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Investigations on ionic polymer actuators based on irradiation-crosslinked sulfonated poly(styrene-ran-ethylene)

왕선륜, 오일권†, 서량
Xuan-Lun Wang, Il-Kwon Oh† and Liang Xu

Key Words : ionomer, poly(styrene-ran-ethylene), ionic polymer metal composites

ABSTRACT

The ion-exchange membrane, Nafion, remains as the benchmark for a majority of research and development in IPMC technology. In this research, we employed a novel ionomer named by sulfonated poly(styrene-ran-ethylene) (SPSE) that is crosslinked by UV irradiation. The sulfonic acid groups were stable during the UV irradiation crosslinking process. Water uptake, ion exchange capacity, and proton conductivity are characterized for both pure SPSE and crosslinked SPSE membrane. The bending responses of SPSE actuators under both direct current (DC) and alternating current (AC) excitations were investigated. The voltage-current behaviors of the actuators under AC excitations are also measured. Results showed the crosslinked SPSE actuators have better electromechanical performance than that of pure SPSE actuator with regard to tip displacement as a novel smart material.

1. INTRODUCTION

Electro-active polymer (EAP) systems are considered to be promising candidates for dynamic sensors, robotic actuators, and artificial muscles. A composite form of ion exchange polymer film with metal electrodes has been extensively investigated because of its balanced mechanical properties with fast response and large deformation. When the electric field is applied to the ion-exchange polymer metal composite (IPMC), the ions move from one surface to the other electrode surface in the form of ion-water clusters, resulting in a bending motion of the composite film. When a voltage is applied in the range of 1.0–10.0V to a hydrated IPMC, the large ionic conductivity is considered to induce the electro-osmosis resulting in a bending of the film towards the positive electrode (anode). Due to its distinguished characteristics of low driving voltage, rapid response, and actuation capability in water, it has been applied to the areas of artificial muscles/actuators/sensors, active catheter, distributed actuation device, underwater robot, micromanipulators, micropump, face-type actuator, wiper of asteroid rover, etc.

The ion-exchange polymers, collectively used in the IPMC system, have been applied in various fields such as electrochemical processes, catalysis, and polymer electrodes. Nafion® and Flemion® are the common membranes used for the actuator/sensor application with fluorocarbon backbones and mobile cations (counter ions). For example, Nafion is a copolymer of tetrafluoroethylene and sulfonyl fluoride vinyl ether, which contains the hydrophobic fluorocarbon and hydrophilic ionic phases resulting in a phase-separated morphology of distinct hydrophobic and hydrophilic regions.

In this research, cross-linked SPSE (X-SPSE) was synthesized via vinyl silane as crosslinking agent under UV exposure. Vinyl silane is commonly used as coupling agent, adhesion promoters and crosslinking agent in plastics industry. It is widely used as a crosslinking agent during the manufacture of cross-linked polyethylene. The silane group is reactive, and in the presence of moisture, it forms Si-O-Si cross-links as the material cures. Ion exchange capacity, proton conductivity and water absorption of the membranes were studied. IPMC actuators employing X-SPSE membrane was developed by traditional electroless plating procedure. And then, its electromechanical performance and electrical behavior were characterized and investigated.

† 교신저자; 전남대학교 기계시스템공학부
E-mail : ikoh@chonnam.ac.kr
Tel : (062) 530-1685, Fax : (062) 530-1689
* 전남대학교 기계공학과
** 전남대학교 기계시스템공학부

2. EXPERIMENTAL

A commercial solution of sulfonated poly(styrene-ran-ethylene) in 1-propanol containing vinyl silane as crosslinking agent was purchased from Aldrich, and styrene is at a weight percent of 76%. The membrane of the ionomer was obtained through a solution casting method commonly used in the fabrication of Nafion membranes. After the membrane was peeled from the casting, it was annealed at 50°C for 24 hrs in order to increase its mechanical stiffness. Next, SPSE membrane was placed into the UV chamber. Double faces of SPSE membrane are treated with UV lights for 5 minutes. The model of UV chamber is UV-RF 750 (YB tech company, Korea).

3. RESULTS AND DISCUSSION

Table. 1. Properties comparison between X-SPSE and pure SPSE membrane

Membrane	IEC (meq./g)	Proton conductivity (S/cm)	Water uptake (%)
Pure SPSE	1.86	1.31×10^{-2}	160
X-SPSE	2.35	1.91×10^{-2}	89.7

Table 1 listed the water absorption, ion exchange capacity (IEC) and proton conductivity for X-SPSE and SPSE membranes. X-SPSE and SPSE membranes were cast from different bottle of commercial solution. The ion exchange capacity was measured using the classical titration method. From this table, we know that X-SPSE have larger DOS value, so its IEC and proton conductivity is better than pure SPSE membrane. However, the water uptake of X-SPSE membrane is smaller than pure SPSE membrane. The result showed that the crosslinking reaction has lightly taken place between SPSE macromolecular and vinyl silane. Crosslinking structure can contribute to the reduction of the water absorption and swelling level for ionic polymer membranes.

Fig. 1 compared the bending response of X-SPSE actuator with pure SPSE actuator upon DC input of 2V voltage. X-SPSE actuators have better bending response compared with pure SPSE actuator. The maximum displacement of X-SPSE actuator reached 2.8 mm after 80 second upon the DC excitation. Fig. 2 compared the tip displacement of X-SPSE actuator compared to pure SPSE actuator under the AC excitation. The result revealed that X-SPSE actuator has larger actuation deformation than pure SPSE actuator and also its response was more harmonious. The reason is probably that X-SPSE ionic membrane has bigger IEC value and proton conductivity in comparison with pure SPSE membranes.

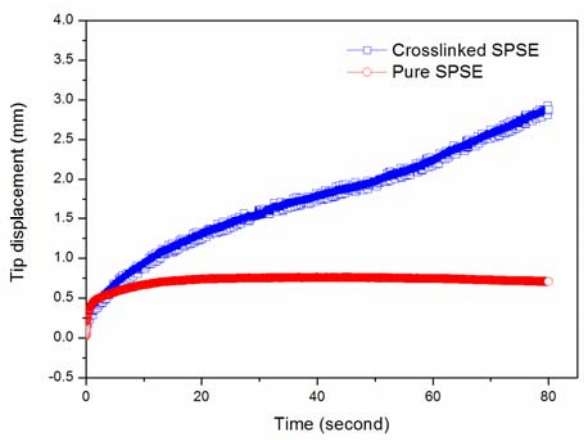

Fig. 1. Bending responses under DC excitation

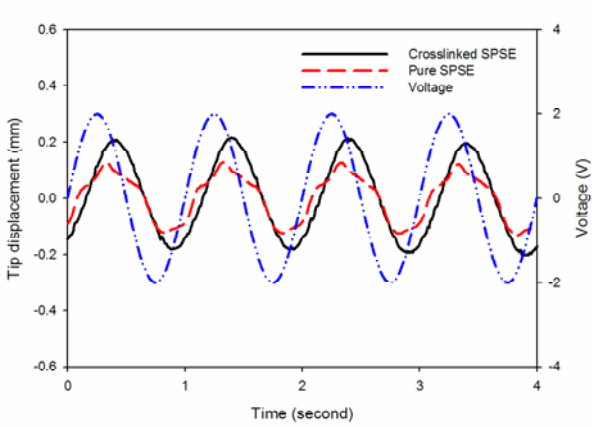

Fig. 2. Bending response under sinusoidal excitation.

4. CONCLUSIONS

In this study, X-SPSE membranes were employed for ionic polymer actuator fabrication. UV irradiation was employed for the crosslinking reaction of SPSE and vinyl silane. Obvious improvements on the bending performance were proved under both AC and DC excitations for X-SPSE actuators in comparison with non-crosslinked SPSE actuators. Moreover X-SPSE polymer actuators have rapid and harmonic bending response under sinusoidal excitations. The tip displacement increased with the increment of driving voltages and decreased with the increment of the applied driving frequencies.

후 기

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