Improvement in Simulation of Injection Molded Short Glass Fiber Thermoplastic Composites

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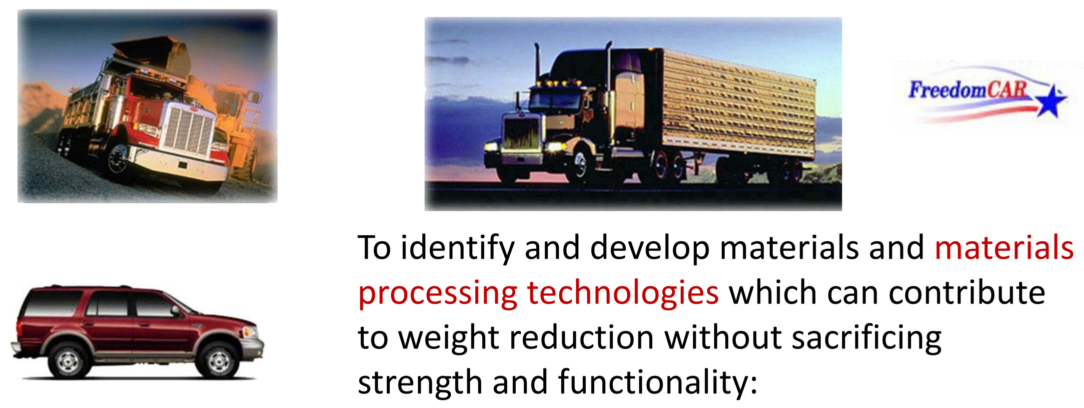
ABSTRACT

- Highly concentrated, injection molded fiber-reinforced polymer composites are one of the materials being considered by the automotive industry to reduce fuel consumption.
- The limitation of this technology is the uncontrolled anisotropy of reinforcing fibers due to flow-induced orientation in the mold during the processing of these composites.
- In this study, center gated disks are used to characterize fiber orientation in the mold. An experimental method for characterization of fiber orientation is developed that requires small sample size and does not suffer from the ambiguity (in identifying fiber footprints) of traditional methods.
- Two fiber suspensions (30 wt. % short glass-fiber Polybutylene terephthalate (PBT) and Polypropelene (PP)) with different rheological characteristics were used in these experiments.
- Four flow regimes can be identified for center-gated disk geometry: Pre-gate, entry, shear and front.
- The initial orientation measured in the entry region presented a fiber distribution different from the random orientation usually assumed in literature for a center-gated disk. In the advancing front region, PBT front has a rugged surface while PP front is more smooth and parabolic.

BACKGROUND

High Strength Light Weight Materials

Office of FreedomCAR and Vehicle Technologies



To identify and develop materials and processing technologies which can contribute to weight reduction without sacrificing strength and functionality:

- Increase the fuel efficiency
- Reduce emissions of class 1-8 trucks

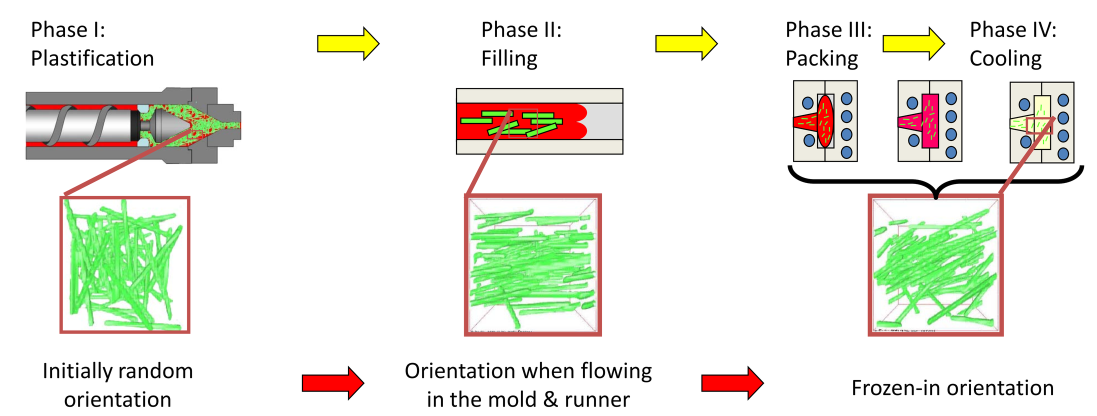
GOAL

To combine numerical simulation and experimental procedures to improve the prediction of microstructure in short glass fiber reinforced thermoplastics

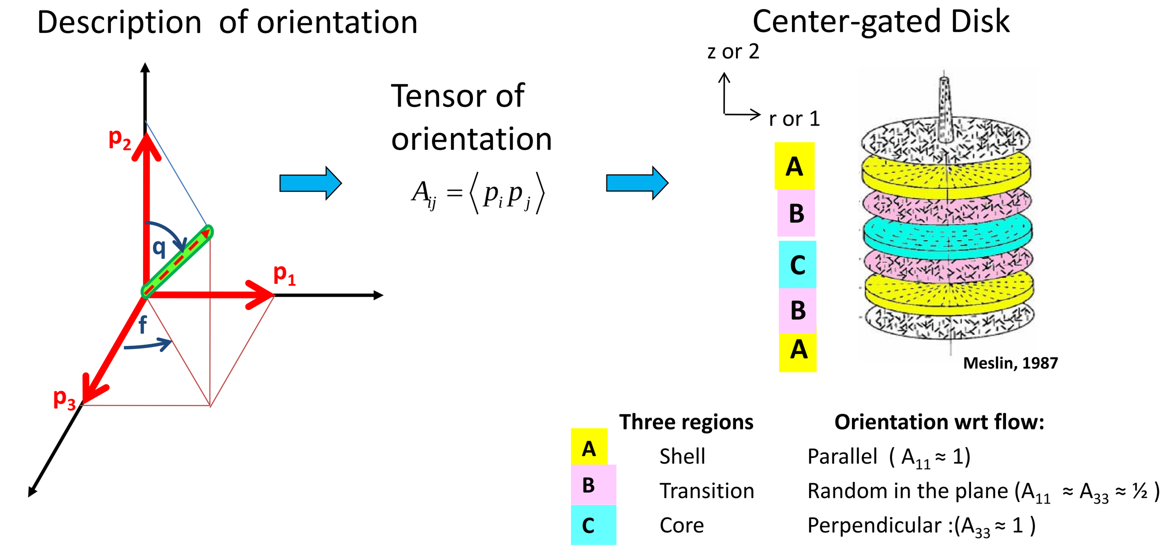
OBJECTIVES

- To simulate the mold filling process for thermoplastic melts reinforced with short fibers using constitutive relations (i.e. stress tensors coupled with a generation expression) which allow coupling between the flow and particle orientation.
- To experimentally evaluate the orientation distribution of glass fibers in an injection molded part

ORIENTATION DURING INJECTION MOLDING



MULTILAYER STRUCTURE



CHALLENGES

- **Modeling of fiber orientation:**
  - **Should the standard model (Folgar-Tucker) be improved to predict the correct evolution of fiber orientation?**
  - **Do inter-particle interactions delay orientation in a concentrated solution?**
  - **Can model parameters be determined by rheological experiments?**
- **Characterization of fiber orientation along the entire flow domain:**
  - **Pre-gate region**
  - **Regions close to the wall**
  - **Advancing Front**
- **Development of a software package to predict fiber orientation:**
  - **Can existing simulation be used for prediction in all regions?**
  - **Stable and accurate numerical technique for advancing front**

MODELLING OF FIBER COMPOSITES

- Balance equations for injection molding

$$\nabla \bullet \underline{v} = 0 \qquad -\nabla p + \nabla \bullet \underline{\underline{T}} = 0 \qquad \underline{\underline{T}} = \underline{\underline{T}}^{fiber} + \underline{\underline{T}}^{matrix}$$

(Mass) (Momentum) (Stress)

- Short glass fibers
  - Constitutive equation: Folgar-Tucker Model with delay (α)

Evolution of orientation tensor

$$\frac{D\underline{\underline{A}}}{Dt} = \alpha\left[\underline{\underline{\nabla v}} \cdot \underline{\underline{A}} - \underline{\underline{A}} \cdot (\underline{\underline{\nabla v}})^T - 2\underline{\underline{d}} : \underline{\underline{\underline{\underline{A}}}} + 2C_I \left|\underline{\underline{d}}\right| \left(\underline{\underline{I}} - 3\underline{\underline{A}}\right)\right]$$

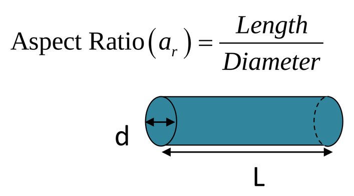
$$\underline{\underline{d}} = \frac{1}{2}\left(\underline{\underline{\nabla v}} + (\underline{\underline{\nabla v}})^T\right)$$

Stress due to oriented particles $\underline{\underline{T}}^{fibers} = v\xi_{str}\underline{\underline{d}} : \underline{\underline{\underline{\underline{A}}}}$

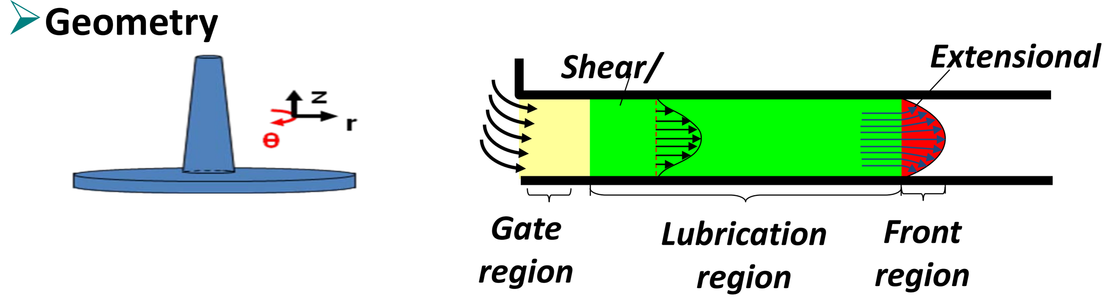
- Polymer matrix
  - Newtonian matrix $\underline{\underline{T}}^{matrix} = 2\eta_s \underline{\underline{d}}$

COMPOSITE MATERIAL

- **Material**
  - **Matrix: Polypropylene (Viscoelastic)**
  - **Filler: 30wt% short glass fiber**
    - **Aspect ratio: 30**



- **Geometry**



EXPERIMENTAL OBSERVATIONS

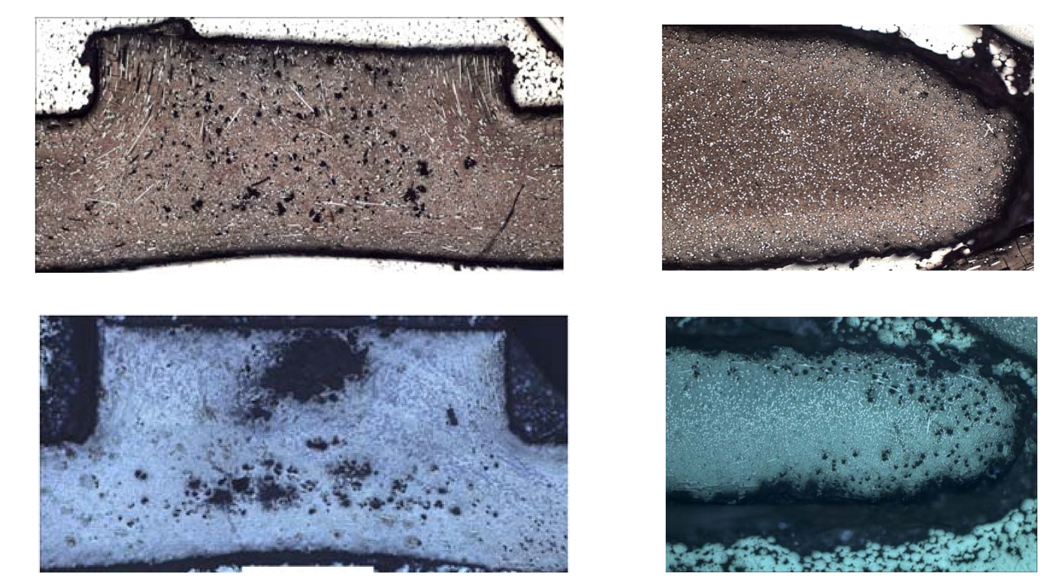


Fig. 1: Microscopic Images of Pre-Gate region (left) and advancing front (right) for PP (top) and PBT (bottom) at 5X

- **Pre-gate**
  - **Presence of entrapped air that influences initial fiber orientation**
  - **Asymmetric distribution of orientation that gets washed out in lubrication region**
  - **PBT has much larger air voids as compared to PP in the gate region**
- **Advancing Front**
  - **Irregular free surface with an almost parabolic shape**
  - **PP has a smooth surface while PBT has rugged surface**
  - **Most of the fibers are aligned in ϑ-direction**
  - **Void spaces present in both matrices. Here too, PBT has more void spaces as compared to PP**

SIMULATION RESULTS

- Center-gated disk (R=3 cm, 2H = 1.38 mm) with experimentally measured initial orientation and a mesh with 48x8 quadrangle and 88 triangle elements

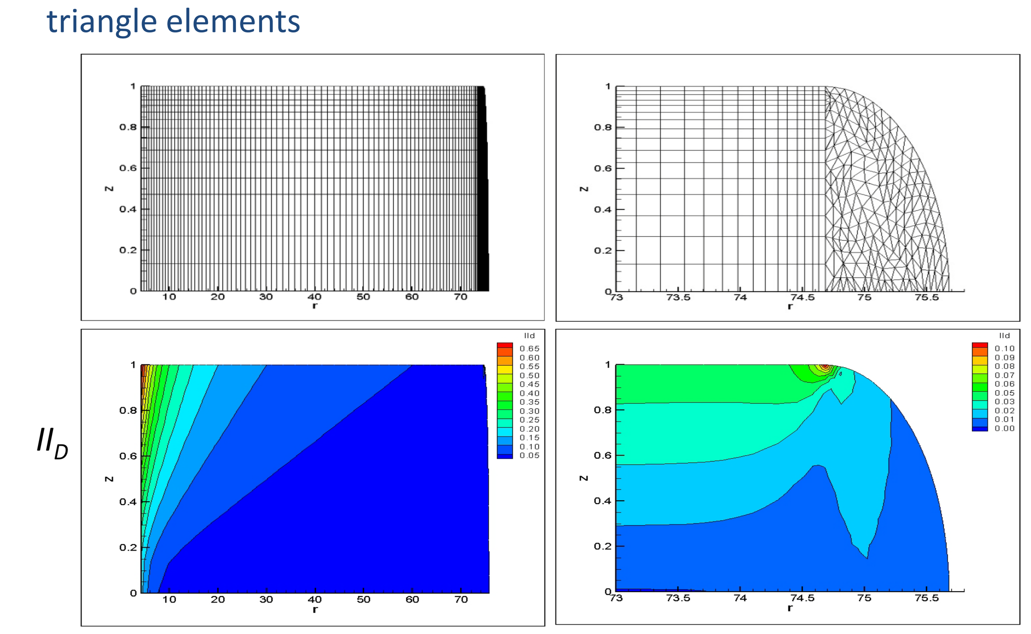


Fig. 2: Mesh used in simulation (top) , full mesh (left) and advancing front magnified (right). Flow kinematics (II_D) are shown at bottom.

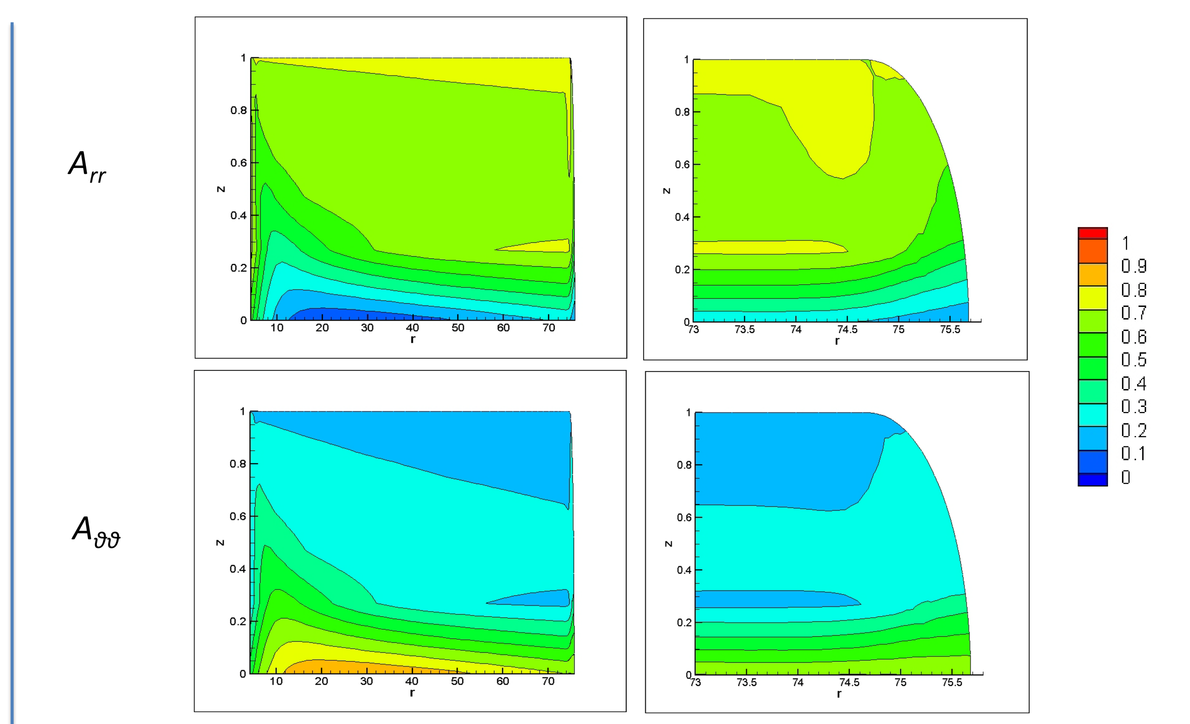


Fig. 3: Predictions of steady state A_{ij} along the entire flow domain using IBOF closure and $C_I = 0.02$

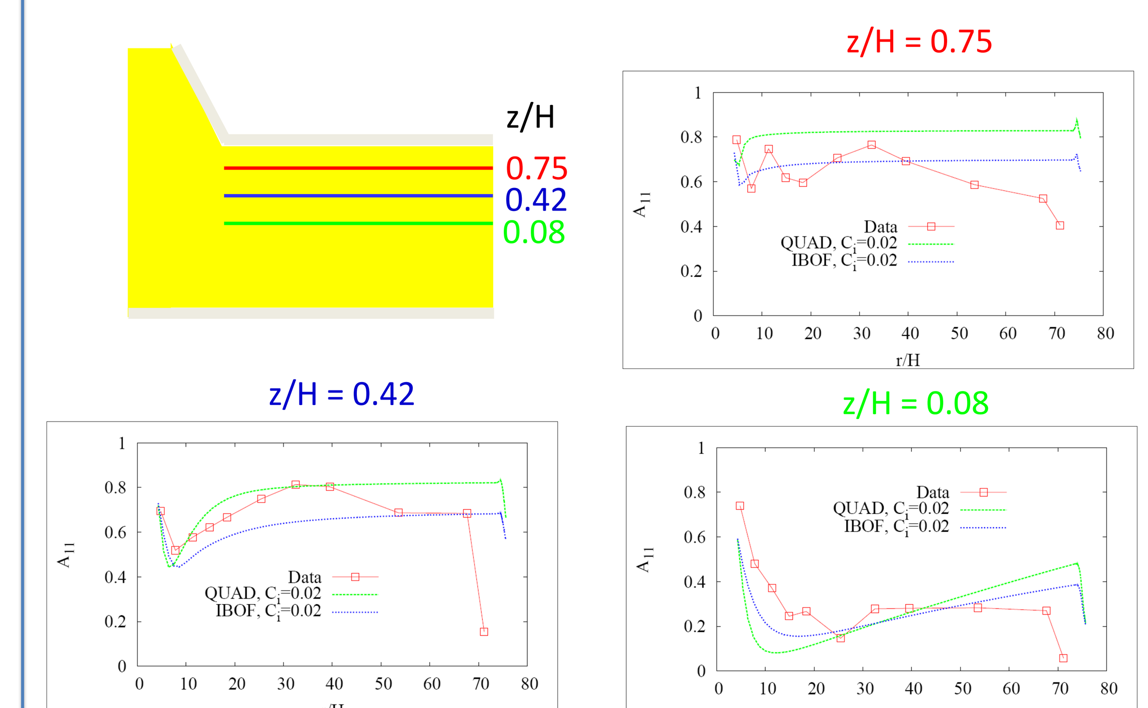
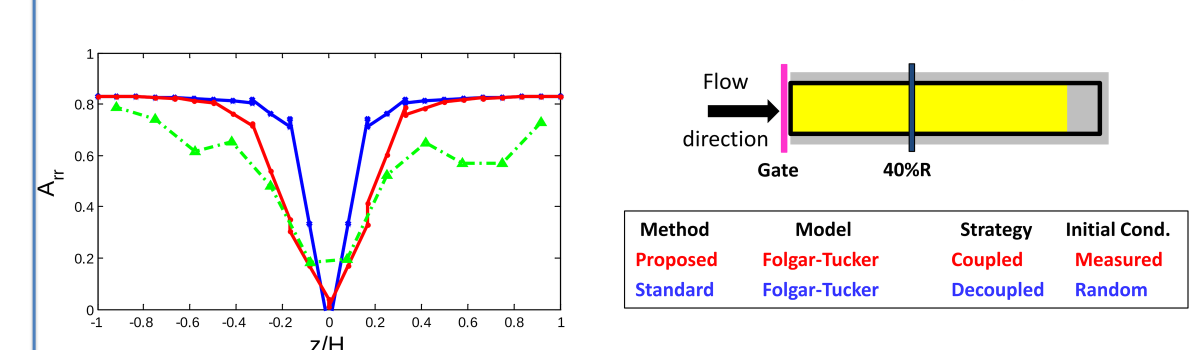


Fig. 4: Comparison of predicted evolution of A_{rr} at different heights (using IBOF and Quadratic closures) with experimentally measured A_{rr}



Method	Model	Strategy	Initial Cond.
Proposed	Folgar-Tucker	Coupled	Measured
Standard	Folgar-Tucker	Decoupled	Random

Fig. 5: Comparison of proposed simulation model with commercial simulation model and experimental data for A_{rr} through the thickness at 40% of flow

ONGOING WORK

- Simulation of fiber orientation works well for Hele Shaw flow approximation. However, close to the advancing front, Hele Shaw simulation overpredicts fiber orientation, especially in PBT
- Current work involves experimental work on advancing front and gate region which are important in defining the fiber orientation.
- Numerical tools are being developed to solve full flow equations for the advancing front and entry region

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