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The effect of anisotropic damage evolution on the behavior of ductile and brittle matrix composites

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ABSTRACT

Anisotropic damage evolution laws for ductile and brittle materials have been coupled to a micromechanical model for the prediction of the behavior of composite materials. As a result, it is possible to investigate the effect of anisotropic progressive damage on the macroscopic (global) response and the local spatial field distributions of ductile and brittle matrix composites. Two types of thermoinelastic micromechanics analyses have been employed. In the first one, a one-way thermomechanical coupling in the constituents is considered according to which the thermal field affects the mechanical deformations. In the second one, a full thermomechanical coupling exists such that there is a mutual interaction between the mechanical and thermal fields via the energy equations of the constituents. Results are presented that illustrate the effect of anisotropic progressive damage in the ductile and brittle matrix phases on the composite's behavior by comparisons with the corresponding isotropic damage law and/or by tracking the components of the damage tensor.

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1. Introduction

In the most general formulation of the continuum damage mechanics, the damage state should be represented by a fourth-order tensor. Such a formulation however would be too difficult and not necessary, Voyiadjis and Kattan (2005) and Lemaitre and Desmorat (2005). Theories with scalar damage variables are the easiest to handle. Anisotropic damage theories are based on second-order damage state representations. Discussions and presentations of continuum damage mechanics and the various formulations of the damage states and their evolution laws can be found in the books by Kachanov (1986), Lemaitre and Chaboche (1990), Krajcinovic (1996), Lemaitre (1996), Voyiadjis and Kattan (2005), and Lemaitre and Desmorat (2005), for example. Applications of continuum damage mechanics theories on composites materials are given by Talreja (1985a,b, 1994), Voyiadjis and Deliktas (1997) Voyiadjis and Kattan (1999), Skrzypek and Ganczarski (1999), Barbero (2008), Haj-Ali (2009), Bednarcyk et al. (2010), Haj-Ali and Aboudi (2010) and references cited there.

Lemaitre et al. (2000) presented a continuum damage theory with anisotropic damage evolution in ductile materials that generalizes the isotropic damage theory of Lemaitre (1985a,b) which is based on a scalar variable. In addition, Lemaitre and Desmorat (2005) presented anisotropic damage model for a brittle material (concrete). The purpose of the present investigation is to couple these theories with a micromechanics model for the prediction of the response of ductile and brittle matrix composites with evolving damage. As is shown in this investigation, the resulting micromechanics analyses enable the study of the effect of anisotropic damage laws by comparisons with the corresponding isotropic damage theories and by tracking the evolutions of the components of the damage tensor.

The micromechanics model that is employed in the present investigation is referred to as *The High Fidelity Generalized Method of Cells* (HFGMC) which is based on the homogenization procedure for periodic multiphase composites. This micromechanics model has been reviewed by Aboudi (2004) and more recently has been shown by Haj-Ali and Aboudi (2009) to provide excellent prediction for (undamaged) nonlinear and inelastic matrix composites by extensive comparisons with finite element solutions. In addition, this micromechanics model has been coupled by these authors to a finite element software to investigate the response of metal matrix composite structures.

This paper is organized as follows. In Section 2, the isotropic and anisotropic damage theories in unreinforced ductile materials are presented. This is follows by the presentation of the anisotropic damage theory of a brittle material. In Section 3, the HFGMC micromechanics theory is outlined. This includes the one-way and fully coupled thermoinelastic HFGMC. In the former theory, the conventional constitutive equations is employed according to which the thermal effects in the constituent affect the mechanical response of the material. In the latter theory, the fully coupled

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