Engineering Property Prediction Tools for Tailored Polymer Composite Structures

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Outline

- Overview
- Objectives
- Approach
- Completed Milestones
- FY 2008 Technical accomplishments
- Future work
- Summary
- Publications

Overview

Timeline

- Start: Sep 2005
- Finish: Sep 2009
- 80% Complete

Budget

- Total project funding
  - DOE: $4,490K (PNNL& ORNL)
- Funding received in FY08
  - $500K per Lab
- Funding expected for FY09
  - $550K per Lab

Barriers

- Barriers
  - A. Cost
  - B. Inadequate supply base
  - C. Design data and modeling tools
- Targets – Use of polymer composites to reduce vehicle weight by 50% by 2012

Partners

- University of Illinois (subcontract by PNNL)
- Moldflow (CRADA with PNNL)
- American Chemistry Council and Automotive Composite Consortium in the Project Steering Committee

Objectives

- **Objective**
  - Enable the optimum design of lightweight automotive structural components using long-fiber injection molded thermoplastics (LFTs)
- **Goals and Scopes**
  - Develop an integrated approach linking process to structural modeling
    - ✓ FY05-FY06: Completed technical feasibility assessment
    - ✓ FY06: Developed thermoelastic property prediction models for LFTs
    - ✓FY07: Developed a fiber orientation model for LFTs – Developed an elastic-plastic and strength prediction model for LFTs
    - ✓FY08: Developed elastic-plastic-damage and creep models for LFTs - Developed an integrated approach linking Moldflow to ABAQUS
  - Develop experimental material characterization & testing methodologies
    - ✓ FY05-FY06: Completed assessment of characterization techniques
    - ✓ FY06: Developed fiber length measurement technique and validated Leeds fiber orientation technique for LFTs
    - ✓ FY07: Developed coupled mechanical testing and micro-tomography apparatus to observe damage processes within LFTs
    - ✓ FY08: Characterized temperature dependence and non-linear properties of LFTs

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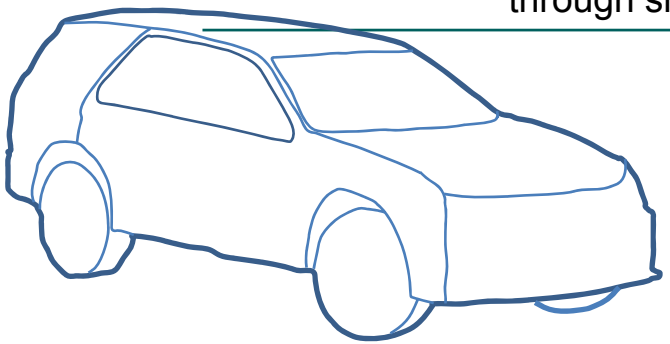
An Integrated Approach Linking Process to Structural Modeling with Experimental Verifications

Creation of a composite part through simulations



LFTs for structural and semi-structural applications

Univ. Illinois/PNNL/MOLDFLOW

Process simulations using
- **A new fiber orientation model**
- **A fiber length attrition model**

Prediction of the composite microstructure

Map fiber length and orientation results into EMTA-ABAQUS

Provide data to validate models

EXPERIMENTS (ORNL)

Microstructural characterizations
- **Fiber length distribution**
- **Fiber orientation distribution**
- **Fiber dispersion**
- **Fiber/matrix debonding and other microdefects**

Mechanical testing
- **Quasi-static and fatigue tests**
- **Creep and impact tests**

EMTA-ABAQUS (PNNL)

EMTA (PNNL code) performs homogenization:
- **Elastic properties**
- **Coefficients of thermal expansion**

Incremental EMTA is implemented in ABAQUS:
- **Elastic-plastic analysis and strength prediction**
- **Creep analysis**
- **Damage and fatigue damage analyses**
- **Impact analysis**

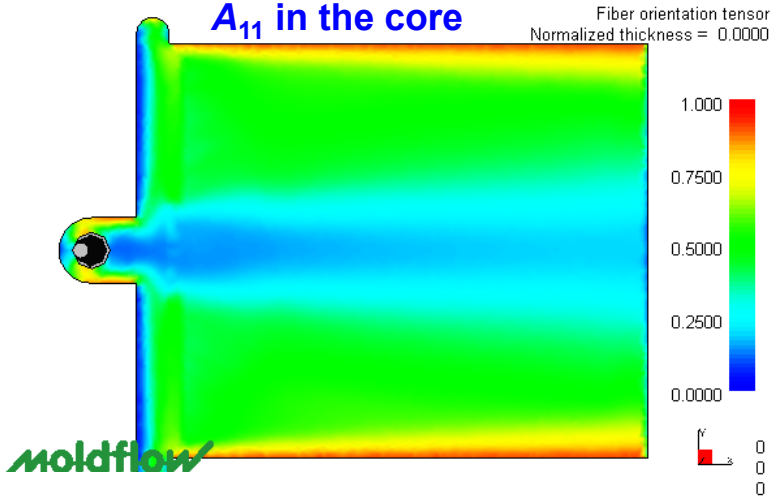
Completed Milestones

- **June 2005 to March 2006 Completed Milestones**
  - First injection-molding trials to produce LFT samples
  - Complete technical assessment of existing process models
  - Complete technical assessment of characterization methods for LFTs
- **FY 2006 Completed Milestones**
  - Complete thermoelastic property prediction for LFTs
  - Determine effect of fiber curvature on elastic properties
  - Validate the Leeds method for fiber orientation measurement for LFTs
  - Develop a method for fiber length measurement
  - Measure fiber length and orientation in LFT samples
- **FY 2007 Completed Milestones**
  - Develop an anisotropic rotary diffusion (ARD) model for fiber orientation in LFTs
  - Develop / implement in ABAQUS an elastic-plastic and strength model for LFTs
  - Establish a CRADA with Moldflow
  - Develop an X-ray tomography unit to identify microstructural evolution of damage
- **FY 2008 Completed Milestones**
  - Implement the new fiber orientation (ARD) model in Moldflow
  - Develop/implement creep and elastic-plastic damage models in ABAQUS
  - Develop an integrated approach linking Moldflow to ABAQUS
  - Perform microstructural characterization and mechanical testing for creep and damage model validations

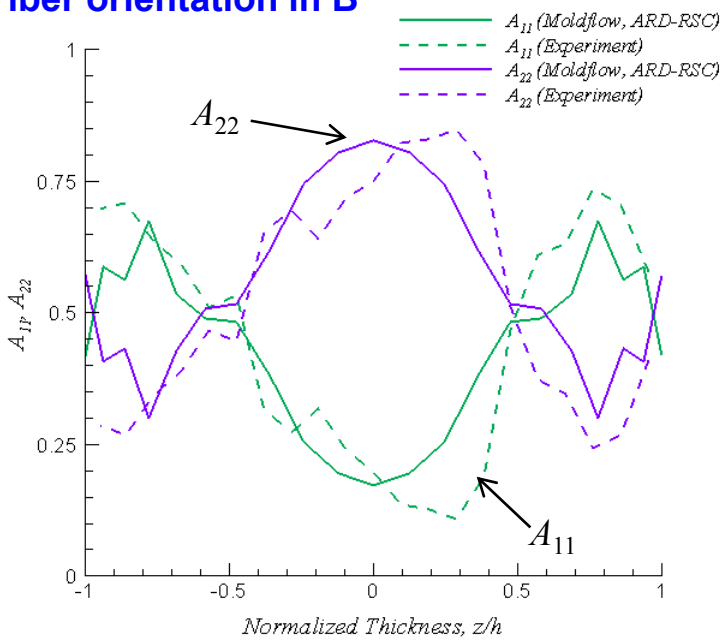
FY 2008 Accomplishments

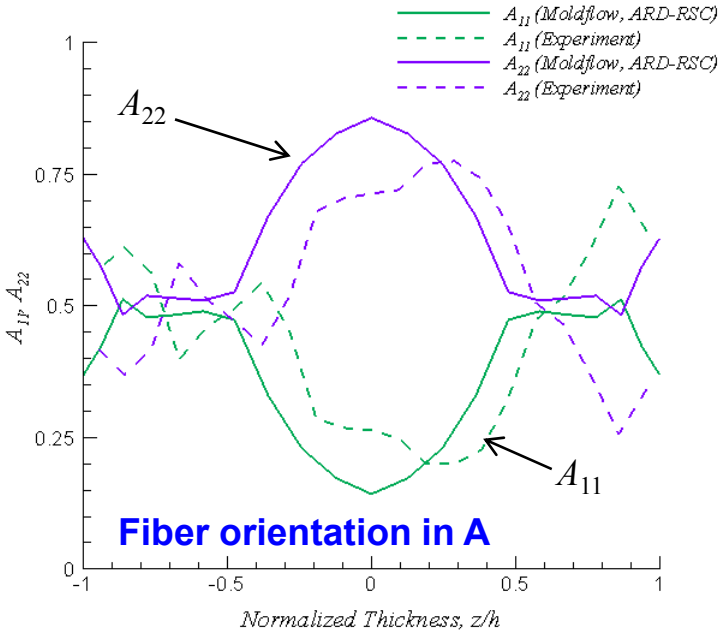
- **Application of the new fiber orientation model (ARD-RSC model)**
  - Material: Glass/PP (40% glass weight fraction)

A_{11} in the core

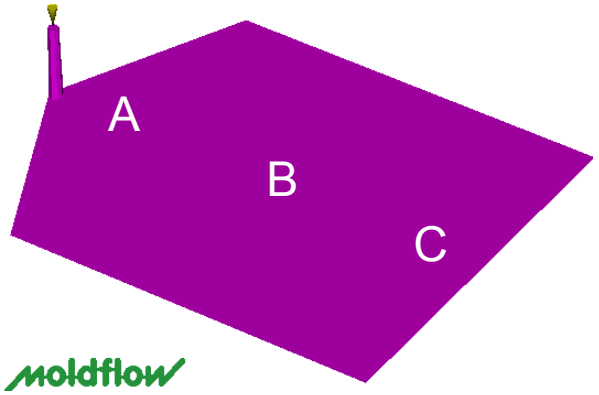


Fiber orientation in B





Fiber orientation in A



Regions A, B, and C were selected for fiber length and orientation measurements

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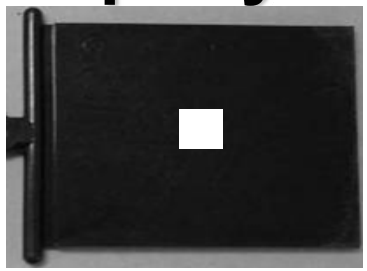
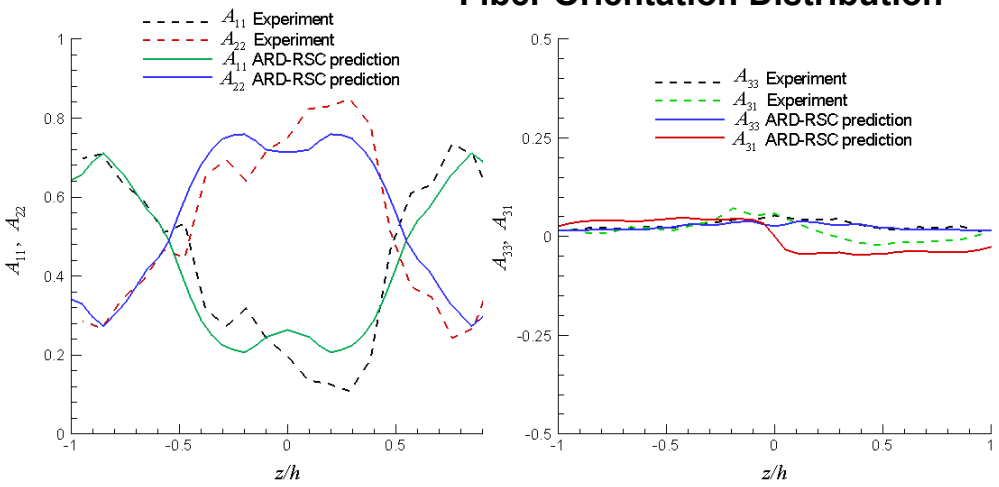
FY 2008 Accomplishments: Property Prediction



Injection-molded glass/PP ISO-plaque

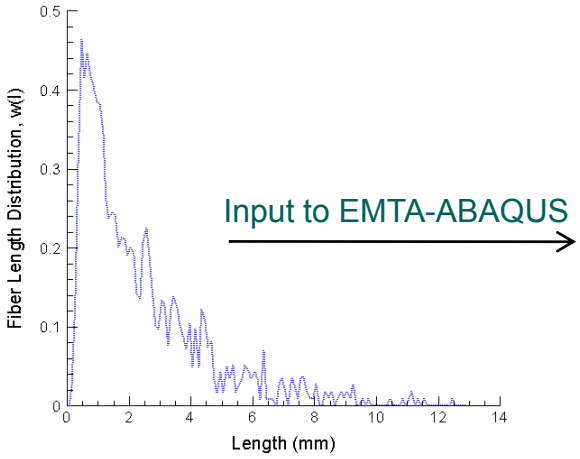
Fiber Orientation Distribution



Elastic Moduli (MPa)

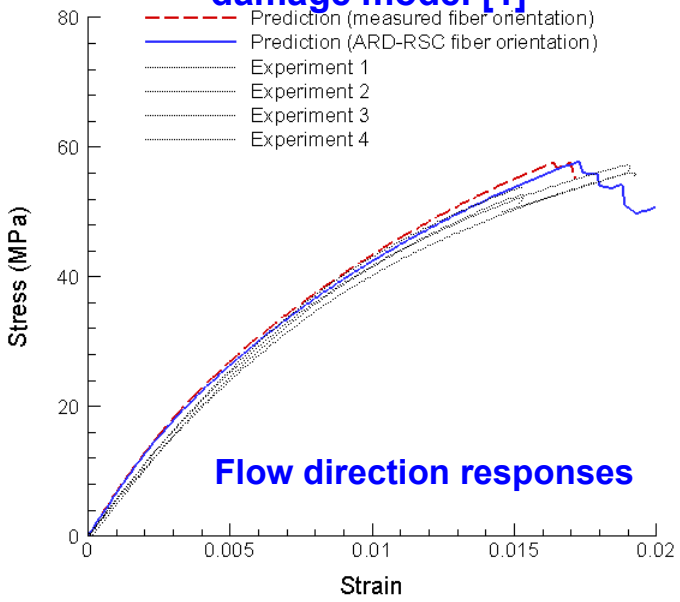
	EMTA (experimental orientation)	EMTA (predicted orientation)	Experiments
E_{11}	**6017**	**5908**	**6063**
E_{22}	**6935**	**6951**	**7211**
E_{33}	3070	3044	
G_{12}	2046	2110	
G_{13}	977	966	
G_{23}	1010	986	

Input to EMTA-ABAQUS



Input to EMTA-ABAQUS

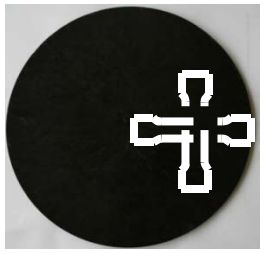
Application of the elastic-plastic damage model [1]

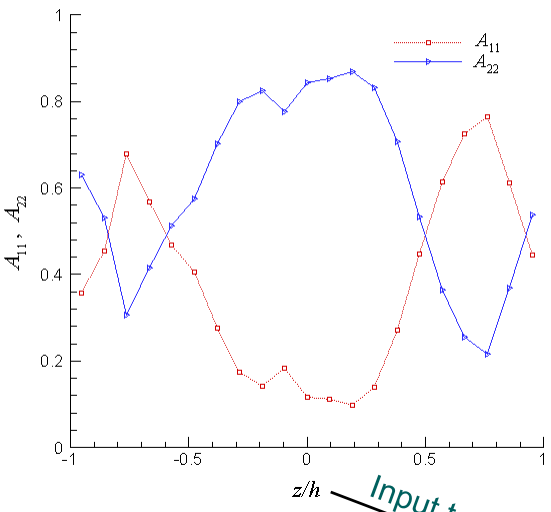


	Flow-Direction Strength (MPa)
EMTA-ABAQUS (experimental orientation)	58
EMTA-ABAQUS (predicted orientation)	58
Experiment	55

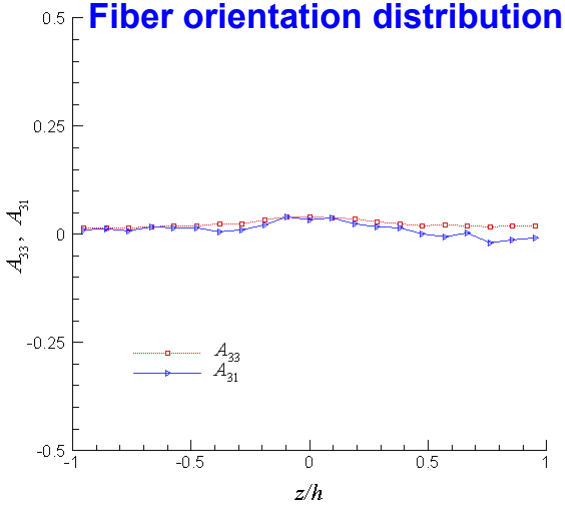
FY 2008 Accomplishments: Creep Modeling

- The creep model implemented in ABAQUS was used to predict the creep responses of glass/PP specimens (EMTA-ABAQUS) [6]

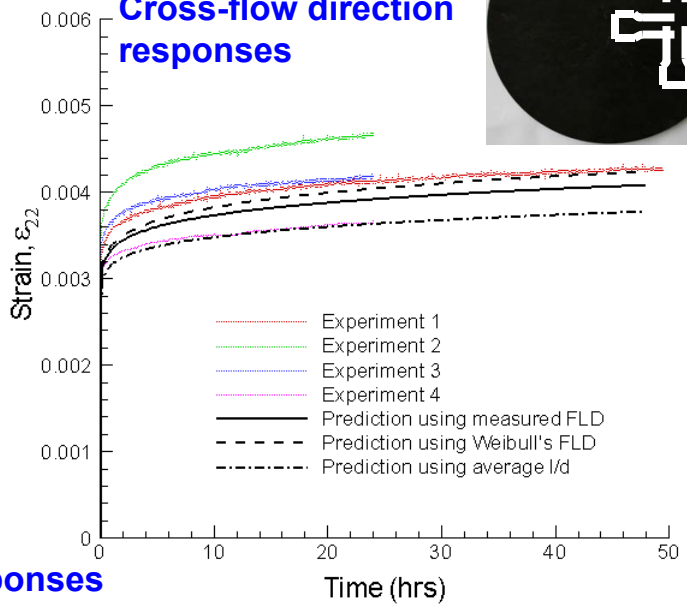




Fiber orientation distribution

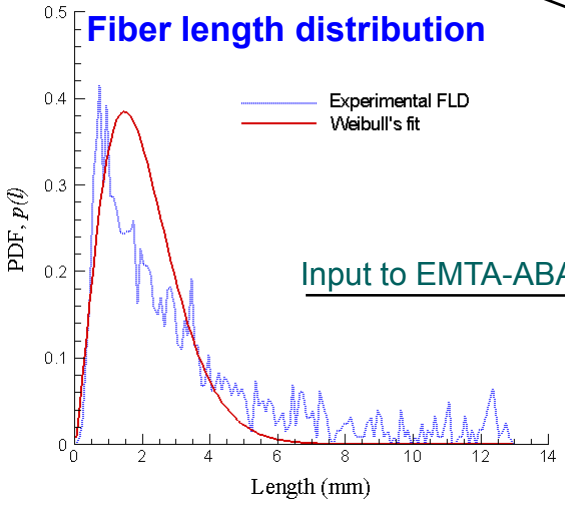


Cross-flow direction responses



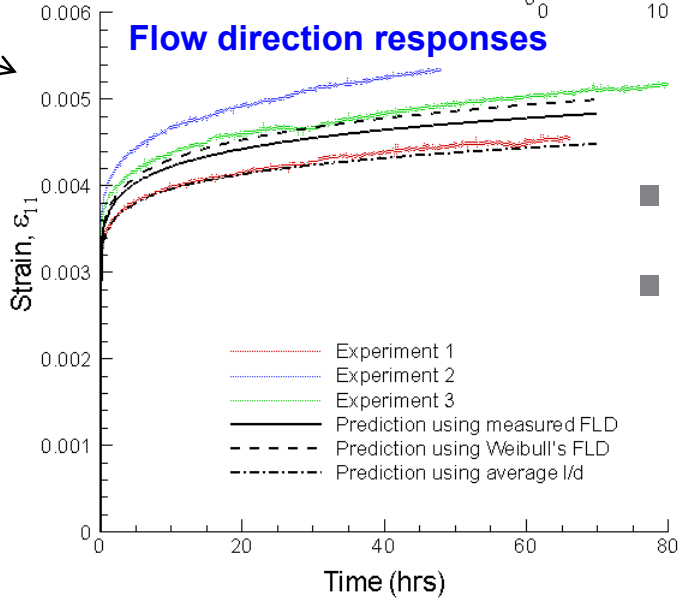
Input to EMTA-ABAQUS

Fiber length distribution



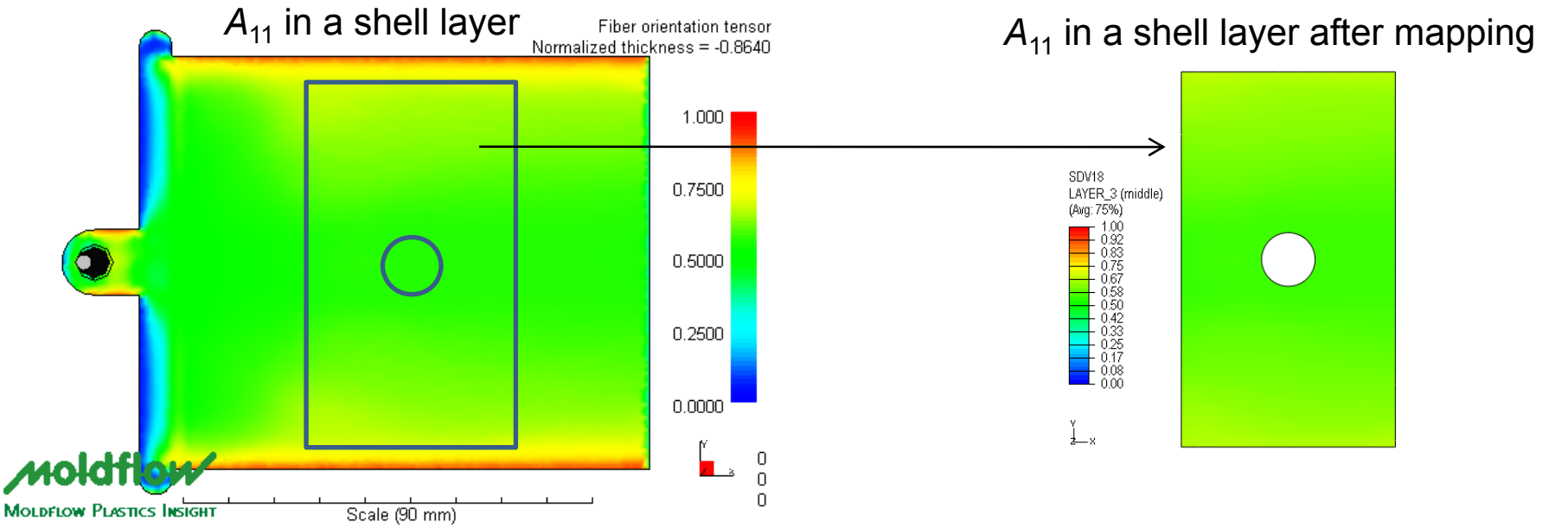
Input to EMTA-ABAQUS

Flow direction responses

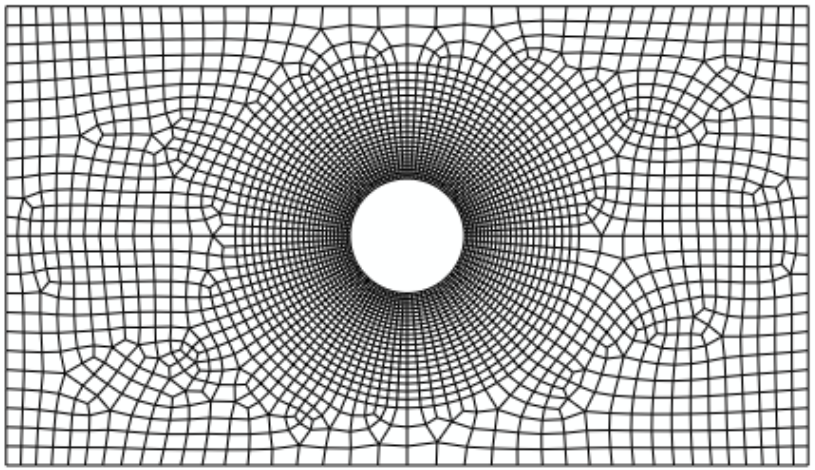


- Higher creep resistance in the cross-flow direction
- Using average fiber aspect ratio leads to under-predicting creep strains

Process-Linked Structural Modeling for a Damage Analysis Using Moldflow-EMTA-ABAQUS



Finite element mesh for structural analysis



EMTA-ABAQUS analyzed a plaque containing a hole removed from a glass/PP ISO-plaque. Fiber orientation was predicted by **Moldflow** using the ARD-RSC model and was then mapped into the ABAQUS mesh for a structural damage analysis using the damage model.

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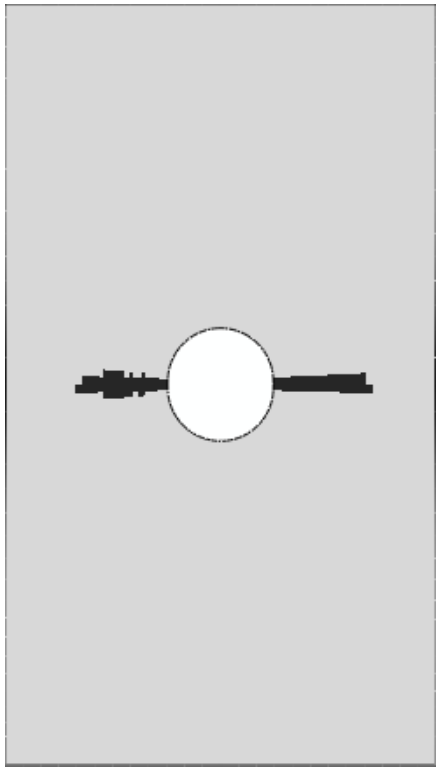
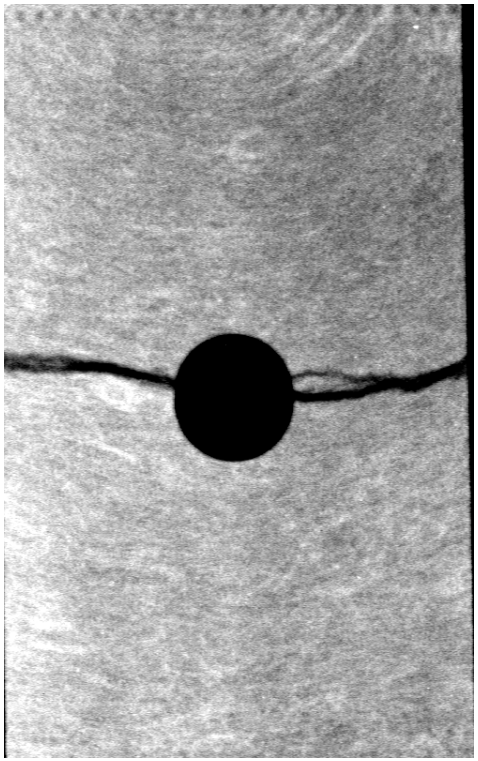
Process-Linked Structural Modeling for a Damage Analysis Using Moldflow-EMTA-ABAQUS (cont.)

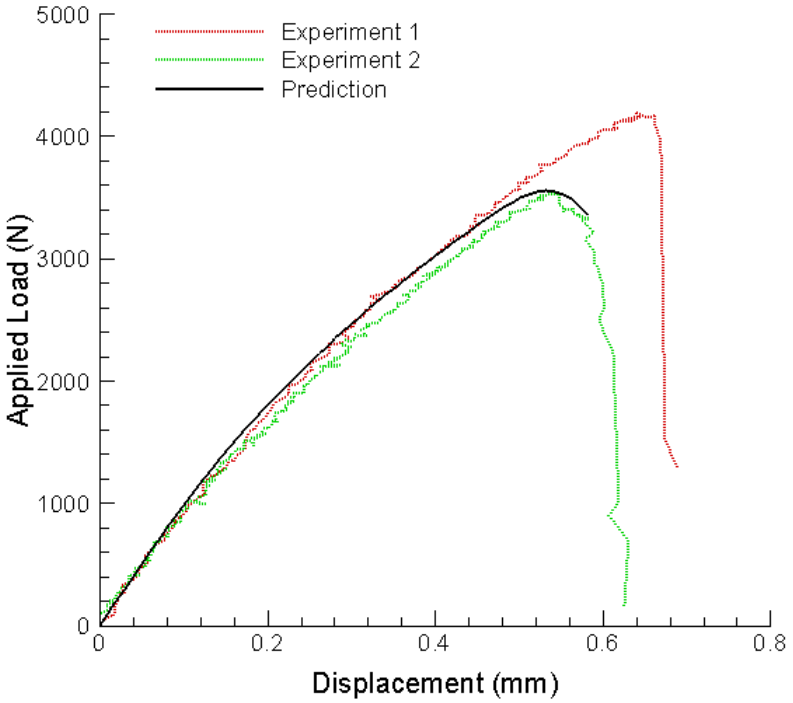
Predicted crack propagation patterns



Experimental crack propagation patterns



Load-Displacement at the grips



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Future Work

- **FY 2009 Work**
  - Develop a fatigue model for LFTs
  - Characterize fatigue behavior of LFTs
  - Develop an impact damage model for LFTs
  - Characterize impact behavior of LFTs
  - Further demonstrate the integrated approach for LFTs

- **Proposed Work for FY 2010 and FY 2011 (Proposed 2 year Project Extension)**
  - Further validate the predictive capabilities for a complex LFT part representative of automotive applications
  - Further validate the predictive capabilities for long-carbon-fiber thermoplastics
  - Transfer the developed engineering tools to the automotive and plastics industries
  - Perform a technical feasibility assessment of existing capabilities for compression molding
  - Determine the extent to which the capabilities developed for injection-molding can be applied to compression molding

Summary

- Lightweight automotive structural components made of LFTs can be designed and processed using capabilities developed in this project.
- **Key accomplishments to date**:
  - A fiber orientation model for LFTs
  - Models for predicting thermoelastic properties, elastic-plastic, damage, and creep behaviors of LFTs – EMTA/ABAQUS capabilities
  - An integrated approach linking Moldflow's process modeling to ABAQUS
  - Characterization tools for determining microstructural features (fiber orientation & length distributions, etc.)
  - Novel testing methods for model development and validation
- Model implementations in commercial leading codes (i.e. Moldflow and ABAQUS) assures that the results will be available in the marketplace.
- Progress of coordinated research to develop predictive and characterization tools is evaluated through periodic review meetings
- Interim results are disseminated via publications and presentations
- Results from this work can be extended to other discontinuous fiber polymer composite processes such as compression molding