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CHARACTERIZATION OF DOUBLE LAYER IPMC BENDING ACTUATION

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ABSTRACT

Ionic polymer-metal composite (IPMC) is an electroactive material that bends when being stimulated electrically. Basically, there are two actuation attributes of IPMC actuator had been investigated which are the actuation force and bending degree. However, characterization on multilayer IPMC actuation had been less studied. Based on the preliminary research, double layer IPMC actuator is performing a non-uniform actuation where the first actuator bends at higher actuation rate compared to the second actuator. Hence, this research was conducted to investigate the double layer IPMC actuation by adjusting some parameters. They are the thickness of the IPMC layer, voltage supply and current supply. Those parameters had been varied to observe the IPMC actuation. The result of this research shows that as the voltage supply varies, the bending degree of the both IPMC layer become uniform at 4V DC when the thickness is 0.025cm. Besides, by changing the thickness of the IPMC actuator, the bending degree of the IPMC actuator gives a linear trend.

Keywords: IPMC, actuator, bending mechanism, double layer actuation.

INTRODUCTION

Beam-like IPMC actuator bends when stimulated by an electrical field as a result of cations movement in the polymer network and vice versa [1]. The applied voltage is responsible for the polymer matrix to swell on one side and shrinks on the other side. This phenomenon results bending motion of the polymer. The double layer IPMC actuator performs larger bending degree compared to the single layer IPMC actuator with the same thickness when stimulated by electric field [2]. This is because the actuation of the IPMC layer depends on its thickness. Thicker IPMC actuator has better actuation force. Thick IPMC actuator was prepared by using electro plate less method and recasting method which are cost high and take longer time [3]. However, based on the beam bending principles, thicker beam has higher deformation resistance. Therefore, it was proposed to prepare the multilayer IPMC by stacking method. This method is very simple method and easy to prepare as well as costs low. However, the bending degrees of the double layer of the IPMC actuator are not uniform [2]. Sometimes, the bottom layer bends with a larger bending degree compared to the top layer. Therefore, the double layer IPMC actuation can be considered as a nonlinear system [4][5]. This research is done to investigate the actuation of the double layer IPMC by identifying the parameters like thickness of the IPMC layer, voltage supply and current supply. Those parameters had been varied to observe the IPMC actuation. The next section discusses the previous researches done in order to investigate the IPMC actuation. In section 3, the methodology of this research is discussed. Result and discussion are discussed in section 4 while section 5 discusses the conclusion and recommendation of this research.

RESEARCH OVERVIEW

An IPMC actuator is made up of a thin ion-exchange polymer membrane which is filled with ionic liquid and it is coated with a thin metal layer from both sides. As a small voltage is applied, an electric field is being generated through the polymer membrane [6][7]. This phenomenon causes ion migration which is resulting in the bending motion. The backbone of the IPMC is usually around 0.2mm to 0.5mm thick and the metal layer is around 20μm. Therefore, IPMC can be used as actuators on a miniature scale driven at low voltages [8].

The IPMCs can create a large bending motion under relatively low input voltage 1V to 5V, which is a unique merit over the other class of EAP actuators [9]. An applied electric field affects the cation distribution within the membrane, where it forces the cations to migrate towards the cathode. This change in the cation distribution produces two thin layers, one near the anode and another near the cathode boundaries [10]. The clusters within the anode boundary layer are depleted of their cations, while clusters within the cathode boundary layer are rich in cation. At the anode and cathode boundary layers, the respective decrease and increase in the concentration of the ions may cause a decrease in the effective stiffness of the polymer in the anode, and an increase in this stiffness in the cathode boundary layer, respectively.

An IPMC layer with higher stiffness exhibits less displacement which is resulting in smaller bending degree [11]. This can be related to the much larger thickness of the IPMC layer, requiring longer time for electrolyte migration and diffusion between the electrodes. Besides, the relationship between the thickness of the IPMC layer and its bending degree can be related to the bending of the cantilever beam as shown in Figure-1.

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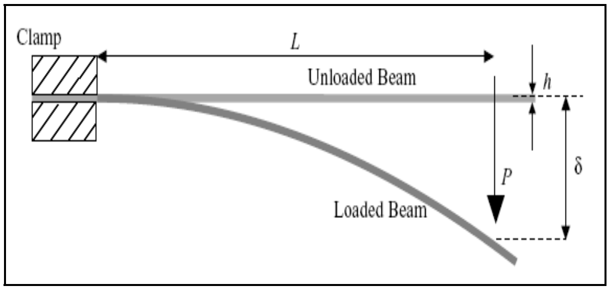

Figure-1. Deflection of a cantilever beam.

The formula for vertical displacement, δ, is given:

$$\delta = \frac{1}{3}\frac{PL^3}{EI} \tag{1}$$

where L is the length of the strip, P is the applied load, E is the Young's Modulus, and I is the second moment of area. The moment of inertia, I for the rectangular section is given:

$$I = \frac{wh^3}{12} \tag{2}$$

From equation (1) and (2),

$$\delta = \frac{4PL^3}{Ewh^3} \tag{3}$$

where w is the width of the beam and h is the thickness of the beam. From the related equations, it can be said that the thickness of the beam, h is directly proportional to the moment of inertia, I but inversely proportional to vertical displacement, δ. This shows that when the thickness, h increases, the moment of inertia, I increases too but the vertical displacement, δ will decrease. This theory is applicable to the bending of the IPMC layer too. The thicker the layer, the smaller it's bending displacement [12].

METHODOLOGY

IPMC actuator preparation

In previous researches, few steps had been carried out to increase the performance of the IPMC [13][14]. Those techniques were definitely increase the IPMC fabrication cost because it required additional substances. The simplest technique is increasing the thickness of the IPMC as it costs lower. However, increasing the thickness of the actuator will decrease the bending degree. Alternatively, a double layer IPMC will be prepared with simple stacking technique without using any recasting method or surface electrode enhancement. IPMC samples with a initial length of 40mm and 10mm width were prepared. The thicknesses of the samples used were about 25mm, 0.45mm and 0.50mm [8].

Experimental setup

Figure-2 depicts the experiment setup for both single and double layer IPMC actuators. An IPMC actuator was clamped at one end, where the actuation voltage was applied. TENMA 72-10495 digital control DC power supply was utilized to supply the voltage. The tip displacement was captured by a video camera and the bending degree was calculated using equation (1). Before each experiment, an actuator cut with the specified size was soaked in the deionized water. The inner porous IPMC layer that stores mobile cations now contains water molecule, which enabled the actuator to operate in air for some time. The time of continuous in-air operation depends on how fast the stored solvent evaporates, and without further packaging, it is about 4 to 5 hours. The experimental temperature and humidity were maintained as 25°C and 27%, respectively [3].

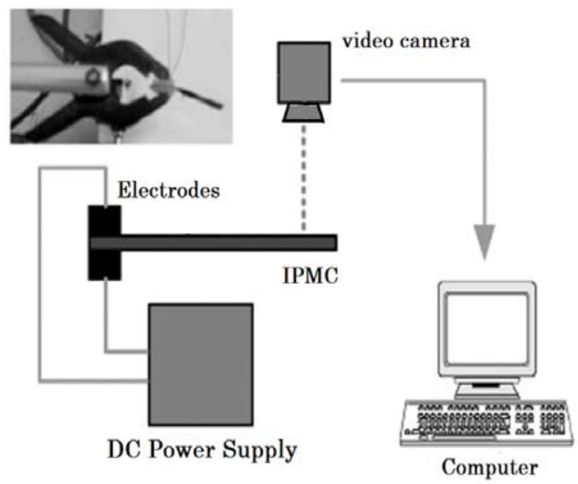

Figure-2. Schematic diagram of experimental setup.

Characterization of IPMC actuator

There were four experiments had been carried out to study the characterization of double layer IPMC bending actuation. The actuation performance was compared between double layer IPMC layer and single layer IPMC layer with same total thickness. In experiment 1, the characterization was carried out to study the actuation of double layer IPMC using various voltage supply. Two layers of IPMC actuators with a thickness of 0.25mm per actuator were prepared as stated in Table 1. The electrodes were connected to the power supply. The supply voltage and current were set to 1.5V and 0.5A respectively. Then, the IPMC layers were stacked in between the electrodes as shown in Figure-2. It was very important to make sure that the IPMC layers were wiped dry before stacking between the electrodes to avoid unnecessary resistance between IPMC and those electrodes. After stacking the IPMC layers, the camera recorder which was connected to the personal computer was turned on to record the bending degree.

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Table-1. Summary of sample number and thickness for every experiment.

Experiment	Sample number	Thickness, t (mm)
1	2	0.25 (for each layer)
2	2	0.25 (for each layer)
3	Sample A: 2	0.25 (for each layer)
	Sample B: 2	0.45 (for each layer)
	Sample C: 2	0.50 (for each layer)
4	Sample A: 2	0.25 (for each layer)
	Sample B: 1	0.50 (single layer)

Then, the power supply turned on allowing the voltage and current supplied to the system. The bending degrees of the IPMC layers were recorded for five bending oscillations. Each oscillation was taken for 4 seconds only. Then, the bending degree of the IPMC layers were measured using a protractor. The experiment was repeated with different voltage supplies by adding 0.5V to the previous voltage supply until the bending degree of the both layers were obtained the same value. For example, starting from 1.5V then continued with 2.0V, 2.5V, 3.0V and 3.5V [15].

In experiment 2, the actuation of double layer IPMC was investigated using various current supplies. The setup of equipments and samples preparation were same as in experiment 1. Here, the voltage supply was fixed at 4.0V where at this value the bending degree of both layers were same as obtained in experiment 1. The current supply was set to be 0.10A. The experiment was carried out as experiment 1 and the bending degrees were measured. Then the experiment was repeated using a current supply of 0.15A, 0.20A, 0.25A, 0.30A, 0.35A, 0.40A, 0.45A and then lastly 0.50A [15].

In experiment 3, the actuation of double layer IPMC was studied using various thicknesses. The setup of equipments and samples preparation were same as in experiment 1. Here, the voltage supply and current supply were set to be 1.5V and 0.5A at starting. The experiment was carried out as experiment 1 and the bending degrees were measured. Then the experiment was repeated as in experiment 1 using the thickness of the double layer IPMC of 0.45mm and then 0.50mm.

For experiment 4, a comparison made in between double layer IPMC and single layer IPMC with same value of total thicknesses. The thickness of the single layer IPMC, t_1 is 0.5mm and the thickness of each layer of the double layer IPMC, t_2 is 0.25mm. This means the total thickness of the double layer IPMC is 0.5mm. Therefore, it can be expressed as below.

$$t_1 = 2t_2 \tag{4}$$

The setup of equipments and samples preparation were same as in experiment 1 for double layer IPMC. The setup of equipments was similar to the other experiments. Here, the voltage supply and current supply were set to be 4.0V and 0.5A for both types of IPMC layers. The experiment was carried out as experiment 1 and the bending degrees were measured.

RESULTS AND DISCUSSION

In experiment 1, the bending degree of the multiple IPMC actuators was observed. As depicted in Figure-3, the bending degree of both of the layers increases as the supplied voltage was increased. However, both actuators showed different bending degree for different supply voltage. The trend shows that the different bending degree between the two IPMC actuators was getting smaller when the supply voltage was increased. As the supplied voltage increment reached 4.0V, both IPMC actuator layers had similar bending degree which was 40°. Therefore, it can be said that sufficient voltage supply to the layers can make the bending of the IPMC layers become linear. In this case, 4.0V voltage supply was needed to make the double layer IPMC with a thickness of 0.25mm each layer to become linear and bend simultaneously. As the voltage supply increased, the percentage difference between both of the layer is decreasing gradually and finally both layers bend simultaneously at a voltage supply of 4.0V as shown in Figure-3. This means a synchronized bending for the double layer IPMC can be achieved by supplying 4.0V to the system.

Meanwhile, the results in experiment 2 showed that the bending degree of the IPMC layers were remained uniform although the current supply varies. As the current supply was increased, the bending degree of both of the layers increases linearly with almost same value as shown in Figure-4. Therefore, it can be said that the non linear actuation of double layer IPMC actuator does not depends on the current supply. In this case, at any current supply the actuation of the double layer IPMC was linear as there was sufficient voltage supply to the system.

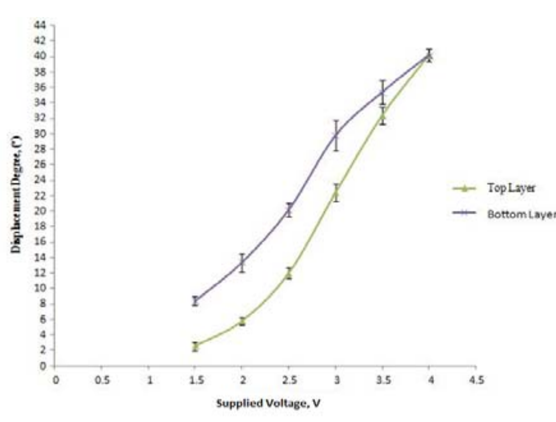

Figure-3. Displacement degree of two layer IPMC actuator at different supply voltage.

Based on the results in experiment 1, experiment 3 was conducted in order to analyze the influence of IPMC

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actuator thickness over the bending performance for multilayer IPMC actuators. In this experiment, as the supplied voltage was increased, the bending degree of both of the layers increases and the difference between the bending degrees of both of the layers decreases at different degree. Figure-5 exhibits that the 0.25mm thick samples show noticeably larger deflection at lower voltage supply of 4.0V compared to 0.45mm samples. The thicker the layer provides higher interfacial surface area of electrodes, and higher stiffness. An IPMC layer with higher stiffness exhibits less displacement which is resulting in smaller bending degree [11]. This can be related to the much larger thickness of the samples, requiring longer time for ion migration and diffusion between the electrodes. As mentioned in previous researches, the electrical model of IPMC consists of few types of resistance as well as capacitance that represents the ion migration process. The thicker IPMC actuator increase the value of the capacitance [2]. On the other hand, the thicker the IPMC actuator, then the voltage limit for simultaneous bending degree for the double layer IPMC actuator was increased too. By referring to Figure-5, the simultaneous actuation voltage limit varies in inverse exponential form. In experiment 4, the bending degree of the double layer IPMC was compared with the bending degree of the single layer IPMC. Figure-6 shows that the bending degree of double layer is larger than that of the single layer IPMC layer. This means the double layer IPMC layer perform much better than that of the single layer IPMC layer with total thickness. This is because it can be related to the larger the thickness of the samples that in contact with the electrode, requiring longer time for electrolyte migration and diffusion between the electrodes. In this case, for double layer, the electrodes were in contact with 0.25mm thick IPMC layer. For single layer, the electrodes were in contact with 0.50mm thick IPMC layer [10]. The recorded difference of the bending degree between single layer and double layer of IPMC actuator was almost 40.2° in average.

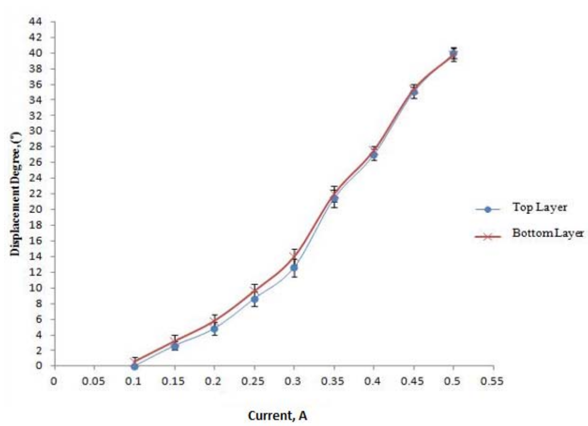

Figure-4. Displacement degree of two layer IPMC actuator at different current.

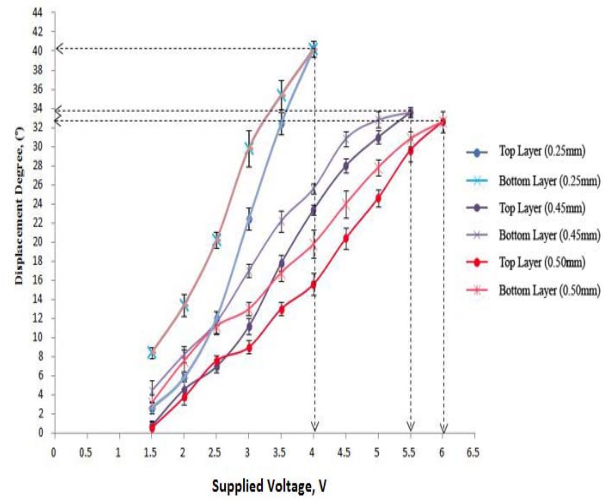

Figure-5. Displacement degree of double layer IPMC actuator with different thickness.

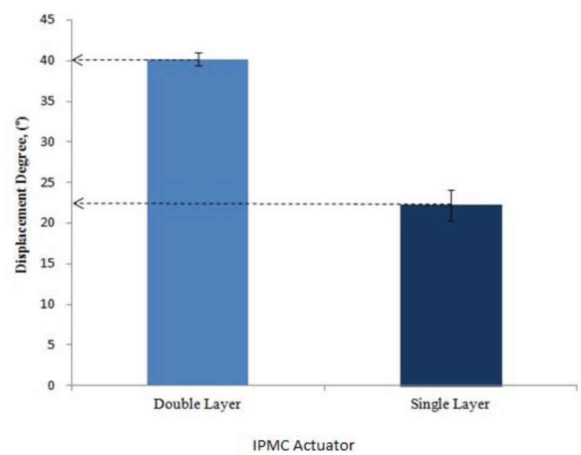

Figure-6. Displacement degree of double layer IPMC actuator.

CONCLUSIONS

In brief, the linear actuation of double layer IPMC depends on the voltage supply. If a sufficient voltage supply is provided to the IPMC layers means the layers will bend simultaneously. The current supply only affects the bending degree of the IPMC layers but not the linear actuation of the layers. If there is sufficient voltage supply, the IPMC layers will be actuated simultaneously using any current supply. Besides that, it's also known that the thickness of the IPMC layer influences the actuation of the layer. The thicker the layer, the higher the voltage needed to actuate the IPMC with desired bending degree. Therefore, multilayer IPMC actuator is more preferred compared to single layer IPMC with larger thickness. This is because multilayer IPMC provides a better bending property compared to the single layer IPMC. In addition, there is only a small voltage supply needed to actuate multilayer IPMC with greater bending degree compared to

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the single layer IPMC which needs a higher voltage supply to actuate. To sum up, the objective of this project is achieved by actuating the double layer IPMC with the desired bending degree where the both of the layers show a simultaneous bending motion.

REFERENCES

[1] H. Andres, Chen, Z., Tan, X. and Kruusma, M. 2009. Feedback Control of a Coupled IPMC Sensor Actuator. ASME 2009 Dynamic Systems and Control Conference Proceeding. 1: 485-491.

[2] Shaari, M. F. and Samad, Z. 2014. Characterization and Parametric Study of Multilayered IPMC Actuator. Advanced Materials Research 983: 161-165.

[3] Nguyen, V.K., Yoo, Y. 2007. A novel design and fabrication of multilayered ionic polymer-metal composite actuators based on Nafion/layered silicate and Nafion/silica nano composite. Sensors and Actuators B: Chemical. 183-190.

[4] Rosly, M. A., Samad, Z., and Shaari, M. F. 2014. Feasibility Studies of Arduino Microcontroller Usage for IPMC Actuator Control. 2014 IEEE International Conference on Control System, Computing and Engineering (ICCSCE). pp. 95-100.

[5] Ahn, K. K., Truong, D. G., Chi Nam, D. N., Yoan, J. T. and Yokata, S. 2010. Position Control of ionic polymer metal composite actuator using quantitative feedback theory. Sensors and Actuators A: Physical. 159: 204-212.

[6] Barramba, J., Silva J. and Branco, P.J.C. 2007. Evaluation of dielectric gel coating for encapsulation of ionic polymer-metal composite (IPMC) actuators. Sensors and Actuators A: Physical. 140: 232-238.

[7] Shaari, M. F., Saw, S.K. and Samad, Z. 2014. Fabrication and Characterization of IPMC Actuator for Underwater Micro Robot Propulsor. Applied Mechanics and Materials. 575: 716-720.

[8] Jang, W. L., Young, T. Y. and Lee, J. Y. 2014. Ionic Polymer−Metal Composite Actuators Based on Triple-Layered Polyelectrolytes Composed of Individually Functionalized Layers. ACS Appl. Mater. Interfaces. 6 (2): 1266–1271.

[9] Hyoung, T. L., Jang, W. L. and Young, T. Y. 2006. Actuation Behavior of a Carbon Nanotube/Nafion IPMC Actuator Containing an Ionic Liquid. Journal of the Korean Physical Society. 49 (3): 1101-1106.

[10] Chen, Z., Um, T. and Bart-Smith, H. 2012. Ionic Polymer-Metal Composite Artificial Muscles In Bio-Inspired Engineering Research: Underwater Propulsion. Smart Actuation and Sensing Systems - Recent Advances and Future Challenges. InTech.

[11] Çilingir, H. D., Menceloglu, Y. and Papila, M. 2008. The Effect of IPMC Parameters in Electromechanical Coefficient Based On Equivalent Beam Theory. SPIE Proceedings, Electroactive Polymer Actuators and Devices (EAPAD). 6297.

[12] Borboni, A. and De Santis, D. 2014. Large Deflection Of A Non-Linear, Elastic, Asymmetric Ludwick Cantilever Beam Subjected To Horizontal Force, Vertical Force And Bending Torque At The Free End. Meccanica. 49: 1327-1336.

[13] Palmre, V., Kim, S. J., Pugal, D. and Kim, K. J. 2014. Improving Electromechanical Output Of IPMC By High Surface Area Pd-Pt Electrodes And Tailored Ionomer Membrane Thickness. International Journal of Smart and Nano Materials. 5: 99-113.

[14] Lee, S. G., Ched Park, H., Pandita, S. D. and Yoo, Y. 2006. Performance Improvement of IPMC (Ionic Polymer Metal Composite) for a Flapping Actuator. International Journal of Control, Automations and Systems. 4: 748-755.

[15] Santos, J., Dente, A. and Branco, P. 2006. Force mechanism generation for electrochemical actuator type IPMC. Universidade Técnica de Lisboa, Portugal.