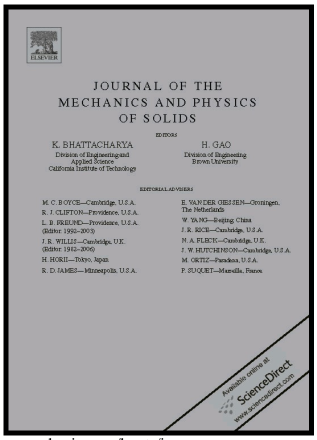

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PII: S0022-5096(16)30147-8
DOI: http://dx.doi.org/10.1016/j.jmps.2016.07.004
Reference: MPS2944

To appear in: *Journal of the Mechanics and Physics of Solids*

Received date: 3 March 2016
Revised date: 23 June 2016
Accepted date: 4 July 2016

Nonlinear electroelastic deformations of dielectric elastomer composites: I — Ideal elastic dielectrics

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Abstract

This paper puts forth homogenization solutions for the macroscopic elastic dielectric response — under finite deformations and finite electric fields — of ideal elastic dielectric composites with two-phase isotropic particulate microstructures. Specifically, solutions are presented for three classes of microstructures: *i*) an isotropic iterative microstructure wherein the particles are infinitely polydisperse in size, *ii*) an isotropic distribution of polydisperse spherical particles of a finite number of different sizes, and *iii*) an isotropic distribution of monodisperse spherical particles. The solution for the iterative microstructure, which corresponds to the viscosity solution of a Hamilton-Jacobi equation in five "space" variables, is constructed by means of a novel high-order WENO finite-difference scheme. On the other hand, the solutions for the microstructures with spherical particles are constructed by means of hybrid finite elements.

Prompted by the functional features shared by all three obtained solutions, a simple closed-form approximation is proposed for the macroscopic elastic dielectric response of ideal elastic dielectric composites with any type of (non-percolative) isotropic particulate microstructure. As elaborated in a companion paper, the proposed approximate solution proves particularly useful as a fundamental building block to generate approximate solutions for the macroscopic elastic dielectric response of dielectric elastomer composites made up of non-Gaussian dielectric elastomers filled with nonlinear elastic dielectric particles.

Key words: Iterated homogenization; Viscosity solution; Microstructures; Electroactive materials; Electrostriction

1. Introduction and main result

Since the turn of the millennium, dielectric elastomer composites — specifically, dielectric elastomers filled with (semi-)conducting or high-permittivity particles — have received increasing attention by the materials research community because of their potential to outperform unfilled dielectric elastomers for employment in emerging technologies (see, e.g., Zhang et al., 2002; Huang and Zhang, 2004; Huang et al., 2005; Carpi and Rossi, 2005; McCarthy et al., 2009, Meddeb and Ouanies, 2012; Liu et al., 2013). At present, however, the microscopic mechanisms responsible for the superior electromechanical properties of this type of electroactive composite materials remain unresolved. In the literature, there are two mechanisms that have been identified as possibly dominant: *i*) the nonlinear elastic dielectric nature of elastomers which heightens the role of the fluctuations of the electric field in the presence of filler particles (Li, 2003; Tian et al., 2012) and *ii*) the presence of high-dielectric interphases and/or interphasial free charges surrounding the filler particles (Lewis, 2004; Lopez-Pamies et al., 2014).

The objective of this two-part paper is to investigate the first of the two mechanisms stated above in the context of nonlinear electroelastic deformations. That is, we view dielectric elastomer composites as two-phase particulate composites — comprising a continuous dielectric elastomer matrix filled by a statistically uniform distribution of firmly bonded inclusions — and study their homogenized (macroscopic or overall) elastic dielectric response when subjected to finite deformations and finite electric fields. In light of the fact that the majority of existing experimental evidence pertains to dielectric elastomers filled with particles

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