A MICROMECHNICAL CONSTITUTIVE MODEL OF EVOLUTIONARY DAMAGE IN RANDOM FIBER COMPOSITES

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Introduction

The goal to provide lighter-weight, more fuel-efficient automobiles capable of greater crashworthiness provides an incentive for continued development of advanced materials. Light-weight Random Carbon Fiber Polymer Matrix Composite (RCFPMC) has the potential to satisfy the requirements, and because of its relatively low cost, it is a strong candidate for automobile applications. Low velocity impact can cause significant damage to RCFPMC in terms of matrix cracks and delaminations inside the composite. Such damage is very difficult to detect and may cause significant reduction in the strength and stiffness of the material.

Following the work of Zhao and Weng (1995) and Ju and Lee (1999), we propose a three-dimensional, micromechanical damage constitutive model for effective elastoplastic behavior of damaged composite material to address the damage response of RCFPMC. In the future, the present micromechanical damage constitutive models will be implemented into finite element code DYNA-3D to address the progressive crushing in composite structures under impact loading.

Overall elastoplastic behavior of random fiber composites

To estimate the overall elastoplastic damage response, an effective yield criterion is derived based on the ensemble-volume averaging process and first-order effects of eigenstrains due to the existence of spheroidal (prolate) fibers. The effective yield criterion, together with the assumed overall associative plastic flow rule and hardening law, constitutes the analytical foundation for the estimation of effective elastoplastic behavior of ductile matrix composites. First, an effective elastoplastic constitutive damage model for aligned fiber-reinforced composites is developed. A micromechanical damage constitutive model for RCFPMC is then developed. The average process over all orientations upon governing constitutive field equations and overall yield function for aligned fiber-reinforced composites is performed to obtain the constitutive relations and effective yield function of RCFPMC.

Evolutionary interfacial debonding

The progressive interfacial debonding may occur under increasing deformations and influence the overall stress-strain behavior of randomly oriented, discontinuous fiber reinforced composites. After the interfacial debonding between fibers and the matrix, the debonded fibers lose the load-carrying capacity in the debonded direction and are regarded as partially debonded fibers. Within the context of the first-order (noninteracting) approximation, the stresses inside fibers should be uniform. For convenience, following Zhao and Weng (1995), we employ the average internal stresses of fibers as the controlling factor. The probability of partial debonding is modeled as a two-parameter Weibull process; see Ju and Lee (1999). Assuming that the Weibull statistics governs, we can express the cumulative probability distribution function of fiber debonding (damage), P_d, at the level of hydrostatic tensile stress as:

$$P_d[(\bar{\sigma}_m)_1] = 1 - exp\left[-\left(\frac{(\bar{\sigma}_m)_1}{S_o}\right)^M\right]$$

where $(\boldsymbol{\sigma}_m)_1$ is the hydrostatic tensile stress of the fibers, the subscript denotes the fiber phase, and S_o and M are the Weibull parameters.

Experimental comparison

We compare our prediction with the experimental data provided by Mergahni and Benzeggagh (1995) in Figures 1 and 2. Since our formulation does not consider inter-fiber interaction, the stress-strain curve for the present prediction is lower than that based on experiment in early stage. As the strain increases, the effect of damage becomes dominant. The stress-strain curves corresponding to the present prediction and the experiment will intersect each other, because the proposed damage constitutive model includes the interfacial debonding only. Therefore, it is concluded that the interaction effect among constituents must be considered in modeling damage behavior of composites for moderately and extremely high fiber volume fraction. Furthermore, damage mechanisms, such as matrix cracking, void nucleation, etc., must be included in our damage constitutive models to offer more realistic damage predictions. Finally, the present model does not account for other damage mechanisms nor impact since these effects are beyond the scope of the present stage of this research. In spite of these limitations, the agreement between the present predictions and experiments is encouraging for possible use of the proposed damage constitutive models for predicting the progressive damage in composite structures.

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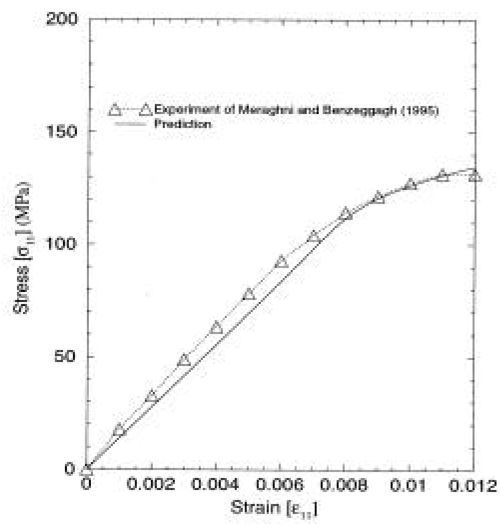

Figure 1. The comparison between the present prediction and experimental data (Meraghni and Benzeggagh, 1995) for overall uniaxial tensile responses of randomly oriented discontinuous fiber composites at initial fiber volume fraction of 0.5.

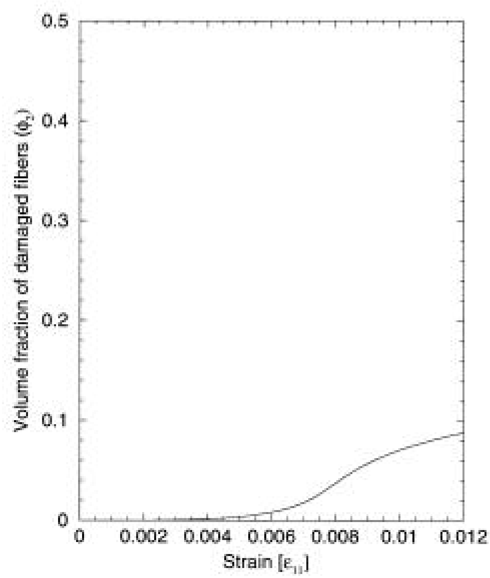

Figure 2. The predicted evolution of debonded fiber volume fraction versus strain corresponding to Figure 1.