A thermodynamically consistent model for shape-memory ionic polymers

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Smart materials have recently attracted the attention of many researchers due to their unique multifunctional properties; however, their practical applications are still somehow limited due to the lack of constitutive models capable of accurate description of their multiphysics behavior. Dealing with ionic polymers with shape memory effects, e.g. the commercially available Nafion™, we propose a thermodynamically consistent model for the fully coupled chemo-electro-thermo-mechanical response to external stimuli. Moving from continuum thermodynamics, the relevant conservation laws are discussed. The constitutive equations are then obtained via an appropriate choice of the Helmholtz free-energy function, through the standard Coleman-Noll procedure. The free-energy function is set by properly linking recognized models for the description of electro-mechanical effects in ionic polymers on one side, and of shape memory effects in polymers on the other side. The instantaneous (elastic) and time-delayed (viscous) response of the polymer in a finite strain setting and the fixation of alternate shape configurations through a thermo-mechanical training are discussed. The obtained model is then implemented in the commercial finite element software Abaqus™ through a UEL (user element) interface. The model and its implementation are validated by comparing calculated numerical results with data obtained from tests conducted in an ad-hoc designed experimental campaign. Results are finally reported on the use of these shape-memory polymers as triggering mechanisms of folding/unfolding of an origami-inspired deployable structure.