Enhanced Composite Modeling Tools

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Composite materials are used in many advanced weapons systems and structures at LLNL. We have previously enhanced our ability to simulate structural response and progressive failure of composite systems in ALE3D (an arbitrary Lagrange/Eulerian multi-physics code developed at LLNL) by porting an existing composite constitutive model (Model 22, the Fiber Composite with Damage Model) from DYNA3D (a nonlinear, explicit, 3-D FEM code for solid and structural mechanics). This year, a more advanced model (DYNA3D Model 62, the Uni-Directional Elasto-Plastic Composite Model) has been implemented. Experiments were conducted to validate the elastic response of the model and to give insights and data needed for the addition of a failure algorithm into the model.

Project Goals

We implemented the Uni-Directional Elasto-Plastic Composite Model into ALE3D. This included implementing the ability to input orthotropic orientation data into prescribed local volume elements. Another modeling goal was to enhance the model by incorporating a failure algorithm that includes matrix delamination, fiber tensile, and fiber compressive failure. Several experiments were conducted to provide data for the verification and validation of the model's implementation in ALE3D.

Figure 1. Fiber composite compression cylinder with 1.0-in.-diameter pin.

Relevance to LLNL Mission

The improved fiber composite material models can be used in simulations (to failure) in the many LLNL programs, such as those for composite munitions, armor penetration, pressure vessels, and rocket motors. This project has been beneficial in supporting the composite modeling efforts within the DoD Joint Munition Program and the Focused Lethality Munition Program. This study supports LLNL's engineering core competency in high-rate mechanical deformation simulations of large complex structures by providing an enhanced capability to model composite structures with ALE3D.

FY2007 Accomplishments and Results

The implementation of the Fiber Composite with Damage model into ALE3D, which was completed in the first year of this project, was verified with several code-to-code comparisons. The hoop stresses in pressurized cylinders from simulations run with DYNA3D, with the new Fiber Composite model in ALE3D, and with an existing anisotropic ALE3D model, all agreed within 1%. This included both explicit and implicit ALE3D runs.

The Uni-Directional Elasto-Plastic Composite model was implemented into ALE3D. An important part of this task was creating an algorithm to initialize and update material directions at the ply and element levels. The model was validated using the same pressurized-cylinder simulations described above, and the results were found to closely match the DYNA3D predictions.

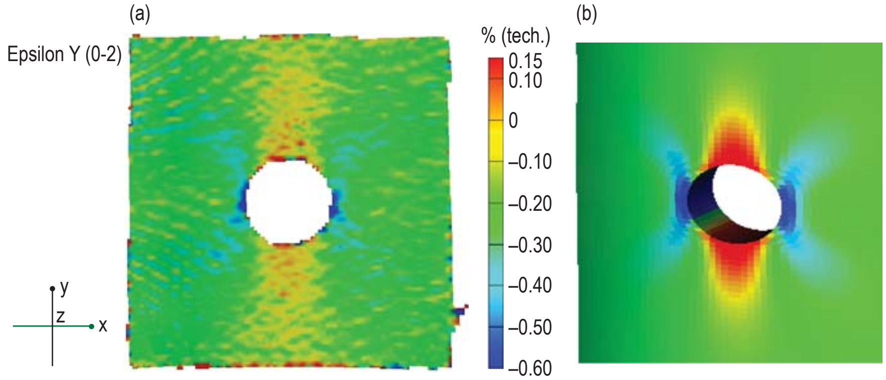

Figure 2. (a) Aramis axial stain results for fiber composite compression cylinder with no pin at 300,000 lbs of load. (b) The ALE3D simulation.

Composite failure mechanisms can be divided into two types: intra-ply failure mechanisms, such as fiber breakage, matrix failure (cracking/crushing), and fiber buckling; and inter-ply failure mechanisms involving ply delamination.

Intra-ply failure can be applied at the ply level and so fits in well with this model's "unit cell" approach. Inter-ply failure that includes crack opening between plies and plies sliding relative to each other affects all layers simultaneously, and so is more difficult to implement. All the relevant mathematical expressions necessary for these functionalities have been derived, and the corresponding changes to the existing code have outlined. Implementation will be undertaken next year.

A series of compression tests to failure were conducted on eight different composite cylinder specimens with different fiber, fiber orientations, and resins. The data collected on the stiffness, Poisson's ratio, and ultimate strength of each specimen provide model validation data for the newly implemented models 22 and 62. The data also provide an expanded source of failure data for upcoming failure model validation in ALE3D.

Strain concentration factors in fiber composite cylinders with holes and bonded pins were measured using the Aramis video strain measurement system. The basic fiber composite cylinder with pin configuration is shown in Fig. 1. Figure 2 shows a comparison for the case of no pin (open hole) between the measured experimental data and the simulated response from ALE3D. The results appear to be very similar.

Strain concentration factors due to focused shear in composites were measured using the specimen shown in Fig. 3. This sample was loaded in compression to produce a concentrated shear band in the composite sample. The Aramis load strain curve is shown in Fig. 4.

Related References

1. Christensen, R., and E. Zywicz, "A Three Dimensional Constitutive Theory for Fiber Composite Laminants," *Journal of Applied Mechanics*, **57**, pp. 948-955, December 1990.

2. Chang, F. K., and K. Y. Chang, "A Progressive Damage Model for Laminated Composites Containing Stress Concentration," *Journal of Composite Materials*, **21**, pp. 834-855, 1987.

FY2008 Proposed Work

In a proposed follow-on project, we will continue to improve fiber composite modeling in ALE3D, with an emphasis on local bending response and progressive damage. We plan to implement ply-level capabilities and damage algorithms taken from a specialized LLNL ply-level composite code known as ORTHO3D, and verify their implementation experimentally.

Figure 3. Composite shear specimen from section of a Mk82.

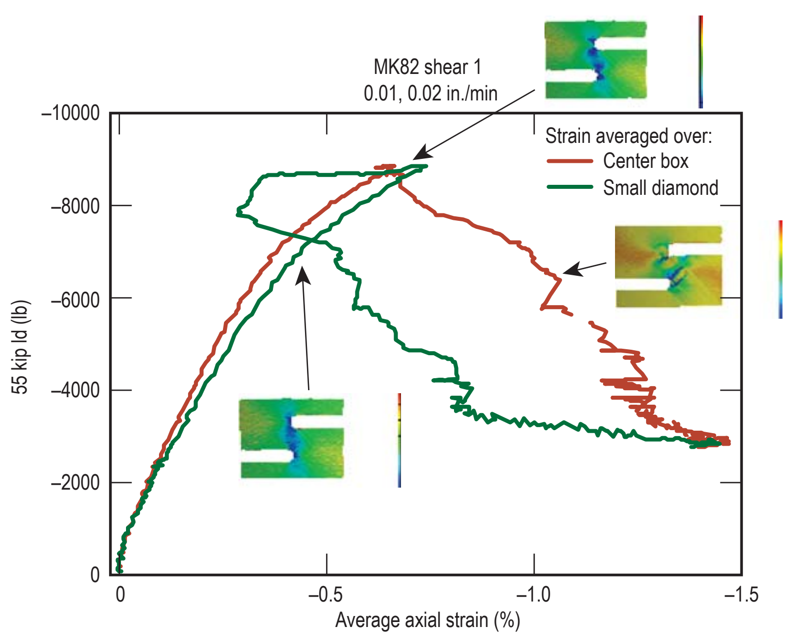

Figure 4. Shear strain concentration in composite Mk82 shear specimen.