Transient Rheology of Polypropylene Melt Reinforced with Long Glass Fibers

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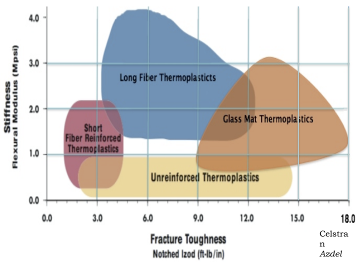
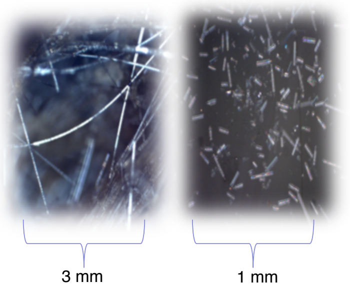
Motivation for Research

Create long fiber reinforced thermoplastic (LFT) materials as a function of processing design for:

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



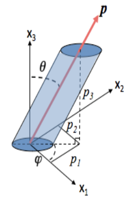


Long fibers exhibit flexibility… Should this be accounted for in an orientation model?

Scope of Research

- Improve the accuracy of currently available LFT orientation simulations for molding processes by using/modifying current fiber orientation theory in combination with using state-of-the-art numerical techniques.
- Establish a method for characterizing long fiber composite fluids based on rheology (independent of molding processes).
- Evaluate the accuracy of the simulations by comparing numerical predictions with experimentally determined orientations in simple and complex flows.

Orientation Representation and Theory



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

$$\underline{\underline{A}} = \begin{pmatrix} 1/3 & 0 & 0 \\ 0 & 1/3 & 0 \\ 0 & 0 & 1/3 \end{pmatrix} \qquad \underline{\underline{A}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Randomly Oriented Fully Oriented

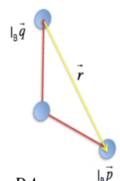
Folgar-Tucker Orientation Model

Generalized Jeffery's for Fibers

$$\frac{D\underline{\underline{A}}}{Dt} = \underline{\underline{A}} \bullet \underline{\underline{\kappa}}^T + \underline{\underline{\kappa}} \bullet \underline{\underline{A}} - [(\underline{\underline{\kappa}} + \underline{\underline{\kappa}}^T) : \underline{\underline{A}}]\underline{\underline{A}}$$
$$+ 2C_I II_D(\underline{\underline{\delta}} - 3\underline{\underline{A}})$$

Folgar-Tucker Term

Bead-Rod Orientation Model



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

Strautins and Latz, *Rheol Acta*, 2007

$$\frac{D\underline{\underline{A}}}{Dt} = \underline{\underline{A}} \cdot \underline{\underline{\kappa}}^T + \underline{\underline{\kappa}} \cdot \underline{\underline{A}} - [(\underline{\underline{\kappa}} + \underline{\underline{\kappa}}^T) : \underline{\underline{A}}]\underline{\underline{A}}$$
$$\boxed{-2k[\underline{\underline{B}} - \underline{\underline{A}}\, tr(\underline{\underline{B}})]} + 2C_I II_D(\underline{\underline{\delta}} - 3\underline{\underline{A}})$$

$$\frac{D\underline{\underline{B}}}{Dt} = \underline{\underline{B}} \cdot \underline{\underline{\kappa}}^T + \underline{\underline{\kappa}} \cdot \underline{\underline{B}} - [(\underline{\underline{\kappa}} + \underline{\underline{\kappa}}^T) : \underline{\underline{A}}]\underline{\underline{B}}$$
$$\boxed{-2k[\underline{\underline{A}} - \underline{\underline{B}}\, tr(\underline{\underline{B}})]} + 2C_I II_D(tr(\underline{\underline{B}})\underline{\underline{\delta}} - 3\underline{\underline{B}})$$

$$\underline{\underline{R}} = \frac{\vec{r}\vec{r}}{tr(\vec{r}\vec{r})} \qquad where \quad \vec{r} = (\vec{p} - \vec{q})$$

Lipscomb Stress Model

$$\underline{\underline{\Pi}} = -P\underline{\underline{\delta}} + \underline{\underline{\sigma}}$$

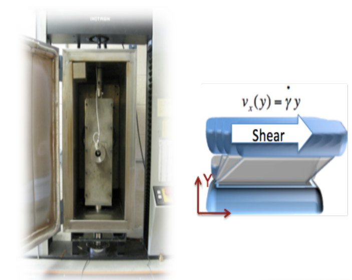
$$\underline{\underline{\sigma}} = \eta_s(\underline{\underline{\kappa}} + \underline{\underline{\kappa}}^T) + c_I\varphi\eta_s(\underline{\underline{\kappa}} + \underline{\underline{\kappa}}^T) + \varphi\eta_s N(\underline{\underline{\kappa}} + \underline{\underline{\kappa}}^T) : (\underline{\underline{A}}\underline{\underline{A}})$$

$$\eta^+ = \frac{\sigma_{12}}{\dot{\gamma}} = \eta_s + c_I\varphi\eta_s + 2\varphi\eta_s N A_{12}^2 \qquad \text{(Stress Growth)}$$

Model Parameters:

- c_1 steady-state viscosity enhancement
- N magnitude of the viscosity overshoot
- C_I isotropic rotary diffusion term
- k flexibility term in Bead-Rod

Experimental Methods and Results

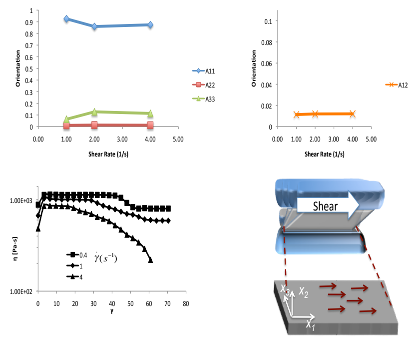


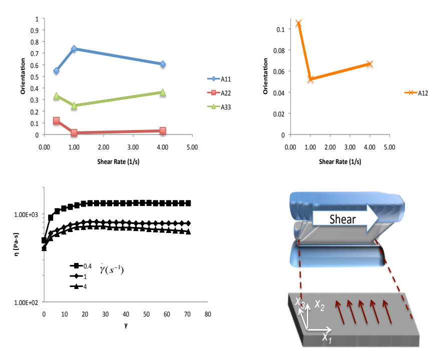
Sliding Plate Rheometer:

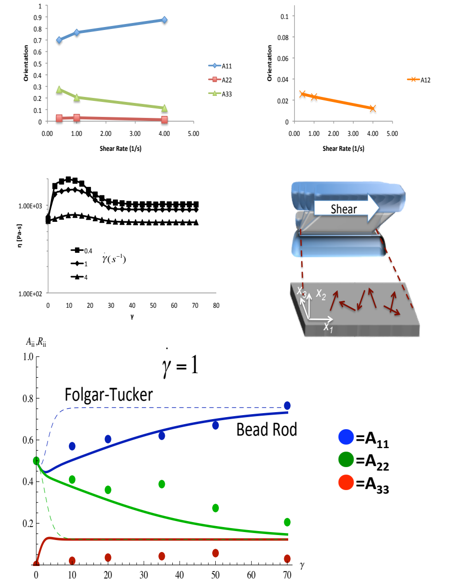
- Rectilinear and homogenous flow
- Reduces unwanted fiber/fiber and fiber/wall contacts
- Localized stress measurements reduce edge effects

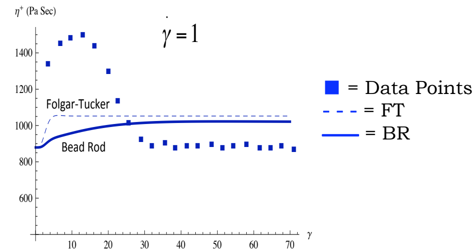
Fiber Orientation Analysis:

- Digital imaging method of Leed's









Conclusions and Future Work

- Long fibers are observed to exhibit flexibility
- Sliding Plate efficiently allows for the study of LFT rheology
- Long Fibers orient in the direction of simple shear, despite their initial orientation.
- Flexibility theory can be used to delay orientation but rheology predictions, using the chosen orientation and stress models, are not consistent with experiment.
- Future desire to track more fibers from shear startup
- Future investigation of Bead-Rod behavior in complex flow

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