An Equivalent Circuit Model for Ionic Polymer–Metal Composites and Their Performance Improvement by a Clay-based Polymer Nano-composite Technique

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ABSTRACT: Ionic Polymer–Metal Composite (IPMC) is a new class of polymeric material exhibiting large strain with inherent soft actuation. The observed motion characteristics of an IPMC subjected to an electric field is highly nonlinear. This is believed to be due primarily to the particle electrodes on the IPMC surface, which is inherently both capacitive and resistive due to particle separation and density. Knowing that the value of resistivity and capacity can be manipulated by the number of metal platings applied to the IPMC, the force response of an IPMC when subjected to an imposed electric field is due to the interaction of an array of capacitors and resistors along with ionic migration. In this effort we attempt to incorporate a capacitive and resistive model into the linear irreversible thermodynamic model. The advantages of using such a model are (i) the possible dynamic predictability of the material itself in connection with capacitive responses; and (ii) the realization of capacitive and resistive effect arising from the particle electrodes and the base polymer, respectively. The behavior of the proposed model can explain typical experimentally obtained values well. Also, an experimental effort to improve the properties of the base polymer was carried out by a novel nanocomposite technique. The experiment results on the current/voltage (I/V) curves indicate that the starting material of ionic polymer–metal composites (IPMCs) can be optimized to create effective polymer actuators.

Key Words: Ionic Polymer-Metal Composites, Nano-composite

INTRODUCTION

Ionic Polymer–Metal Composites (IPMCs) have been studied extensively for quite awhile now. They are very attractive because of their capability of producing large deformations in the presence of low driving voltages (Oguro et al., 1993; Shahinpoor et al., 1993, 1998, 2003; Asaka et al., 1995; De Gennes et al., 2000; Shahinpoor and Kim, 2000, 2001, 2002a,b; Shahinpoor and Mojarrad, 2000; Mallavarapu et al., 2001; Nemat-Nasser and Thomas, 2001; Newbury and Leo, 2001; Tadokoro et al., 2001; Kim and Shahinpoor, 2002a,b, 2003). An applied mechanical deformation of an IPMC will engender a voltage as well paving the way for various sensor/damper applications (Sadeghipour et al., 1992; Shahinpoor et al., 2003). For a detailed description of current and future applications of an IPMC, the reader is referred to Kim and Shahinpoor (2002a) where it is shown that the field varies from micro-to-macro potential applications in various fields of engineering.

Ionic Polymer–Metal Composites would be ideal for operation in aqueous media because of the material’s affinity for water despite their good capability of dry operation (Shahinpoor and Kim, 2002b). The IPMC’s behavior is directly related to the level of hydration of the material. This is because the material utilizes the migration of hydrated cations (or other solutes along with solvents). Another unique characteristic of the material is that the observed motion characteristics of an IPMC subjected to an electric field is highly nonlinear (Mallavarapu et al., 2001; Namat-Nasser and Thomas, 2001; Newbury and Leo, 2001; Shahinpoor and Kim, 2001).

A popular form of IPMCs is a perfluorinated sulfonate membrane, with metal composites chemically placed within the membrane (Millet et al., 1989; Asaka et al., 1995; Shahinpoor et al., 2003). The initial