ACC 100
Predictive Technology Development and Crash Energy Management

Khaled W. Shahwan, PhD – Project Leader
Chair – ACC100
Chrysler Technology Center – Scientific Labs.
Chrysler LLC
Auburn Hills, Michigan, USA

Project ID: lm_09_kia

This presentation does not contain any proprietary, confidential, or otherwise restricted information

AUTOMOTIVE COMPOSITES CONSORTIUM

ACC100 Overview

Timeline

- Project start: 2007
- Project end: 2011
- Percent complete: 40%

Barriers

- Materials’ cost & availability
- Materials’ characterization & testing standards
- Universally robust and truly predictive modeling tools
- Complex physics of damage

Budget

- Total project funding:
  - $1,975K
  - DOE share: 100% CA
  - OEM share: % In-Kind match
- FY07 funding: $375K
- FY08 funding: $400K
- FY09 funding: $425K

Collaborators

- CHRYSLER Ford GM
- Oak Ridge National Lab. (DoE)
- University of Michigan
- Northwestern University
- Rensselaer Polytechnic Institute
- Nottingham University (UK)
- Excel Pattern Works, Inc.

ACC100 Objectives I

- Investigate which major structural members can be re-designed using lightweight fiber-reinforced automotive composites without degrading crashworthiness and structural safety.
- Investigate which leading materials' candidates (fibers, matrix/resin, architecture) can be the most viable for crashworthiness that lead to increased strength, stiffness, energy absorption while reducing component structural mass by at least 50%.
- Characterize such materials by measuring their mechanical properties.
- Design and build structural tubes of various configurations using the above materials and perform quasi-static and dynamic crush tests to assess their energy absorption.
- Develop computer models to analyze vehicle structures using such advanced materials. The mostly phenomenological models proved to be a useful simulation tool albeit not "truly" predictive on a robust basis—***truly predictive tools are needed.***
- Employ all of the above information and know-how to demonstrate such technologies.

% Achieved = 100%

ACC100 Objectives II

- Characterize nonlinear composites’ properties and their constituents within a hierarchical framework (manufacturing, life cycle) for automotive applications.
- Characterize the dominant micro-, meso-, and macro-mechanical mechanisms responsible for damage initiation, progression, and energy absorption.
- Characterize the coupled material-structural (local-global) behavior of composites in order to direct the development of new and improved material systems and models.
- Develop, verify and validate efficient and robust modeling and analysis tools for the prediction of damage initiation, progression, energy absorption, and overall crush behavior of composite components in lightweight vehicle structures using state-of-the-art micromechanical, phenomenological and hybrid approaches.
- Develop design, testing, modeling and analysis guidelines for lightweight automotive composites applications in vehicle development.

% Achieved (as of Q4 2008) **= 40%**

ACC100 Projects

To understand the physics of crush mechanics of automotive lightweight composite structures, the ACC100 has initiated, supported and led numerous projects—*most have been completed, few are on-going*. The following is a partial list:

1. **Biaxial Response & Failure of Braided Carbon Fiber Composites (Experimental & Computational)**
2. **Strain Rate Effects on Glass Fiber & Carbon Fiber Polymer Matrix Composites (Experimental)**
3. **Progressive Crush in Carbon-Based Textile Composites (Computational & Experimental)**
4. **Hierarchical Modeling of FRP Materials/Structure for Lightweight Automobile Crashworthiness Simulation (Experimental & Computational)**
5. **Energy Absorption of Triaxial Braided Composite Tubes (Experimental & Computational)**
6. **Novel Approaches to Predicting Structural Performance of Textile Composite Materials & Structures (Computational)**
7. **Rate Dependent Effects of Crush Zone Morphology of Polymer Composites (Experimental)**
8. **Collapsible Shell for Finite Element Crashworthiness Simulation of Composite Structures (Computational)**
9. **Constitutive Modeling of Discontinuous Carbon Fiber Polymer Composites (Computational)**
10. **Crash Performance of Bonded Structures (Experimental & Computational)**

% Completed of #1- #10 to-date: 100%

ACC100 Projects … Cont’d

11. **The Effects of Existing Damage on the Energy Absorption Potential of Polymer Composites Structures (Experimental & Computational)**
12. **Effects of Friction on Energy Absorption (Experimental)**
13. **Interface Analysis of ACC Composite Samples (Experimental)**
14. **Lateral Bending of Composite Tubes (Experimental & Computational)**
15. **Development of Sandwich Composite Concepts for Automotive Applications (Experimental & Computational)**
16. **Crash Performance of Bonded Structures (Experimental & Computational)**
17. **The Effects of Existing Damage on the Energy Absorption Potential of Polymer Composites Structures (Experimental & Computational)**
18. **Effects of Friction on Energy Absorption (Experimental)**
19. **Interface Analysis of ACC Composite Samples (Experimental)**
20. **Lateral Bending of Composite Tubes (Experimental & Computational)**
21. **Development of Sandwich Composite Concepts for Automotive Applications (Experimental & Computational)**
22. **Post Peak Response Characterization of 2D Triaxially Braided Composites (Experimental & Computational)**

% Completed of #11- #22 to-date: 100%

ACC100 Projects … Cont’d

23. **Multiscale Modeling for Crash Prediction of Composite Structures (Computational)**
24. **Crashworthiness Assessment of Tubular RaFC Structures Based on Micro and Interfacial Mechanics (Experimental & Computational)**
25. **Size Effects in Textile Composites (Experimental & Computational)**
26. **Modeling of the Manufacturing Process Induced Effects on the Matrix Properties of Textile Composites (Experimental & Computational)**
27. **Design, manufacturing and static/dynamic testing of random carbon fiber structural tubes (Experimental)**
28. **Computer Aided Engineering Modeling Database Development for Crash Energy Management and Predictive Applications (Experimental & Computational computer database)**

% Completed of #23- #28 to-date: 40%

ACC100 Projects … Cont'd

The following slides are designed to highlight some of the current (on-going) ACC100 projects titled:

- Multiscale Modeling for Crash Prediction of Composite Structures
- Modeling of The Manufacturing Process Induced Effects on Matrix Properties of Textile Composites
- Size Effects in Textile Carbon Composites

Multiscale Modeling for Crash Prediction of Composite Structures

Overview:

Principal Investigator: Rensselaer Polytechnic Inst.

Duration: 1 year (Phase I); and 1 year (Phase II)

Budget: $101,775 (Phase I)
$110,000 (Phase II)

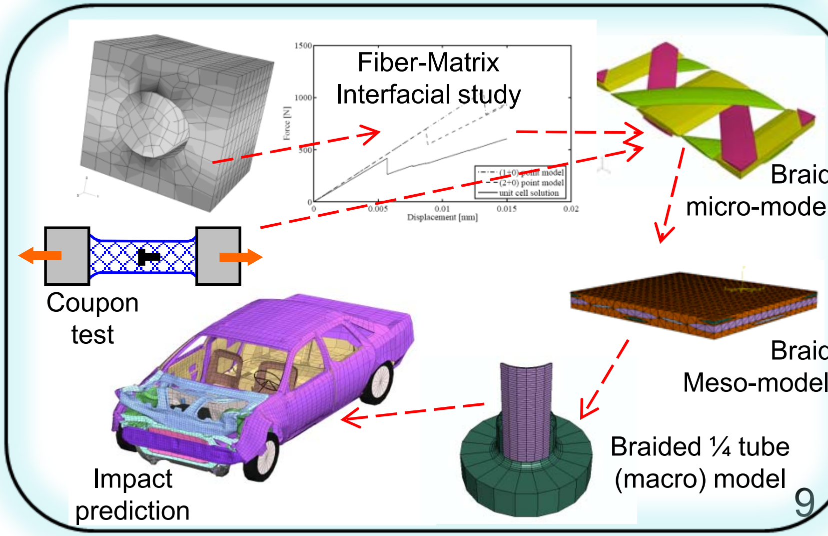
% Completion: Phase I – 100% complete
Phase II – 10% complete (on-going)

Approach:

1. Collect mechanical properties from tube crush, coupon, and interface/interphase test data
2. Develop a mathematical up-scaling (from fine to coarse levels) using homogenization
3. Develop a computational up-scaling (to reduce the complexity of full micromechanical model)
4. Identify dominant parameters from representative sub-sets based of experimental data optimization
5. Develop a GUI to interface and channel all of the above into a commercial nonlinear FEA solver
6. Verify and validate with coupon & tube crush data

Objectives:

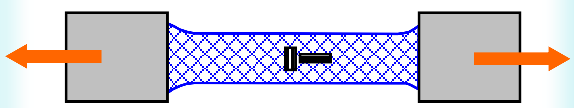
1. To develop a multiscale modeling tool to predict the static and dynamic crush of large automotive structural components (e.g., axial crush of tubes) made of fiber-reinforced textile composites
2. The tool must be capable of efficiently predicting the overall structural response while significantly reducing full model order/size
3. The tool must be implemented within commercial FEA solvers and must be able to identify robustly dominant energy-absorption mechanisms under static and dynamic loading situations

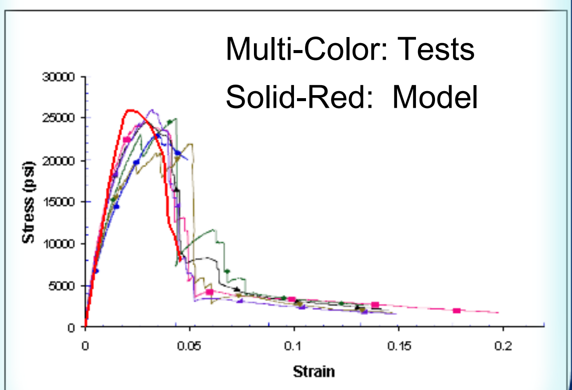


Multiscale Modeling for Crash Prediction of Composite Structures

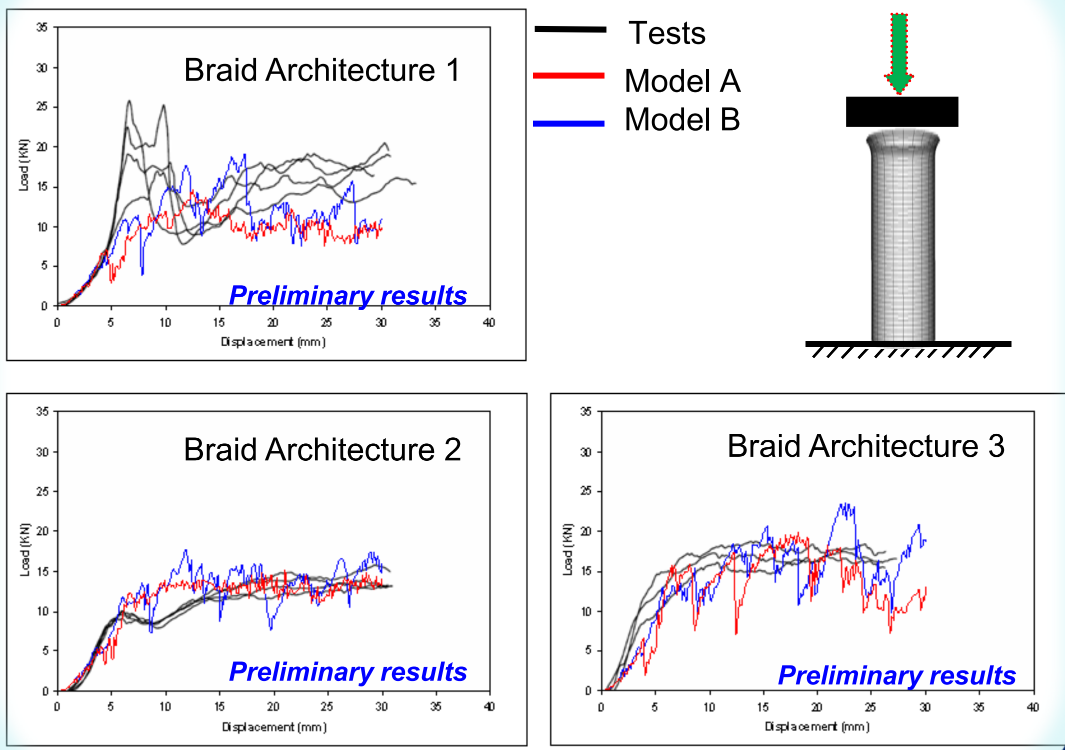
Example Results (Modeling & Testing):

Quasi-Static Tensile Tests on Braided Coupons





Braided Carbon Tubes



Modeling of The Manufacturing Process Induced Effects on Matrix Properties of Textile Composites

Overview:

Principal Investigator: University of Michigan

Duration: 2.5 years

Budget: $520,786

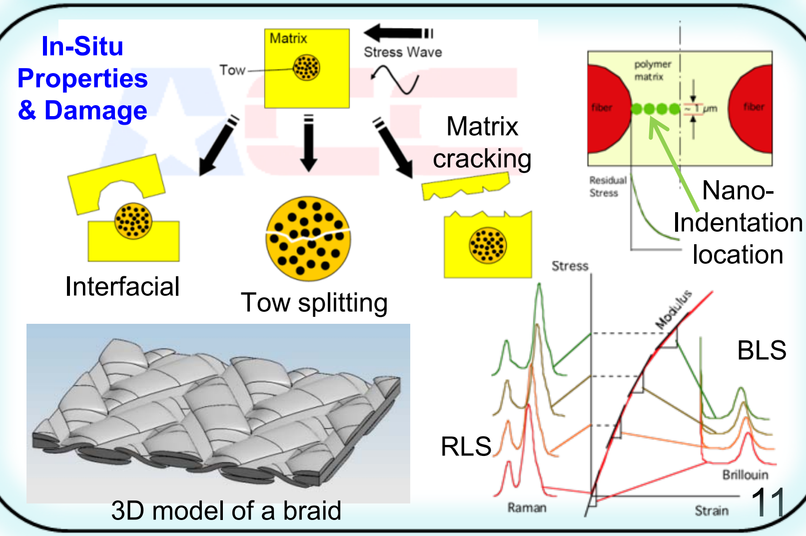
% Completion: 40% complete (on-going)

Approach:

1. Carry out an extensive nano-indentation studies to characterize the local fiber & matrix properties in different braid architectures and resin systems
2. Carry out extensive experiments using optical techniques (Raman Light & Brillouin Light Scattering—RLS & BLS) to measure evolution of thermo-micro-mechanical properties in space/time
3. Develop & validate a computational tool to model & predict *in-situ* material properties in braids
4. Implement the above into 3D FEA of a braided structure to study *in-situ* effects on matrix damage

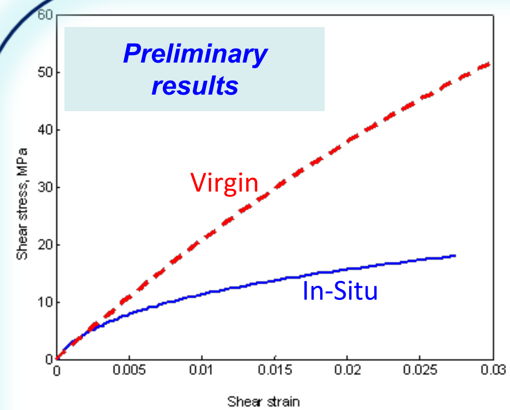
Objectives:

1. To extensively investigate via experimental characterization local *in-situ* properties of matrix-fiber systems in braided carbon textile composites
2. To develop an analytical and qualitative under-standing of the evolution of local properties during curing and develop a modeling capability to predict the final values of *in-situ* properties needed to characterize the mechanical response
3. To develop a comprehensive methodology that is able to quantify & robustly predict local properties prior to implementation into global FEA models

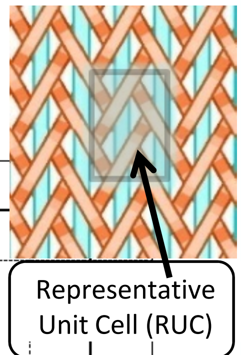


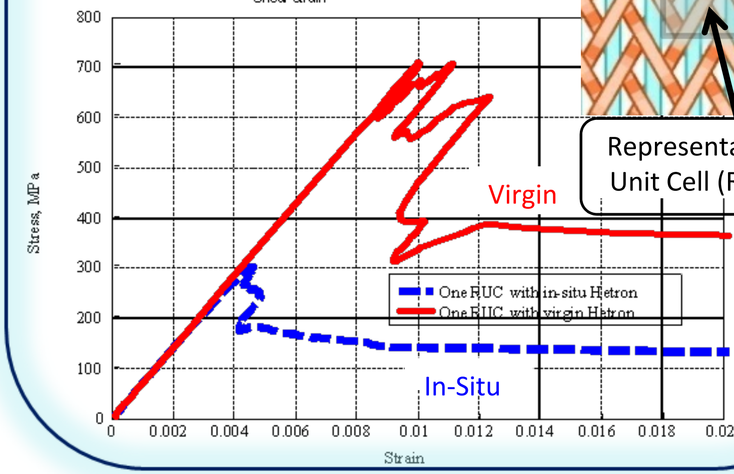
Modeling of The Manufacturing Process Induced Effects on Matrix Properties of Textile Composites

Example Results (Modeling & Testing):

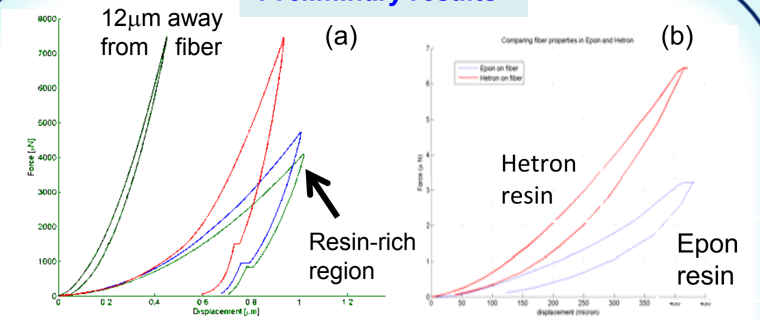


Difference in σ-ε relationship between *in-situ* vs. virgin properties (left) can result in strength variations of the braided composite at the RUC level.

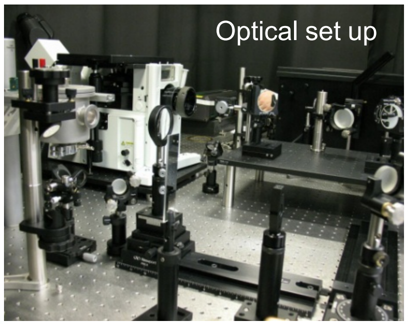


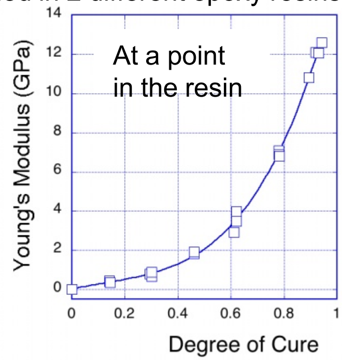


Preliminary results



Force-displacement (F-d) relationships from nano-indentation tests: (a) at locations in the matrix near/away from the fiber; (b) at a point on a fiber embedded in 2 different epoxy resins





Young's Modulus as a function of Degree of Cure obtained using optical techniques & molecular dynamics simulation

Size Effects in Textile Carbon Composites

Overview:

Principal Investigators: University of Michigan
Northwestern University

Duration: 2 years

Budget: $466,826

% Completion: 60% complete (on-going)

Approach:

1. Carry out an extensive testing program on different carbon braid architectures and different coupon/plaque sizes with different damage sizes
2. Develop novel methods to efficiently model large specimens using micro-mechanics coupled with damage evolution/progression mechanisms
3. Carry out all of the above under quasi-static and dynamic loading conditions
4. Implement the above into FEA of carbon braids, & recommend ways to incorporate size effects in modeling practices & testing standards

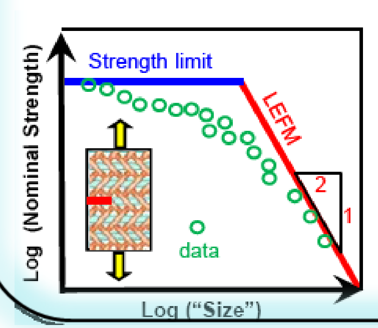
Objectives:

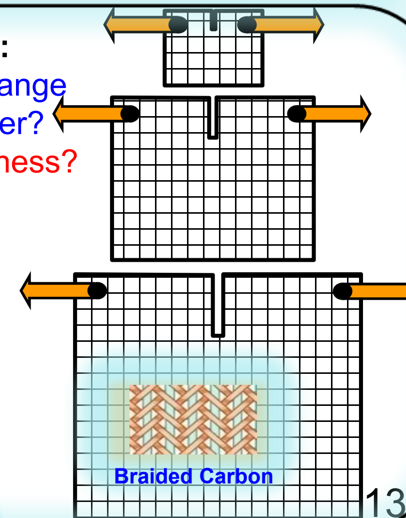
1. To extensively investigate via experiments Size (Scale) Effects' presence in braided carbon textile composites. *["Size" here refer to damage (crack) size w.r.t. structural size, <u>not</u> finite element mesh size w.r.t. structural size (not mesh sensitivity)]*
2. To develop novel validated approaches to model, predict and incorporate size effects efficiently in material models of large carbon-braided textile composites using commercial FEA solvers
3. To develop and recommend modeling and testing methodologies/standards accounting for size

Fundamental Questions:

Does nominal strength change as the specimen gets larger?

How about fracture toughness?

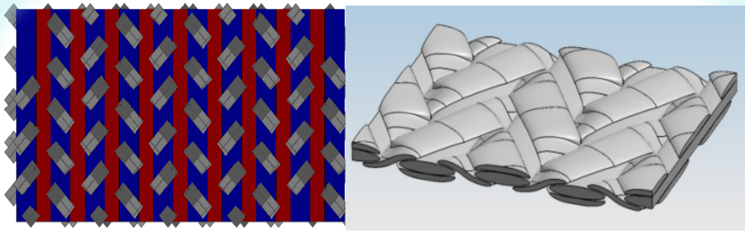




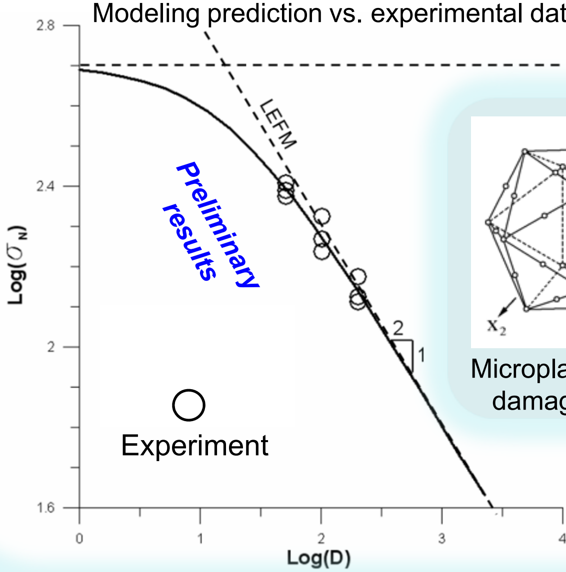
Size Effects in Textile Carbon Composites

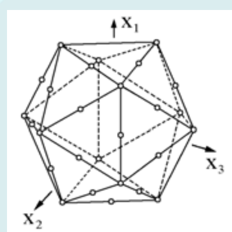
Example Results (Modeling & Testing):

Different levels of micro-FEM/FEA of braids

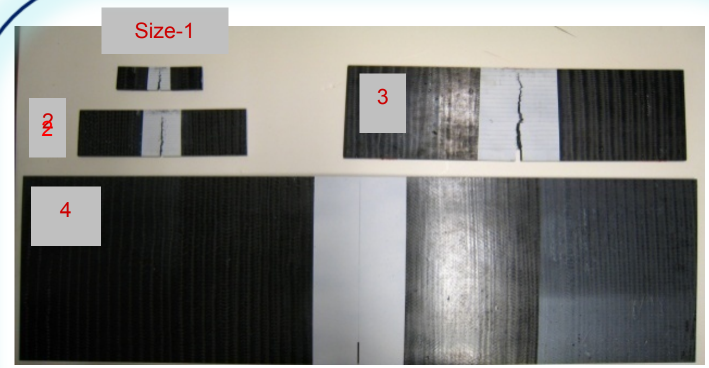


Modeling prediction vs. experimental data

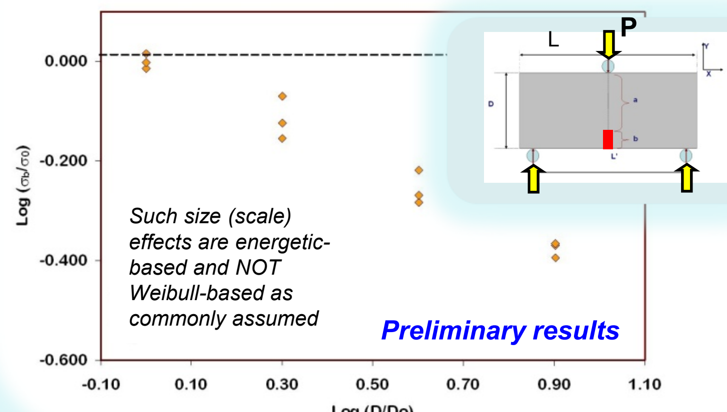




Microplane material damage models



Coupons & Plaques for all 4 sizes being tested



Experimental data for Log(strength) vs Log(size)

ACC100 Future Plans/Projects

The following is a list of some of the future plans that are under consideration by the ACC100 (2010-2013):

- Investigate and implement novel ways to mitigate size-effects in textile composites in order to facilitate simpler testing characterization and modeling methodologies for future applications
- Study the environmental and in-service effects on the performance of structural carbon-fiber composites especially on damage initiation and progression mechanisms
- Design and execute several Demonstrative Projects in order to demonstrate all the know-how (testing, modeling, impact) developed thus far using automotive primary-structural components (e.g., full composite front-end; roof structures; B-pillar assembly)

Summary

- It is of prominent importance for the reviewers to appreciate the fact that knowledge and know-how developed for characterizing and modeling steel structural components are mostly non-transferable to lightweight fiber-reinforced polymeric composites. This fact is commonly overlooked or not given its due importance.
- The cost of carbon-fiber reinforced textile composites (material and manufacturing) is one of the factors limiting their wide use at the current time. Further, unlike for high-cost aerospace composites, developing characterization and predictive tools for less-expensive non-aerospace structural composites has been a formidable task.
- The constant change in market availability of some fibers, sizes, adhesives is another major obstacle in the way of speedy advancements especially on the modeling development and validation front.
- One of the focus topics in designing lightweight automotive composites for crashworthy applications is on their abilities to absorb and manage impact energy. Such an essential requirement dictates a focus on characterizing the post-peak structural response regime. Unlike most aerospace designs, this is somewhat unique to automotive designs which are required to meet safety regulations for certification, as well as major consumer rating standards.