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 Polypropylene (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 rough 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

MODELING OF FIBER COMPOSITES

Balance equations for injection molding

\[ \begin{align*}
\rho & = \text{const} \\
\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} & = 0 \\
\rho \nabla \cdot \mathbf{v} & = - \nabla p + \nabla \cdot \mathbf{T} \\
\rho \frac{\partial \mathbf{v}}{\partial t} & = - \nabla p + \nabla \cdot \mathbf{T} + \rho \mathbf{g}
\end{align*} \]

Short glass fibers

Constitutive equation: Folgar-Tucker Model with delay (a)

Evolution of orientation tensor

\[ \frac{d}{dt} \mathbf{Q} = \frac{1}{2} \left( \mathbf{Q} \mathbf{v} - \mathbf{v} \mathbf{Q} + \mathbf{Q} \mathbf{v} \times \mathbf{v} \right) + \tau \mathbf{Q} + \frac{1}{2} \left( \mathbf{Q} + \mathbf{Q}^T \right) \]

Stress due to oriented particles

\[ \sigma_{ij} = 2 \eta \frac{\partial \mathbf{Q}}{\partial t} \]

Polymer matrix

Newtonian matrix

COMPOSITE MATERIAL

- Material: Polypropylene (Viscoelastic)
- Fiber: 30 wt% short glass fiber
- Aspect ratio: 30

Geometry

Shear/ Extensional

Gate region

Lubrication region

Front region

EXPERIMENTAL OBSERVATIONS

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

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

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

ONGOING WORK

- Simulation of fiber orientation works well for Hole Shaw flow approximation. However, close to the advancing front, Hole 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

For additional information please contact:

Dr. D. G. Baird
dbaird@vt.edu

Dr. P. Wapperom
pwapperom@math.vt.edu

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Department of Chemical Engineering, Virginia Tech

Macromolecules and Interfaces Institute, Virginia Tech

Department of Mathematics, Virginia Tech