On the formulation and computational implementation of polyconvex electro-mechanics: phenomenologically invariant-based approaches and homogenised rank-n models

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Key Words: *polyconvexity, transversely isotropicity, dielectric elastomers, electro-elasticity*

The fabrication of evermore sophisticated miniaturised soft robotic components made up of Electro-Active Polymers (EAPs) is constantly demanding parallel development from the in-silico simulation point of view. The incorporation of crystallographic anisotropic microarchitectures, within an otherwise nearly uniform isotropic soft polymer matrix, has shown great potential in terms of advanced three-dimensional actuation (i.e. stretching, bending, twisting), specially at large strains, that is, beyond the onset of geometrical pull-in instabilities. To accommodate for this response, this paper presents two alternative approaches to account for anisotropic responses, namely, invariant-based polyconvex transversely isotropic model and homogenised rank-n models. This research expands previous work developed by some of the authors [1,2] and that of Schröeder and Neff [3] in the context of polyconvexity for materials endowed with crystallographic architectures in single physics mechanics.

The paper also summarises key important results both in terms of existence of minimisers and material stability. The high nonlinearity of the quasi-static electro-mechanical problem is resolved via a monolithic multi-scale Newton–Raphson scheme, which is enhanced with a tailor-made arc length technique, used to circumvent the onset of geometrical instabilities. A tensor cross product operation between vectors and tensors and an additive decomposition of the micro-scale deformation gradient (in terms of macro-scale and fluctuation components) are used to considerably reduce the complexity of the algebra. The possible loss of ellipticity of the homogenised constitutive model is strictly monitored through the minors of the homogenised acoustic tensor. In addition, a series of numerical examples is presented in order to demonstrate the effect that the anisotropic orientation and the contrast of material properties, as well as the level of deformation and electric field, have upon the response of the EAP when subjected to large three-dimensional stretching, bending and torsion, including the possible development of wrinkling.

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