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A new framework for large strain electromechanics based on convex multi-variable strain energies

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ABSTRACT
Following the recent work of Bonet et al. (2015), this paper postulates a new convex multi-variable variational framework for the analysis of Electro Active Polymers (EAPs) in the context of reversible nonlinear electro-elasticity. This extends the concept of polyconvexity (Ball, 1976) to strain energies which depend on non-strain based variables introducing other physical measures such as the electric displacement. Six key novelties are incorporated in this work. First, a new definition of the electro-mechanical internal energy is introduced expressed as a convex multi-variable function of a new extended set of electromechanical arguments. Crucially, this new definition of the internal energy enables the most accepted constitutive inequality, namely ellipticity, to be extended to the entire range of deformations and electric fields and, in addition, to incorporate the electro-mechanical energy of the vacuum, and hence that for ideal dielectric elastomers, as a degenerate case. Second, a new extended set of variables, work conjugate to those characterising the new definition of multi-variable convexity, is introduced in this paper. Third, both new sets of variables enable the definition of novel extended Hu–Washizu type of mixed variational principles which are presented in this paper for the first time in the context of nonlinear electro-elasticity. Fourth, some simple strategies to create appropriate convex multi-variable energy functionals (in terms of convex multi-variable invariants) by incorporating minor modifications to a priori non-convex multi-variable functionals are also presented. Fifth, a tensor cross product operation (de Boer, 1982) used in Bonet et al. (2015) to facilitate the algebra associated with the adjoint of the deformation gradient tensor is incorporated in the proposed variational electro-mechanical framework, leading to insightful representations of otherwise complex algebraic expressions. Finally, under a characteristic experimental setup in dielectric elastomers, the behaviour of a convex multi-variable constitutive model capturing some intrinsic nonlinear effects such as electrostriction, is numerically studied.