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Micromechanical modeling of smart composites considering debonding of reinforcements

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ABSTRACT

Using the information of the microstructure, this paper presents the development of an incremental constitutive law governing the response of an electro-magneto-thermo-mechanical smart composite. In this development, different shapes of reinforcements that have magneto-electro-thermo-elastic properties that differ from the matrix material are considered. Shapes such as ellipsoidal (spherical, prolate and oblate) particles, elliptical and circular cylindrical fibers, disk and ribbon can be treated provided that the corresponding Eshelby tensor is used. The debonding of the reinforcements from the matrix is also a part of the microscopic process considered. The developed incremental constitutive law not only predicts the macroscopic and microscopic electro-magneto-thermo-mechanical-elastic behavior of composites while considering the debonding process, but it also characterizes their different macroscopic effective properties such as permittivity, permeability, stiffness moduli, pyroelectricity, pyromagnitivity and thermal expansion coefficient in different directions. Moreover, the developed constitutive law is applicable to porous materials and composites with multiple reinforcements and porosities. In the two examples considered below, particular attention is devoted to assessing the effects of both the shape and the concentration of the inclusion and/or porosity and the damage evolution on the multiphysical microscopic and macroscopic behaviors and the effective properties. The first example sheds light on obtaining the macroscopic effective properties, taking into account the piezoelectric $BaTiO_3$ continuous fibers embedded in the piezomagnetic $CoFe_2O_4$ matrix. While in the second example, mechanical loading is considered, epoxy is taken as the matrix material and the response of the composite is presented while the evolution of damage in terms of debonding is taking place.

1. Introduction

Composite materials consisting of piezoelectric and piezomagnetic phases have drawn a significant interest due to the rapid development in adaptive material systems. However, the increased complexity of the microstructure in these materials complicates their analysis. One possible route to solve such complexity is to achieve useful models that calculate the effective material properties. Therefore, many studies were concerned with the prediction of the effective or overall properties using various techniques. For instance, Aboudi (2001) employed a homogenization micromechanical method to predict the effective moduli of electro-magneto-thermo-elastic composites. Results for fibrous and periodically bilaminated composites were compared with the generalized method of cells and the Mori–Tanaka predictions. Li and Dunn (1998b) developed a micromechanical approach to analyze the average fields and effective properties of heterogeneous media that exhibit full coupling between stationary elastic, electric and magnetic fields. Using the solutions obtained for inclusion and inhomogeneity problems in an infinite magneto-electro-elastic medium (Li and Dunn, 1998a), they established exact relations for the internal field distribution inside a heterogeneous magneto-electro-elastic solid. In addition, they obtained closed-form expressions for the effective moduli of fibrous and laminated composites as well as the exact connections between the effective thermal moduli and the effective magneto-electro-elastic moduli of two-phase composites. Li (2000) studied the average magneto-electro-elastic field in a multi-inclusion or an inhomogeneity embedded in an infinite matrix and developed a numerical algorithm to evaluate the magneto-electro-elastic Eshelby tensors for the general material symmetry and ellipsoidal inclusion. Based on the framework of the Variational Asymptotic Method for Unit Cell Homogenization (VAMUCH), Tang and Yu (2009) developed a micromechanics approach to predict the effective properties as well as the local fields of periodic smart materials responsive to fully coupled electric, magnetic, thermal and mechanical fields.

Voids exist in smart materials and some inclusions may be partially or fully debonded from the matrix. These can be attributed to

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