Reuses of the Ionic Polymer metal composites (IPMCs) with various thicknesses

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Abstract. The IPMCs with various thicknesses were manufactured by a hot-pressed method and their actuations in terms of tip force and displacement when being reused with different treatments were investigated. Three selected treatments are no treatment, treatment in deionized water or 2M NaCl solution. To achieve the great tip force and displacement when the IPMCs were reused, no treatment is a better way for the thin 1-film, and treatment in NaCl solution for the 2- and 4-films. For the thick 6-film, treatment in 2 M NaCl is appropriate to achieve the great tip force and treatment in deionized water to achieve the great displacement.

1. Introduction

Ionic polymer-metal composite (IPMCs) actuators are smart materials which change shape in response to an external electrical stimulus [1]. They are regarded as one of the most appropriate bionic materials for their low electrical driving forces, quick displacement velocity and bending movement and can be applied as the artificial finger[2], jellyfish[3], micro-controller[4] and robots to implement the various assignment, such as gathering the data and samples[5] , operating the cells and so on.

IPMCs are composed of an ion-exchange polymer membrane, generally the perfluorinated polymers such as nafion, with two metal electrodes chemically plated on its surfaces. When an adequate potential is applied across the hydrated IPMC, it shows fast bending motion towards its positively charged surface and generate the driving forces [6]. The magnitude and speed of the bending motion of water-based IPMCs may depend on the ionic conductivity and thickness of the polymer, the structure and capacitance of the electrodes, the water content of the polymer and the mobility of the counter cations [7]. However, the nafion-based IPMC actuators have a drawback of low driving force, which limit their applications. Many researchers modified the IPMC electrodes to enhance the driving force, but it required complex and strict fabrication processes.

Recently, Sun [8] manufactured the thick IPMCs through solution casting. Furthermore, Dr. Y. H. Kim [9] proposed a simple hot-press method to adjust the thickness of the IPMCs. They approved that in air the generated tip force of the IPMCs is proportional to the number of stacked films. But how the IPMCs with various thicknesses actuate when being reused in different treatments was never studied.

In this paper, the IPMCs with various thicknesses were fabricated and their tip forces and displacements when being reused with no treatment, treatment in deionized water or 2 M NaCl solution were discussed.

2. Experimental

2.1 Fabrication of IPMCs.

Nafion®-117 from Dupont with a thickness of 0.18 mm was used as the ionic polymer membrane. Tetraamineplatinum(Ⅱ) chloride hydrate [$Pt(NH_3)_4Cl_2$] (98%) was purchased from Sigma-Aldrich. All materials were used as received.

Four IPMC specimens with various thicknesses were prepared in a hot-pressing method suggested by Kim [9]. The numbers of stacked films were 1, 2, 4, and 6, and respectively expressed as the 1-film, 2-film, 4-film and 6-film in this paper. Fabrication of the IPMCs was carried out by a two-step chemical plating method reported by our work [10].

2.2 Measurement and characterization.

An IPMC actuator was cut into specimens with dimensions of 6 mm in width and 45 mm in length. One edge of the IPMCs was clamped and the tip force was measured using a balance with the sensitivity of 0.0001g [11]. The displacement of the IPMCs under an applied voltage was recorded by a digital camera. Reuses of the IPMCs were performed at 4.5 V of DC power for 1 min. Before each use, the IPMCs were handled respectively with no treatment, treatment in deionized water or 2 M NaCl solution for 5 min.

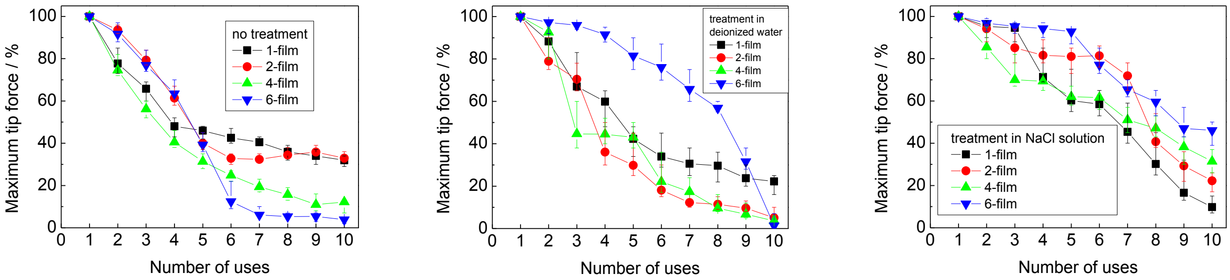
3. Results and discussion

3.1 Tip forces of the IPMCs with various thicknesses.

Fig. 1 shows the maximum tip force losses of the IPMCs with various thicknesses when being reused in different ways. It is found that reuses of the IPMCs with three treatments mentioned all lead to the decrease in maximum tip force. When being reused with no treatment, for the first five times, the 1- and 4-films decrease more than the 2- and 6-films. After that, the maximum tip forces of the four IPMCs decrease in order of the increasing thickness. The 1-film decreases the least, and the 6-film decreases the most (Fig. 1a). After being reused ten times, the thick 4- and 6-films decreases respectively to 12 and 3 percent of their original maximum tip forces; whereas the thin 1- and 2-films still retain about 33 percent.

Compared with no treatment, treatment in deionized water results in a larger decrease in maximum tip force except the 6-film in Fig. 1b. The 6-film still maintains 90 percent of the original after being reused four times, 55 percent after being reused eight times and finally decreases to 1 percent.

In the case of treatment in NaCl solution (Fig. 1c), after being reused four times, the four IPMCs obviously show a lower decrease in maximum tip force. The 6-film shows the lowest decrease and maintains 90 percent, the 4-film 80 percent and the 1- and 2-films close to 60 percent. After being reused ten times, the remained maximum tip forces of the four IPMCs ascend in order of the increasing thickness. The 1-, 2-, 4- and 6-films respectively show 9, 22, 31 and 46 percent.



(a) (b) (c)

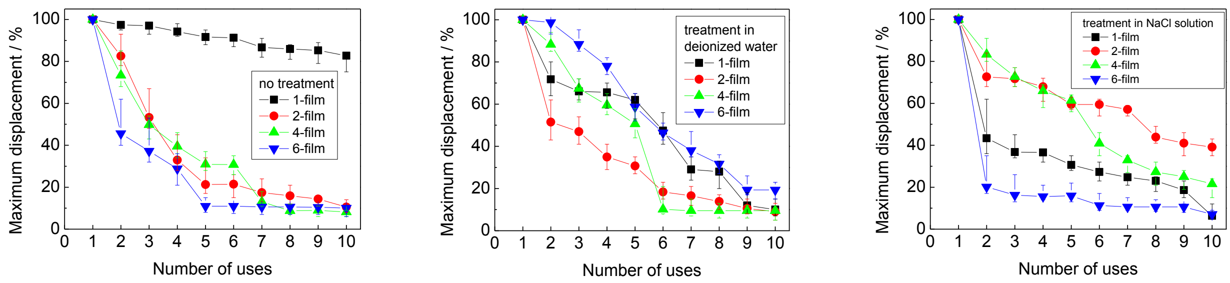
Fig. 1 Maximum tip force losses of the IPMCs with various thicknesses when being reused in different ways. (a) no treatment; (b) treatment in deionized water; (c) treatment in 2M NaCl solution

In conclusion, to achieve the great maximum tip force, the thin 1-film can be reused with no treatment and the thick 2-, 4- and 6-films are suggested to be reused in NaCl solution. This may be explained by that the thick IPMCs, which possess the long ionic migration channel, require both the hydrated cations and water more complemented.

3.2 Displacement of the IPMCs with various thicknesses

Fig.2 shows the maximum displacement losses for the IPMCs with various thicknesses when being reused in different methods. Three treatments all show a decrease in maximum displacement. When being reused with no treatment, the 1-film slowly decreases in maximum displacement and after being reused ten times still retains more than 80 percent of the original (Fig. 2a). However, the 2-, 4- and 6-films finally decrease to about 10 percent.

Compared with no treatment, treatment in deionized water (Fig. 2b) demonstrates a lower decrease in maximum displacement for the 2-, 4- and 6-films. Especially for the 6-film, after being reused five times the 6 film shows 58 percent of the original maximum displacement, evidently higher than 10 percent with no treatment. After being reused ten times, the 6-film still retains 19 percent, and the 2- and 4-films decrease to about 10 percent, close to that with no treatment. The 1-film finally declines to 10 percent, much lower than that with no treatment.



(a) (b) (c)

Fig. 2 Maximum displacement losses of the IPMCs with various thicknesses when being reused in different ways. (a) no treatment; (b) treatment in deionized water; (c) treatment in 2M NaCl solution

In comparison with no treatment and treatment in deionized water, treatment in 2M NaCl solution results in a greater decrease in maximum displacement for the 1- and 6-films and lower decrease for the 2- and 4-films (Fig. 2c). When being reused twice, the 1-, 2-, 4- and 6-films respectively show the maximum displacement of 43, 72, 83 and 20 percent. However, after being reused ten times, the 2-film retains 40 percent and the 4-film 21 percent, the 1- and 6-films close to 10 percent.

These experimental results illustrate that the reusing types influence the maximum displacements of the IPMCs with various thicknesses. In order to obtain the greater maximum displacements, the 1-film should be reused with no treatment, the 2- and 4-films with treatment in NaCl solution, and the 6-film with treatment in deionized water. These may be explained by that the hydrated cations have to be supplemented when the thickness increases. But when the thickness exceeds four films, water, in place of the hydrated cations, becomes the key to maintain the displacement.

4. Summary

The IPMCs with various thicknesses were fabricated and effects of reuses of IPMCs with no treatment, treatment in deionized water and NaCl solution on the maximum tip forces and displacements were discussed. For the thick IPMCs, to maintain the greater maximum tip force, complementation of both the hydrated cations and water by treatment in NaCl solution is necessary; to achieve the greater maximum displacement, the deionized water plays a more important pole than the NaCl solution. Our experimental results are very interesting and instructive to optimize the actuations.

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