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An elastoplastic multi-level damage model for ductile matrix composites considering evolutionary weakened interface

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Abstract

An elastoplastic multi-level damage model considering evolutionary weakened interface is developed in this work to predict the effective elastoplastic behavior and multi-level damage evolution in particle reinforced ductile matrix composites (PRDMCs). The elastoplastic multi-level damage model is micromechanically derived on the basis of the ensemble-volume averaging procedure and the first-order effects of eigenstrains. The Eshelby's tensor for an ellipsoidal inclusion with slightly weakened interface [Qu, J., 1993a. Eshelby tensor for an elastic inclusion with slightly weakened interfaces. Journal of Applied Mechanics 60 (4), 1048–1050; Qu, J., 1993b. The effect of slightly weakened interfaces on the overall elastic properties of composite materials. Mechanics of Materials, 14, 269–281] is adopted to model particles having mildly or severely weakened interface, and a multi-level damage model [Lee, H.K., Pyo, S.H., in press. Multi-level modeling of effective elastic behavior and progressive weakened interface in particulate composites. Composites Science and Technology] in accordance with the Weibull's probabilistic function is employed to describe the sequential, progressive weakened interface in the composites. Numerical examples corresponding to uniaxial, biaxial and triaxial tension loadings are solved to illustrate the potential of the proposed micromechanical framework. A series of parametric analysis are carried out to investigate the influence of model parameters on the progression of weakened interface in the composites. Furthermore, the present prediction is compared with available experimental data in the literature to verify the proposed elastoplastic multi-level damage model.
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Keywords: Elastoplastic behavior; Evolutionary weakened interface; Multi-level damage model; Particle reinforced ductile matrix composites (PRDMCs)

1. Introduction

Ductile matrix composites (e.g., metal matrix composites, MMCs) reinforced with various shapes of particles, fibers or whiskers have been used in aerospace, electronics and a variety of other engineering applica-

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tions. In particular, MMCs combine the properties of high strength and high modulus ceramics with those of high ductile metals or alloys to produce enhanced mechanical properties of the composite over metal or alloys (Ravi et al., 2007).

Particle or fiber reinforced ductile matrix composites are in general subjected to a number of damage modes on the microscale (Drabek and Bohm, 2004). Debonding phenomenon existed in between particles and the matrix is one of the major damage modes in particle reinforced ductile matrix composites (PRDMCs) and its effect on the mechanical behavior of the composites has to be well addressed for an accurate analysis of the composites (Lee and Pyo, in press). Ju and Chen (1994c) developed a micromechanical formulation to predict the effective elastoplastic behavior of two-phase PRDMCs under arbitrary loading histories by considering the first-order stress perturbations of elastic particles on the ductile matrix. Ju and Tseng (1996, 1997) further improved Ju and Chen's (1994c) work by incorporating second-order stress perturbations due to pairwise particle interactions.

Qu (1993a,b) derived the Eshelby's tensor for an ellipsoidal inclusion with slightly weakened interface in an elastic matrix of infinite extent where the weakened interface between the inclusion and the matrix was modeled by a spring layer of vanishing thickness. Lee and Pyo (2007) proposed a micromechanics-based elastic damage model to predict the effective elastic behavior and weakened interface evolution in particle composites. The Eshelby's tensor for an ellipsoidal inclusion with slightly weakened interface (Qu, 1993a,b) was adopted in their formulations to model the weakened interface. Most recently, Lee and Pyo (in press) proposed a multi-level elastic damage model based on a combination of a micromechanical formulation and a multi-level damage model to predict the effective elastic behavior and progressive weakened interface in particulate (brittle) composites. Their multi-level damage model in accordance with the Weibull's probabilistic function described the sequential, progressive weakened interface in the composites.

The primary objective of the present work is the extension of the framework of Lee and Pyo (in press) to accommodate the elastoplastic behavior and multi-level damage evolution in PRDMCs. Following Lee and Pyo (in press), the four-level elastic damage model, which was illustrated in Fig. 1 of Lee and Pyo (in press), is adopted for a complete description of the sequential progression of weakened interface in the composite: (1) Level 0 of two-phase composite state consisting of a ductile matrix and perfectly bonded particles; (2) Level 1 of three-phase composite state consisting of a ductile matrix, perfectly bonded particles and particles having mildly weakened interface; (3) Level 2 of four-phase composite state consisting of a ductile matrix, perfectly bonded particles, particles having mildly weakened interface and particles having severely weakened interface; (4) Level 3 of five-phase composite state consisting of a ductile matrix, perfectly bonded particles, particles having mildly weakened interface, particles having severely weakened interface and completely debonded particles.

Since two different damage modes of weakened interface (mildly weakened interface and severely weakened interface) are assumed to occur sequentially (Lee and Pyo, in press), weakened interface would be developed and transformed from one mode to another as deformations or loadings continue to increase. Accordingly, there may be two different modes of weakened interface (mildly weakened interface and severely weakened interface) occurring simultaneously at the Level 2 of four-phase composite state. It will be followed by three different modes of weakened interface (mildly weakened interface, severely weakened interface and complete debonding) occurring simultaneously at the Level 3 of five-phase composite state at the next step. The two-parameter Weibull statistics is adopted to estimate the volume fraction of particles with different modes of weakened interface.

Particles are assumed to be non-interacting, randomly dispersed, elastic spheres that are initially embedded firmly in the ductile matrix with perfect interfaces. It is also assumed that the progression of weakened interface is governed by the average internal stresses of perfect bonded particles (Phase 1) as well as the Weibull parameters (Weibull, 1951). Numerical examples corresponding to uniaxial, biaxial and triaxial tension loadings are solved to illustrate the potential of the proposed micromechanical framework. A series of parametric analysis are carried out to investigate the influence of model parameters on the progression of weakened interface in the composites. Furthermore, the present prediction is compared with available experimental data in the literature to further illustrate the elastoplastic damage behavior of the present framework and to verify the proposed elastoplastic multi-level damage model.

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