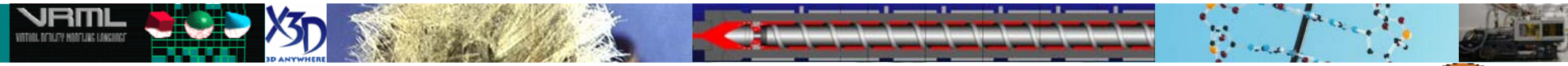


Visualization of Fiber Orientation in Highly-Concentrated, Glass Fiber-Reinforced, Injection Molded Thermoplastic Composites Using Web3D Technology

Vélez-García, G.M.[1], Polys, N.F.[2], Wapperom, P.[3], Baird, D.G.[4], and Kriz, R.D.[5]

[1]Macromolecules and Interfaces Institute, [2]Virginia Tech Research Computing, [3]Mathematics Department, [4]Chemical Engineering Department, and [5]Engineering Science and Mechanics

Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

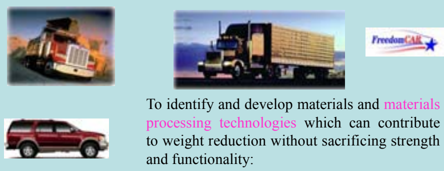
ABSTRACT

Orientation tensors are commonly used to represent orientation in fiber composites. They are excellent and compact tool to describe the orientation in mathematical terms. However, the visualization of the orientation tensors is not straight forward. Therefore, in this paper we present a simple method to visualize fiber orientation in composite using a virtual reality modeling language (VRML) tool. This tool is used to describe the experimental orientation and simulation results for an injection molded center-gated disk. The results show an easy way to visualize and understand the complex structure of orientation in composites.

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 programs to improve the prediction of microstructure in short glass 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.
- A key aspect of this work will be an experimental evaluation of the predicted fiber or particle orientation distribution throughout an injection molded part.

INNOVATION IN VISUALIZATION

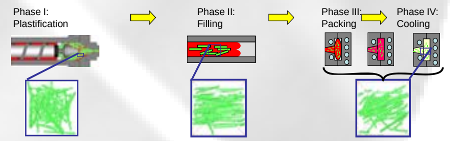
We have introduced virtual reality tools through Web3D to visualize the micro-structure of fiber reinforced melts.

- An effective environment for the unified visualization of 3D orientation data from experiment (microscopy) and numerical simulation.
- Interactive Web3D publication provides a simple and intuitive way to understand fiber orientation data

WEB 3D

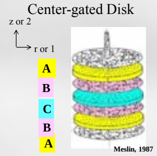
Refers to the International Standards Organization (ISO) standards of the Web3D Consortium (web3d.org). Declarative languages like Virtual Reality Modeling Language (VRML) and Extensible3D (X3D) enable interactive 3D multimedia environments and animations to be deployed over web protocols. These standards are by nature cross-platform (e.g. desktops, CAVE) and integrate with common web technologies such as XML and Webservices.

ORIENTATION DURING INJECTION MOLDING



MULTILAYER STRUCTURE

Center-gated Disk



Meslin, 1987

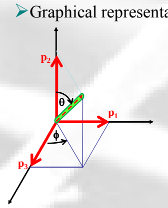
Three regions		Orientation wrt flow:
A	Shell	Parallel ($A_{11} \approx 1$)
B	Transition	Random in the plane ($A_{11} \approx A_{33} \approx ½$)
C	Core	Perpendicular :($A_{33} \approx 1$)

DESCRIPTION OF FIBER ORIENTATION

- Single fiber
  - Vector of orientation

$$\underline{p} = p_1\underline{\delta}_1 + p_2\underline{\delta}_2 + p_3\underline{\delta}_3$$
$$p_1 = \sin\theta\cos\phi$$
$$p_2 = \sin\theta\sin\phi$$
$$p_3 = \cos\theta$$

  - Graphical representation



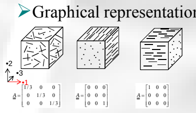
- Population of fibers
  - Distribution function

$$A_{ij} = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} p_i p_j \psi(\theta,\phi)\sin\theta\, d\theta\, d\phi = \oint p_i p_j \psi(\underline{p})\, d\underline{p}$$

  - Orientation tensor

$$A_{ij} = \langle p_i p_j \rangle = \sum_{i=1}^{N}\sum_{j=1}^{N} p_i p_j$$

  - Graphical representation



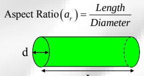
ADVANTAGES OF VISUALIZATION OF ORIENTATION DATA USING WEB3D

- Ability to visualize and inspect fiber orientation data interactively
- Observe tri-dimensional features in the data, e.g. dispersion not evident in 2-D images.
- Good method of orientation representation for a non-technical audience.

COMPOSITE MATERIAL

- Material properties
  - Matrix: PBT (Newtonian)
  - Filler: 30wt% short glass fiber
    - Aspect ratio: 30

$$\text{Aspect Ratio}(a_r) = \frac{Length}{Diameter}$$



- Model parameters obtained from rheometry

Orientation parameters	
C_I	0.02
α	0.40

Stress parameters	
$\nu\xi_{str}$	5000 Pa s
η_s	373 Pa s

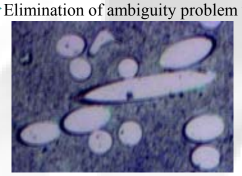
EXPERIMENTAL DETERMINATION OF FIBER ORIENTATION

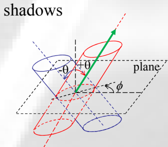
- Procedure:

Polishing → Plasma etching → Image acquisition (reflective microscopy using motorized stage) → Semi-automatic image analysis (customized)

EXPERIMENTAL RESULTS

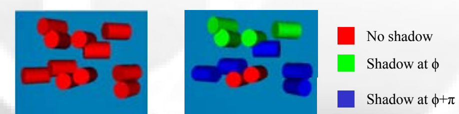
- Elimination of ambiguity problem using shadows





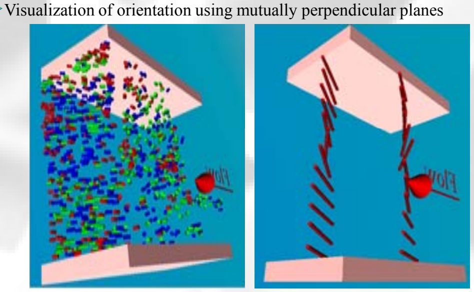
Ambiguity problem in method of ellipses:

- 3D Visualization



Ambiguous data: Unambiguous data:

- Visualization of orientation using mutually perpendicular planes



Raw data Averaged data

MODELLING OF COMPOSITES

- Balance equations for injection molding

$$\underline{\nabla}\bullet\underline{v} = 0 \qquad -\underline{\nabla}p + \underline{\nabla}\bullet\underline{\underline{T}} = \underline{0} \qquad \underline{\underline{T}} = \underline{\underline{T}}^{fiber} + \underline{\underline{T}}^{matrix}$$

(Mass) (Momentum) (Stress)

- Short glass fibers
  - Constitutive equation: Folgar-Tucker Model with delay (α)

Evolution of orientation tensor

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

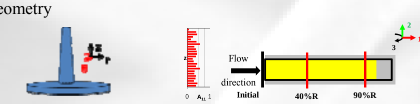
$$\underline{\underline{d}} = \frac{1}{2}\left(\underline{\nabla}\underline{v} + (\underline{\nabla}\underline{v})^T\right)$$

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

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

SIMULATION RESULTS

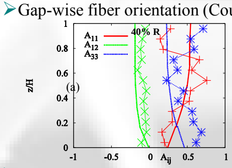
- Geometry



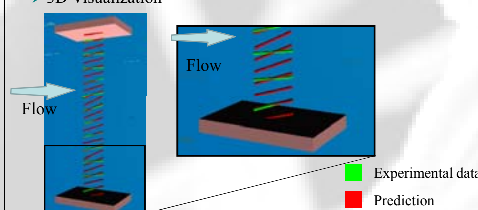
- Center-gated disk (R=3 cm, 2H = 1.38 mm) with experimentally measured initial orientation and a 12x30 mesh

- Numerical technique
  - Solve at every time step (coupled approach)
    - Balance Equation or Hele-Shaw flow approximation
      - Galerkin FEM
    - Constitutive equations
      - Discontinuous Galerkin FEM
    - Find the new mesh coordinates

- Experimental vs numerical fiber orientation
  - Gap-wise fiber orientation (Coupled flow and orientation)



  - 3D Visualization



FINDINGS

- Model parameters determined by rheometry can be used to simulate fiber orientation
- Modified procedure let us to improve the fiber orientation measurement using reflective microscopy.
- The delay model and coupled flow and orientation improve prediction of fiber orientation.
- In the investigation of fiber reinforced melts, Web3D and interactive visualization environments provide a low-cost and effective means to analyze the relationships between experimental and simulated results

ACKNOWLEDGEMENTS

- NSF/DOE: DMI-052918
- MS&IE-IGERT program
- Virginia Tech
- University of Puerto Rico
- ORNL

For additional information please contact:

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

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

Dr. N.F. Polys npolys@vt.edu