Impact Modeling of Random Carbon Fiber Composites

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http://www-explorer.ornl.gov/composites

Summary for FY1999

Modeling

1. Developed a number of material models based on micro-mechanics that include fiber debonding, matrix micro-cracking and fiber failure.
2. Implemented material models into Dyna3d and performed simulations for simple geometries
3. Documented developments in journal papers, conference proceedings and technical report

Experiments

1. Developed new fixture design for characterization of controlled crash failure of composite materials
2. Tested several composite materials materials for fixture evaluation and development
3. Documented developments in project reports and conference proceedings

Modeling

Constitutive Modeling for Impact Simulation of Random Fiber Composites

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Modeling - Summary

Objective

To develop analytical and numerical tools that efficiently predict the behavior of carbon-fiber based random composites in vehicular crashworthiness simulations

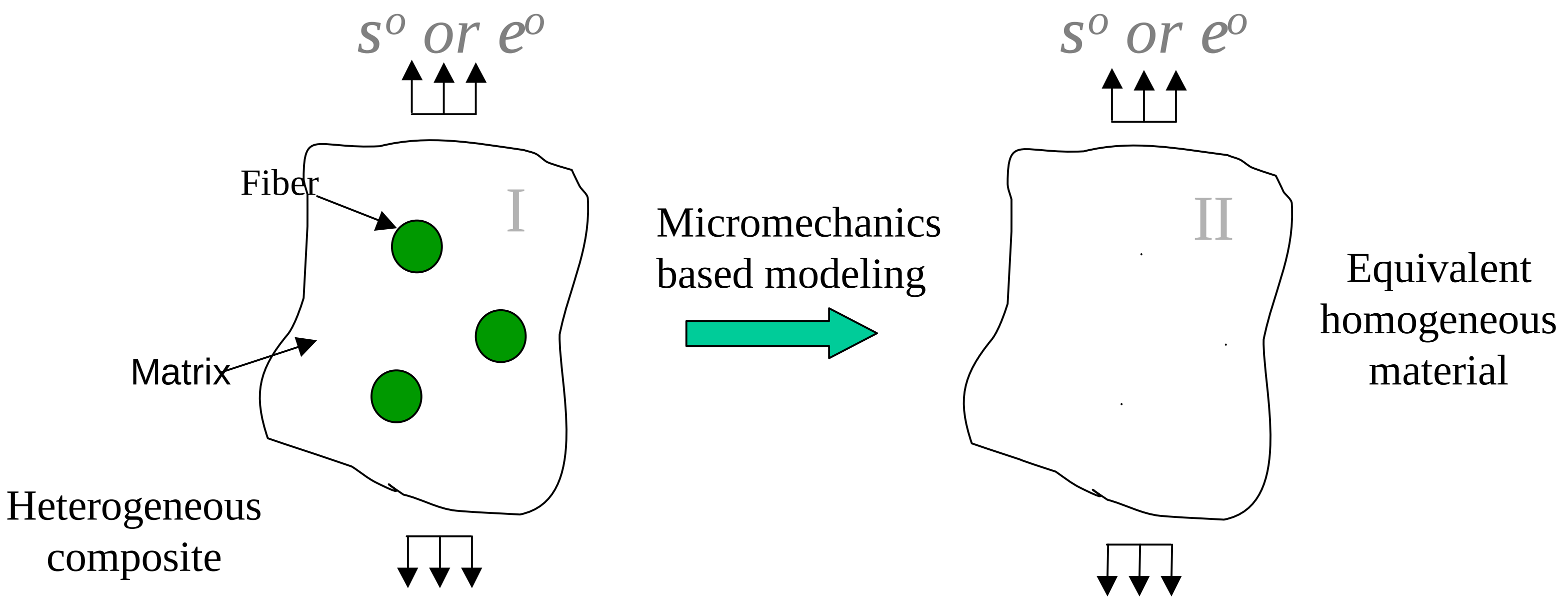
Accomplishments

Material constitutive models have been developed based on micromechanical formulation and combination of micro- and macro-mechanical damage criteria

Developed models incorporate probabilistic micromechanics for modeling of evolutionary damage in composite

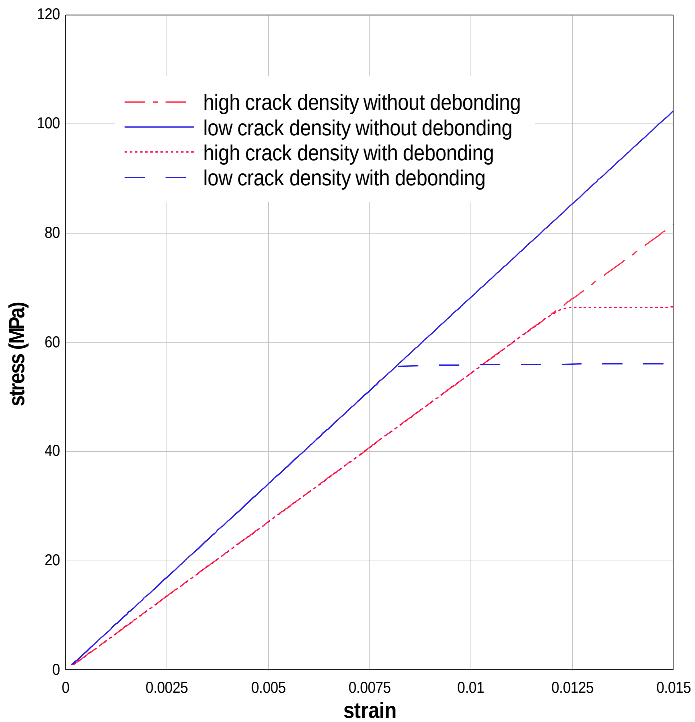
Models are implemented into finite element code DYNA3D to simulate crashworthiness of composites

Micromechanics and Equivalence Principle

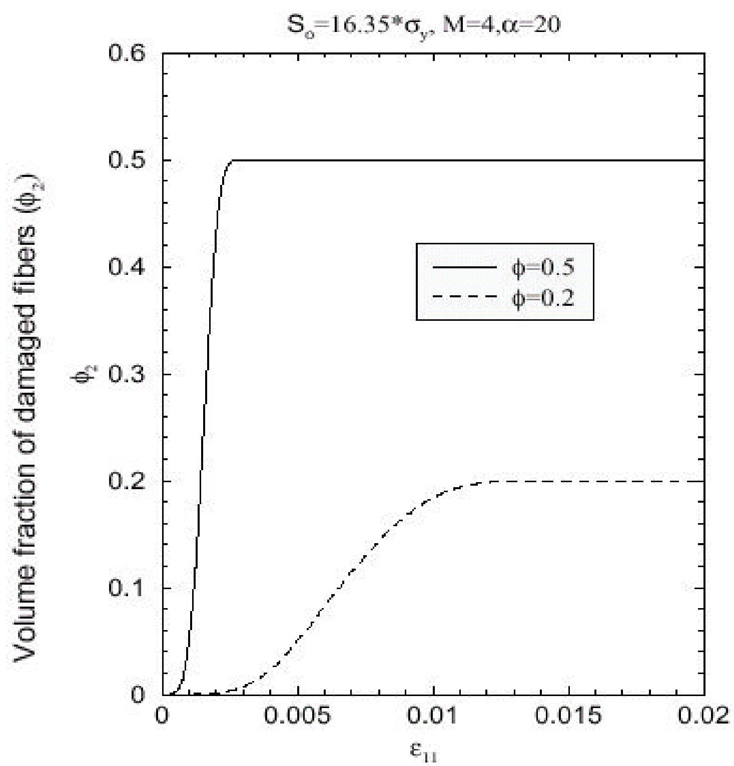


Heterogeneous composite is replaced by equivalent homogeneous material using equivalent principles based on homogenization

Mechanical Response of Composite

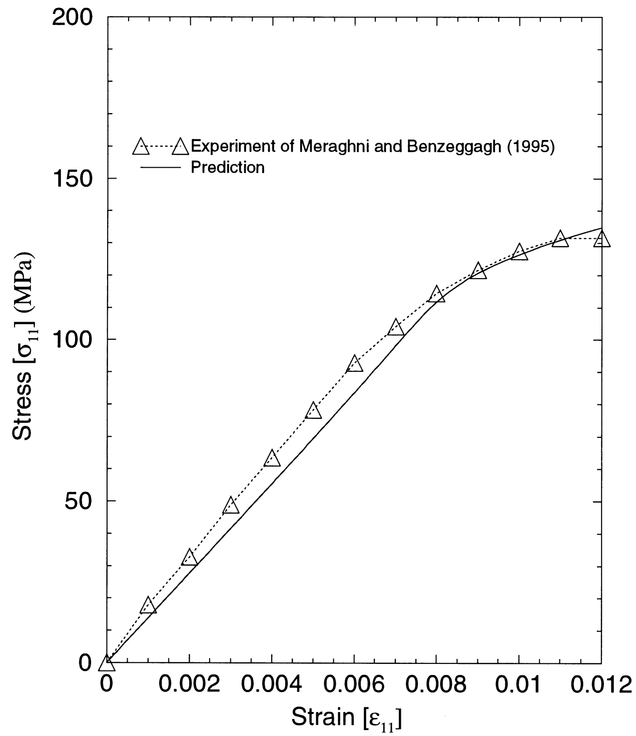


Low crack density increases apparent yield point

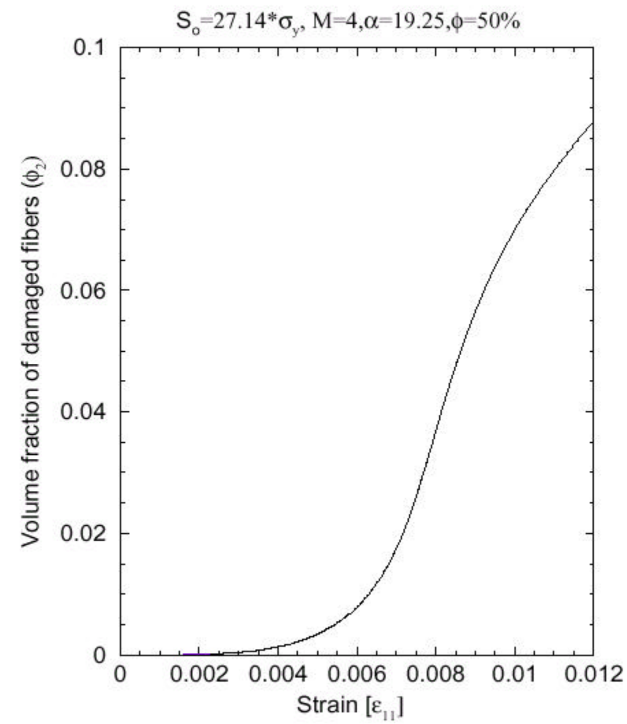


Composite with high initial volume fraction of fibers shows quick damage evolution

Experimental Comparison



Mechanical response



Evolution of damaged fibers in material

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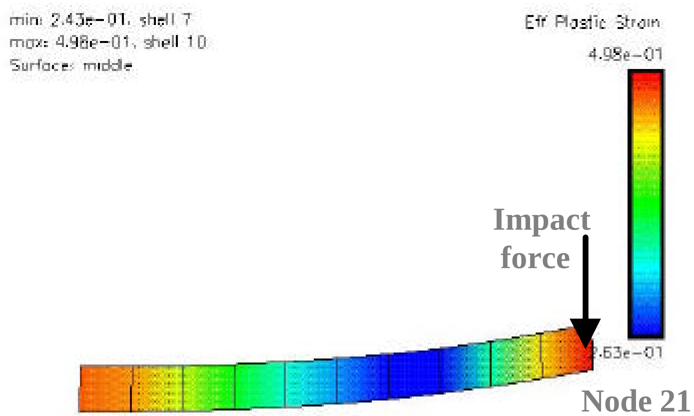
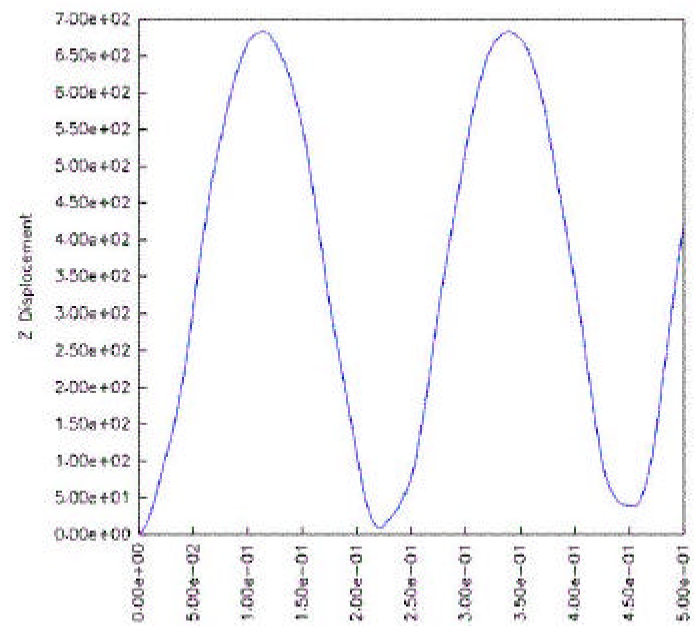
Preliminary Impact Simulations



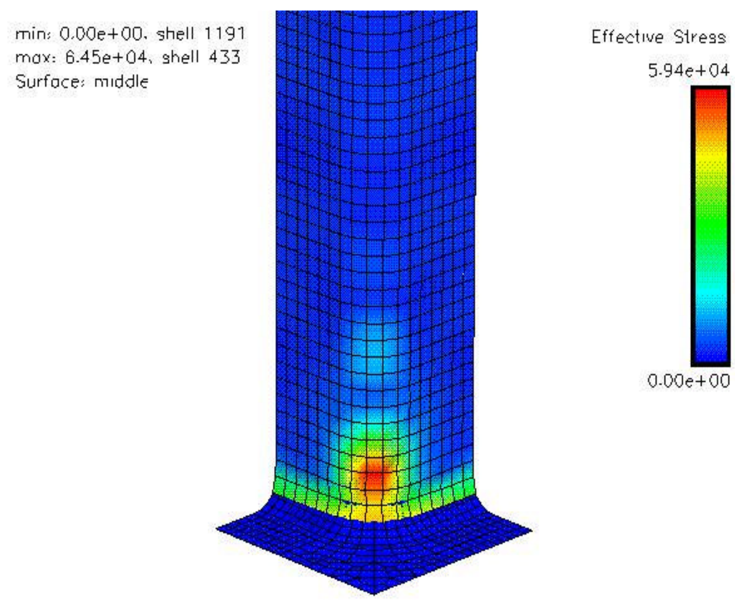
Damage index during impact



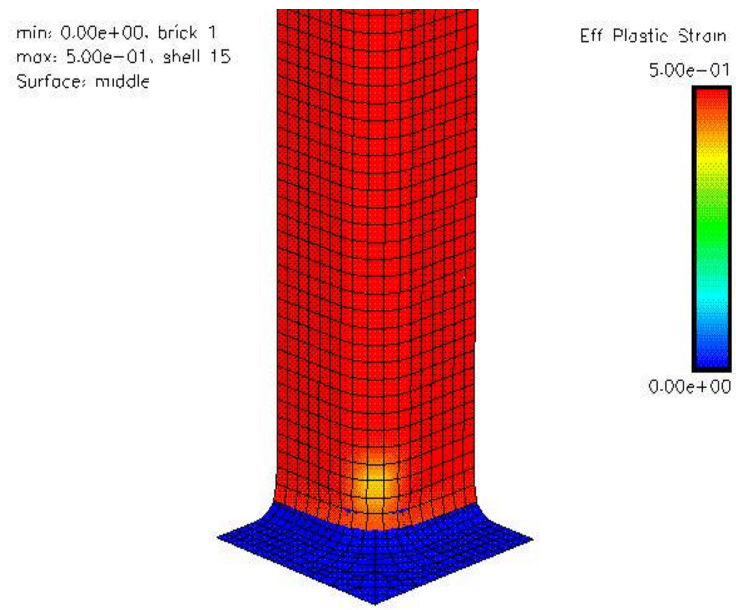
Displacement in the z-direction at node 21

Simulation is used for identification of model characteristics for solving boundary value problems

Initial Tube Impact Simulations



Effective stress during impact

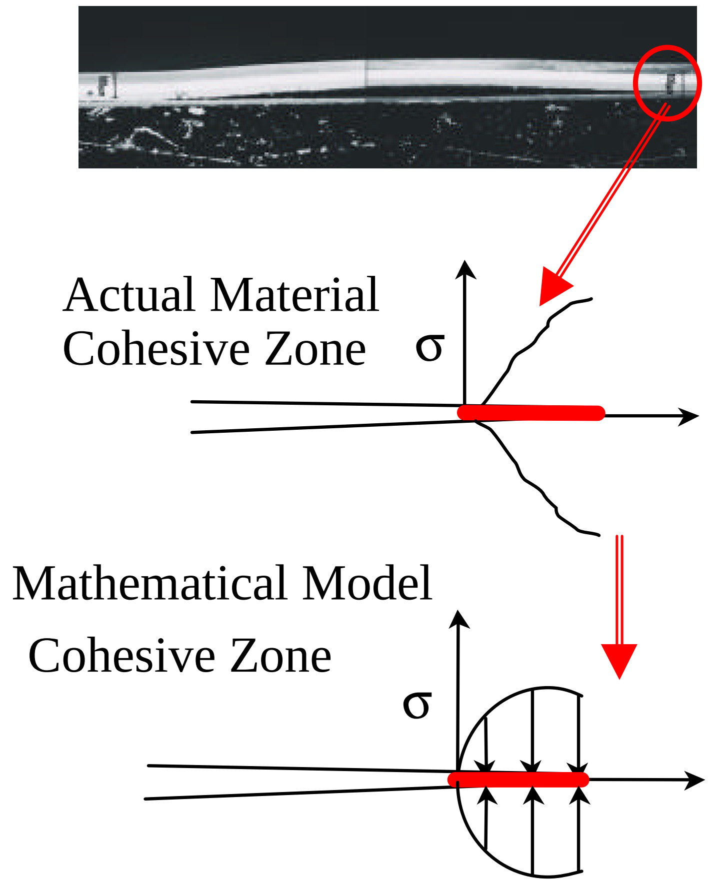


Damage index during impact

Simulation is used for analysis of material model features in tube crush test. The model does not incorporate material failure (FY2000 task)

Modeling of Delamination in Composites

- Many possible fracture mechanisms across interfaces
  - van der Waals forces
  - Adhesion bond breaking
  - void formation and coalescence
- Fracture mechanisms could be rate-independent or rate-dependent



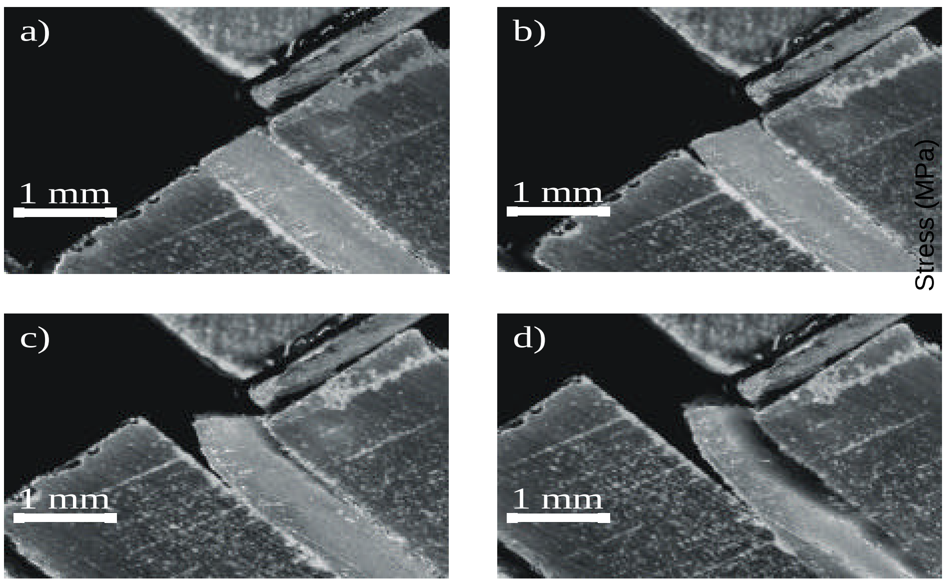
Cohesive Zone Modeling of Delamination

- Cohesive zone models implemented as cohesive elements are used simulate various fracture mechanisms
- Cohesive zone tractions account for the energy dissipation during crack formation and propagation during delamination failures
- Composite bulk material behavior modeled by regular finite elements and can be elastic, elastic-plastic, viscoelastic, etc.
- *Easy to handle automatic delamination nucleation, crack path selection, and multiple failure locations*

Delamination - Technical Issues

- Separation of composite bulk and interfacial contributions to measured global fracture energy
- Effect of bulk material behavior, i.e. viscoelasticity, plasticity, and composite ply orientations on measured global fracture energies
- Insights into 3-D effects at free edges/corners that cause failure initiation
- Mechanical performance issues - first cracking strength, stiffness degradation, post-failure strength, impact energy, under quasi-static and dynamic conditions
- Structural scaling effects of geometry on accompanying energy absorption and failure modes

Example: Compressive Shear Test of Automotive Windshield Experiments - Simulation

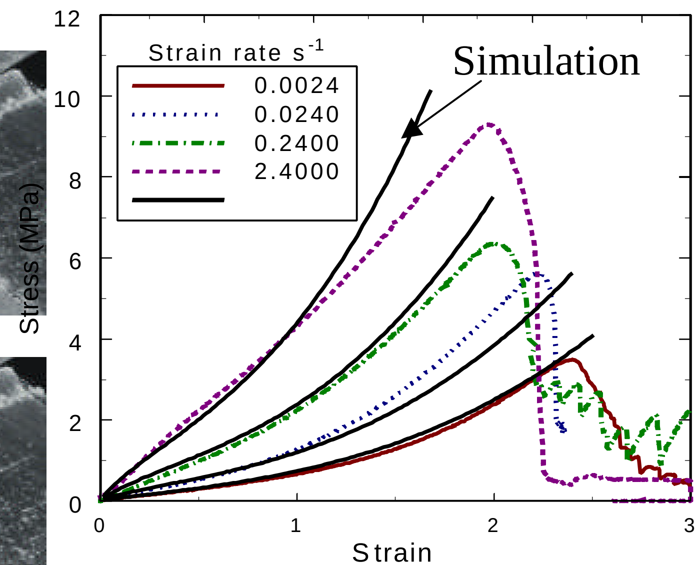


(a) Initial configuration

(b) Crack initiation

(c) Stable crack growth

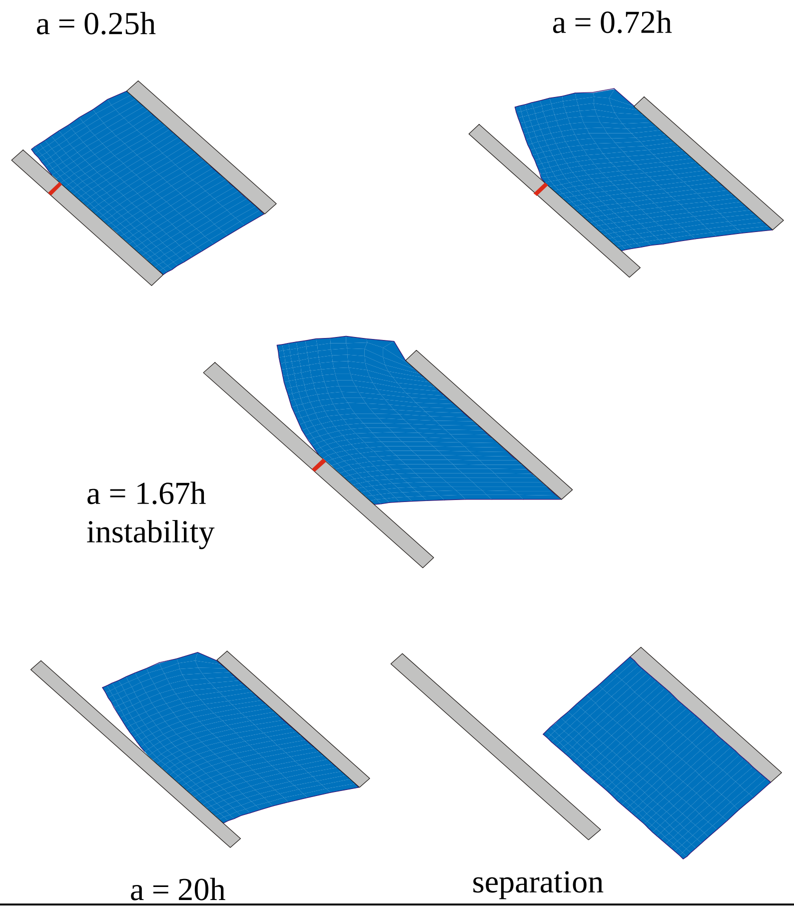
(d) Instability associated with peak stress



Experimental and simulated stress-strain curves

Compressive Shear Test of Automotive Windshield

- Successful in modeling the stable and unstable regimes of crack growth



Delamination Modeling - Summary

- Family of cohesive elements will be used to model degradation of ply-wise material structural integrity
- Separates constitutive description of fracture and bulk material properties
- Suitable for various materials and solution procedures
- Promising for use in multiple failure situations
- Need to validate cohesive zone modeling approach by comparison with experiments from quasi-static and dynamic failure tests
- Refine and develop cohesive zone models for fracture mechanisms accompanying failures in composites

<u>Experiments</u>

Energy Absorbing Mechanisms in Composite Strips under Progressive Crushing

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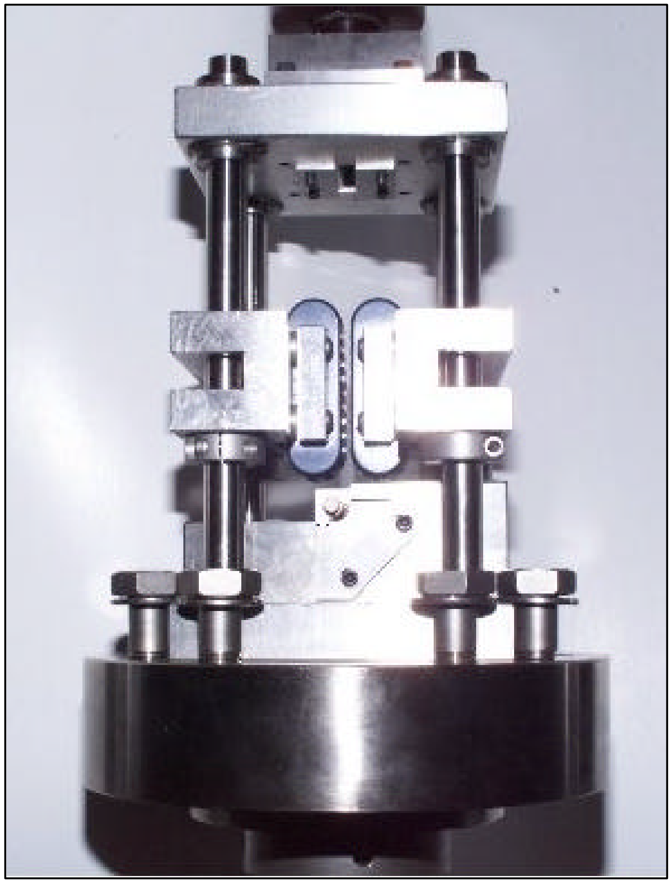
Objectives of Experimental Work

- Develop an experimental setup for discerning the deformation behavior and damage mechanisms that occur during progressive crushing of composite materials.
- Provide experimental data to support the development of analytical material damage models.
- Isolate damage modes associated with frond formation in composite tubes by testing plate geometries and investigate the effects of:
  - plate width, plate thickness, strain rate, contact profile shape, contact profile constraint

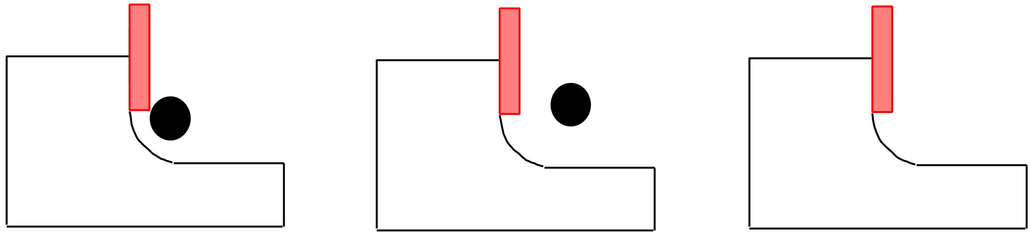
ORNL Fixture



- Modified version of existing test fixture used for crush testing of composite plates
- Observable crush zone
- Long crush length: approximately 50 mm
- Interchangable contact profile
- Out-of-plane buckling prevented by roller supports
- Frictionless roller for contact profile constraint
- Frictional forces can be quantified (TBD)
- Adaptable for dynamic testing

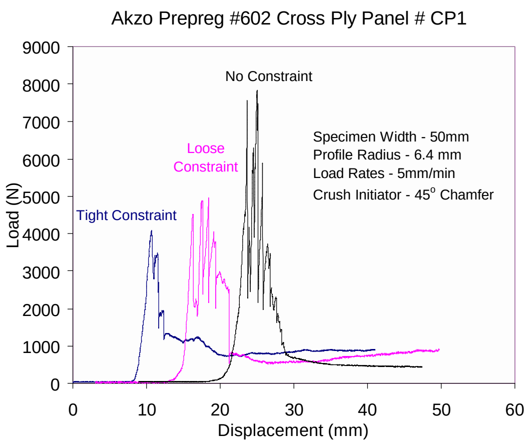
Roller Constraint Effect

- Fixture allows for activation of different damage mechanisms
  - Delamination
  - Fiber micro-buckling
  - Fiber kink bands
  - Fiber fracture

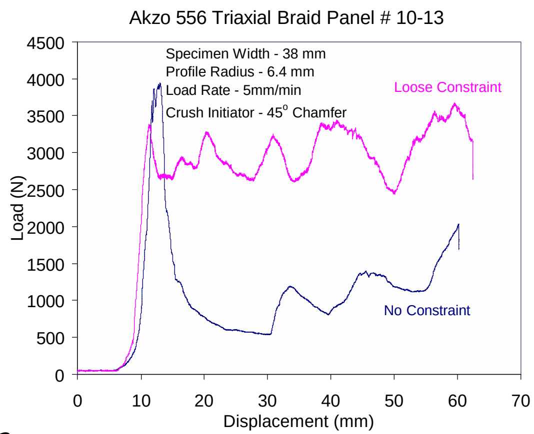


a) Tight constraint b) Loose constraint c) No constraint

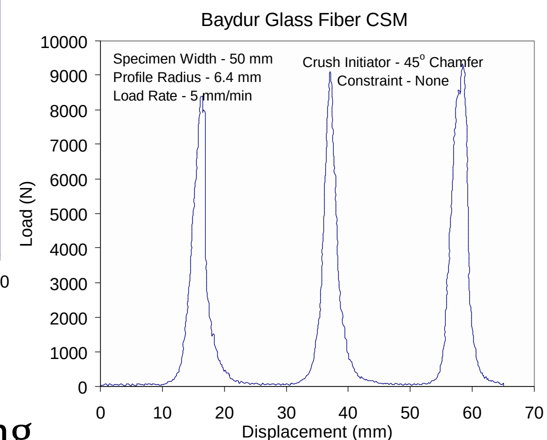
Typical Load-Displacement Traces



Graphite Cross-Ply
Failure mode: Delamination



Graphite Braid
Failure mode: Fiber Buckling



Glass CSM
Failure mode: Fracture

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Experiments - Summary

- Designed unique test fixture for conducting progressive crush tests on representative automotive composite materials
- Validated and demonstrated test methodology for using a roller constraint to activate/deactivate certain damage mechanisms
- The effects of constraint condition, profile shape, specimen width, and loading rate will be investigated for chopped carbon fiber/epoxy laminates
- Alternative energy absorbing mechanisms will be studied by considering alternative specimen geometries
- Modifications to the test fixture design will be explored for conducting dynamic tests

Plans for FY2000

Modeling

1. Develop continuum mechanics based material models that will incorporate results from micro-mechanical models
2. Develop continuum mechanics based model for handling post-peak response in the material (model will address ACC’s concern about ubiquitous "m"-s)
3. Develop delamination model based on cohesive theory approach (model will be used to handle degradation of laminate integrity)

Experiments

1. Perform tests on P4A materials and on other carbon fiber composites if necessary.
2. Analyze different failure modes
3. Develop procedures for triggering different failure modes and mapping loading and constraint space conditions