Thinking Out of The *Metallic* Box

ACC Activities & Challenges

Presentation by

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Automotive Composite Consortium

AUTOMOTIVE COMPOSITES CONSORTIUM

U. S. Council for Automotive Research

2008 Plastic and Composite Intensive Vehicle (PCIV) Safety Workshop

US-DOT/RITA Volpe Center, Cambridge, MA, USA

August 04, 2008

Automotive Composites Consortium

AUTOMOTIVE COMPOSITES CONSORTIUM

Formed in August 1988

To conduct joint research programs on structural polymer composites for automotive applications on a pre-competitive basis. (http://www.uscar.org/guest/index.php)

Members:

CHRYSLER

Ford

GM

U. S. Council for Automotive Research

USCAR Founded in 1992

Is an umbrella organization with the goal to further strengthen the technology base of the U.S. auto industry through cooperative research and development. (http://www.uscar.org/guest/index.php)

It is authorized under the 1984 Cooperative Research Act.

It is governed by the 3-member council which includes the R&D Vice-Presidents of Chrysler, Ford and GM.

Automotive Composites Consortium

ACC is organized into several working groups:

- **Crash Energy Management**
- Processing
- Materials
- Joining

ACC overseas numerous projects and activities, examples include: Focal Project I, II, III, and IV

Focal Projects of the ACC

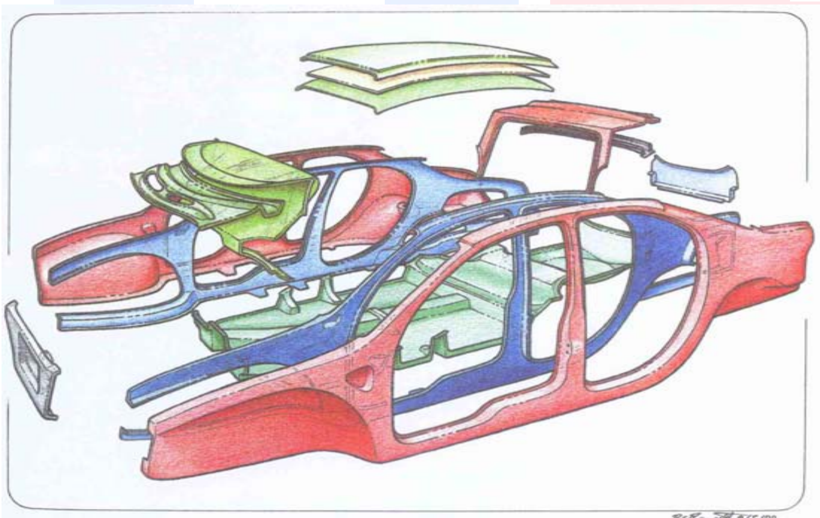
FP I

Composite Front End

FP II

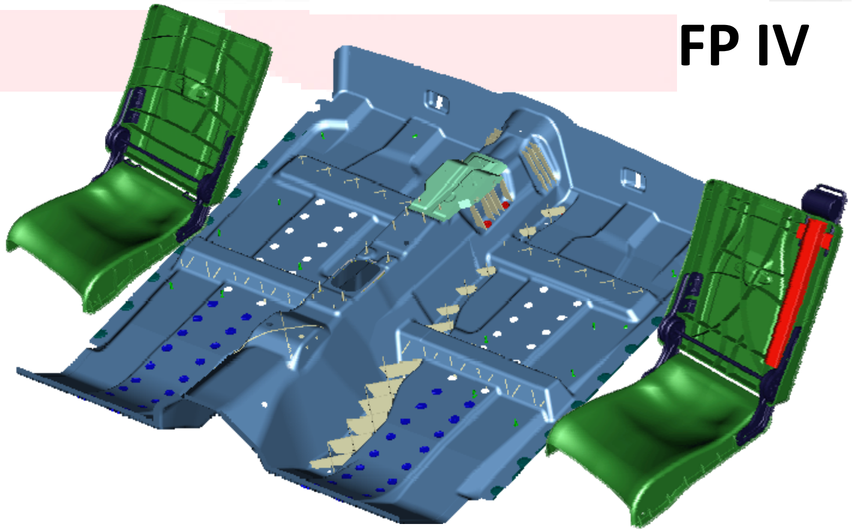
Composite Pick-Up Box

FP III



Composite-Intensive BIW

FP IV



Composite Underbody & Seats

Thinking Out of The *Metallic* Box

The motivations behind the above title are:

1. Knowledge/knowhow developed over the decades on how to test, characterize, model and predict the response of metallic-based structures DO NOT fully transfer to their fiber-reinforced polymeric-based counterparts!
2. Fiber-reinforced polymer matrix composites are multi-phase materials that introduce, by definition, many new complex/interactive/multi-scale mechanical phenomena that DO necessitate new physics-based analysis tools.
3. Unlike in metallic structures where crush and damage mode are dominated by few energy-absorption mechanisms, in composites there are a host of unique mechanisms as well as a constant dynamic interaction between the various local/global phenomena.
4. The concept of local composite properties is very complex—they are strongly dependent on the state of response/damage, local architecture and properties, and manufacturing. In metals, the concept is more well-defined!

Crash Energy Management Working Group

The objectives of the Energy Management Working Group are to:

1. Characterize composites' properties and their constituents.
2. Characterize the dominant micro-, meso-, and macro-mechanical mechanisms responsible for damage initiation, progression, and energy absorption.
3. Develop, verify and validate efficient and robust physics-based modeling and analysis tools for the prediction of damage initiation, progression, energy absorption, and overall crash behavior of composite structural components using micromechanical, phenomenological or hybrid approaches.
4. Develop design, testing, modeling and analysis guidelines for structural composites in automotive applications.

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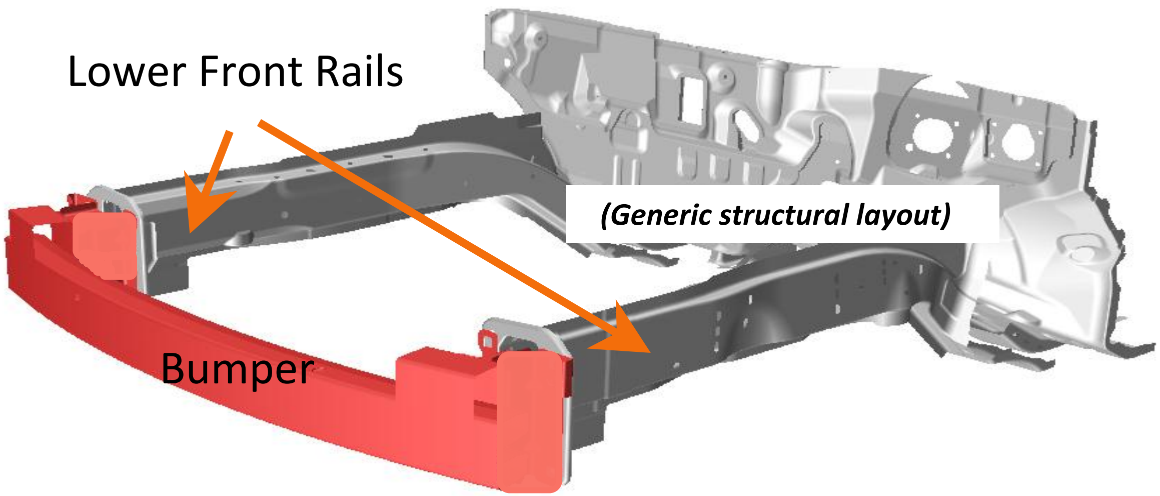
Structural Tubes

The shown front rails in a vehicle structure play an important role in absorbing the impact energy. Hence, understanding the response of composite structural tubes and their energy-absorption characteristics is a natural focus in automotive crashworthiness.



Vehicle Front-End Structure (partial view)

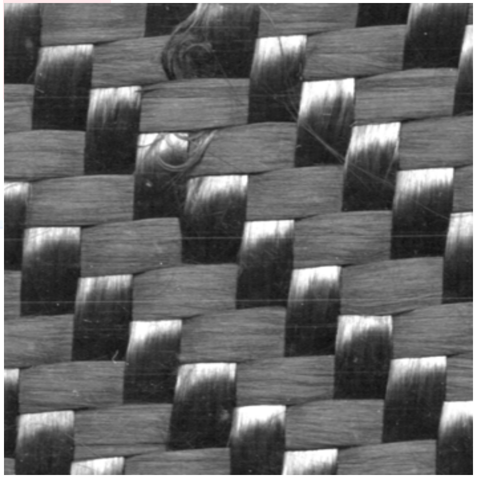
Composite Materials—Selections

Some of the composite materials being investigated for automotive structural application—Examples:

Random Chopped Fibers

Carbon/Glass

0/90 Textile



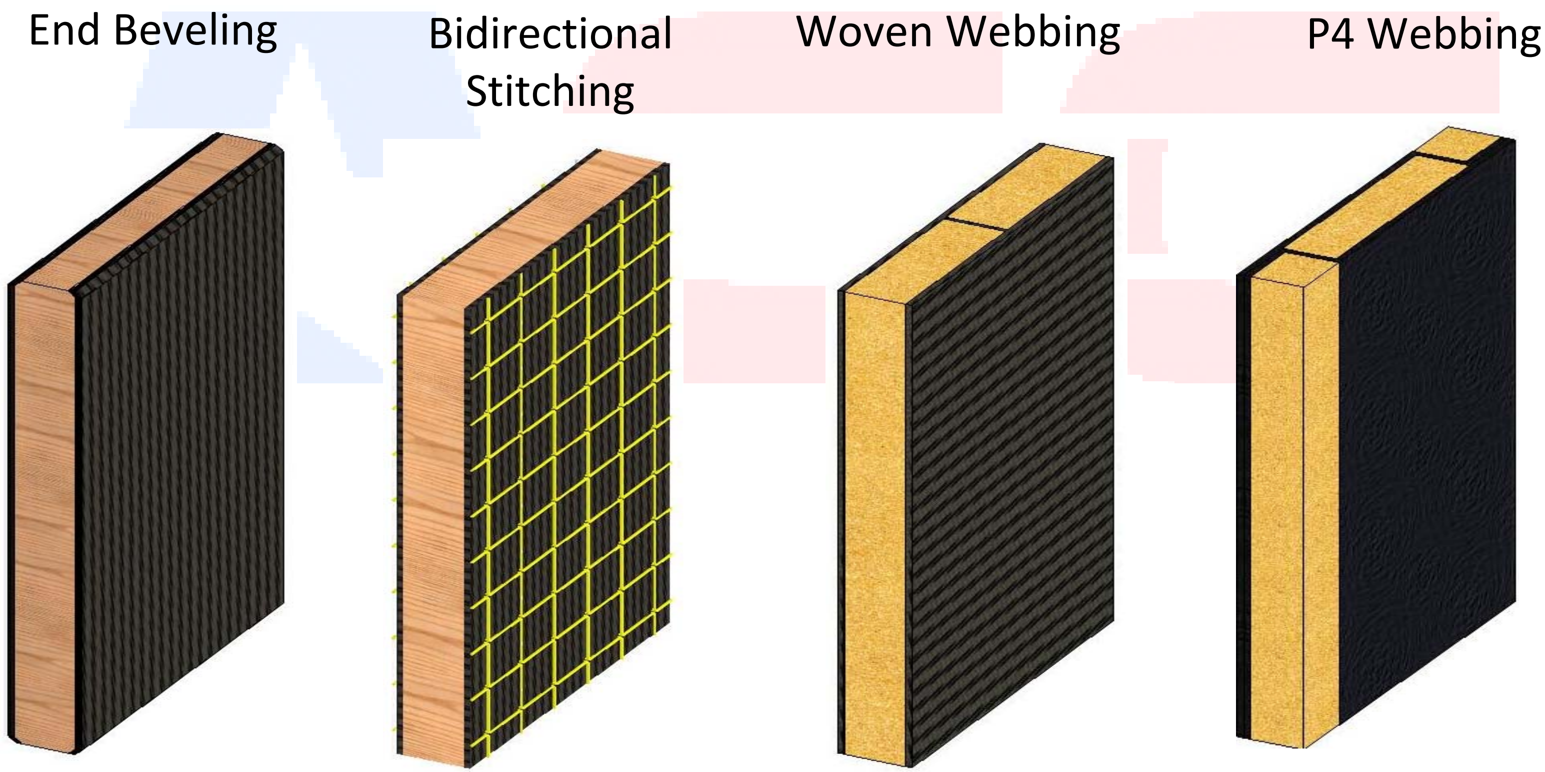
Carbon/Glass

0/30/45/60 Textile (Braided)

Carbon/Glass

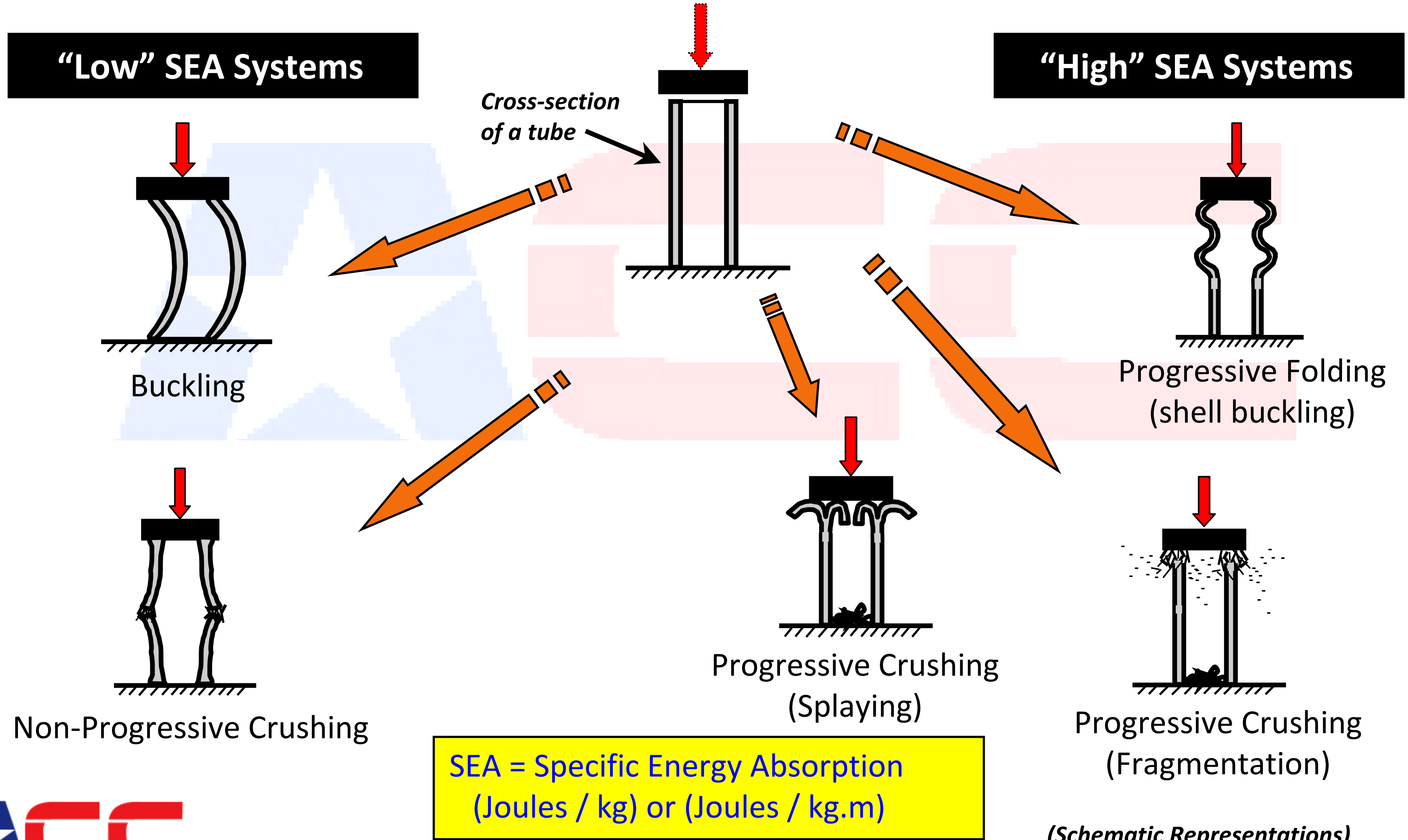
Composite Materials—Selections

Some of the composite sandwich constructions which have been investigated for automotive structural application—Examples:



Source: Final Report to ACC, by Dan Adams, Univ. of Utah, 2007

Energy Absorption in Structural Tubes



SEA = Specific Energy Absorption
(Joules / kg) or (Joules / kg.m)

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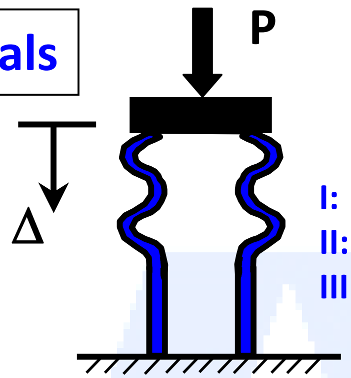
Energy Absorption in Structural Tubes

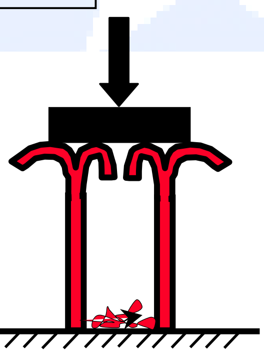
Metals



Progressive Folding
(shell buckling)

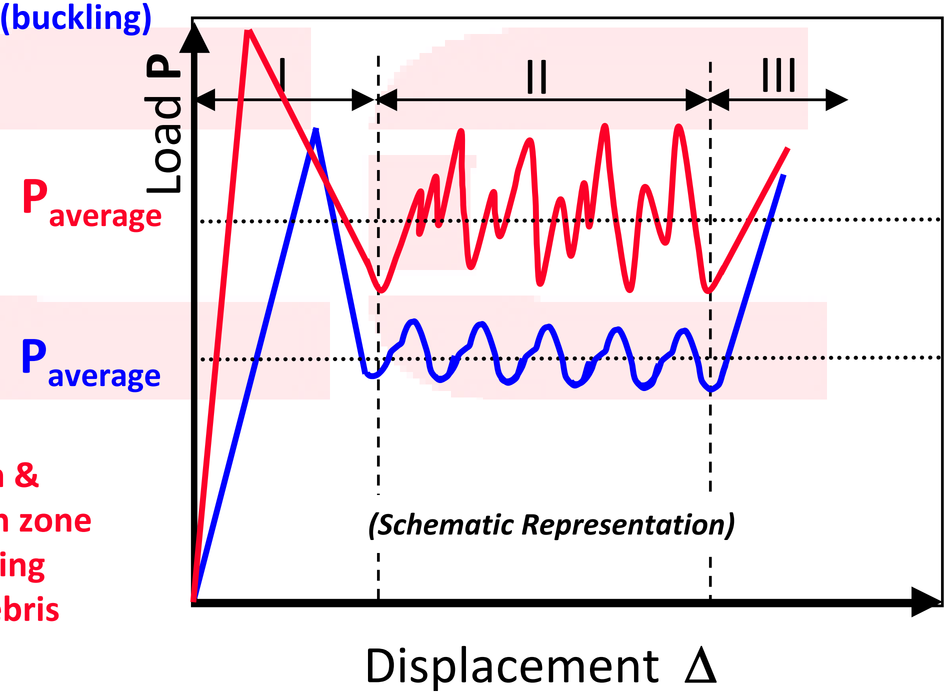
I: Axial deformation & fold initiation (no global bending/buckling)
II: Progressive folding (buckling)
III: Compaction

Composites



Progressive Crushing
(splaying mode)
(“thick” walls with chamfered ends)

I: Axial deformation & formation of crush zone
II: Progressive crushing
III: Compaction of debris



(Not all metal and composite tubes behave as shown)
(Regimes I, II & III are not always well defined & distinct)

(Schematic representations of selected qualitative/generic examples)

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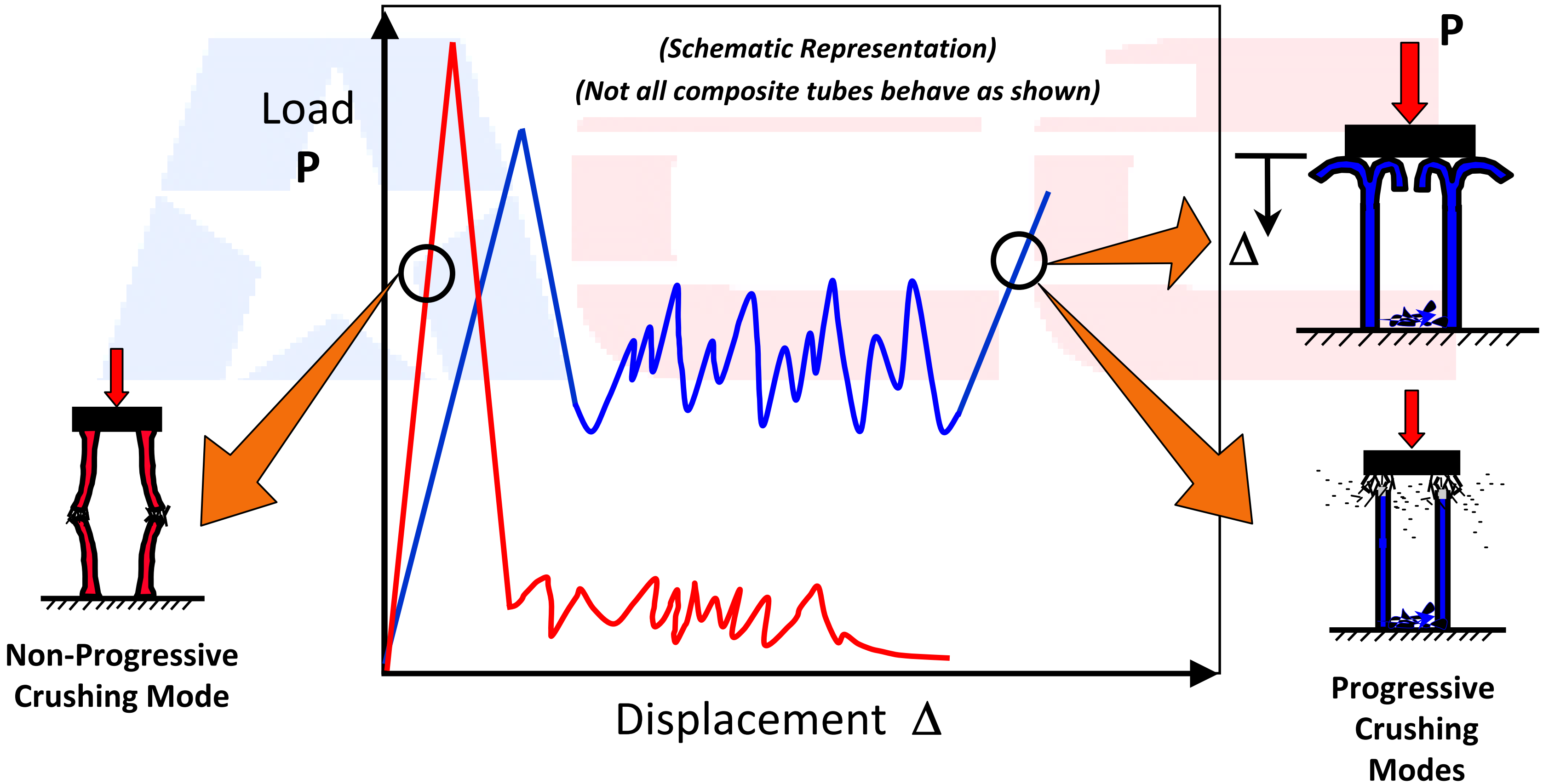
Energy Absorption in Structural Tubes

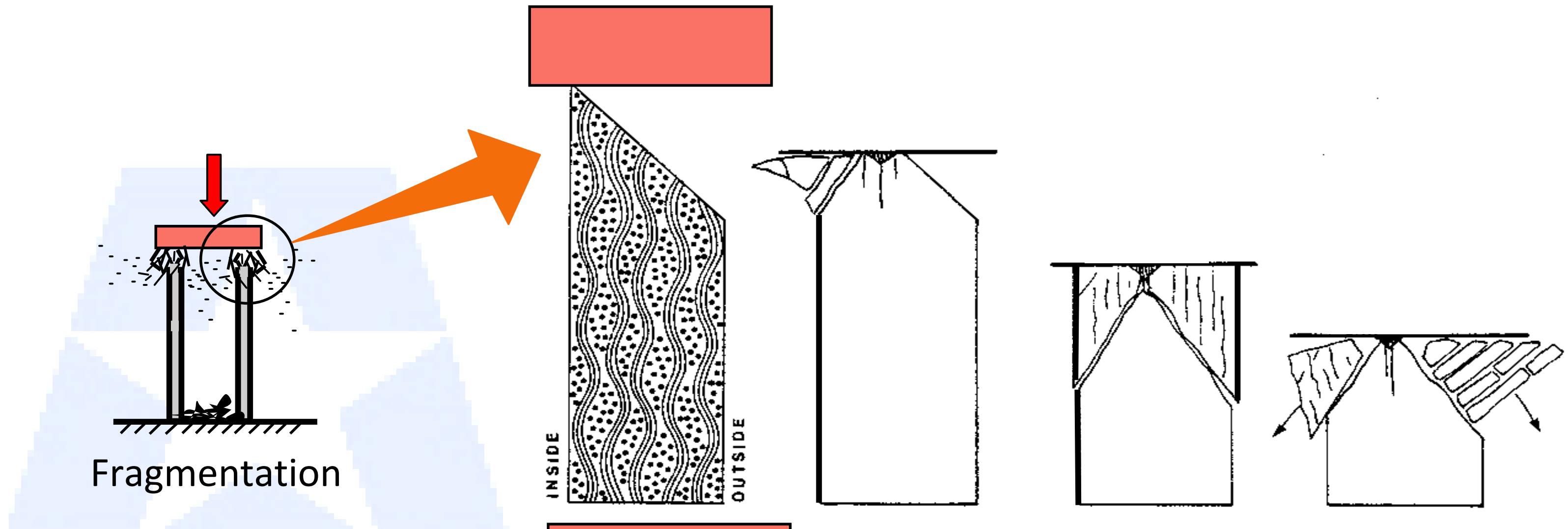
Composites



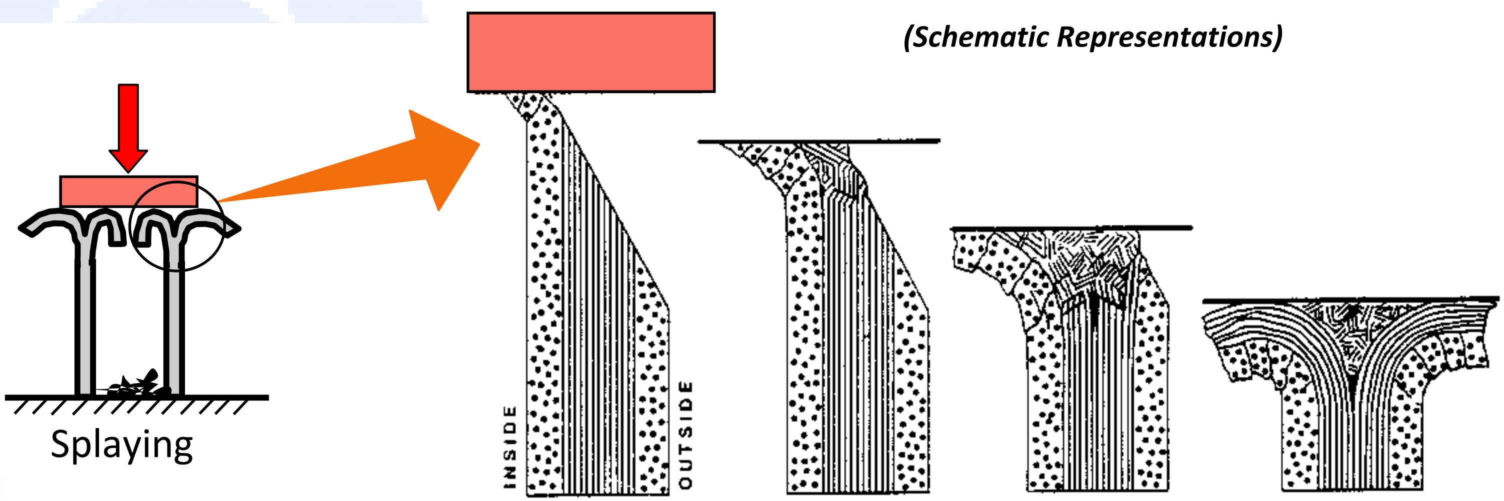
(Schematic representations of selected qualitative/generic examples)

Energy Absorption & Crush Mechanics

Progressive Crushing Modes in Composites—Examples:



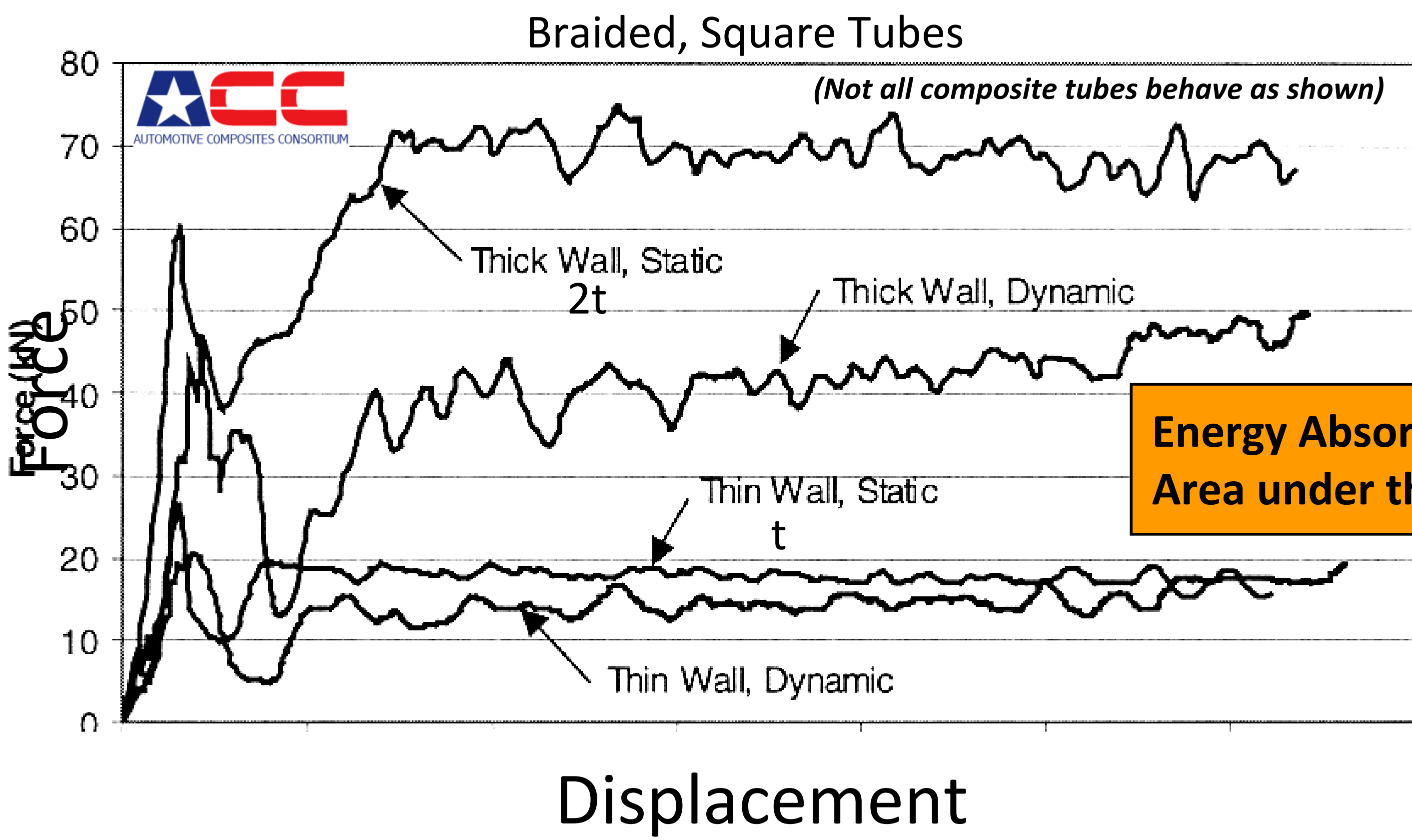
(Schematic Representations)



Source: Sketches from the Report to the ACC by Derek Hull, Univ. of Liverpool, UK, 1994

Energy Absorption & Crush Mechanics

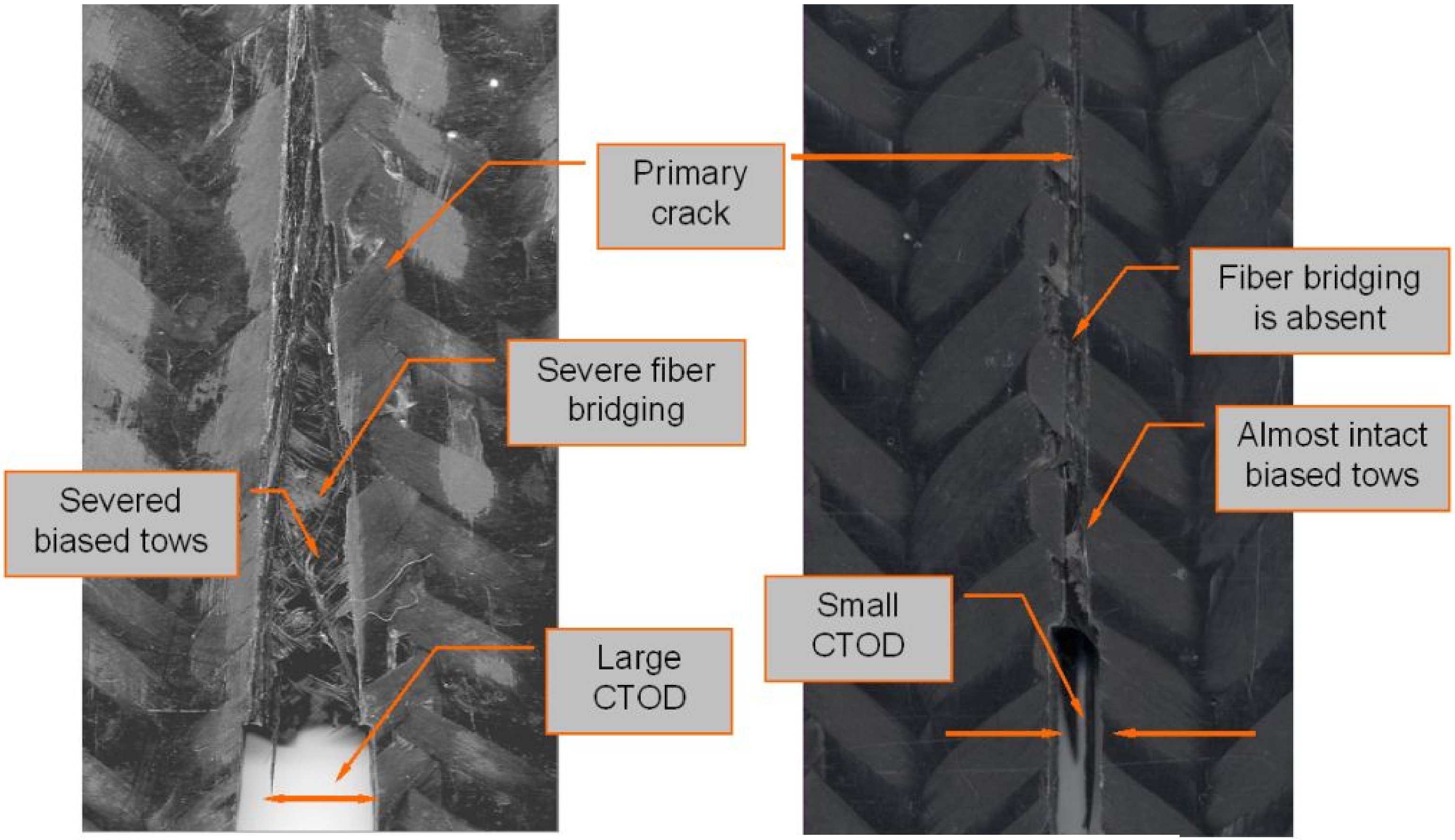
Composite tube thickness and loading speed can affect its progressive crush response—Examples:



Energy Absorbed = Area under the curve

Energy Absorption & Crush Mechanics

Resin effects on the extent of damage zone & mode—Examples:



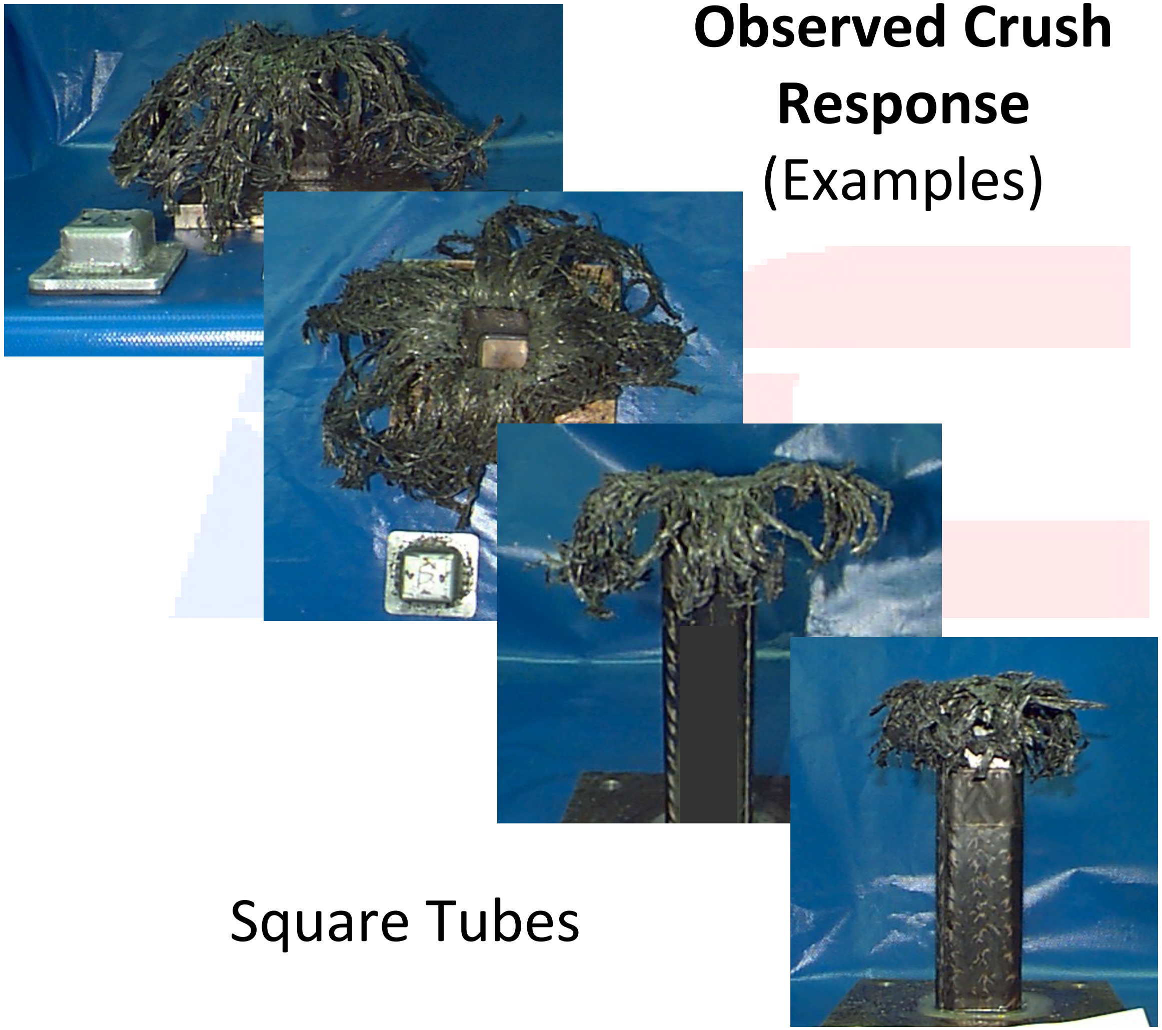
Resin A **Resin B**

(all other testing and specimens' attributes being equal)

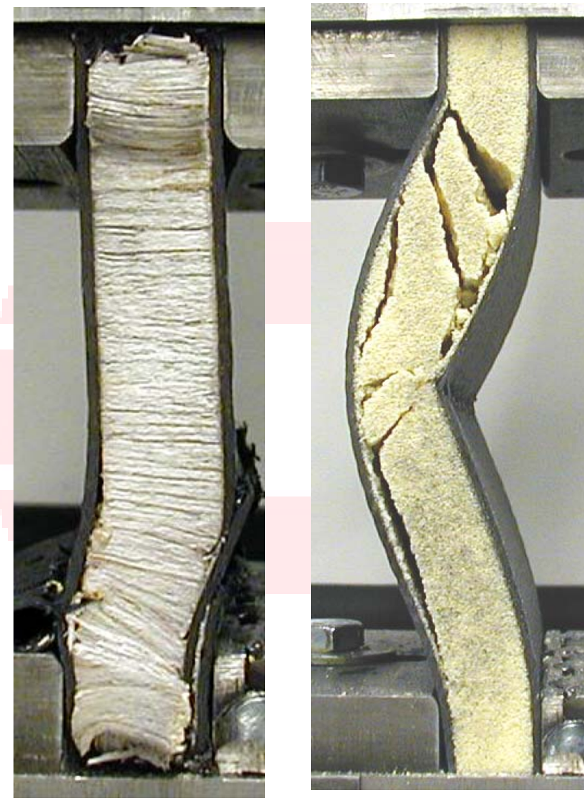
Source: A. Salvi, A. Waas, A. Caliskan, 2008

Energy Absorption & Crush Mechanics

Observed Crush Response
(Examples)



Square Tubes

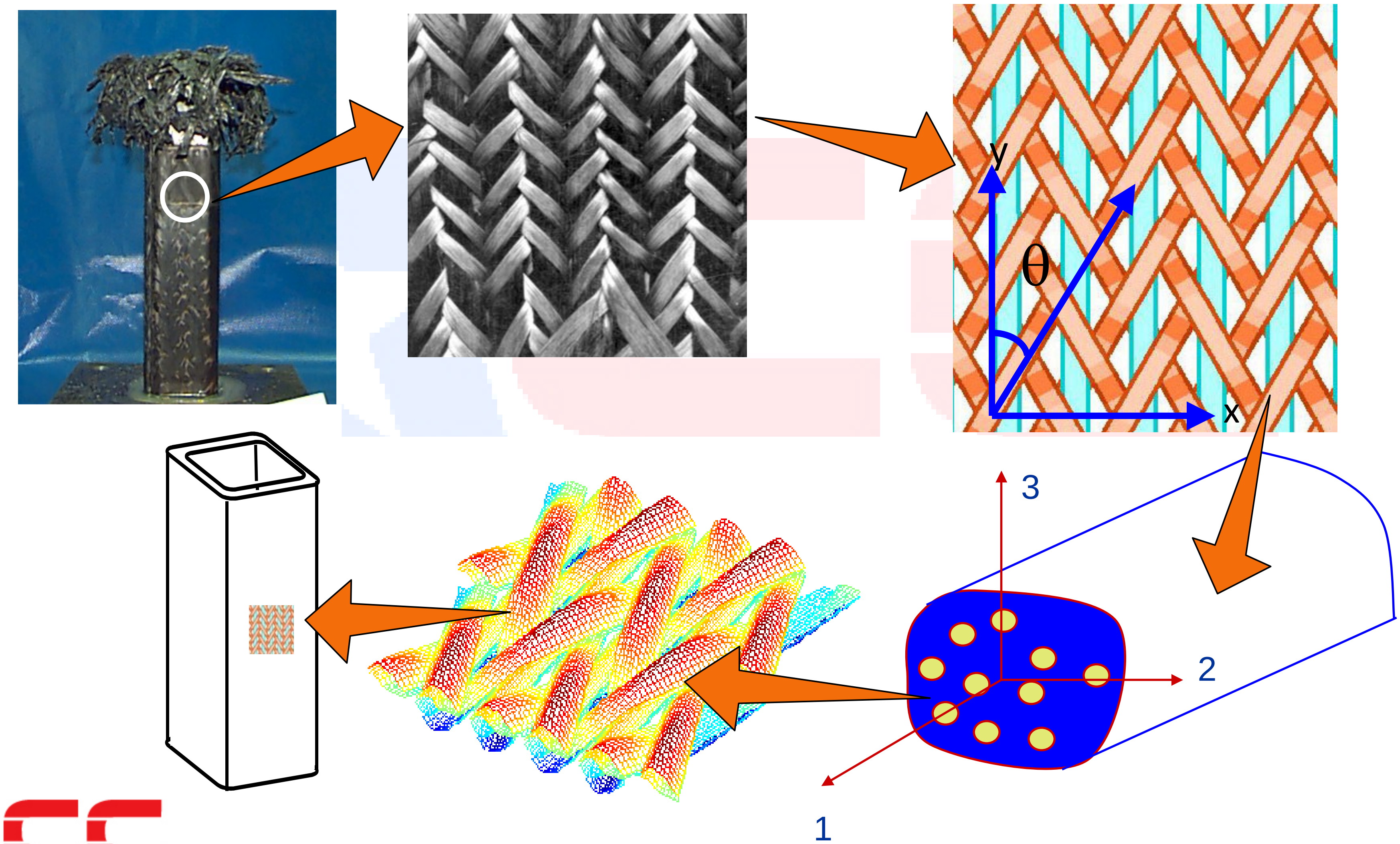


Sandwich Panels

Source: Report to ACC, by D. Adams, Univ. of Utah, 2007

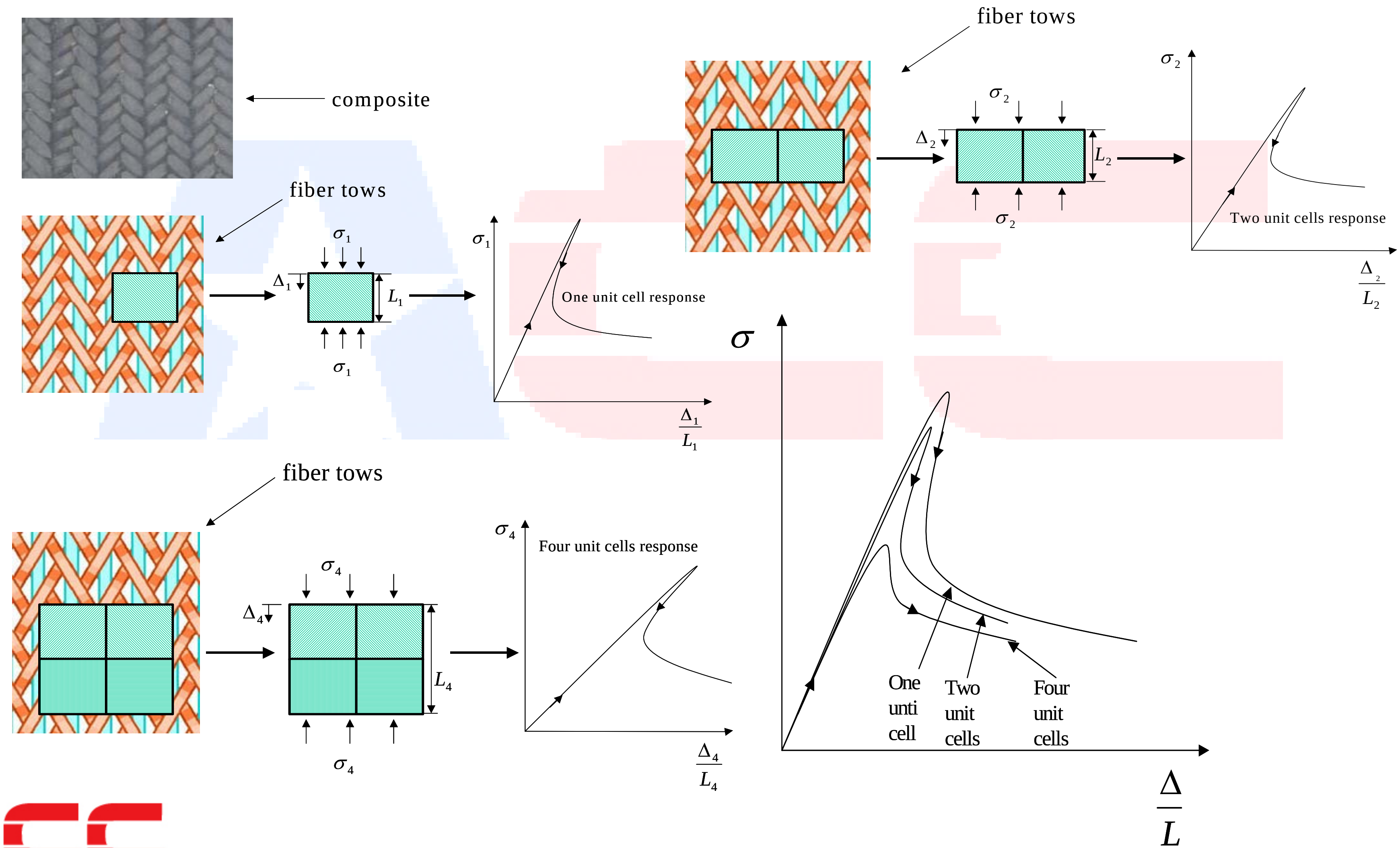
Energy Absorption & Crush Mechanics

Matrix, fibers, tows, and structural modeling—Examples:



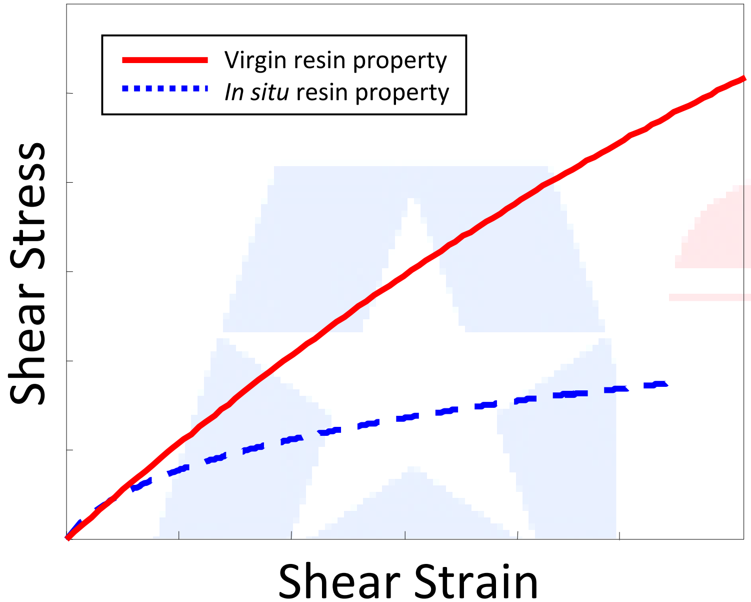
Energy Absorption & Crush Mechanics

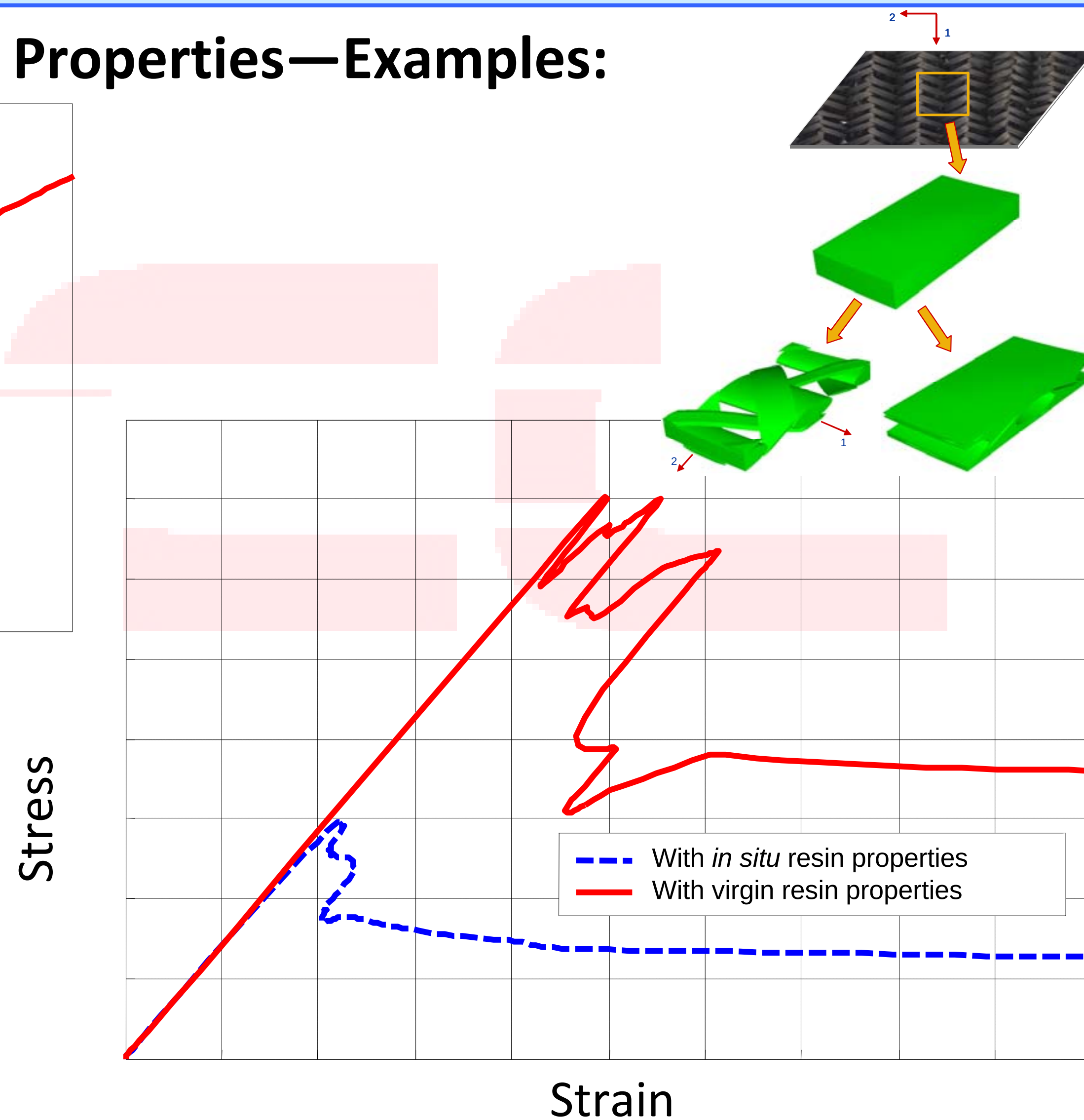
Representative Unit Cell (RUC) concept:



Energy Absorption & Crush Mechanics

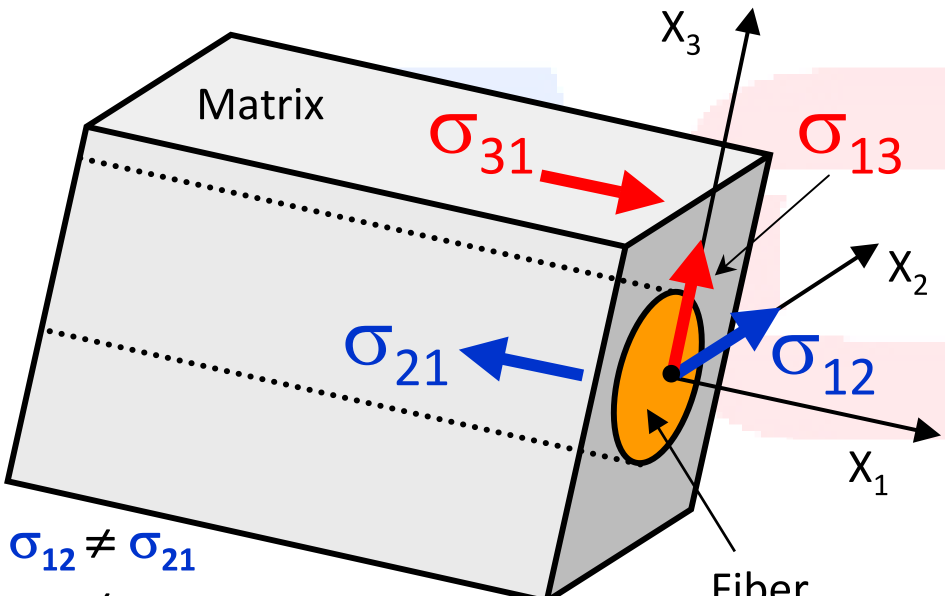
Modeling Issues: *In-Situ* Properties—Examples:





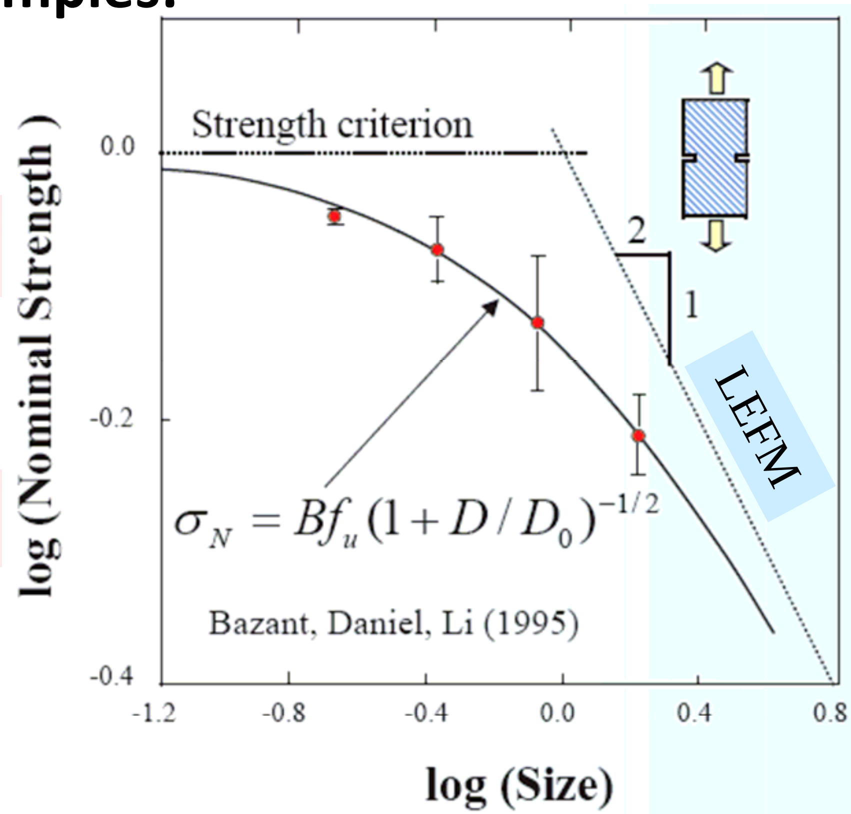
Energy Absorption & Crush Mechanics

Modeling Issues: Size Effects—Examples:



Couple-Stresses

A natural length scale is introduced; many complex tests are required for characterization



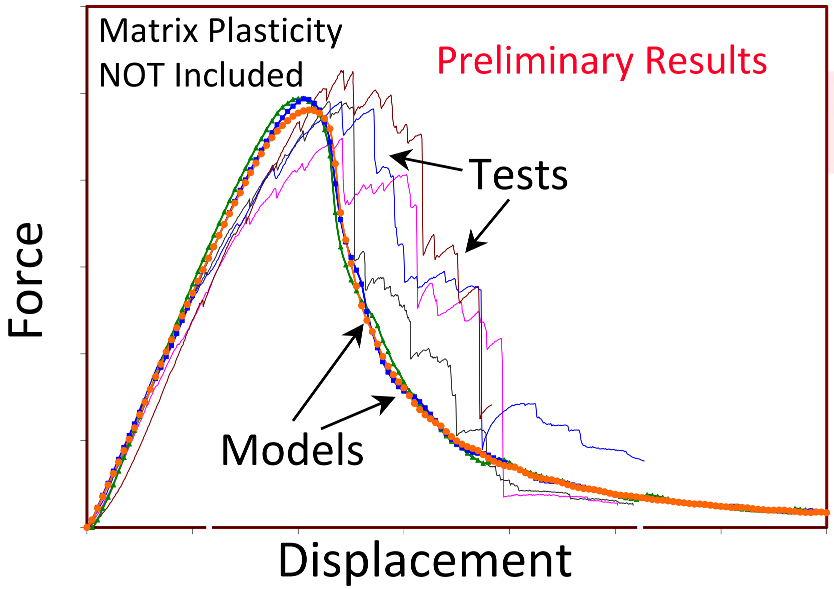
Energetic-Based Envelope

Not a result of statistical flaws' distribution; driven by size of damage to global scale

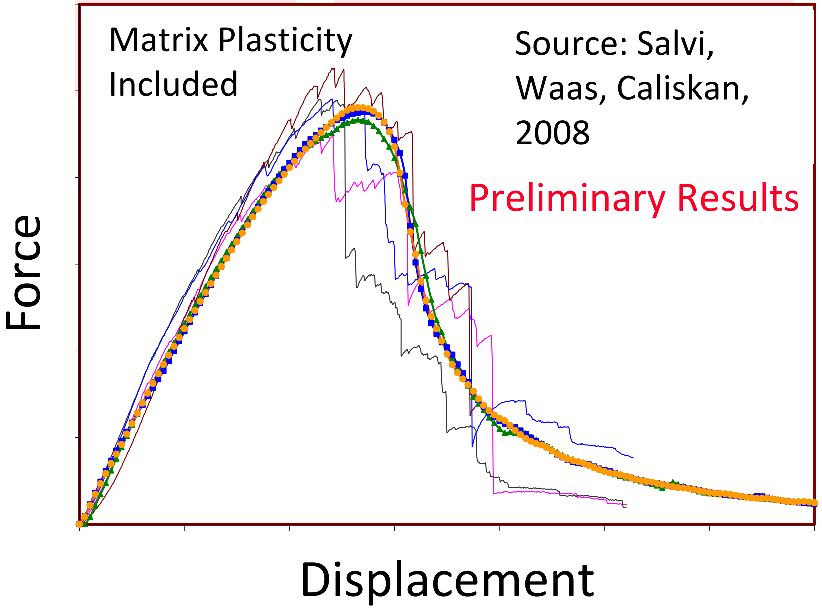
Energy Absorption & Crush Mechanics

Modeling and validations—Examples:

Experimental vs. modeling (using Discrete Cohesive Zone Modeling-DCZM)

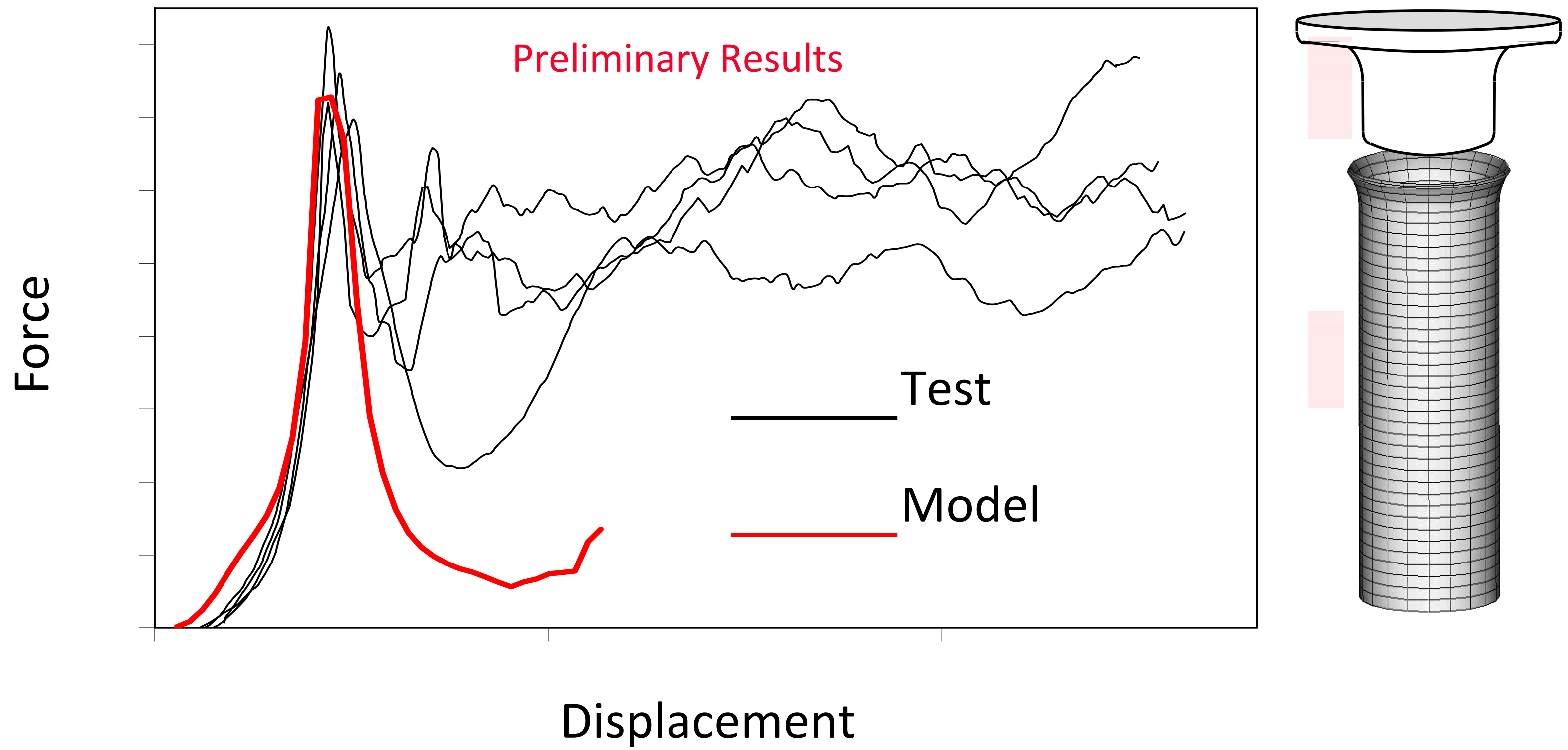


Braided flat specimen



Energy Absorption & Crush Mechanics

Modeling and validations—Examples:



EMWG Projects/Activities (partial list)

To understand the fundamental physics of crush mechanics of composite structures, the EMWG has initiated & supported the following projects (*most have been completed*):

- **Biaxial Response & Failure of Braided Carbon Fiber Composites** **(Experimental & Computational)**
- **Strain Rate Effects on Glass Fiber & Carbon Fiber Polymer Matrix Composites** **(Experimental)**
- **Progressive Crush in Carbon-Based Textile Composites** **(Computational & Experimental)**
- **Hierarchical Modeling of FRP Materials/Structure for Lightweight Automobile Crashworthiness Simulation** **(Experimental & Computational)**
- **Energy Absorption of Triaxial Braided Composite Tubes** **(Experimental & Computational)**
- **Novel Approaches to Predicting Structural Performance of Textile Composite Materials & Structures** **(Computational)**
- **Rate Dependent Effects of Crush Zone Morphology of Polymer Composites** (Experimental)

EMWG Projects/Activities (partial list)

- **Collapsible Shell for Finite Element Crashworthiness Simulation of Composite Structures** (Computational)
- **Constitutive Modeling of Discontinuous Carbon Fiber Polymer Composites** (Computational)
- **Crash Performance of Bonded Structures** (Experimental & Computational)
- **The Effects of Existing Damage on the Energy Absorption Potential of Polymer Composites Structures** (Experimental & Computational)
- **Effects of Friction on Energy Absorption** (Experimental)
- **Interface Analysis of ACC Composite Samples** (Experimental)
- **Lateral Bending of Composite Tubes** (Experimental & Computational)
- **Development of Sandwich Composite Concepts for Automotive Applications** (Experimental & Computational)
- **Crash Performance of Bonded Structures** (Experimental & Computational)
- **The Effects of Existing Damage on the Energy Absorption Potential of Polymer Composites Structures** (Experimental & Computational)
- **Effects of Friction on Energy Absorption** (Experimental)

EMWG Projects/Activities (partial list)

- **Interface Analysis of ACC Composite Samples** (Experimental)
- **Lateral Bending of Composite Tubes** (Experimental & Computational)
- **Development of Sandwich Composite Concepts for Automotive Applications** (Experimental & Computational)
- **Post Peak Response Characterization of 2D Triaxially Braided Composites** (Experimental & Computational)
- **Multiscale Modeling for Crash Prediction of Composite Structures** (Computational)
- **Crashworthiness Assessment of Tubular RaFC Structures Based on Micro and Interfacial Mechanics** (Experimental & Computational)
- **Size Effects in Textile Composites** (Experimental & Computational)
- **Modeling of the Manufacturing Process Induced Effects on the Matrix Properties of Textile Composites** (Experimental & Computational)

… and many more

ACC/EMWG Research Collaborators

Too many to mention all, however, they include:

- **Academic/Research Centers:**
  Composite Structures Labs. (University of Michigan-Ann Arbor)
  Center for Advances in Mobility and Composites (Univ. of Michigan-AA)
  Multiscale Science and Engineering Center (Rensselaer Polytechnic Institute)
- **Universities:**
  Univ. of Michigan-Ann Arbor, Northwestern, Stanford, RPI, Rutgers, Univ. of Nottingham (UK), Univ. of Utah, Virginia Tech., Univ. of California, Michigan State Univ., and Univ. of Cincinnati, … *to mention a few*
- **PI Disciplines (testing & computational):**
  Mechanical, Aerospace, Civil, and Material/Polymer Science Engineering
- **U.S. National Labs:**
  ORNL, and LLNL