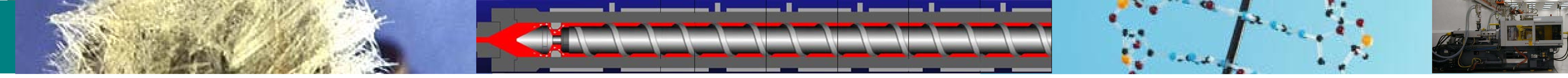


Experimental Orientation in Injection Molding of Short Glass Fiber Thermoplastic Composites

Syed Mazahir*, Gregorio Velez-Garcia**, Peter Wapperom*** and Donald Baird*
*Chemical Engineering, Virginia Tech
**Macromolecules and Interfaces Institute, Virginia Tech
***Mathematics, Virginia Tech

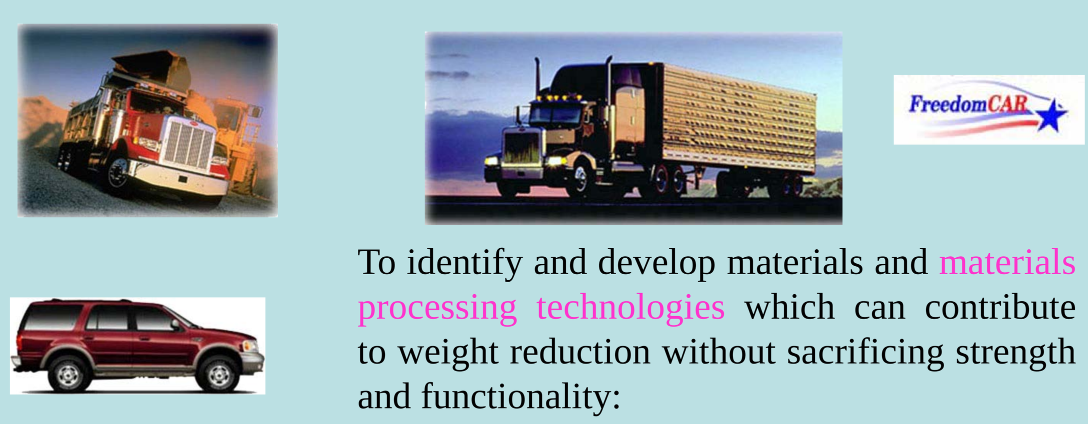
ABSTRACT

Highly concentrated, injection molded fiber-reinforced composites are one of the strategies considered by the automotive industry to reduce fuel consumption. The limitation of this technology is the uncontrolled anisotropy due to flow-induced orientation during the forming stage of the parts. In this study, two center gated disks with diameters 1.38 mm and 2.05 mm were used to characterize fiber orientation in the mold. An experimental method 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 PBT and 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 micrographs of the pre-gate region showed presence of entrapped air that is influencing the fiber orientation in this region. 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. There was an asymmetric distribution of fiber orientation in the entry region that gradually got washed out as the flow progressed through the shear region and the central core having fibers oriented in θ-direction evolved in thickness throughout the lubrication region. The advancing front showed interesting differences between PBT and PP. With PBT, moving front had a rugged surface while with PP it is more smooth and parabolic. Moreover, in PP, almost all fibers seem to be oriented in θ-direction while in PBT some of the fibers are aligned along the profile of the moving front.

BACKGROUND

High Strength Weight Reduction Materials

Office of FreedomCAR and Vehicle Technologies



To identify and develop materials and materials 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

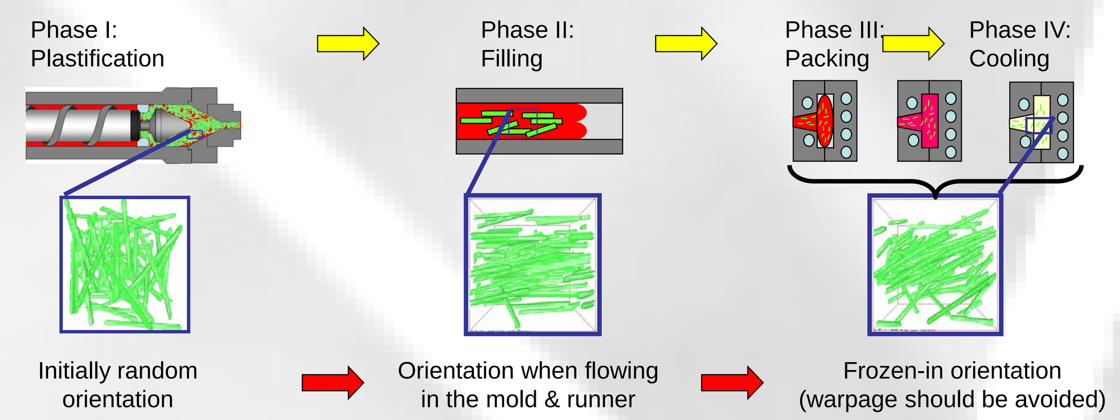
OBJECTIVES

- 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

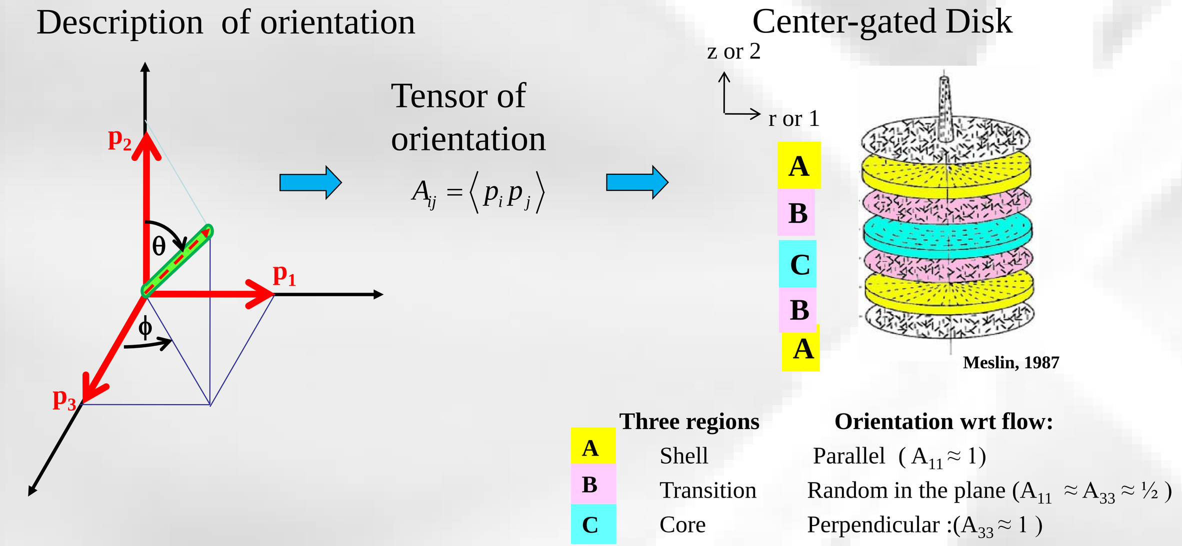
INNOVATION

Use of constitutive relations, which contain the micro-structural aspects of the reinforced melts.

ORIENTATION DURING INJECTION MOLDING



MULTILAYER STRUCTURE



CHALLENGES

- **Model fiber orientation correctly:**
  - **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?**
- **Measure particle orientation**
  - **Characterize the orientation along the entire flow domain**
    - **Pre-gate region**
    - **Regions close to the wall**
    - **Advancing Front**
- **Develop numerical simulation tool to predict fiber orientation using parameters obtained from rheology**
  - **Do results strongly depend on inlet orientation at the gate?**
  - **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

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

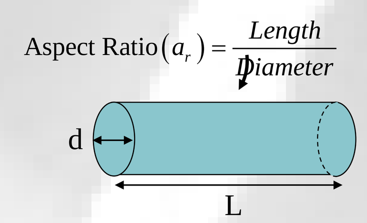
$$\underline{\underline{d}} = \frac{1}{2}\left(\nabla\underline{v} + (\nabla\underline{v})^T\right)$$

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

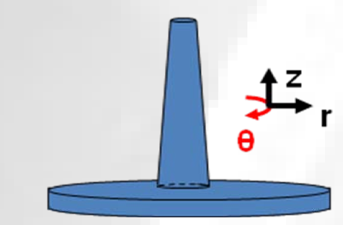
- Polymer matrix
  - Newtonian matrix $\underline{\underline{T}}^{matrix} = 2\eta_s\underline{\underline{d}}$

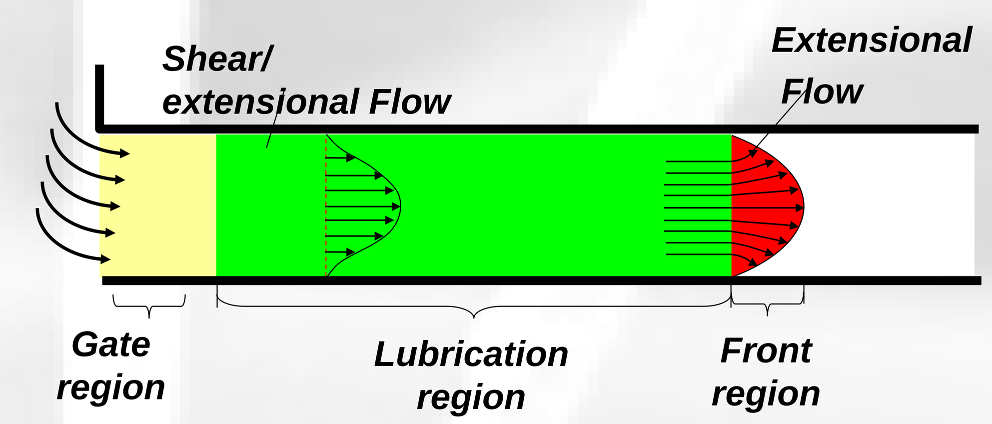
COMPOSITE MATERIAL

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

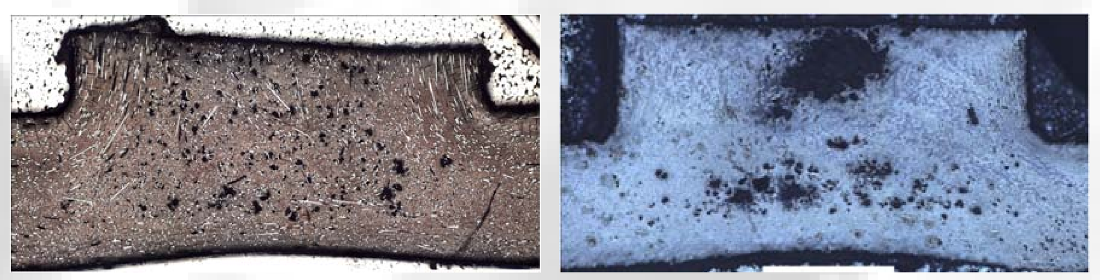


- **Geometry**





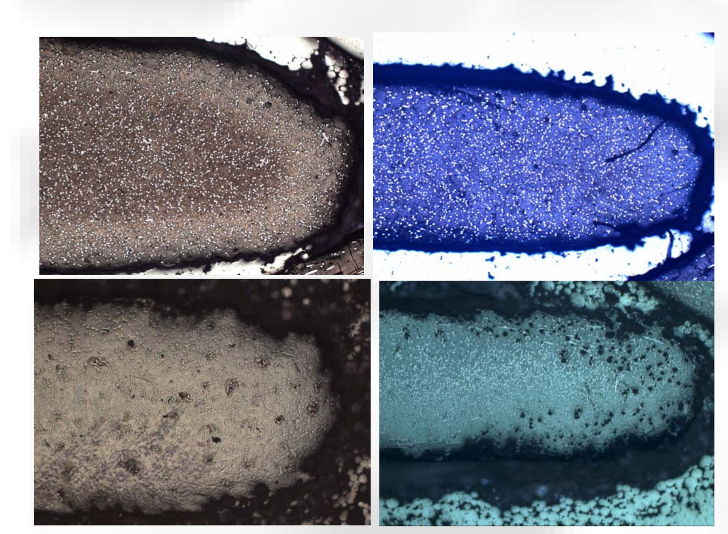
OBSERVATIONS IN THE ENTRY REGION



Microscopic Images of Pre-Gate region for PP (left) and PBT (right) at 5X Zoom

- **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**

OBSERVATIONS IN THE ADVANCING FRONT

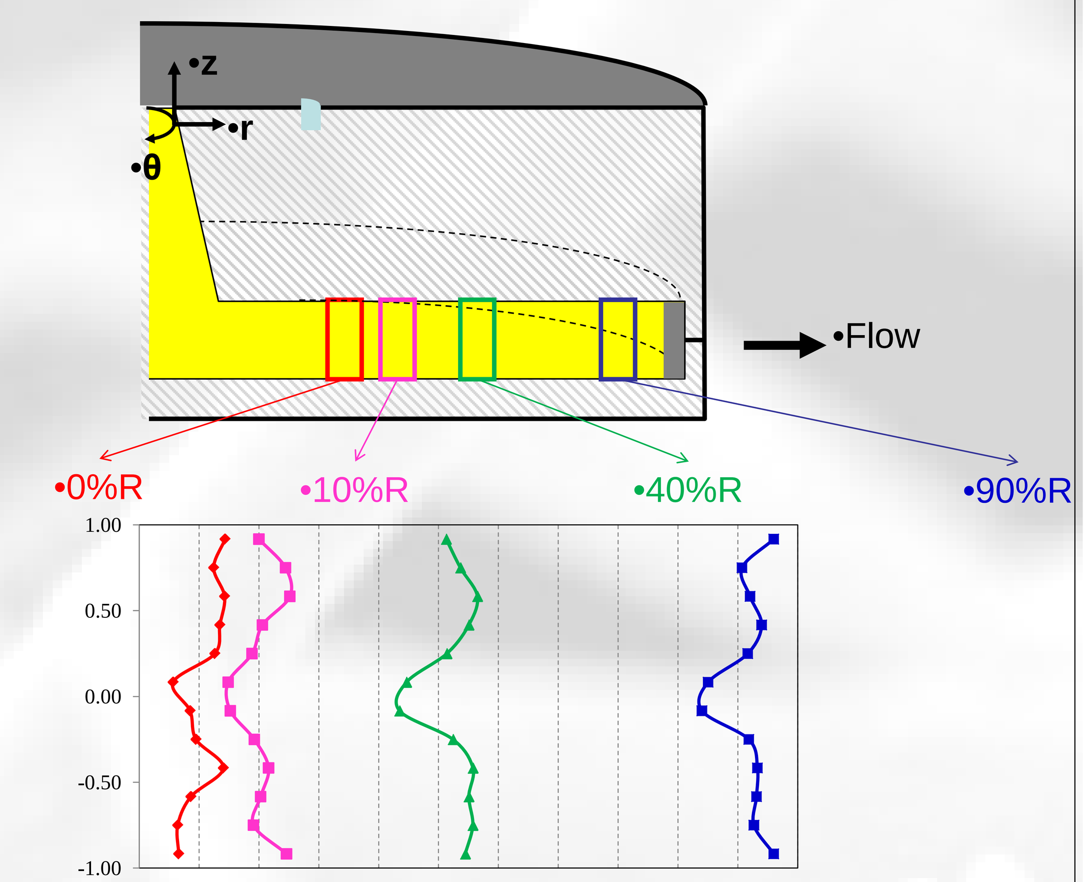


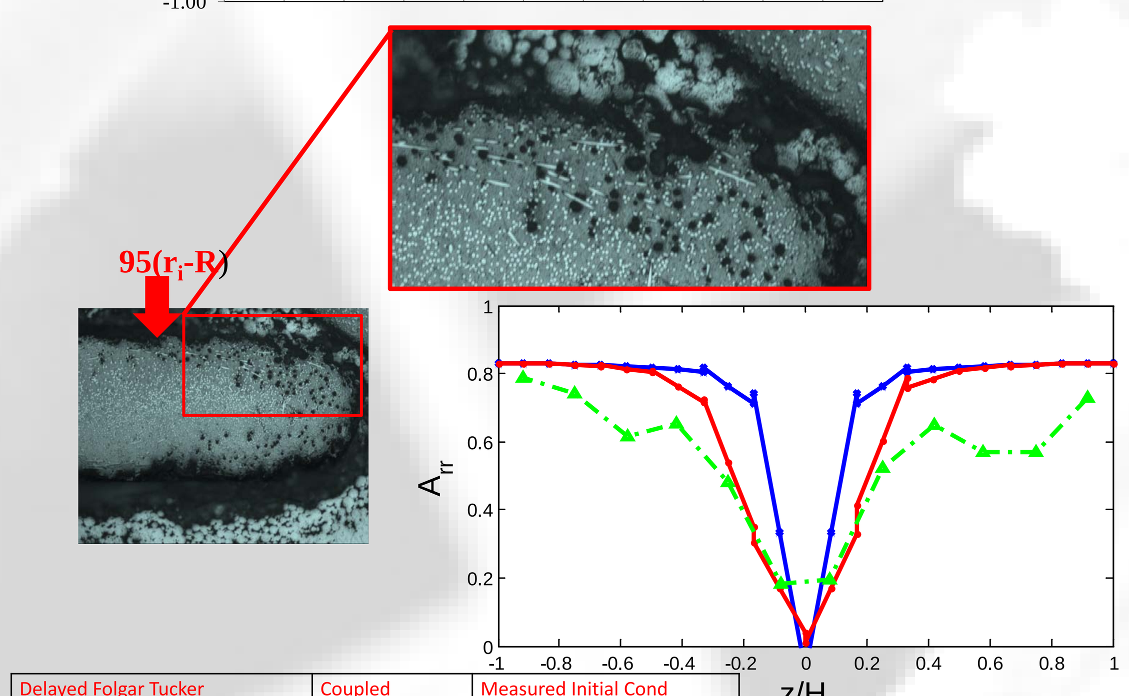
Microscopic Images of Advancing Front for PP (top) and PBT (bottom) at 5X Zoom

- **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 WORK

- Center-gated disk (R=3 cm, 2H = 1.38 mm) with experimentally measured initial orientation and a 12x30 mesh
- Evolution of wall-to-wall A_{rr} orientation tensor





Delayed Folgar Tucker	Coupled	Measured Initial Cond
Folgar Tucker	Decoupled	Random Initial cond
Experimental Orientation		

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
- Simulation will focus on solving full flow equations for the advancing front

ACKNOWLEGEMENTS

- NSF/DOE: DMI-052918
- ICTAS
- Virginia Tech

For additional information please contact:
Dr. P. Wapperom pwappero@math.vt.edu
Dr. D.G. Baird dbaird@vt.edu