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Overall electroelastic moduli of particulate piezocomposites with non-dilute BCC microstructure

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ABSTRACT

The present paper addresses an analytical method to determine the overall behavior of piezocomposite materials containing body centered cubic (BCC) distribution of arbitrary oriented ellipsoidal heterogeneities. This approach is based on the extension of the electromechanical equivalent inclusion method (EMEIM) to interacting multi-inhomogeneities. In this treatment the short and long range interactions of the piezoelectric particles are appropriately incorporated through the homogenizing eigenstrain–electric field. The periodicity of the microstructure of the medium suggests representing the eigenfields in terms of Fourier series, accounting for the matrix–particle, interparticle and interaparticle interactions with high precision. The proposed method is also extended to problems, where the reinforcement particles may have very thick and/or functionally graded (FG) coatings. Through consideration of several complex scenarios the robustness and applicability of the proposed theory are demonstrated. Accordingly, the effects of volume fraction, thickness and electroelastic moduli of coating, as well as shape and orientation of the coated ellipsoidal reinforcements on overall behavior of piezocomposite are thoroughly examined. A strong dependence of overall response of piezocomposite on the microstructure of their reinforcement particles is recognized.

1. Introduction

As monolithic piezoelectric materials suffer from several drawbacks, they may be replaced by particulate piezocomposites, which combine the superior electroelastic properties of piezoelectric particles with the toughness and flexibility of the host matrix. In fact, particulate reinforced piezocomposites became important materials to modern engineering applications due to their favorable electromechanical properties. Nowadays, these high performance materials are being widely used in smart materials and structures like sensors, actuators and ultrasonic imaging systems [1–3]. The particles in these materials may be encapsulated by several coating layers of distinct electromechanical properties. In this, the transition zone may be created inadvertently by chemical reactions between particles and matrix or may be created intentionally to improve thermo-electro-mechanical properties of solids (Beckert et al. [4], Wang et al. [5], Torah et al. [6] and Lin and Sodano [7]). For instance, the formation of micromechanical gradients in the transition zone around the inhomogeneities is a well-known phenomenon. In their region the porosity is maximum in the proximity of the particle and decreases with distance away from the particle. For that reason, the electromechnical properties of the transition zone are functionally graded (FG), i.e. its composition varies continuously from the core particle to the surrounding matrix.

The microgeometry and the associated property of each phase of the particle ensemble, thickness of the coatings, volume fraction of particles and their coatings, distribution and alignment of the particles, as well as the interface conditions are of great importance in controlling the overall electro-mechanical behavior of piezocomposite materials. Attention should be given not only to the interaction within the phases of a given particle ensemble, but one should properly consider the interaction between all phases of the ensembles of piezoelectric particles. Examination of the literature reveals that in the estimation of the macroscopic behavior of particle reinforced piezocomposites most of the existing theories are pertinent to single-phase particles. For example, for a study on piezocomposites with random microstructure, see Dunn and Taya [8], Wu [9] and Fang et al. [10]. On piezocomposites with periodic distribution of single phase piezoelectric particles, the work of Wei et al. [11] should be mentioned. In the past, a few investigations have been devoted to the random distribution of thinly coated particles; see, for example, Li [12], Jiang et al. [13], Dinzart and Sabar [14] and Lin and Sodano [15]. Generally speaking, the overall behavior of piezocomposites with periodic multi-coated piezoelectric inhomogeneities appears to

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