Asociación Argentina de Mecánica Computacional

Mecánica Computacional Vol XXXIII, págs. 925-925 (resumen)
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San Carlos de Bariloche, 23-26 Setiembre 2014

HOMOGENIZATION ESTIMATES FOR THE ELECTROMECHANICAL RESPONSE OF TWO-PHASE FERROELECTRIC COMPOSITES

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Abstract. Ferroelectricity refers to the capacity of certain polar dielectrics to sustain a spontaneous electrical polarization that can be altered by application of an external electric field. Since this change in polarization is usually accompanied by a mechanical deformation, ferroelectrics are electro-deformable materials which find applications as sensors and actuators, energy harvesters, material damping enhancers, and other microdevices. Ferroelectric ceramics such as barium titanate and lead zirconate titanate are probably the most prominent examples among this class of materials.

The search for electro-deformable materials with specific combinations of properties not found in monolithic ferroelectrics has recently motivated the development of an increasing variety of two-phase ferroelectric composites. Composites with different purposes have been produced, for instance, by dispersing ferroelectric ceramic particles in a nonpolar polymeric matrix, by dispersing metallic particles in a ferroelectric ceramic matrix, and by dispersing ferroelectric ceramic inclusions in a ferroelectric polymeric matrix. Ferroelectric ceramics with controlled porosity have also been produced for certain acoustic applications. Now, under sufficiently high electric fields, all these composites exhibit significant electrical hysteresis and dissipation. The main contribution to that overall dissipation comes from the change of spontaneous polarization in the ferroelectric phase, and its precise amount depends on the dielectric response of each of the constituents and their geometrical arrangement. The purpose of this work is to estimate theoretically such dependence for general electromechanical loading histories.

To that end, the electro-deformable behavior of the constituent phases is described via a stored energy density and a dissipation potential in accordance with the theory of generalized standard materials. An implicit time-discretization scheme is used to generate a variational representation of the overall response in terms of a single incremental potential. Estimates are then generated by constructing sequentially laminated microgeometries of particulate type whose overall incremental potential can be computed exactly. Because they are realizable, by construction, these estimates are guaranteed to conform with any material constraints, to satisfy all pertinent bounds. Predictions for the electro-deformability of three-dimensional composites and porous ferroelectrics are reported and discussed in the light of existing experimental data.