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A UNIFIED METHODOLOGY FOR THE HOMOGENIZATION OF PERIODIC MATERIALS WITH DAMAGE

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ABSTRACT

A unified elasticity-based approach is proposed to model the evolution of damage in periodic heterogeneous materials based on the use of displacement discontinuity functions. These functions may represent cracks or traction-interfacial separation laws within the flexible interface model framework. The approach is incorporated into the finite-volume direct averaging micromechanics (FVDAM) theory and its utility demonstrated by revisiting the classical fiber/matrix debonding phenomenon observed in SiC/Ti composites.

Keywords: micromechanics, homogenization, finite-volume method, damage, crack growth, fiber/matrix debonding.

INTRODUCTION

Damage evolution in heterogeneous materials continues to receive considerable attention in the literature due to current emphasis on sustainability and efficiency in modern structural designs. The problem is a complex one due to the many local damage and failure mechanisms that occur in heterogeneous materials with large microstructure-induced stress fluctuations and stress gradients, including microcracks, phase debonding and separation. Crack growth in such circumstances is typically non self-similar, requiring continuous re-meshing of the analysis domain within the variational framework, together with the application of the appropriate crack-growth criterion for the particular material system. To mitigate these complications, the flexible interface concept has been proposed in the literature, and implemented in variational-based computer codes to naturally track damage progression.

Herein, we propose a unified approach for the treatment of damage in heterogeneous materials that allows simulation of crack growth and phase separation based on the flexible interface model within the same framework. The approach is based on the introduction of displacement discontinuity functions previously used in the solution of interfacial crack problems in multilayered materials (Chen and Pindera, 2007). The discontinuity functions are obtained upon solution of auxiliary equations that represent either traction-free crack face conditions, or interfacial separation between phases governed by nonlinear traction-interfacial separation laws. The approach is implemented into the finite-volume direct averaging micromechanics (FVDAM) theory (Cavalcante et al., 2012) to demonstrate its utility in the context of the classical fiber/matrix debonding problem in SiC/Ti unidirectional composites.

RESULTS AND CONCLUSIONS

The material parameters of the SiC fibers and elastic-plastic strain-hardening titanium matrix are given in the table, with hardening represented by the effective stress - effective plastic strain curve $\sigma_{eff} = \sigma_{yield} + H_p \varepsilon_{eff}$. The SiC fiber volume fraction is 0.40, and the unit cell representative of unidirectional SiC/Ti composite with a fiber/matrix disbond is show in the figure.

Table 1 - Material parameters of the elastic SiC fibers and elastic-plastic Ti matrix.

Material	***E* (GPa)**	ν	σ_{yield} **(MPa)**	H_p **(MPa)**
SiC fiber	400.0	0.25	---	---
Ti matrix	91.04	0.36	758	2003

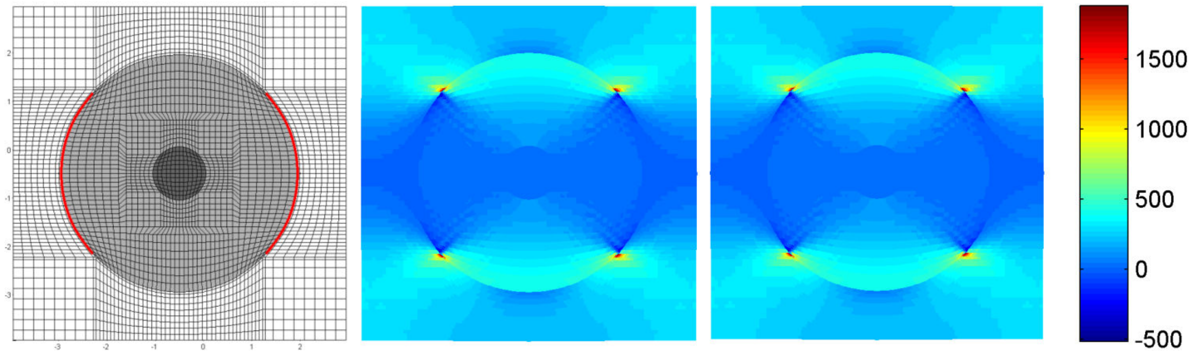

Fig.1 - Unit cell representative of the unidirectional SiC/Ti composite with an interfacial crack subjected to transverse loading (left), and the ensuing transverse normal stress distributions obtained from the standard (middle) and unified (right) approaches (color bar in MPa).

Included in the figure are the normal stress distributions due to the applied transverse load obtained from the standard and unified approaches. In the standard approach, the crack is treated as a traction-free boundary in the solution of the unit cell problem governed by a single system of equations for the unknown surface-averaged displacements within the FVDAM framework. In the unified approach, the primary system of equations is constructed of interfacial surface-averaged displacements required to be continuous, and boundary displacements subject to periodicity conditions. The fiber/matrix disbond is governed by an auxiliary system of equations that is coupled with the primary system. As observed in the figure, identical stress distributions are obtained using both approaches. Use of a nonlinear traction-interfacial separation law facilitates efficient simulation of progressive debonding around the interface without the complication of applying a computationally intensive energy release rate criterion.

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