CMMI-0853537

Transient Shear Rheology of Long Glass Fiber Filled Polypropylene Using a Sliding Plate Rheometer

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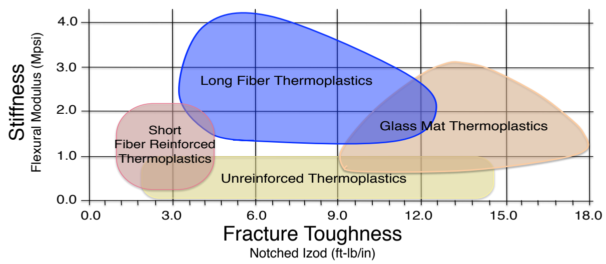
Project Scope:

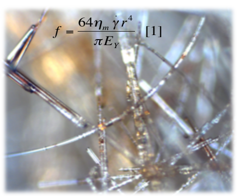
The manufacturing of Long Glass Fiber Thermoplastic (LGFT) parts possesses competitive advantages in a variety of industries, but the physical characteristics of the final part (shrinkage, warpage, strength, stiffness, etc.) are very dependant on flow induced fiber orientation.

Industrially Used Materials …Orientation is Important!

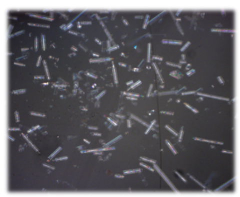


Long Fibers are Flexible, Short Fibers are Rigid

3 mm



1 mm

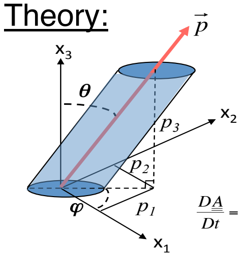


Project Definition:

✧Use rheology as a tool to provide a link between the deformation response of LGFTs and its transient microstructure, and establish a method for determining unbiased modeling parameters (based on this link).

✧Evaluate the accuracy of the simulations by comparing numerical predictions with experimentally determined orientations in both simple and complex flows.

Theory:



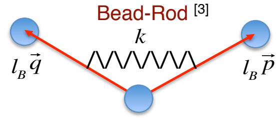
$$\underline{A} = \int \vec{p}\vec{p}\,\psi(\vec{p},t)\,d\vec{p}$$
$$\underline{A}_4 = \int \vec{p}\vec{p}\vec{p}\vec{p}\,\psi(\vec{p},t)\,d\vec{p}$$
$$\underline{\kappa}^T = \nabla \underline{v}$$

Folgar-Tucker [2]

$$\frac{D\underline{A}}{Dt} = \underline{A}\cdot\underline{\kappa}^T + \underline{\kappa}\cdot\underline{A} - (\underline{\kappa}+\underline{\kappa}^T):\underline{A}_4 + 2C_I\dot{\gamma}(\underline{I} - 3\underline{A})$$

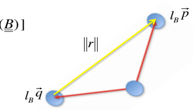
Should an orientation model account for fiber flexibility?

Bead-Rod [3]



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

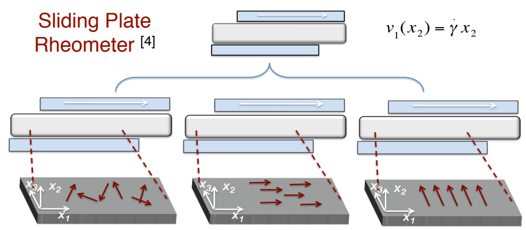
$$\frac{D\underline{A}}{Dt} = \alpha\left(\underline{A}\cdot\underline{\kappa}^T + \underline{\kappa}\cdot\underline{A} - [(\underline{\kappa}+\underline{\kappa}^T):\underline{A}]\underline{A} + \frac{l_B}{2}[\vec{C}\vec{\mu} + \vec{\mu}\vec{C} - 2(\vec{\mu}\cdot\vec{C})\underline{A}] - 2k[\underline{B} - \underline{A}\,tr(\underline{B})] + 2C_I\dot{\gamma}(\underline{I} - 3\underline{A})\right)$$
$$\frac{D\underline{B}}{Dt} = \alpha\left(\underline{B}\cdot\underline{\kappa}^T + \underline{\kappa}\cdot\underline{B} - [(\underline{\kappa}+\underline{\kappa}^T):\underline{A}]\underline{B} + \frac{l_B}{2}[\vec{C}\vec{\mu} + \vec{\mu}\vec{C} - 2(\vec{\mu}\cdot\vec{C})\underline{B}] - 2k[\underline{A} - \underline{B}\,tr(\underline{B})] + 2C_I\dot{\gamma}(\underline{I} + 3\underline{B})\right)$$
$$\frac{D\vec{C}}{Dt} = \underline{\kappa}\cdot\vec{C} - (\underline{A}:\underline{\kappa})\vec{C} + \frac{l_B}{2}[\vec{\mu} - \vec{C}(\vec{\mu}\cdot\vec{C})] - k\vec{C}[1 - (tr(\underline{B})]$$
$$\vec{\mu} = \sum_{i=1}^{3}\left(\sum_{j=1}^{3}\sum_{k=1}^{3}\left[\frac{\partial^2 v_i}{\partial x_j \partial x_k} + K_{ijk}\right]A_{jk}\right)\vec{e}_i$$

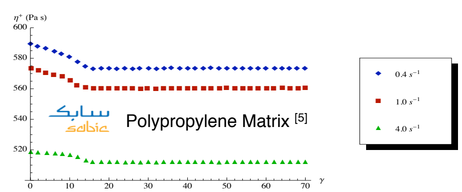


Experiment:

Sliding Plate Rheometer [4]

$v_1(x_2) = \dot{\gamma}\,x_2$

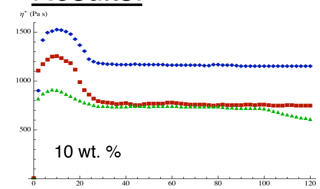




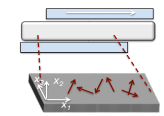
References:

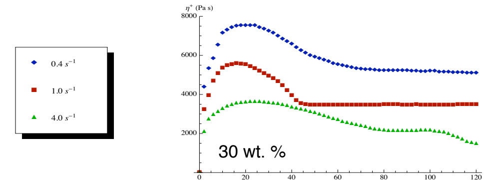
[1] Switzer and Klingenberg, Int. J. Multiphase Fluids, 2002
[2] Folgar and Tucker, J. Rein. Plast. Comp, 1984
[3] Strautins and Latz, Rheol. Acta., 2007
[4] Giacomin McGill Unieversity, 1987
[5] Donated material from Ann Marie Burnell and Sabic

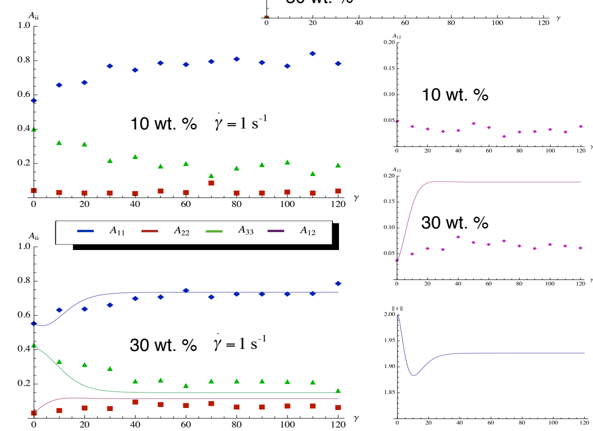
Results:



Initially Random







$l_B = 1,\ \alpha = 0.25,\ C_I = 0.035,\ k = 0.08,\ K_{311} = K_{323} = K_{133} = 0.3$

Conclusions:

✧The rheology of LGF filled polypropylene exhibits large transient stress overshoots.
✧Shear thinning occurs with increased shear rate. Also, viscosity is enhanced with increased concentration.
✧Orientation evolution occurs over the same strain region as does the dynamic shear stress response.
✧The Bead-Rod model may be used to approximate the transient orientation, but its link to the rheology is not yet understood.