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MODELING OF SINGLE CRYSTAL MAGNETOSTRICTION BASED ON NUMERICAL ENERGY RELAXATION TECHNIQUES

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Giant magnetostrictives and ferromagnetic shape memory alloys have received much attention from researchers due to their unique coupling properties that potentially enable novel active material-based applications, e.g. as sensors, actuators, transducers or energy harvesters. The modeling of nonlinear magnetostrictive response is typically based either on phenomenological macroscale approaches or alternatively on the variational theory of *micromagnetics* [1]. The latter predicts the evolution of magnetic microstructures under the influence of mechanical and magnetic fields, but requires simulations on very small time and length scales. Due to the complexity of realistic microstructures, it is then generally not feasible to simulate the response of samples of technologically-relevant size. In light of this, DeSimone and James [2] developed the *constrained theory of magnetoelasticity*, which is capable of predicting many relevant features of the macroscopic magneto-mechanical response, without requiring the detailed knowledge of the underlying domain structure. This micromechanically-motivated variational theory was derived from micromagnetics and is valid for phase changing materials whose free-energy densities grow steeply away from its minima. The set of admissible macroscopic states can then be constructed through the convex combination of the local deformation and magnetization states associated with the energy wells.

The presented approach builds on the DeSimone and James theory and aims to overcome some of its limitations, particularly that (i) dissipation is not considered, (ii) elastic strains are omitted and (iii) the magnetizations are rigidly attached to easy axes. The second and third limitations are due to the assumption of the *high anisotropy limit*. In the first step of extending the approach, the hysteretic nature of the response is accounted for by introducing an appropriate dissipation functional in an incremental variational setting. Secondly, the infinite anisotropy constraints are removed to allow for "non-energy-well"-states, with respect to local deformations and magnetization orientations. The associated

incorporation of elastic strains necessitates assumptions about the total strains in each of the martensitic variants. Furthermore, a magnetocrystalline anisotropy energy contribution is added to the incremental potential, whose zeros define the easy axes. The variant strains and local magnetization orientations represent additional microstructural degrees of freedom, which are determined via minimization of an incremental energy potential. In this manner, a relaxed energy density is obtained which serves as an approximation of the mathematically and physically desired quasiconvex hull. In the results presented here, we restrict our attention to *convexification*, since it offers the possibility of accounting for multiple martensitic phases in a straightforward manner and yields numerically robust algorithms. Representative numerical examples are discussed and compared to predictions based on the constrained theory. On-going work is concerned with extending existing numerical relaxation techniques, which are based on a rank-one convexification w.r.t. first and second-order laminates, that have successfully been employed in the context of conventional shape memory response [3], to the magnetomechanically-coupled case.

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