

Experimental investigation on the bending response of multilayered Ag-ionic polymer-metal composite actuator for robotic application

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Abstract

Ionic polymer-metal composites (IPMCs) are electro-active polymers that undergo bending deformation with the stimulus of a relatively small electric field. In this research we fabricate multilayered structure of IPMC actuator using chemical decomposition method and investigate the influence of bending response on applied input voltage. The experimentally obtained results had been compared to single layered IPMC actuator. The result shows that the increment of layer on base material (Nafion-117) had increased the actuation capability of IPMC actuator. The tip displacement increases up to 20% for three layered and around 30% for four layered compared to single layered IPMC actuator under the application of 1.0V. This finding would be useful for the application where higher bending displacement is required i.e., in the robotic and biomimetic application with a very small input voltage. Copyright © 2018 VBRI Press.

Keywords: Ionic polymer-metal composite, thickness manipulation, actuator, bending characteristics.

Introduction

Ionic polymer-metal composites (IPMCs) are one of the electro-active polymer that experience bending response under an electrical stimulus as an actuator as a result of cation movement in the polymer network, or vice versa as sensor, or both. IPMCs are highly attractive materials now-a-days because of its lightweight, large deformation under low driving voltage, flexible operation. These characteristics make Ionic polymer-metal composites to use as sensors and actuators in wide range of industrial and medical applications. [1,2,3,4,5]. However, their low bending response and low blocking force causing the barrier for achieving commercial applications. Recent advancement in fabrication of IPMC technologies such as multilayer configuration, compositing with nano sized materials and improvement in electroding process are approaching to reduce the gap [6, 7, 8]. A number of researchers have attempted to use various electrode metals, like Au, Pt, Pd, Ag and other conducting metals, over the past years for plating purpose [9, 10, 11, 12, 13, 14]. Among these metals, Pt, Au and Pd are well-known electrode, but they are highly expensive sources. Hence in this work we use Ag as the electrode metal.

The double layer IPMC actuator performs larger bending response compared to the single layer IPMC actuator when stimulated by electric potential [15]. As

the actuation depends upon the thickness of the actuator, thick IPMC actuator was prepared by using electro less plating method and recasting method which are costly and time-consuming processes [16]. By increasing the ionomer thickness and surface area of the Pd-Pt electrodes, IPMCs has been fabricated to improve its electromechanical performance by increasing its blocking force compared to conventional type of IPMC actuators [17]. Solution recasting method has been adopted to fabricate triple-layered Nafion composite membrane and electroless plating methods are used to fabricate IPMC which exhibits higher tip displacements and higher blocking force compared to conventional single-layered IPMC [18]. To improve the performance of IPMC actuator, fine Pt and Pd nanoparticules were impregnated on the surface of the Nafion membrane using thermal decomposition method and IPMC was fabricated [19]. To enhance the force generation capacity of the IPMC actuator, thickness of the ion-exchange membrane was varied by different method to fabricate IPMC [20]. For a multilayered IPMC actuator different design factors are taken into account to predict a theoretical model [21].

In this work, a simple and efficient fabrication process was developed to fabricate the Ag-IPMC with uniform distribution of silver particles over the base polymer using chemical decomposition method. This method for fabrication of low cost IPMC increases the

bending actuation capability of the IPMC actuator. For single layered IPMC actuator the actuation force is small and the input voltage is restricted to some extent. To improve the bending deflection and actuation force capability, a multilayered IPMC actuator has been developed in this work which can be used in the robotic applications.

Experimental

Materials/ chemicals details

Nafion-117 as base polymer, silver nitrate (AgNO_3) as silver salt, dilute ammonia solution (NH_3) to prepare diamminesilver (I) hydroxide, sodium hydroxide (NaOH) for providing Na^+ cations into the membrane, dextrose anhydrous GR ($\text{C}_6\text{H}_{12}\text{O}_6$) as reducing agent to reduce the silver cations to silver metal, hydrochloric acid (HCl), 2N solution as a cleaning agent and lastly distilled water for cleaning were used for fabrication of Ag-IPMC actuator.

Material synthesis

In the present work chemical decomposition method was followed to fabricate the proposed Ag-IPMC. The IPMC fabrication followed the traditional scheme composed of surface roughening, adsorption, reduction and developing process as illustrated in Fig. 1.

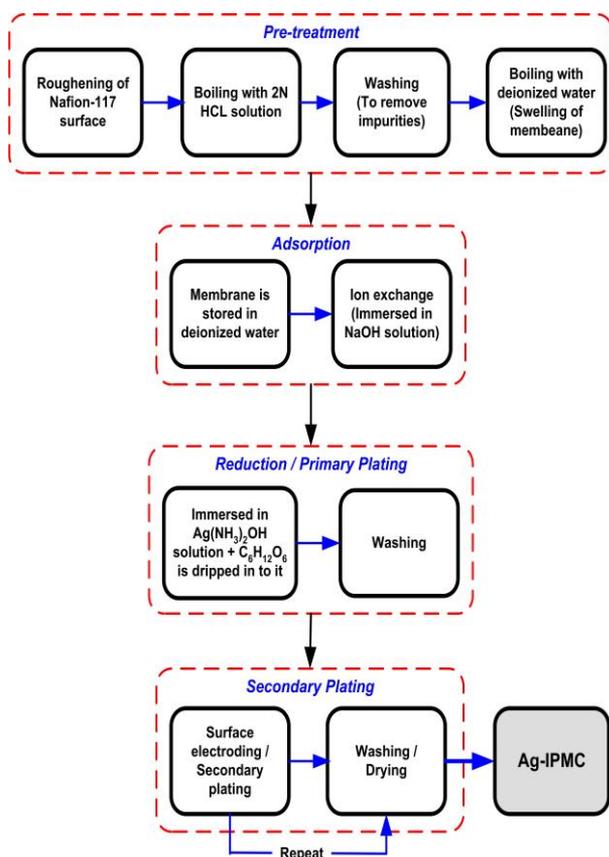


Fig. 1. Fabrication procedure for Ag-Ionic polymer metal composite actuator.

(a)



(b)



Fig. 2. Photograph of the (a) Nafion-117 membrane, (b) Fabricated Ag-IPMC.

Electroless plating method was adopted for the preparation of Ag-IPMC actuator. A conventional Ag-IPMC as a reference sample was also fabricated by following the methods that was proposed by Biswal *et al.* [14]. The new method for fabricating multilayered Ag-IPMC was performed without repeating the initial compositing process, called reduction/primary plating process over conventional Ag-IPMC. The multilayered plating was applied by repeating the secondary plating process over the conventional Ag-IPMC. The photographs of the Nafion-117 membrane and the fabricated Ag IPMC are shown in Fig. 2 (a) and (b), respectively.

Characterizations

Bending characteristics of fabricated IPMC

Silver electrode IPMC actuator was fabricated in the laboratory and cut into a size of 20×5 (mm^2) for the experimental study. Three different kinds of specimens, a conventional Ag-IPMC, three layered Ag-IPMC and four layered Ag-IPMC, were prepared. The experiment was conducted in fully hydrated state of IPMC actuator in a cantilever mode. Voltage is applied from a DC power source (0–32 V DC, 0–2 A, Testronix) through copper strips attached to the fixed end. During this process the bending of the IPMC is observed and video images are taken (Maker: Sony, Model: DSC-H20) which are then used to obtain the corresponding tip deflections and the bending characteristics are calibrated. Before starting the experiment, the IPMC is considered to be fully hydrated state by boiling IPMC actuator in distilled water for 30 min, that is, solvent content is assumed to be 100%.

Solvent (Water) Loss under DC Electric Potential

Hydration level is one of the important issues which influence the bending actuation of the IPMC actuator. When an electrical potential is applied across the thickness of the IPMC actuator, the mobile cations with water molecules travels towards the cathode causing the bending deformation in IPMC actuator. Generally, water is used as the solvent for conventional IPMC actuator. It is observed that gradual decrease of solvent in open environment adversely affects the bending performance of the IPMC actuator. In the present study, solvent loss under DC input voltages is found out by carrying several experiments in an open environment. Before each experiment, the samples are immersed in the distilled water, boiled for 30min and then kept for 24h. The weight of the samples before and after full hydration is measured to calculate the water uptake.

Results and discussion

The schematic diagram of bending configuration is shown in Fig. 3 (a), while Fig. 3 (b) shows the experimental setup to obtain the bending characteristics of the Ag- IPMC actuator subjected to a DC input voltage (0.2–1.2V).

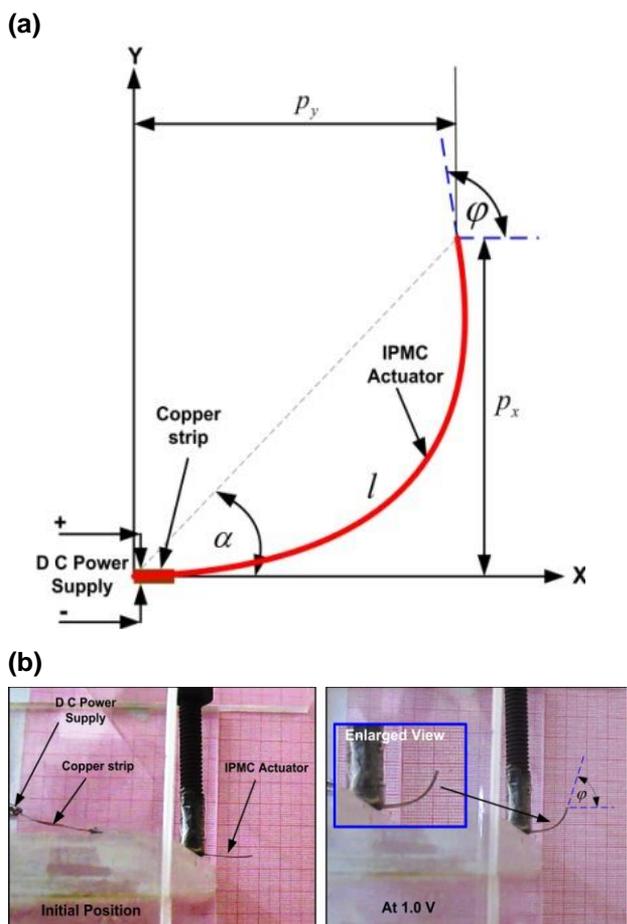


Fig. 3. (a) Schematic diagram of the bending configuration of an IPMC actuator for an input voltage V, (b) Experimental setup for initial position and bending at 1.0 V.

For each input voltage after 30 s the tip position (p_x , p_y) of the IPMC has been measured and the experimental data for tip position (p_x , p_y) with an applied voltage (V) for 1st, 3rd and 4th coating is plotted in Fig. 4 (a) and (b) respectively. From the graph it is clearly observed that as the number coating over the base material (Nafion-117) increases the tip deflection is also increases.

Table 1 shows the percentage increase in tip deflection (Y-deflection) of 3rd and 4th coating Ag-IPMC compare to the single coating Ag-IPMC actuator. Single coating tip deflection data for Ag-IPMC has been taken from the previous experimental observation of Biswal *et.al.* [22].

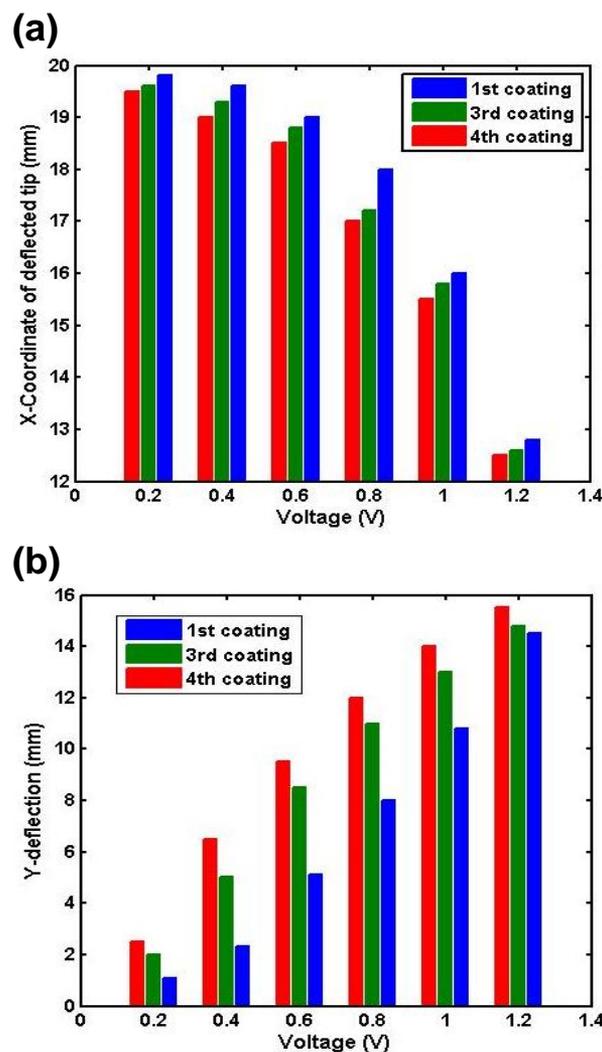


Fig.4. Tip position of the (a) X-Coordinate, (b) Y-Coordinate of the Ag-IPMC actuator for different input voltage

Table1. Percentage increase in the tip deflection (Y-deflection) of 3rd and 4th coating Ag-IPMC actuator over 1st coating Ag-IPMC actuator [21].

	0.2V	0.4V	0.6V	0.8V	1.0V	1.2V
Y-deflection (3 rd Coating)	81.8 %	117.8 %	66.6 %	37.5 %	20.3 %	2.0 %
Y-deflection (4 th Coating)	127.2 %	182.6 %	86.2 %	50 %	29.6 %	6.8 %

From the table it can be observed that except at 0.4V the percentage increase in tip deflection is gradually decreasing as the applied voltage increases. This is due to the loss of solvent (water) which is present in the actuator. In initial condition the solvent present in the actuator is assumed to be 100% and it reduces as the voltage increases and the time elapsed. From the previous work we find that the surface-electrode resistance of Ag-IPMC is the lowest and most stable, which shows that it will generated more bending deflection and blocking force compared to the other electrode materials.

A theoretical relationship has been established for experimental X- coordinate deflection Y-coordinate deflection data. The experimental deflection data has been plotted with cubic order polynomial curve fitting approximation as shown in Fig. 5 (a) and Fig. 5 (b). It is observed from the graph that the pattern of bending is almost same for both the actuator.

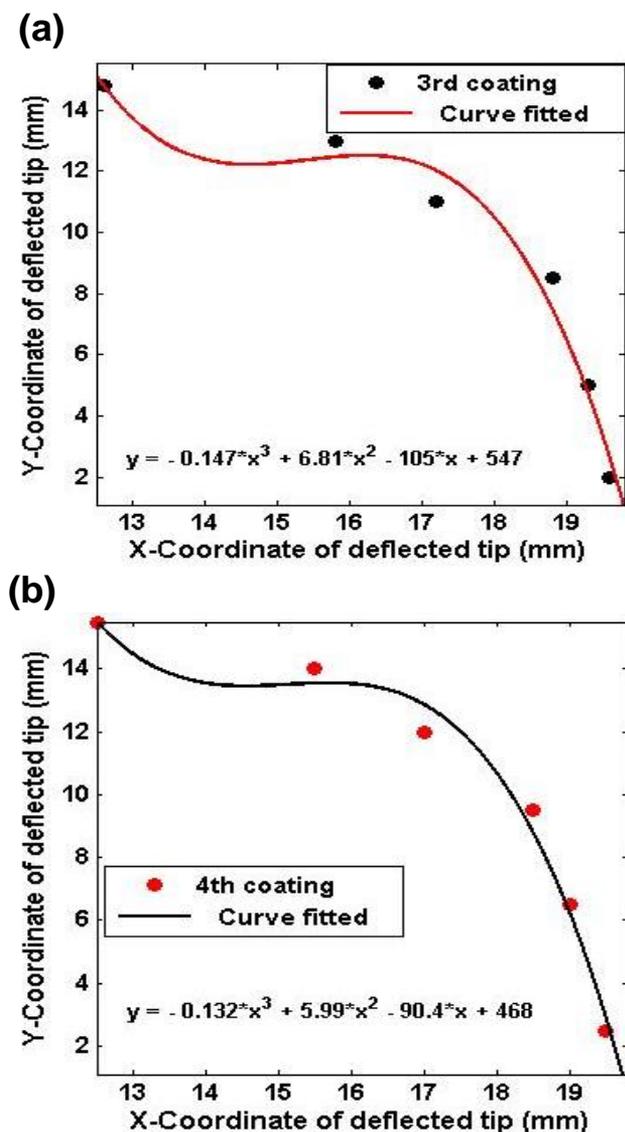


Fig. 5. Curve fitted along the experimentally obtained X and Y-deflection data for (a) 3rd coating, (b) 4th coating Ag-IPMC actuator.

As shown in Fig. 3 (a), the tip angle (ϕ) can be obtained from the X and Y- coordinates of the end tip position by the equation as given below.

$$\phi = 2 \times \tan^{-1} \left(p_y / p_x \right) \quad (1)$$

By using the equation (1) the experimental tip deflection data have been calculated for 1st, 3rd and 4th coating IPMC actuator and plotted in Fig. 6(a). Fig. 6(b) shows the effect of coatings on the bending pattern of IPMC for various input voltages.

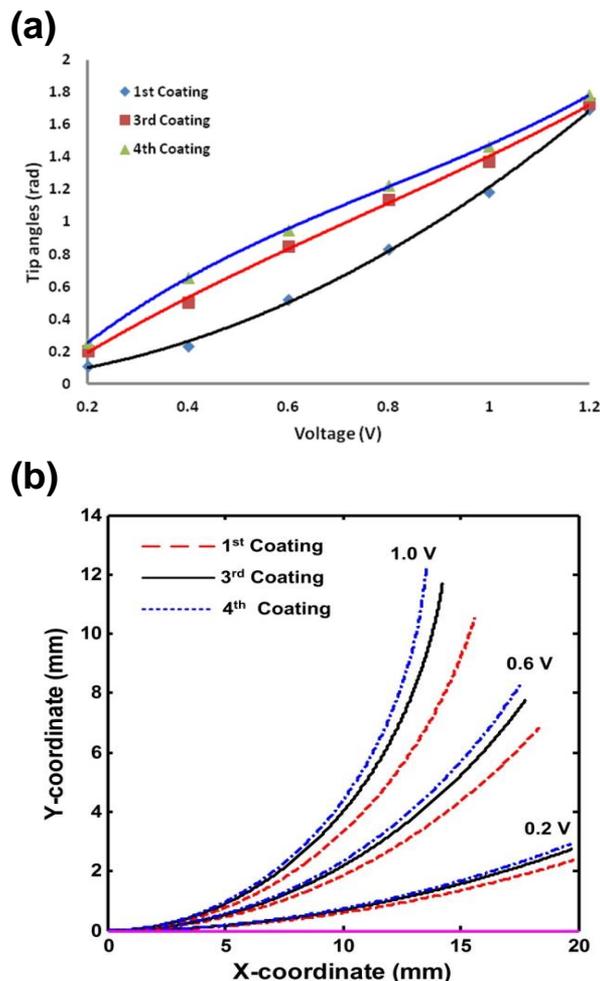


Fig. 6. (a) Change in tip angles of Ag-IPMC actuator with input voltage, (b) Bending deflection of Ag-IPMC actuator for various input voltage

Water uptake by the IPMC actuator can be expressed by the equation given below:

$$M_{wu} = \frac{W_{fh} - W_{dry}}{W_{dry}} \quad (2)$$

where, M_{wu} is the water uptake, W_{fh} and W_{dry} is the weight of the fully hydrated and dried IPMC sample. Experimentally water uptake of an Ag-IPMC sample ($20 \times 5 \times 0.2(\text{mm}^3)$) is found to be around 30%.

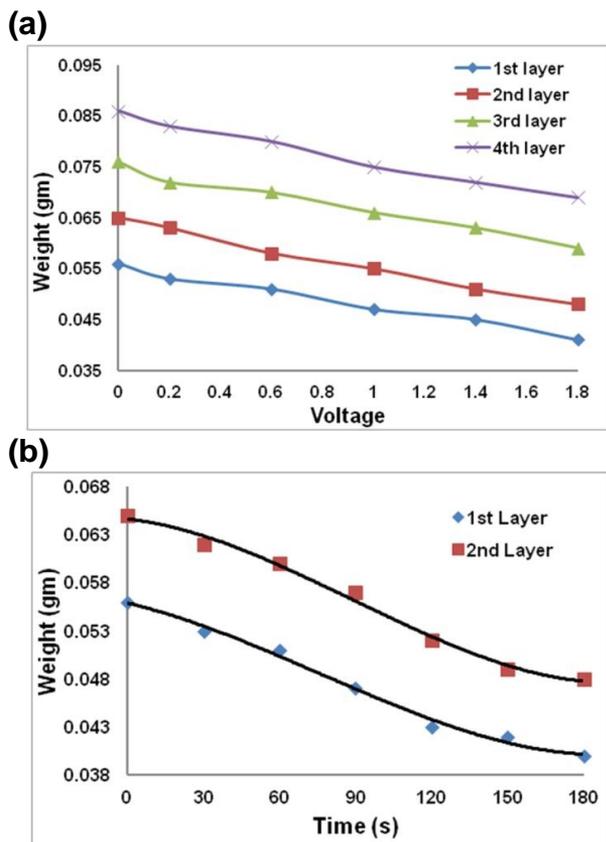


Fig. 7. Weight losses from IPMC (a) with input voltages, (b) with time period at 0.4V DC.

Solvent (water) loss was calculated by experimenting fully hydrated IPMC samples of size 20×5 (mm²). DC voltage from 0.2 V to 1.8V with increment of 0.4V is applied to hydrated IPMC samples for a time period of 30s. The weight of the each IPMC samples (1st, 2nd, 3rd and 4th layered) before and after application of each input voltage is measured using a digital measuring balance and loss in weight of the IPMC samples are plotted in Fig. 7(a). In the second experiment, by applying a DC voltage of 0.4V for different time periods solvent (water) loss is calculated for fully hydrated IPMC samples of size 20×5 (mm²). The weight of the sample before and after the experiment (example: after applying input voltage for 30s, 60s etc.,) is measured using a digital measuring balance and the weight loss for 1st and 2nd layered IPMC samples are plotted in Fig. 7(b). It is observed that around 98% of the solvent is lost with the application of 0.4 V DC input voltage for the time period of 180s.

Conclusion

In summary, multilayered silver coated Ionic Polymer Metal Composite has been fabricated by chemical decomposition method. Multilayered IPMC actuator induces a remarkable enhancement in bending deformation compared to conventional single layered IPMC actuator. This study would be useful for

developing high performance IPMC actuator in designing stage of a small scale robot and underwater vehicles that require higher actuation force at a higher bending displacement.

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