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Magneto-electro-elastic coated inclusion problem and its application to magnetic-piezoelectric composite materials

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ABSTRACT

In this work, a micromechanical model for the estimate of the magneto-electro-elastic behavior of the magnetic-piezoelectric composites with coated reinforcements is proposed. The coating is considered as a thin layer with properties different from those of the inclusion and the matrix. The micromechanical approach based on the Green's functions techniques and on the interfacial operators is designed for solving the magneto-electro-elastic inhomogeneous coated inclusion problem. The effective magneto-electro-elastic properties of the composite containing thinly coated inclusions are obtained through the Mori–Tanaka's model. Numerical investigations into magneto-electro-elastic moduli responsible for the magneto-electric coupling are presented as functions of the volume fraction and characteristics of the coated inclusions. Comparisons with existing models are presented for various shape and orientation of the coated inclusions.

1. Introduction

Consecutively to their attractive applications in smart and adaptative systems using their magneto-electro-mechanical energy conversion capacities, the study of such dedicated 'magneto-electro-elastic' materials has become more extensive in recent years. The coupled phenomena like piezoelectricity and piezomagneticity can be found in some natural single crystals (Alshits et al., 1992) and more widely in specifically dedicated composites (Harshe et al., 1993). The prediction of the overall properties of 'magneto-electric-elastic' composites has aroused great interest among researchers, in particular in the description of the coupled phenomena induced from discontinuous reinforcements. A better understanding of the interaction of microstructures and coupling effects such as magnetolectricity is essential for the comprehensive design of novel materials for desired applications. The magneto-electric (ME) coupling effects result from cross or product properties which are absent from each phases of the composite as described by the Nan et al. (2008) in their review.

The concept of hybrid fiber constituted of a core surrounded by a high performance piezoelectric materials has appeared recently for the sake of improvement of electroelastic properties (Torah et al., 2004). Xie et al. (2008) synthesized hybrid multiferroic $CoFe_2O_4$-$Pb(Zr_{0.52}Ti_{0.4})O_3$ nanofibers by electrospinning and obtained good ferroelectric and ferromagnetic properties measured by piezoresponse force microscopy. The effective properties of a composite are highly affected by the magneto-electro-elastic characteristics and the geometry of the interphase between the constituents. Consequently, studying the influence of a coating layer in 'magneto-electric-elastic' composites may be valuable to better understand the transmission of mechanical, electrical and magnetic fields throughout the inclusion toward the matrix for the sake of improvement of the strength and/or the ME. The increase of the strength may be obtained for example via the introduction of a stiff interphase of defined thickness as demonstrated by Kari et al. (2008) for elastic composites. The ME enhancement is more tricky as it implies coupled mechanical, electrical and magnetic properties. The voluntary introduction of an active interphase (in the sense of the ME) allows to comprehend the transmission of the different fields from the core towards the matrix. A parametric analysis conducted in a further publication may also provide the better material combination for core, coating and matrix to enhance the ME coupling. An interphase layer may be also introduced to model the debonding between the particles and the matrix (Sevostianov and Kachanov, 2007) or to describe hybrid magneto-electric composites synthesized with a core–shell (Islam et al., 2008).

First attempts to model the ME in multilayered composites were restricted to simplified material behavior (Harshe et al., 1993) or to particular geometry: fibrous (Benveniste, 1995) or lamellar composites (Huang et al., 1998). Huang and Kuo (1997) generalized the classical method based on inclusion formulation and Huang et al. (1998) extended the resolution to various shape inclusions thanks to the extension of the classical Eshelby's elastic tensor to magneto-electric behavior. The Green's functions techniques allowed the ME analysis via various homogenization scheme (Mori–Tanaka, self-consistent…), for multi-inclusion and

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