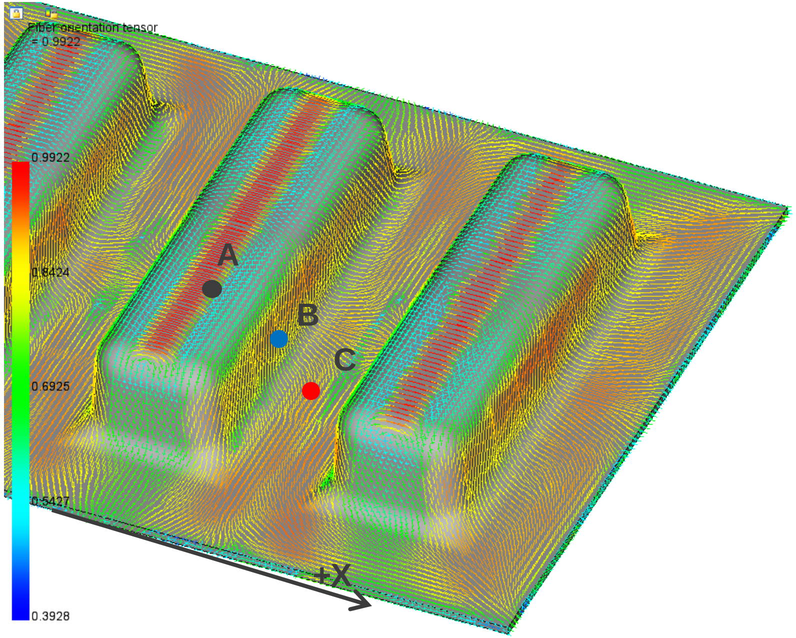
Case 2: Fiber Orientation; Three Charges

- The predicted principal fiber orientation throughout the part is shown when filled using the three charges





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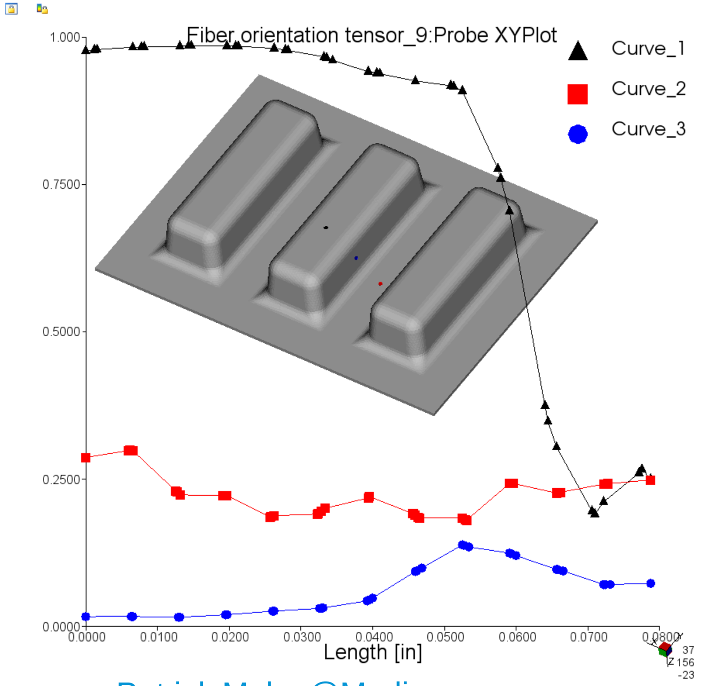
Case 2: Three Charges; A11 Fiber Orientation; RSC/ARD-RSC Model

- The predicted fiber orientation in the A11 direction (X-direction) for the Plasticomp compound is shown at the three points with the three charge configuration



- A (Black)
- C (Red)
- B (Blue)

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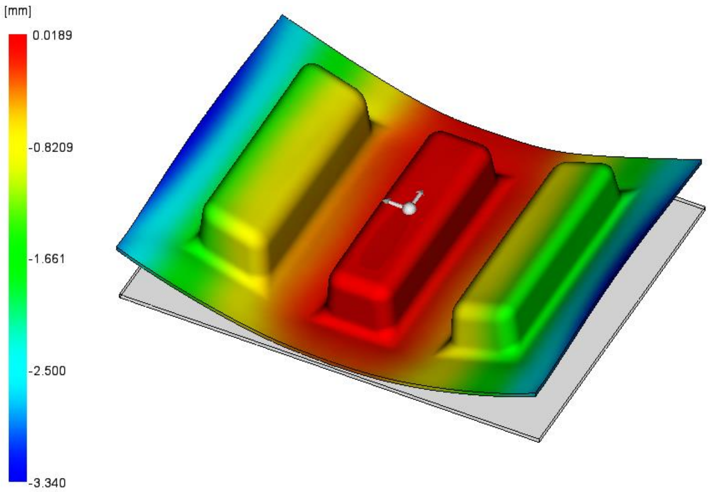
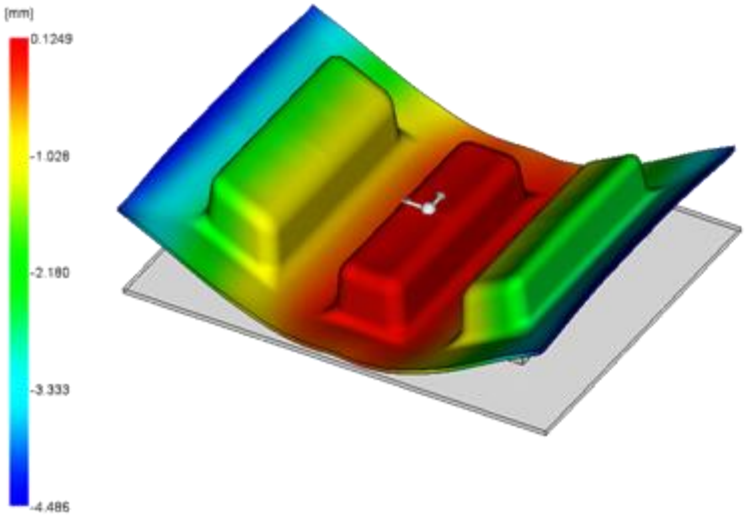
Warpage Comparison – Charge Placement

- The predicted part out-of-plane deformation of each case is shown

Case 1 – 3.36 mm



Case 2 – 4.61 mm



Conclusions & Next Steps

- Compression molding can provide benefits over injection molded parts by using and maintaining greater fiber length during processing, resulting in some increased mechanical properties and the ability to further lightweight components

- The Folgar-Tucker model tends to predict slightly more deflection, in the same mode, than the RSC fiber model with a random initial fiber orientation

- Initial fiber orientation in the charge can have a significant effect on the resulting warpage of the molded part

- Charge pattern and size has a significant effect on final fiber orientation and part deflection

- Further simulations are required to correlate the simulated results to the measured results from actual molding trials

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