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# Multiphysics modeling of ionic electroactive polymers

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Due to their large deformation capability, ionic electroactive polymers (iEAPs) are promising materials for several engineering applications. They can be used, for example, as actuators and sensors in artificial muscles, biomedical devices, microrobots, etc. The mode of action in iEAPs is based on the exploitation of the mobility or diffusion of ions to produce large bending deformations. Typically, high performance (large actuation) iEAPs contain an ionic polymermetal composite (IPMC) composed of ionic polymeric film saturated with solvent and counter ions, sandwiched between two compliant metal electrodes. The internal solvent redistribution between the electrodes due to the application of an external electric field will result in the swelling of one side of the IPMC and contraction of the other, thereby causing a bending deformation of the composite film ([1, 2]). In contrast to electric EAPs, iEAPs require drive voltage as low as 1-5V.

From the experimental point of view, Bar-Cohen [3] performed experiments for characterizing the behavior of an IPMC based on an experimental setup developed for data acquisition from IPMC strips that were subjected to various levels of tip mass load. Various studies sought to determine the effect of the chemical properties on the mechanical properties and on electromechanical coupling (e.g. [4, 5]). Specifically, Tadokoro et al. [4] proposed a physiochemical hypothesis that the migration of sodium ions and water molecules in the actuator membrane could cause eigenstrains. Gong et al. [5] extended the model proposed by Tadokoro et al. [4] and studied the non-linear water molecule diffusion resistance force present in the process of sodium ion migration and its effect on the electromechanical properties of IPMCs. Tamagawa et al. [6] focused on the time-dependent nominal Youngs modulus and force generated from IPMCs.

From the computational point of view, Toi and Kang [2] proposed a finite element model, with the explicit inclusion of the viscosity terms in transportation processes. However, the chemo-electro-mechanical coupling was treated weakly and the formulation was based on small deformation theory. An extension of this model was carried by Gong et al. [5] taking water molecule diffusion resistance into account. Nemat-Nasser and Zamani [7] developed a multi-level analysis that accounts for the chemo-electro-mechanical coupling in IPMCs, in which spatial and temporal variations of the cation distribution across the thickness of the IPMC was determined in the first level and the changes in the osmotic, electrostatic, and elastic forces were obtained in the second. In a similar approach, Woosang et al. [8] presented a multi-level analysis for studying the electro-osmosis and equilibrium

hydration effects of Flemion-based IPMCs. Specifically, Woosang et al. [8] introduced a one-dimensional finite element formulation based on the PetrovGalerkin method that determines the electrochemical responses of a Flemion membrane. The mechanical responses of Flemion-based actuators was then obtained. In contrast to many studies, the mechanical model of Woosang et al. [8] accounts for large deformations. However, the developed finite element was based on the standard Bubnov-Galerkin, which is inappropriate for modeling polymers that are considered as nearly incompressible materials. Moreover, the constitutive equation in Woosang et al. [8] is valid for small strains.

In the present paper we aim to provide a multiphysics model for the in silico study of ionic electro active polymers (iEAPs). Specifically, the present work will govern the constitutive equations for the coupled chemo-electro-mechanical behavior of iEAPs. Also, a new finite element formulation that accounts for chemo-electro-mechanical coupling will be presented.

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