A Maxwell stress-based explanation of back-relaxation in ionic polymer metal composites

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Ionic polymer metal composites (IPMCs) are electro-responsive laminate microstructures for sensing and actuation, consisting of an ionic electroactive polymer saturated with mobile ions, plated within noble metal electrodes [1].

Since about two decades, the back-relaxation of IPMCs, inherent their bending response in time due to an applied voltage across their electrodes, has attracted the interest of the scientific community. However, the physical origin of IPMC back-relaxation has so far remained elusive.

We put forward an explanation of this phenomenon based on the Maxwell stress [2]. Our analysis relies on the electrochemomechanical theory developed in [3]. On the basis of a semi-analytical perturbative solution validated with a finite element code, we demonstrate that IPMC actuation is governed by the nonlinear competition of osmotic and electrostatic effects. The osmotic pressure leads to a rapid bending toward the anode, whereas the Maxwell stress leads a slow relaxation toward the cathode. The competition of these two phenomena depends on the applied voltage. At a voltage in the order of the thermal voltage, IPMC actuation is dominated by the osmotic stress. At larger applied voltages, the Maxwell stress becomes more relevant, leading to back-relaxation. Among several contributions, the magnitude of the back-relaxation may be modulated by steric effects that are related to the size of the mobile cations.

References

[1] *Shahinpoor, M., Kim, K.J., "Ionic polymer–metal composites: I. Fundamentals," Smart Materials and Structures* **10***, 819-833 (2001).*

[2] *Porfiri, M., Leronni, A. and Bardella, L., "An alternative explanation of back-relaxation in ionic polymer metal composites," Extreme Mechanics Letters* **13***, 78-83 (2017).*

[3] *Cha, Y., Porfiri, M., "Mechanics and electrochemistry of ionic polymer metal composites," Journal of the Mechanics and Physics of Solids* **71***, 156-178 (2014).*