Micromechanical Modeling of Energy to Failure for Randomly Oriented Short Fiber Composites

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

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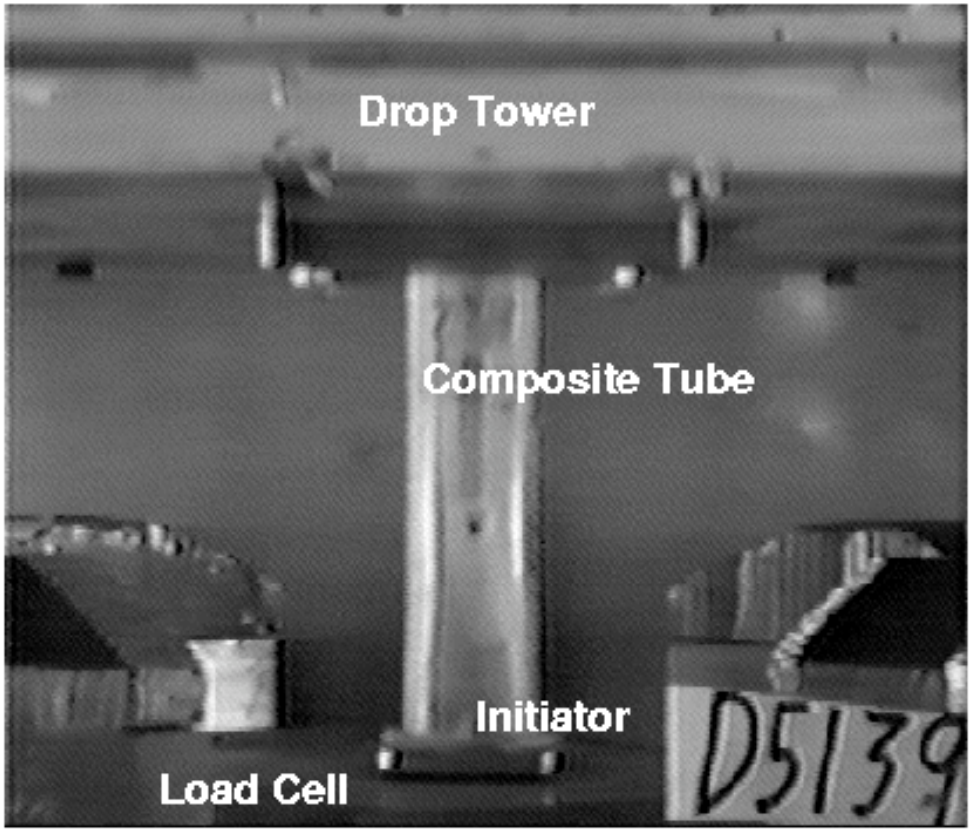
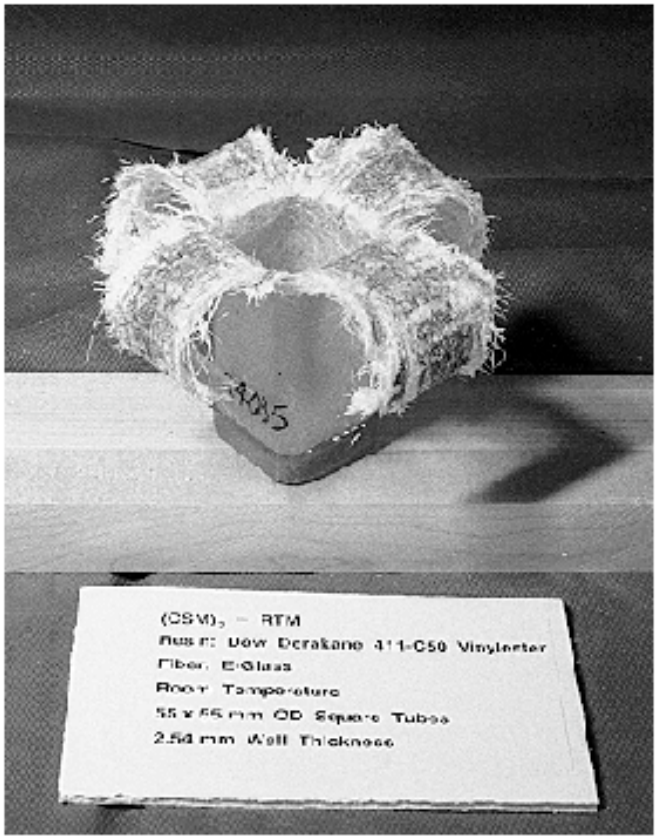
Outline

- Motivation
- Modeling of random fiber composite microstructure
- Model for material failure
- Experiment

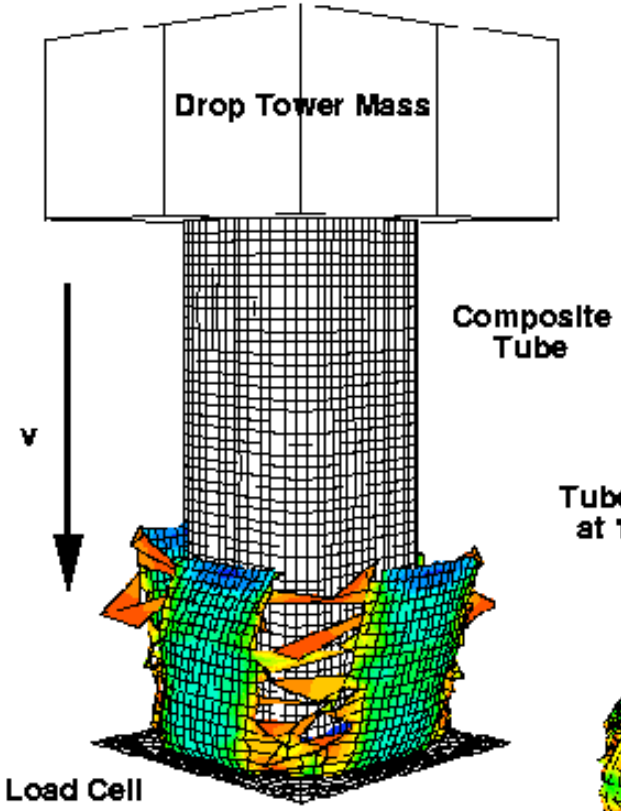
Drop Tower Test of CSM Tube

CSM: Continuous Strand Mat
Swirled Glass Fibers, similar results to glass RFC

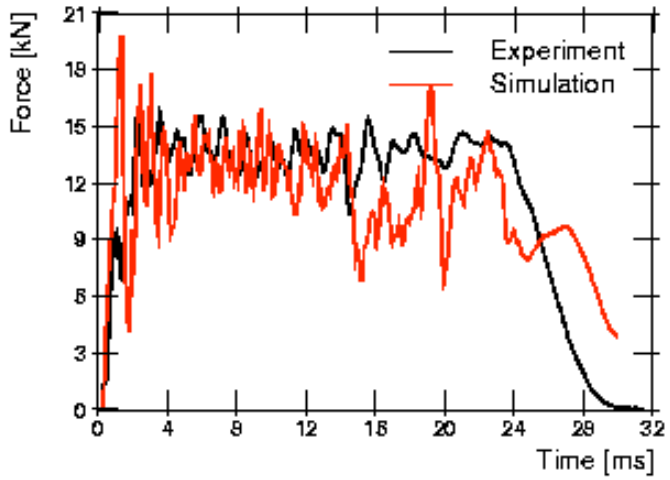




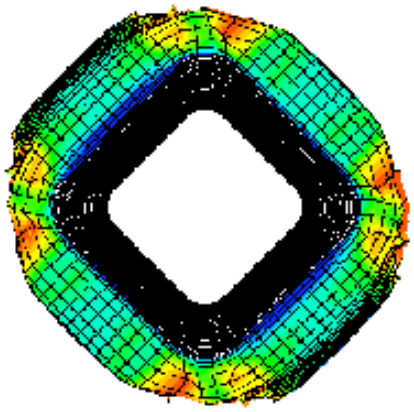
Constitutive Modeling of Composite Materials for Impact Analysis



Tube crush at 10 ms.



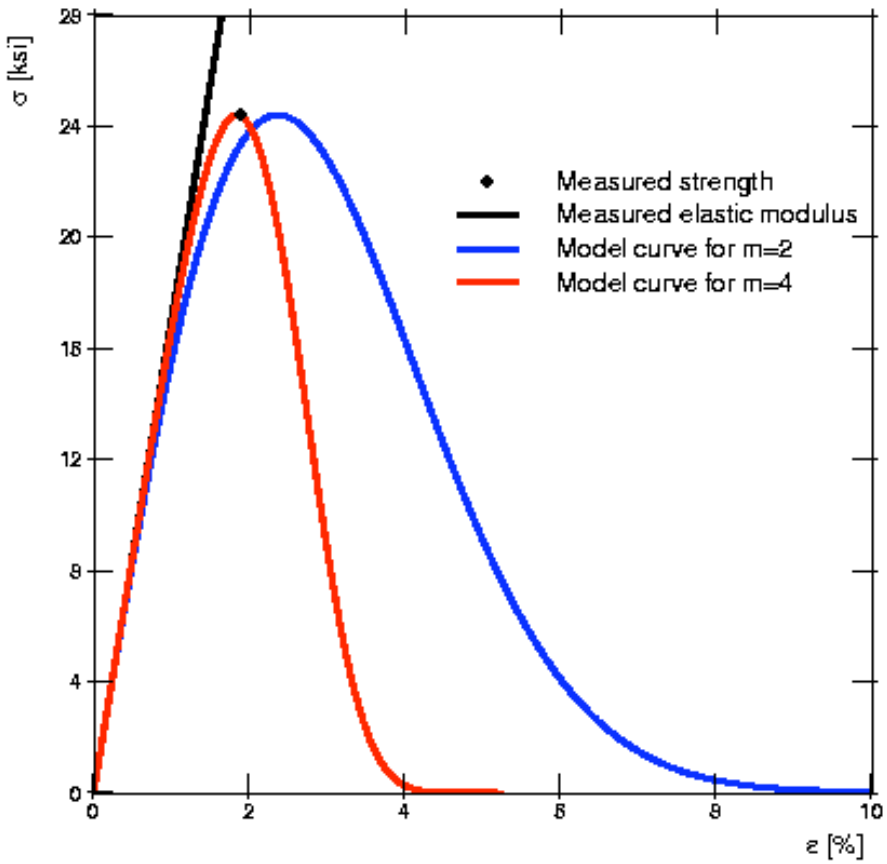
Developed constitutive models are capable of modeling progressive crushing of glass fiber composites. The models were verified against static and dynamic experiments.



Disspated energy is proportional to the area below the force trace.

The stable crushing of composite structures can provide adequate energy dissipation for structural crashworthiness while reducing weight.

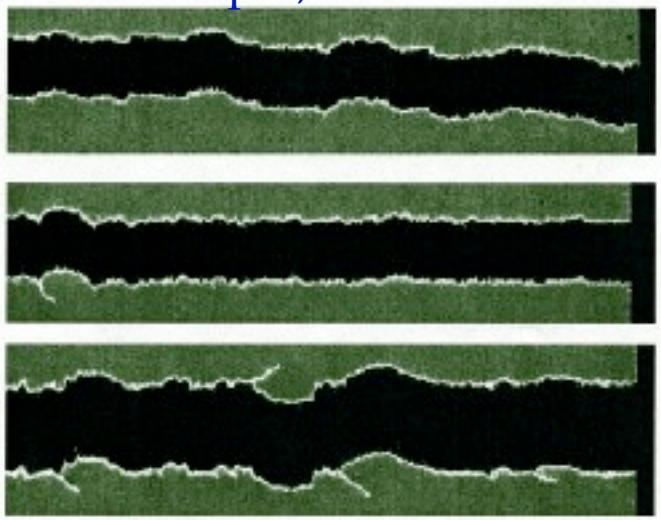
CSM Continuum Damage Model



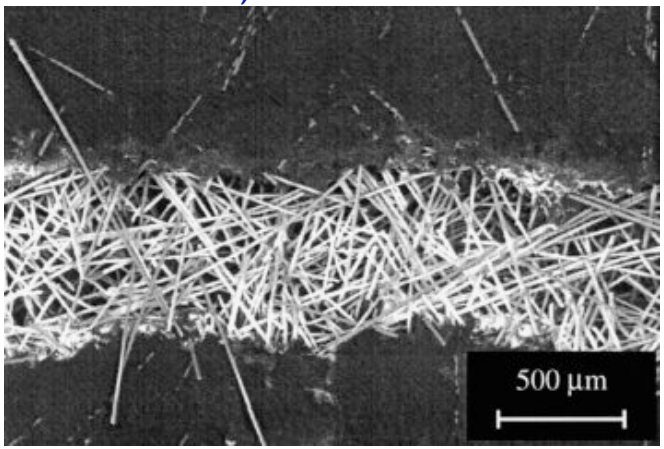
- Damage evolves as uncorrelated phenomena
- Model is based on
  - Strain tensor split
  - Parallel bar model
  - Weibull distribution of flaw strengths in bars
  - Viscous regularization in the strain softening range
- Uniqueness of the solution depends on determining energy to break and size of the failure region

Failure Zones in Fiber Networks

Paper, Alava et al. 2000



Glass + PE, Geers et al. 1999



- Failure zone morphology is similar for materials based on fiber networks

Glass + EP, Lavengood 1974

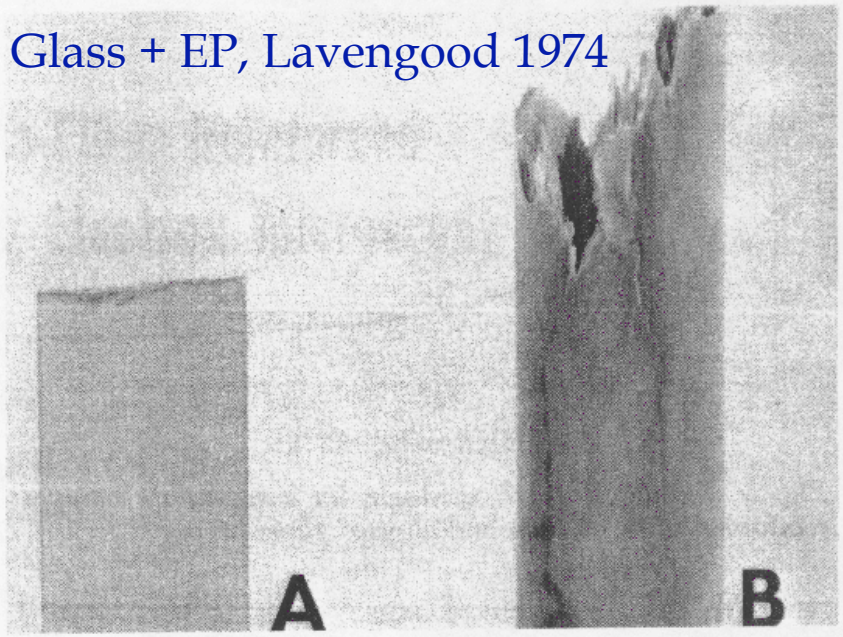
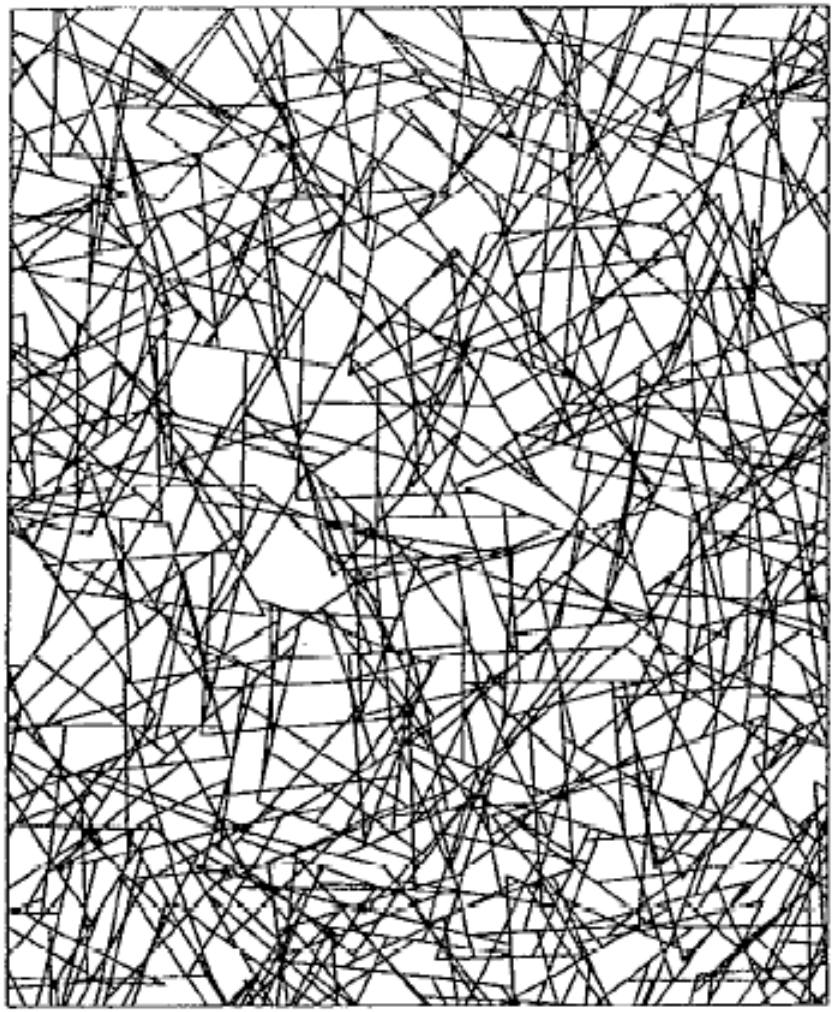


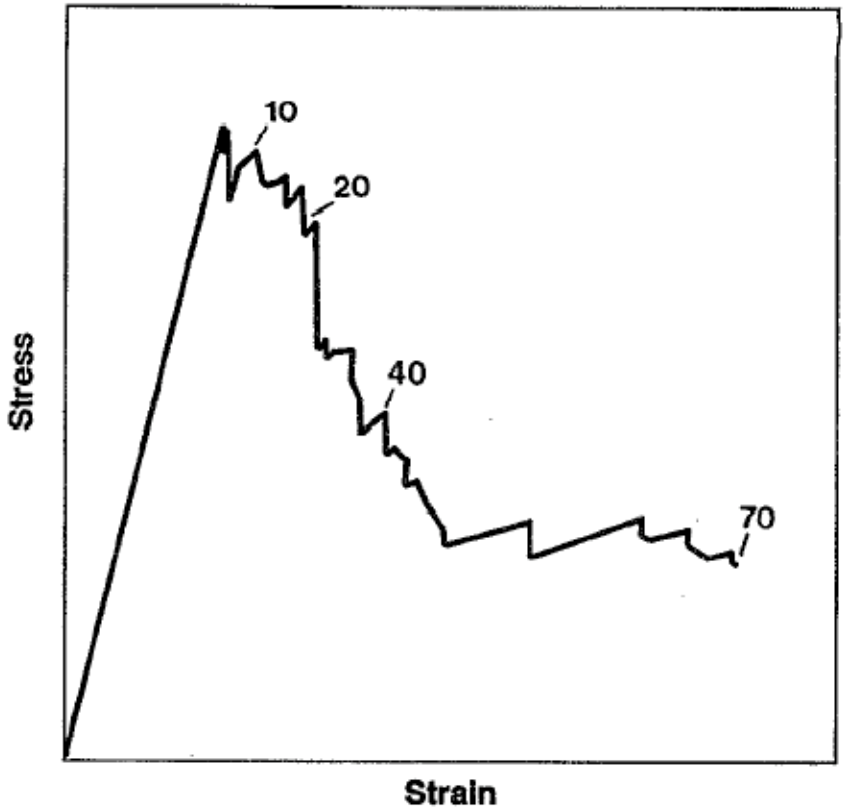
Fig. 7. Typical fracture patterns for (a) randomly oriented and (b) aligned fiber composites.

Microstructural Models of Fiber Networks



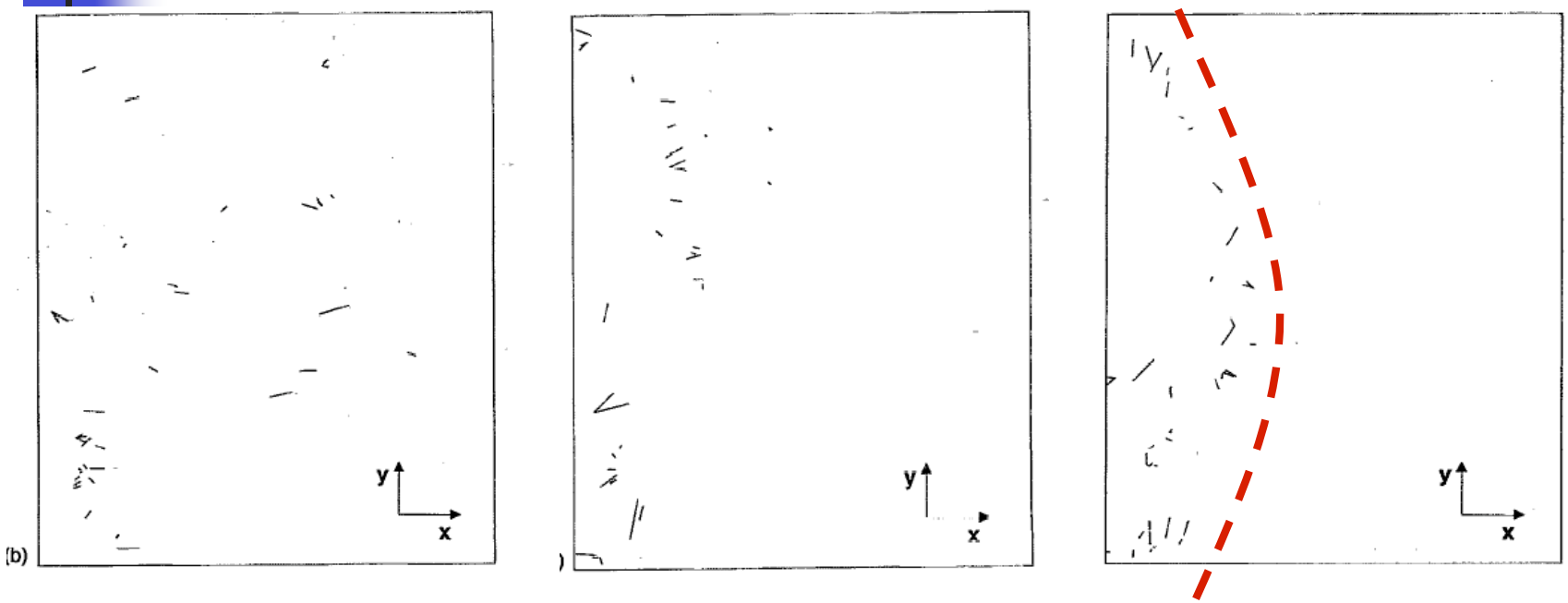
- Astrom et al. 1994
- Alava et al. 1997
- Models used for analyzing uniaxial tensile strength and fracture process
- Employed simplifying assumptions make model more applicable to RFC

Uniaxial Tensile Failure



- Astrom at al. (1994)
- Microfailure can occur via bond and fiber breaks

Network Failure Process

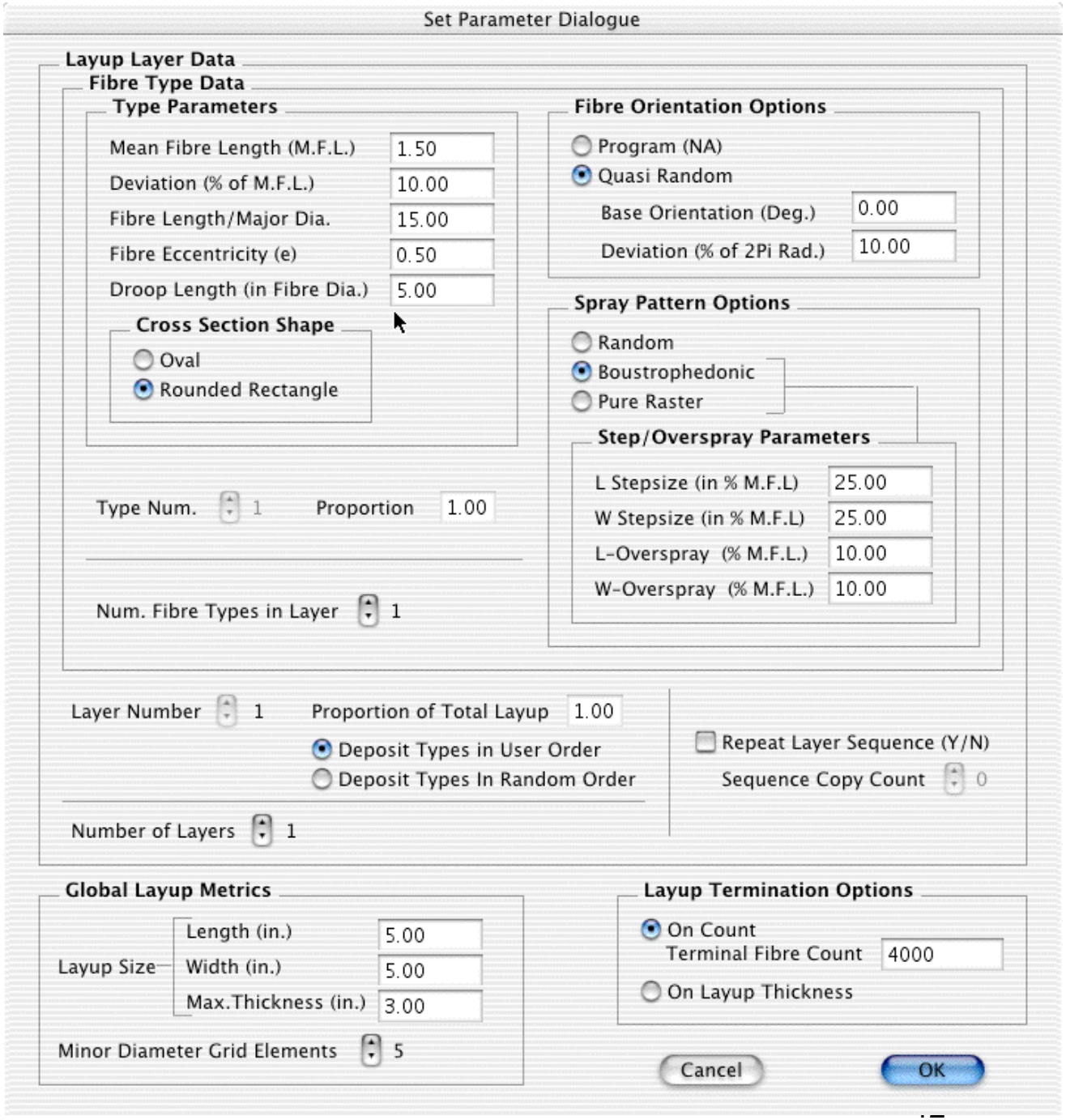


- The initial “percolation” damage switches to a one-dimensional process at onset of ultimate failure
- Instead of crack growth, the failure is governed by *uncorrelated events in one dimensional zone* that extends across the system
- At the end only a number of more or less parallel chains keep the network from falling apart

FNSim

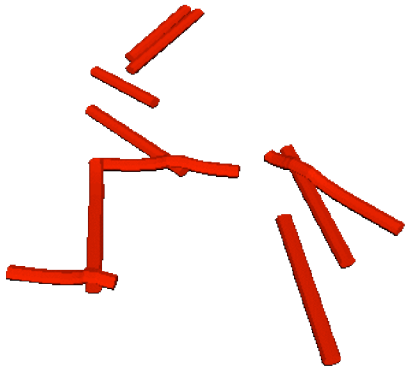
- Program has been developed to model the fiber deposition process and analyze the structure and properties of the resulting fiber networks
- The program can simulate a variety of fiber deposition patterns, orientations, fiber types, layers, network densities, and thicknesses.

Program Controls

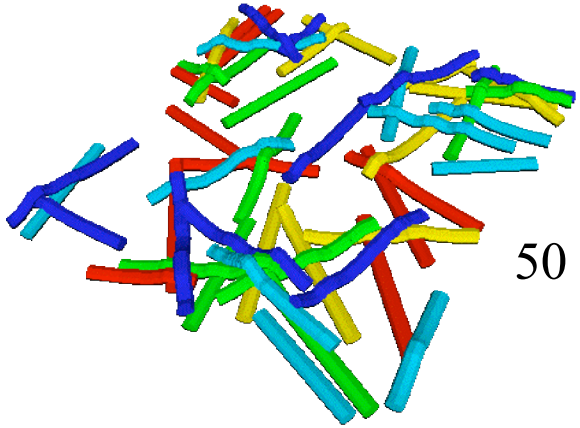


- Models 3-D structure of fiber network
- Distribution of contacts, voids, segment lengths, fiber undulation, layers, etc.
- Mixture of fiber types

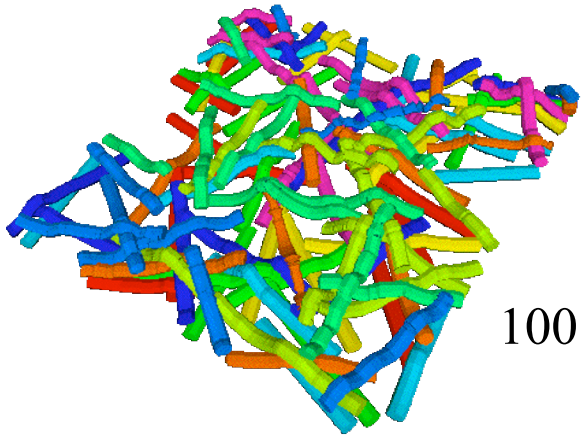
Fiber Deposition Process



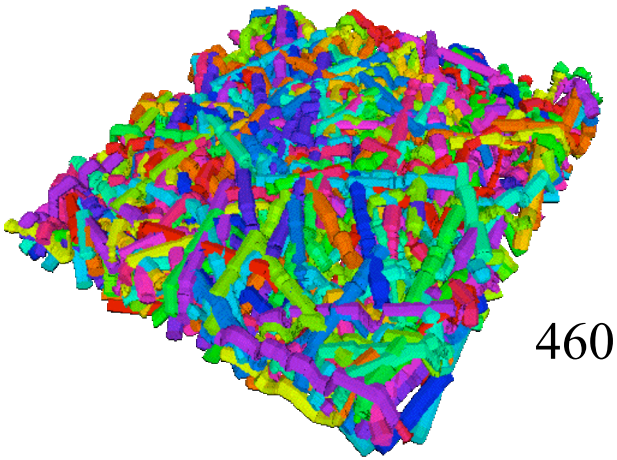
10 fibers



50 fibers

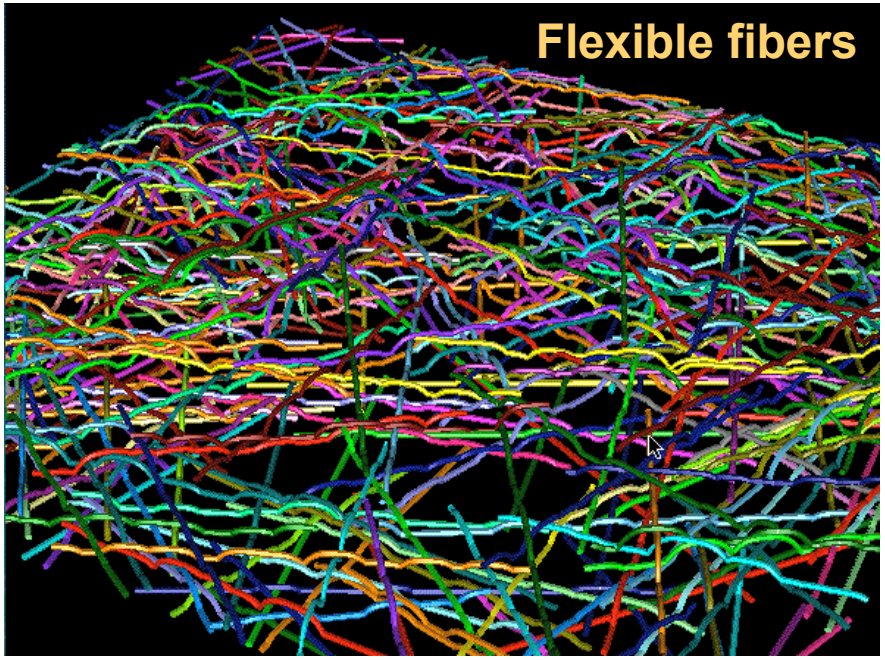


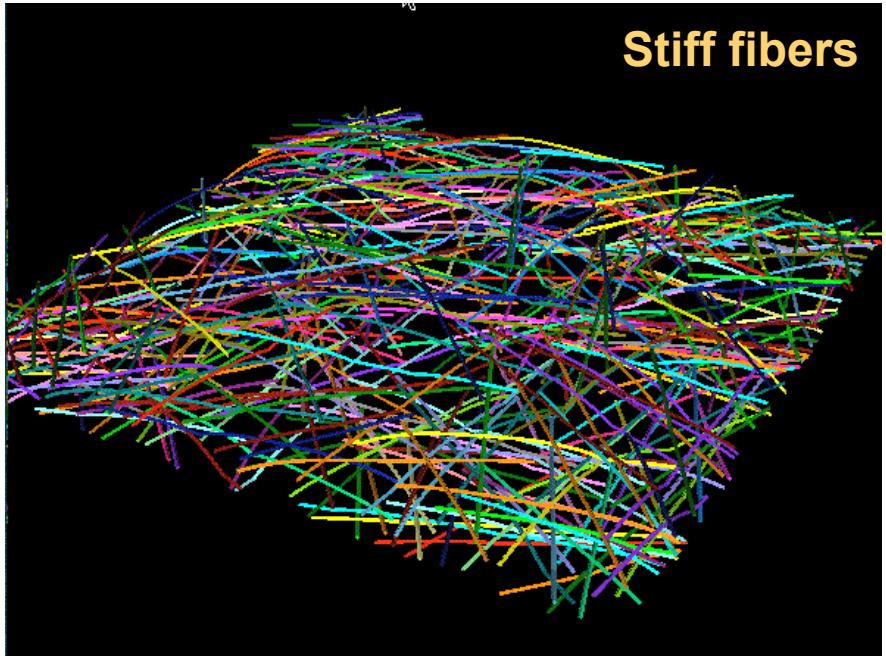
100 fibers



460 fibers

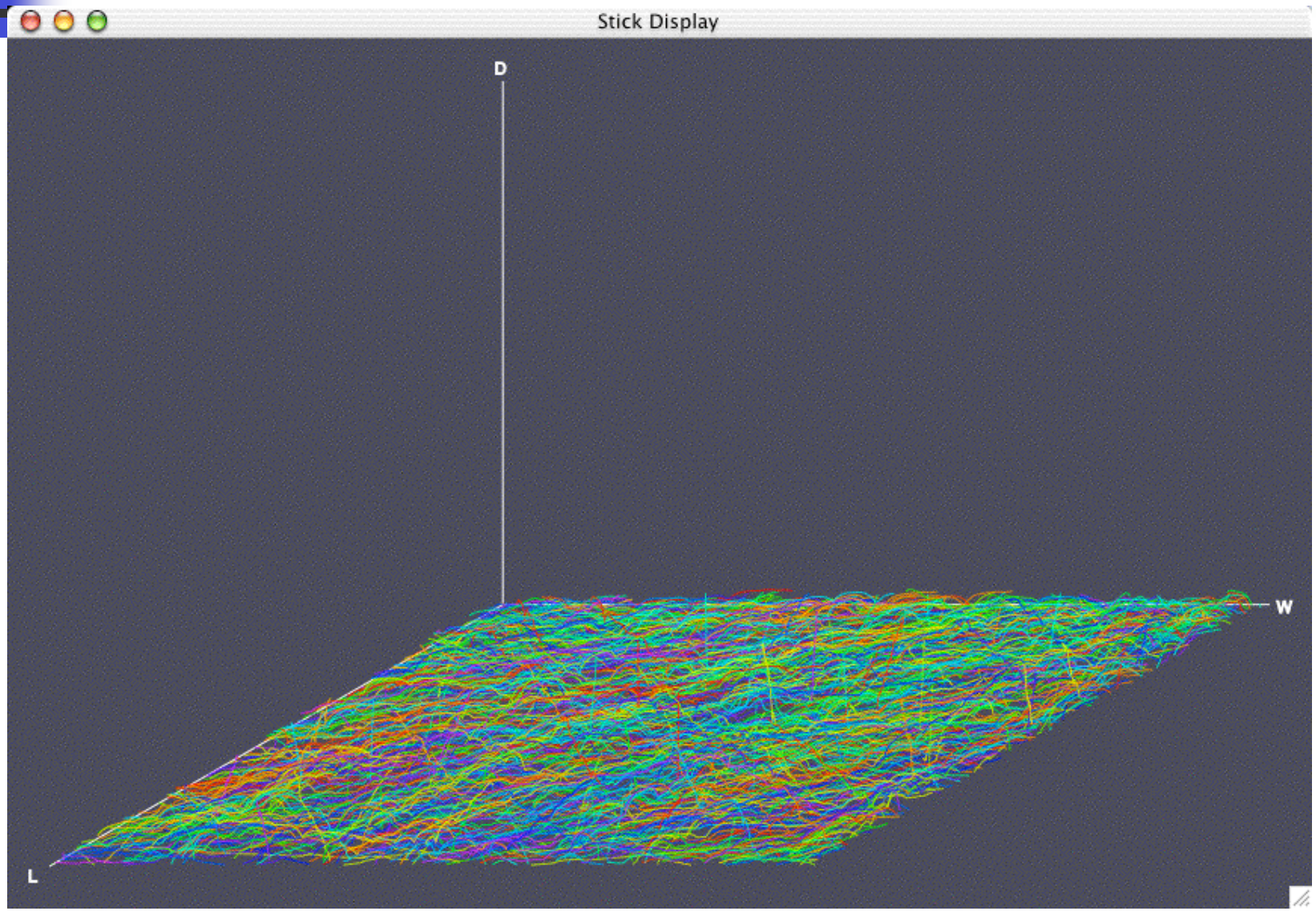
Relevance to Mechanical Models



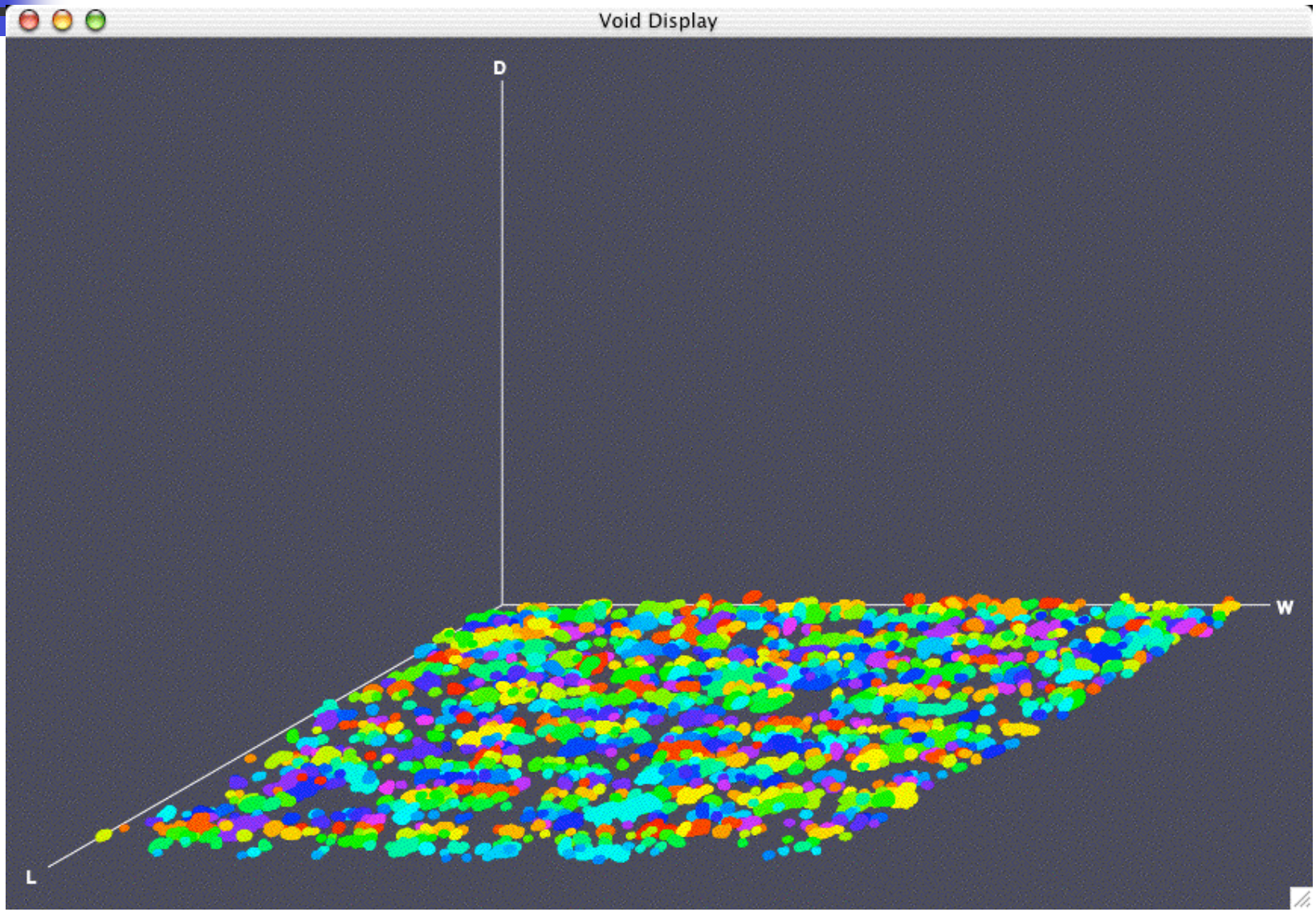


- Experiments and random fiber network simulations show that damage localizes into 1-D zone with uncorrelated fiber breaks
- Failure in fibers (tows) occur in the segments between fiber's connection with the network
- Fiber segment is the length on the fiber between its two consecutive contacts with the other fibers
- Fiber segment determines internal length

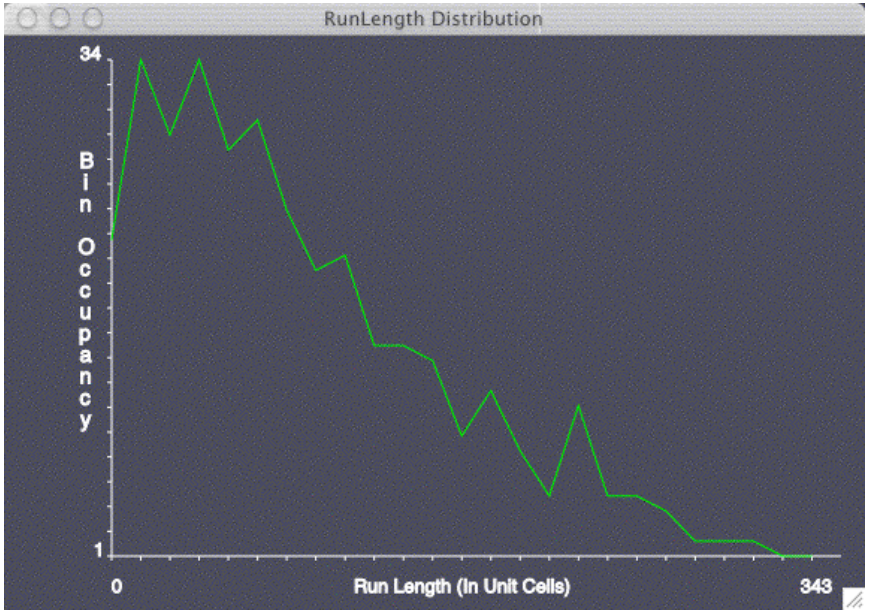
Fiber Centerline Display

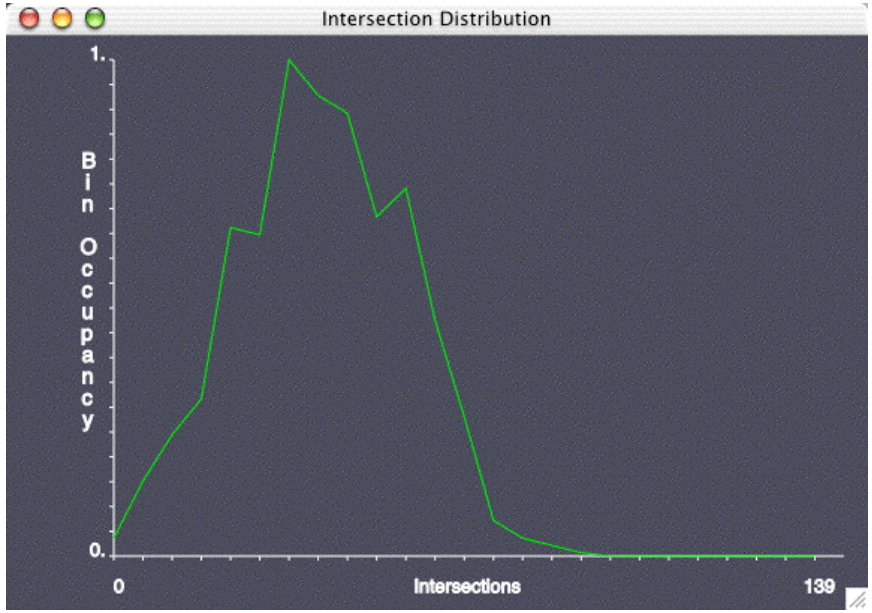


Void Distribution



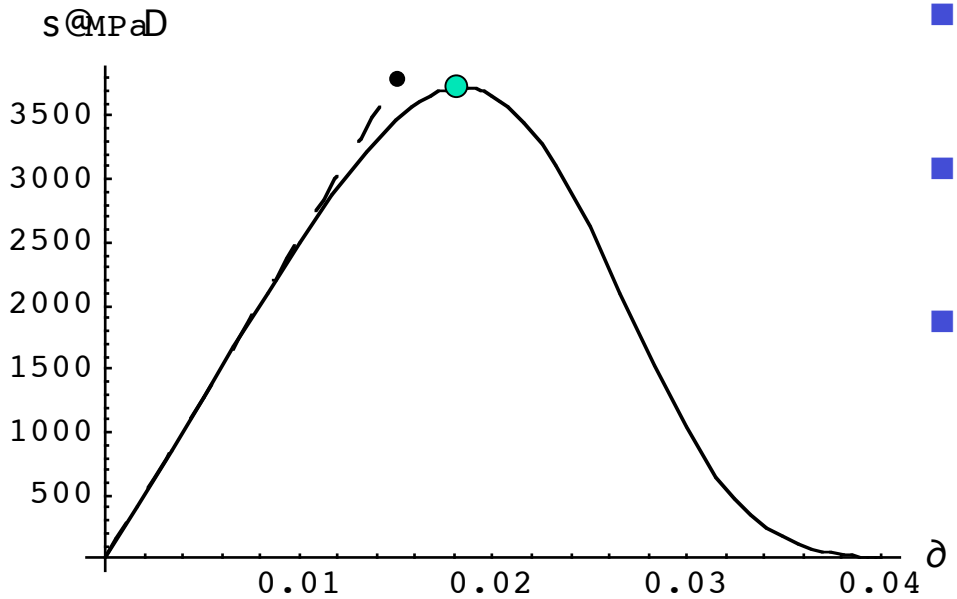
Fiber Network Statistics





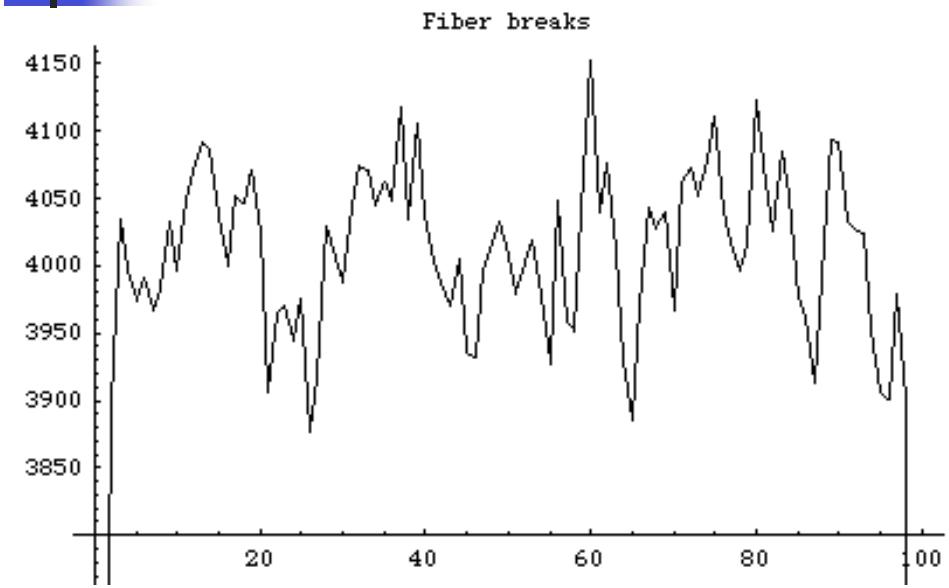
- Distribution of segment lengths has characteristics of Poisson distribution
- Number of fiber-to-fiber intersections has Gaussian character
- The averages of the above statistical distributions are currently used in the constitutive model to determine average segment length over whichthe fiber failure occurs
- Actual statistical distribution can be used for further model improvement

Carbon Fiber (Tow) Model



- Based on experiments by fiber manufacturer
- **Strength is a function of tow length**
- It is the basic failure mechanism in composite
- The energy to of a tow's segment is used to estimate failure energy and scaling of energy dissipation with the domain (finite element) size

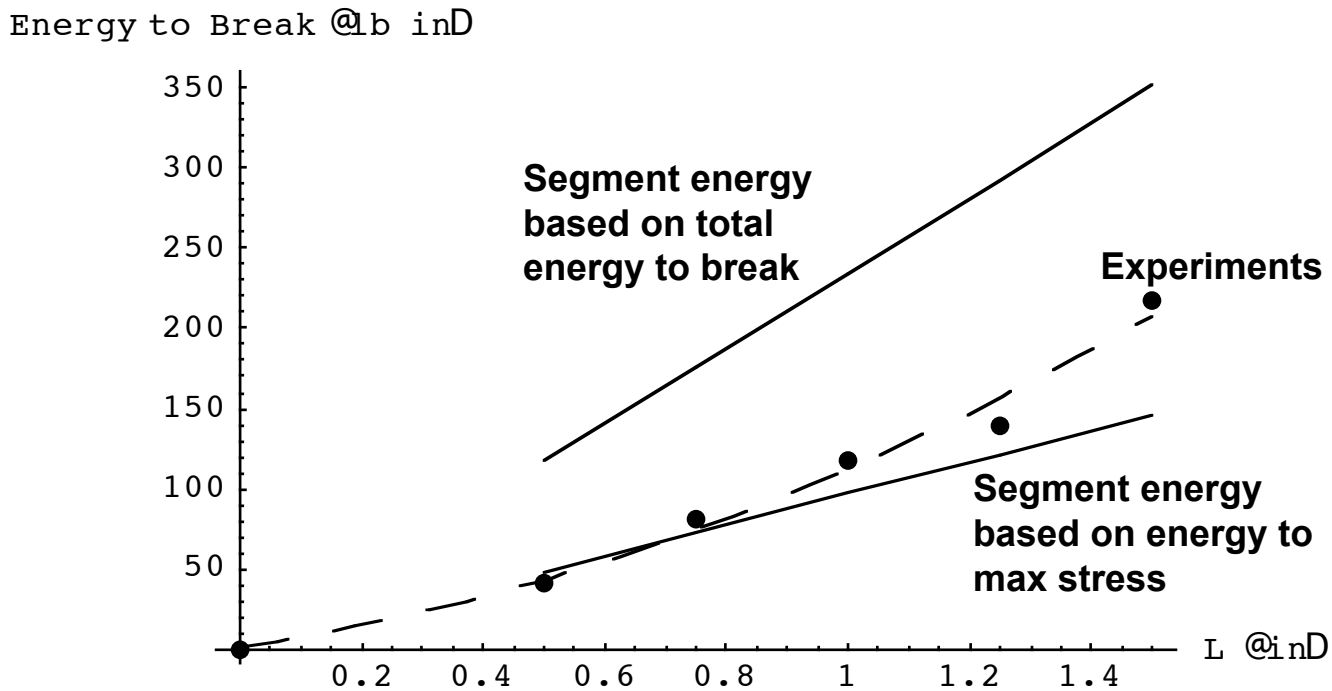
Fiber Distribution along Possible Failure Lines

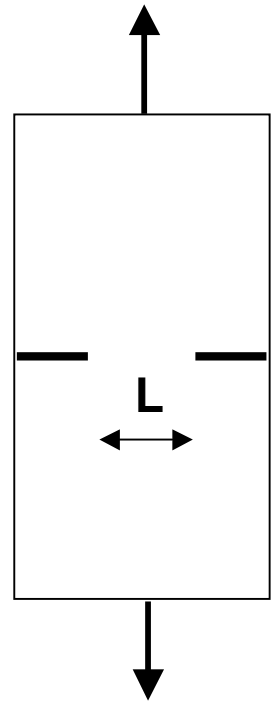


Distribution of fibers crossing scan lines in specimen

- Failure occurs in 1-D zone orthogonal to the direction of principal tensile stress as uncorrelated event
- Fiber network simulations are used to determine the average number of fibers that crosses the failure line
- Energy to break is then determined by the number of fibers breaking and the fiber segment energy to break
- This energy is important to develop scaling of failure energy

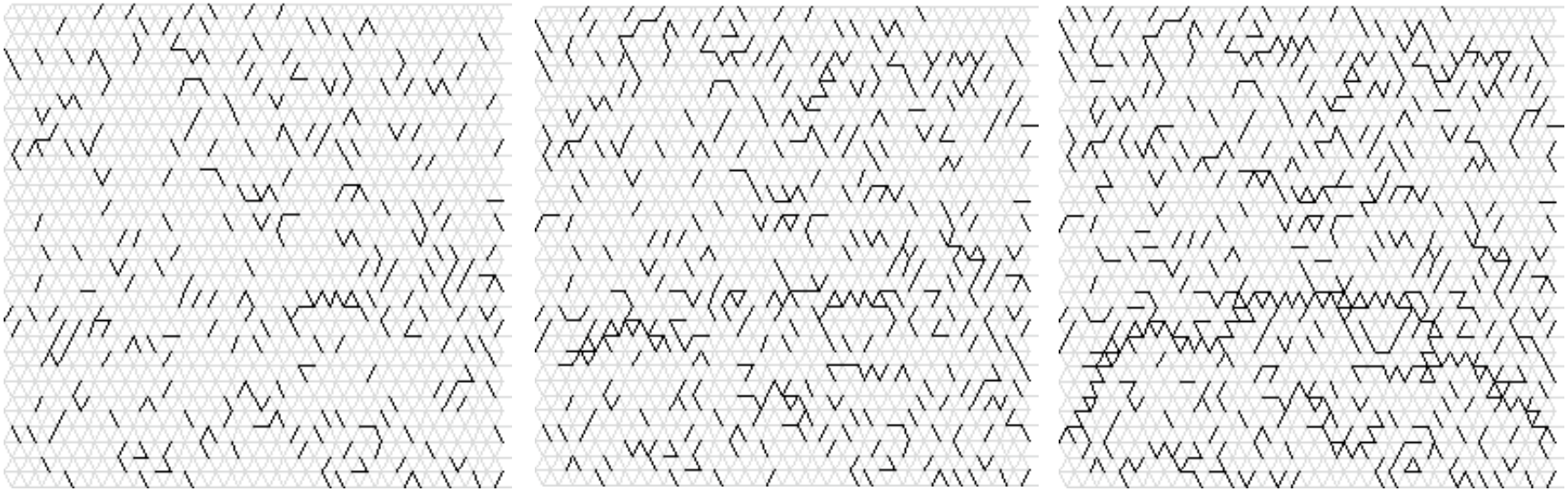
DENT Energy to Break (A)





- Experiments are performed on P4 composite
- Lower and upper solid lines (model) provide good bounds for the energy to break
- Model is linear in segment length (no scaling)

Mesoscopic Modeling of Damage Evolution



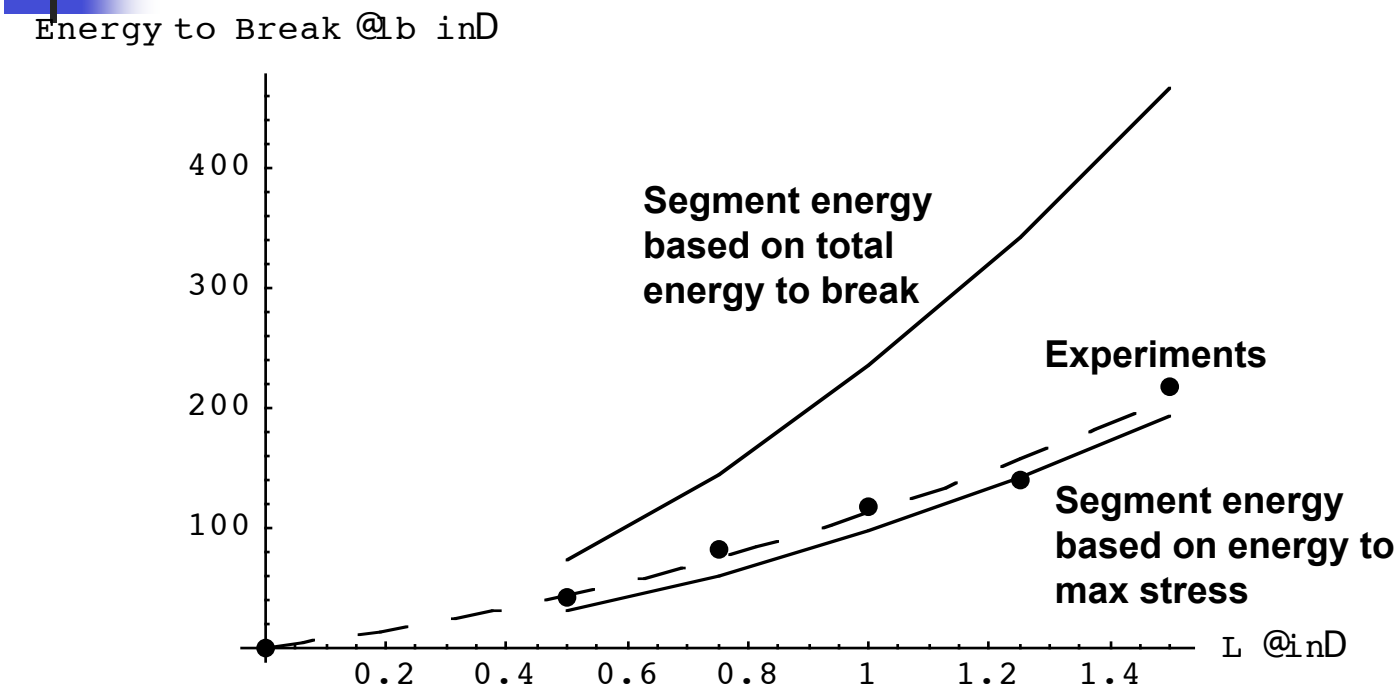
Nucleation Phase: Diffusive Damage

Growth Phase: Stress Concentration effects are dominant

Coalescence: Localization of damage to form a percolating crack

- Number of broken bonds scales as $L^{1.7}$

DENT Energy to Break (B)



- The number of broken segments is scaled with exponent 1.7 (obtained from lattice simulations, see next graph)
- Fiber failure segment length was the same as in the previous graph
- The results confirm model assumptions

Summary

- Fiber network microstructure has been linked to resulting mechanical properties
- Failure in random fiber composite occurs in 1-D uncorrelated fashion in a band of finite size
- Verified model assumptions by DENT experiments
- Developed program is applicable to a variety of problems
  - Composites, battery substrates, colloid suspensions, filters, paper, forest products, soft tissue, biomechanics, etc.