Long Glass Fiber Orientation in Thermoplastic Composites Using a Model that Accounts for the Flexibility of the Fibers

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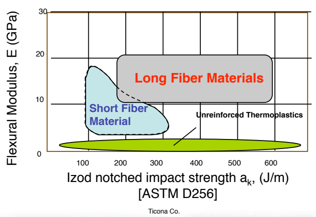
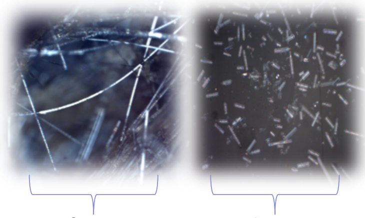
Motivation for Research

Create fiber reinforced materials as a function of injection-molding design for:

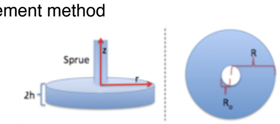
- Increased strength properties
- Production of relatively light weight materials
- More energy efficient transportation





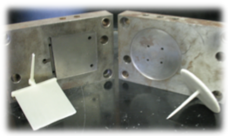
Scope of Research

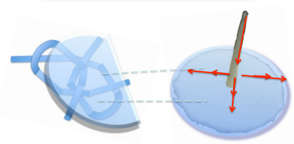
- Implement and evaluate current/new theories to model fiber orientation in complex flow
- Evaluate model parameters from rheological experiments
- Implement the use of stable numerical methods based on the discontinuous Galerkin Finite element method



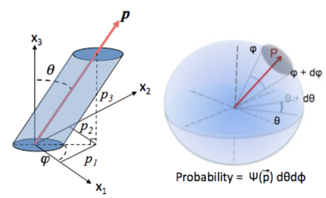
$$v_r(r,z) = \frac{3\dot{Q}}{8\pi h r}\left[1-\left(\frac{z}{h}\right)^2\right]$$

$$v_z(r,z) = 0$$





Obtain velocity field and solve fiber orientation in an uncoupled manner. How do we model fiber orientation?

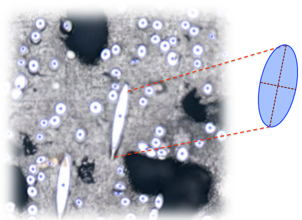


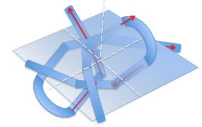
$$\mathbf{A} = \int \vec{p}\vec{p}\,\psi(\vec{p},t)\,d\vec{p}$$

$$\mathbf{A} = \begin{bmatrix} 1/3 & 0 & 0 \\ 0 & 1/3 & 0 \\ 0 & 0 & 1/3 \end{bmatrix} \qquad \mathbf{A} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

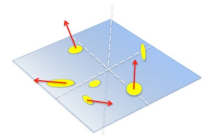
Random — Fully ordered in x_1-direction

Obtain fiber orientation from polished micrographs using a digital imaging technique





A single flexible (long) fiber possibly exhibits many orientations in different planes.



Rigid (short) fibers exhibit only one set of orientation data along its length.

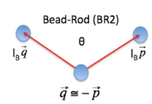
Folgar Tucker Model

$$\frac{D\underline{\underline{A}}}{Dt} = \Big[\underbrace{\underline{\underline{A}}\bullet\underline{\underline{\kappa}}^T + \underline{\underline{\kappa}}\bullet\underline{\underline{A}} - 2\,\underline{\underline{D}}:\underline{\underline{A}}_4}_{\text{Generalized Jeffery for Fibers}} + \underbrace{2C_1 II_D(\underline{\underline{\delta}} - 3\underline{\underline{A}})}_{\text{Folgar-Tucker Term}}\Big]$$

Though popularly used for short fiber simulations, we want to know how this model performs when being used to predict long fiber orientation.

What about a model that accounts for fiber flexibility?

Bead-Rod Model



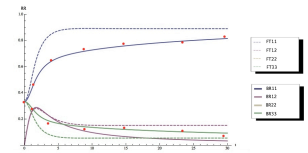
$$\underline{\underline{A}} = \int \vec{p}\vec{p}\,\psi(\vec{q},\vec{p},t)\,d\vec{p}\vec{q}$$
$$\underline{\underline{B}} = \int \vec{q}\vec{p}\,\psi(\vec{q},\vec{p},t)\,d\vec{p}\vec{q}$$
$$\vec{C} = \int \vec{p}\,\psi(\vec{q},\vec{p},t)\,d\vec{p}\vec{q}$$

$$\frac{D\underline{\underline{A}}}{Dt} = \underline{\underline{A}}\cdot\underline{\underline{\kappa}}^T + \underline{\underline{\kappa}}\cdot\underline{\underline{A}} - [(\underline{\underline{\kappa}}+\underline{\underline{\kappa}}^T):\underline{\underline{A}}]\underline{\underline{A}} + \frac{l_B}{2}[\vec{C}\vec{\mu} + \vec{\mu}\vec{C} - 2(\vec{\mu}\cdot\vec{C})\underline{\underline{A}}] - 2k[\underline{\underline{B}} - \underline{\underline{A}}\; tr(\underline{\underline{B}})]$$

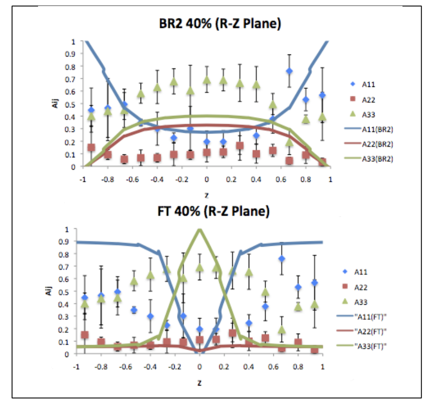
$$\frac{D\underline{\underline{B}}}{Dt} = \underline{\underline{B}}\cdot\underline{\underline{\kappa}}^T + \underline{\underline{\kappa}}\cdot\underline{\underline{B}} - [(\underline{\underline{\kappa}}+\underline{\underline{\kappa}}^T):\underline{\underline{A}}]\underline{\underline{B}} + \frac{l_B}{2}[\vec{C}\vec{\mu} + \vec{\mu}\vec{C} - 2(\vec{\mu}\cdot\vec{C})\underline{\underline{B}}] - 2k[\underline{\underline{A}} - \underline{\underline{B}}\; tr(\underline{\underline{B}})]$$

$$\frac{D\vec{C}}{Dt} = \underline{\underline{\kappa}}\cdot\vec{C} - (\underline{\underline{A}}:\underline{\underline{\kappa}})\vec{C} + \frac{l_B}{2}[\vec{\mu} - \vec{C}\left(\vec{\mu}\cdot\vec{C}\right)] - k\vec{C}[1-(tr(\underline{\underline{B}})]$$

$$\vec{\mu} = \sum_{i=1}^{3}\left(\sum_{j=1}^{3}\sum_{k=1}^{3}\frac{\partial^2 v_i}{\partial x_i \partial x_k}A_{jk}\right)\vec{e}_i$$



Long transient behavior, consistent with experiment, can be explained via the Bead-Rod model by attributing this behavior to fiber flexibility.



Conclusions and Future Work

- Long fiber composites exhibit flexibility
- Transient behavior can be explained by the Bead-Rod model via flexibility within the model
- Long fiber orientation in complex flow is broader than predicted by Folgar Tucker
- Bead-Rod model parameters must be fit from rheology in the near future
- More complex flow data is needed for long fibers to affirm the Bead-Rod model's validity

Acknowledgments

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