e-TIME 2004
National Conference on emerging trends in Mechanical Engineering
February 05-06 2004, KDKCE, Nagpur
Paper Number:e-TIME/109/e-06

FINITE ELEMENT ANALYSIS OF ELASTO-PLASTIC AND TENSILE DAMAGE RESPONSE IN CARBON – CARBON COMPOSITES UNDER VEHICULAR CRUSH CONDITIONS

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ABSTRACT

This paper presents the impact simulation of carbon-fiber-reinforced composites for automotive applications. The biaxial loading of composites are modeled using the nonlinear, finite element code DYNA3D using a user-defined material subroutine to simulate the dynamic, inelastic behavior and the progressive damage of the composite materials. The damage model considering crack and progressive interfacial debonding is numerically simulated to study the elasto-plastic behavior of randomly oriented, crack-weakened, progressively debonded composites containing discontinuous fibers. The dominant damage mechanisms are matrix cracks initiating at the fiber ends and fiber-matrix debonding, and the damage process is controlled by the flexural deformations.

1. INTRODUCTION

Automotive structures manufactured from carbon fiber based composites offer the potential for significant advantages in weight, durability, design flexibility, and investment cost [1, 2]. While substantial experience with graphite-fiber laminated composites exists in the aerospace community, little knowledge exists in how carbon-fiber composites respond in automotive type applications during impact-induced "crash" loading conditions (i.e., "crush"). Furthermore, predictive analytical and numerical tools required to evaluate accurately and design carbon fiber automotive structures for crush do not currently exist. The actual mechanisms of failure are dependent on fiber length, tow size, crush speed, triggers and geometry of the structure [3, 4, 5].

This paper presents the study elasto-plastic and tensile damage response in carbon-fiber composites under vehicular crush conditions. The nonlinear finite element code DYNA3D is used for this problem. DYNA3D uses a user-defined material subroutine to simulate the dynamic, inelastic behavior and the progressive damage of the carbon fiber composites. The damage model considering crack and progressive interfacial debonding is simulated to illustrate the elasto-plastic behavior of randomly oriented, crack-weakened, progressively debonded composites containing discontinuous fibers.

In this study, the carbon fibers are assumed to be elastic spheroids and are randomly oriented in a ductile matrix. The Weibull's probabilistic function is used to model the varying probability of progressive partial fiber debonding.

2. FINITE ELEMENT MODELING

It is necessary to characterize the behavior of materials under impact loading conditions to describe the various phenomena taking place during impact. The characterization involves not only the stress-strain response at large strains and different strain rates, but also the accumulation of damage and the mode of failure. Such complex material damage behavior under dynamic loading is difficult to describe in analytical models. In numerical simulations, constitutive models of nearly any degree of complexity can be incorporated into the code. Therefore, the constitutive models derived are implemented into the nonlinear finite element code using a user-defined material subroutine to simulate the dynamic in-elastic behavior and the progressive damage of the composite materials. While the implicit integration is chosen with an automatic time increment because it is not restricted to mildly nonlinear deformations or short response times, the explicit method is computationally attractive when the response time of interest is within an order of magnitude of the time it takes for a stress wave to travel through the shell thickness. Accordingly, the developed damage models are implemented into the explicit finite element code DYNA3D for implicit simulations that require a very small time step.

The methodology used in this work is based on the strain-driven algorithm in which the stress history is to be uniquely determined by the given strain history, mainly because of its computational efficiency in the framework of the explicit time integration computer program DYNA3D. The two-step operator splitting methodology is also adopted to split the elastoplastic loading process into the elastic predictor and the plastic corrector. In this present work, the shell elements are used. The discretization and biaxial loading of the carbon-carbon composite is shown in Fig-1.

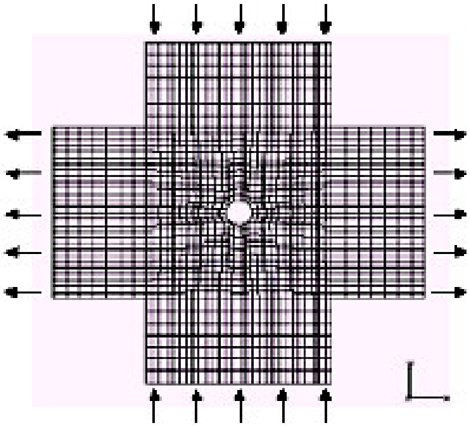

Fig-1 Discretization composite sample

3. MATERIAL PROPERTIES AND LOADING

The volume fraction is taken as 0.5 and the Poisson's ratio is assumed to be 0.23 for both the matrix and fibers. As a debonding property of the fiber-matrix interface, four sets of the Weibull parameters are used: S_o = 0.109X150 MPa and M = 4; S_o= 0.80X150 MPa and M = 4; S_o = 1.09X150MPa and M = 4; and S_o = 10.9X150MPa and M = 4. The normalized effective elastic modulus and the contract ratios are shown in Fig-2.

The geometry and loading conditions in this problem are symmetric along the x- and y-axes. The composite specimen is loaded proportionally with the rate of 125 N/sec in biaxial compression and tension in the ratio of 1:1.

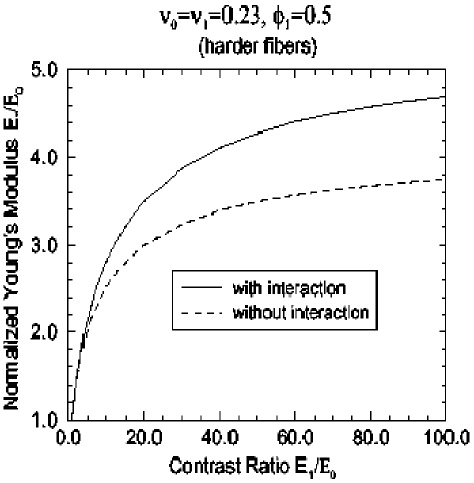

Fig-2 Comparison of Elastic ratios with or without inter fiber interaction

4. RESULTS AND DISCUSSION

A computational model of the cruciform shaped composite specimen and loading conditions are shown in Fig-3. The sequence of damage contours during biaxial loading, representing the growth of damage zone due to the advancing damage one emanating from the edges of the cutout is shown in Fig-4. The identified damage mechanisms include local crushing of the chamfer, matrix cracking at the ends of the fibers, and fiber-matrix debonding. When testing under the unconstraint condition, fiber pullout, fiber breakage, and fiber buckling was observed. The loose and tight constraint conditions resulted in more predictable damage mechanisms. The response consisted of four distinct stages: the first stage being an initial rapid load increase, the second stage was a rapid load decrease, followed by the third stage that was a gradual load saturation, and then finally the fourth stage where stable crushing occurred at a constant mean load.

The fracture surface of carbon-carbon composite tested using four-point bending is shown in Fig-5. The dominant damage mechanisms are matrix cracks initiating at the fiber ends and fiber-matrix debonding, and the damage process is controlled by the flexural deformations.

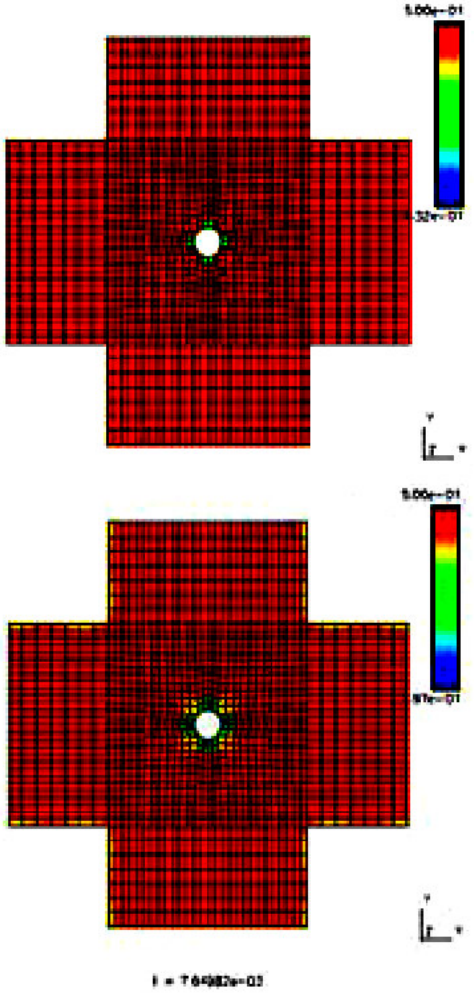

Fig-4 Contours of damage index, indicating the volume fraction of damaged fibers, during biaxialloading

5. CONCLUSIONS

The nonlinear, finite element code DYNA3D was used with user-defined material subroutine to simulate the dynamic, inelastic behavior and the progressive damage of the composite materials. The damage model considering crack and progressive interfacial debonding is simulated to study the elasto-plastic behavior of randomly oriented, crack-weakened, progressively debonded composites containing discontinuous fibers. The dominant damage mechanisms are matrix cracks initiating at the fiber ends and fiber-matrix debonding, and the damage process is controlled by the flexural deformations.

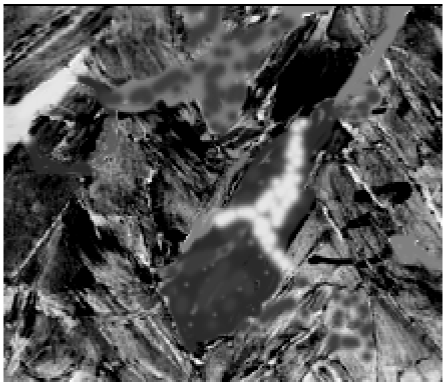

Fig-5 Fracture surface of carbon reinforced composite

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