Advanced Composite Modeling Capabilities for ALE3D

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Composite structures are increasingly being used in advanced weapon and armor systems, as well as in a variety of other applications. We had previously implemented several composite material models in ALE3D (a 3-D arbitrary Lagrangian-Eulerian, or ALE, multiphysics LLNL hydrocode) by porting constitutive models from DYNA3D (an explicit 3-D structural dynamics code). Over the past two years, we extended our composite modeling capabilities by adding more realistic failure mechanisms, implementing strain-driven progressive damage, implementing layer-specific damage, and creating tools for estimating homogenized composite material properties (Fig. 1). We also began investigation of finite deformation kinematics necessary for modeling many anisotropic composite materials and initiated experimental work studying thermal dependence, degradation, and damage of composites.

Project Goals

Our goal is to be able to efficiently model composite materials under a wide variety of environments, including large and/or high velocity deformations. Specific goals include:

1. capturing the failure modes specific to different types of composites with different layups, such as fiber breakage, fiber buckling, and through-thickness crush;
2. modeling states of partial damage, and allowing damage to evolve progressively within an ALE framework;
3. capturing the damage to individual layers or fiber families;
4. accurately modeling finite deformations of composites in an ALE framework; and
5. incorporating thermal sensitivity of composite properties and thermally-driven or thermally-assisted damage.

In addition, we require experimental characterization of composite material properties, tools for rapidly estimating appropriate properties of layups, and experimental validation of our models.

Relevance to LLNL Mission

Modeling composite structures before, during, and after failure is necessary for many LLNL programs. Applications include next-generation composite munitions; magazines, damage containment, and insensitive munitions; pressure vessels; rocket motors; and armors. By extending our modeling capabilities to composites, this work enhances LLNL's core competency in simulation of engineering structures under extreme loading conditions.

FY2009 Accomplishments and Results

Implementation of multilayer damage mechanics was a key accomplishment. Previous composite material models were homogenized—a single damage criterion was established for the entire composite layup, and damage to any layer affected strength in every direction. This approach is inaccurate for composites with a relatively small number of fiber families (*e.g.*, woven Kevlar composites). The new multilayer damage mechanics represents a generalization of the homogenization techniques used in previous models. The kinematic formulation assumes in-plane isostrain and out-of-plane

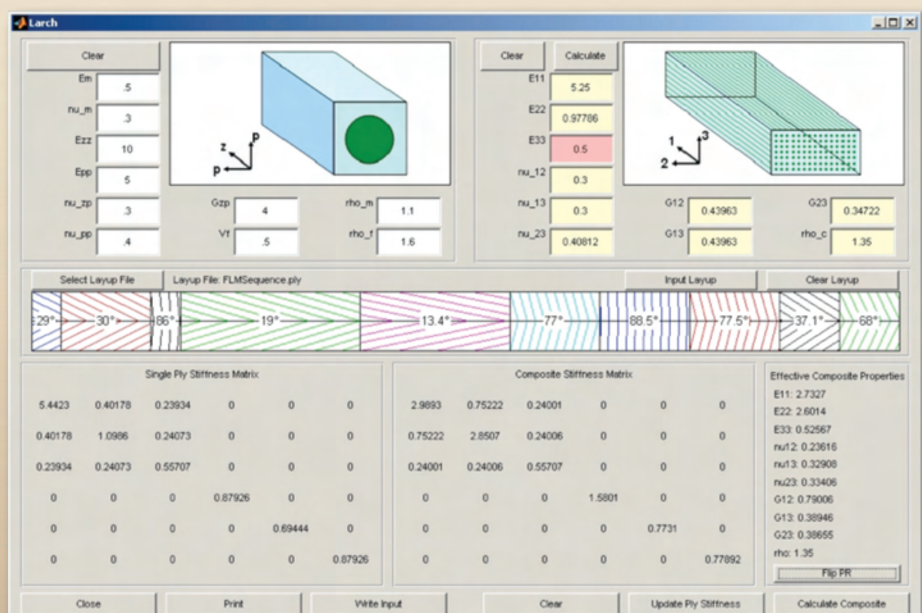

Figure 1. User interface for the LLNL Analytical fiber Reinforced Composite Homogenizer (LARCH), a tool for rapidly estimating composite properties from the properties of its components and layup.

isostress across all layers. The strain and damage in each layer evolves separately according to this kinematic framework. Delamination is also supported. In this manner, it is possible to track the effects of different levels of damage to different fiber families and predict the progressive failure of the entire composite (Fig. 2). This model was implemented into the ALE3D version 4.10 release and is extensively documented in its manual.

Finite deformation in an ALE framework was also explored. Large strains and rotations are challenging to capture in an ALE framework because tensors like a deformation gradient are difficult to maintain accurately in the presence of advection. Several potential algorithms were identified that may prove effective, including modified stretch tensors and quaternions to track material deformations. This study has laid the groundwork for these algorithms to be implemented and tested in future work.

Finally, we have initiated a study of the thermal response of composites. Composite properties (especially strength) change at temperature, and sufficient time at temperature can induce damage, through softening or charring of the composite matrix. In FY2009, a related project began experiments to measure these behaviors, consisting of axial compression-to-failure tests on composite tubes held at a given temperature after a prescribed thermal history (Fig. 3). This data will enable thermal dependence and damage of carbon fiber composites to be implemented into models in the future.

Future work in this field can entail implementing, testing, and improving the finite deformation algorithms, adding thermal effects into the material models, or focus on modeling ply-by-ply mechanics to accurately simulate the localized bending response of thin composite structures.

Related References

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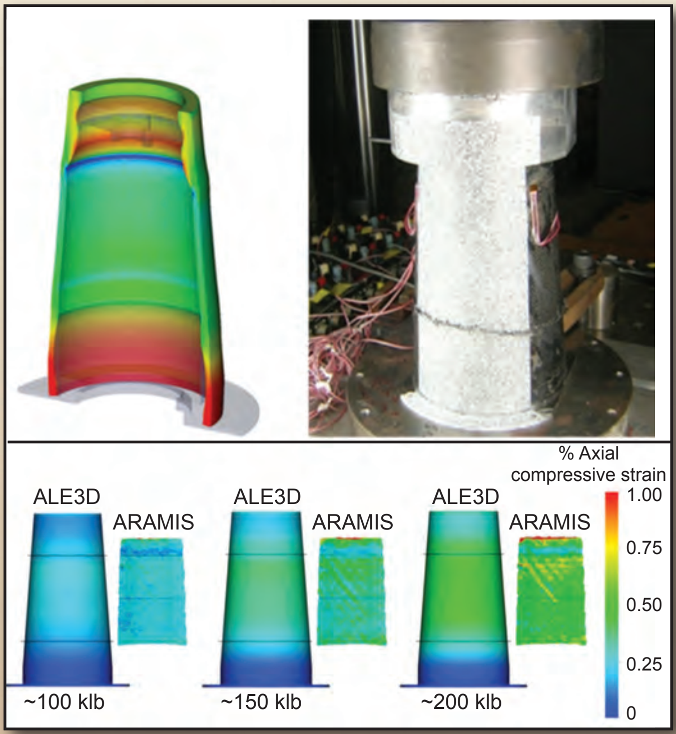

Figure 2. Structural analysis (ALE3D) of a conical composite case section and comparison to axial compression test data (ARAMIS).

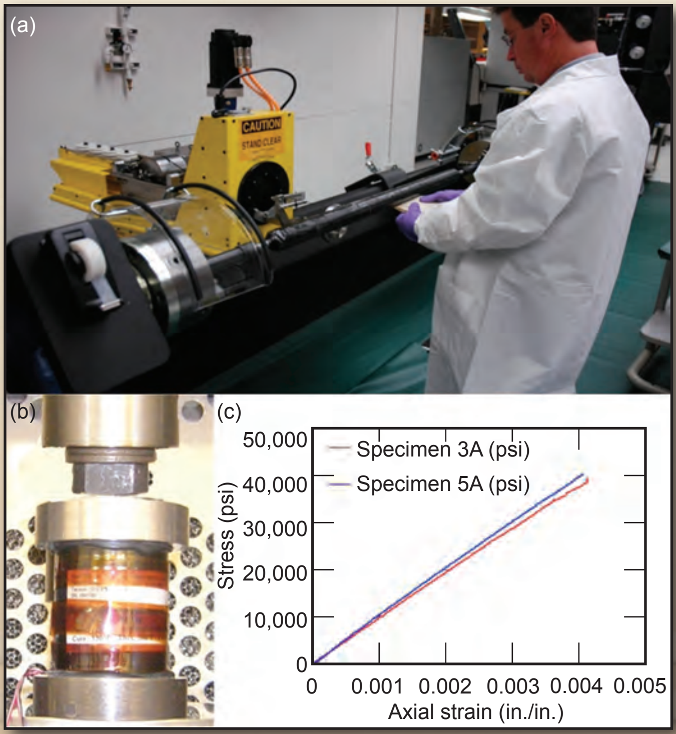

Figure 3. Composite thermal damage tests: (a) photograph of 2-in. composite tubes being manufactured; (b) instrumented composite tube being compressed in an oven; (c) stress-strain response of composite tube at temperature up to failure.