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Bending behavior of an electrically activated complex forming hydrogel

Kang De Yao* and Shan Sun

Department of Material Science and Engineering, Tianjin University, Tianjin 300072, China

SUMMARY

The complex forming poly[(ethylene glycol-co-proplene glycol)-g-acrylamide] : polyacrylic acid interpenetrating polymer network hydrogel is able to bend under electric field "stimuli". pH, ionic strength gradients and voltage can influence it's bending degree. So we may improve the samples' "responsive" speed through manipulating those factor in the further study in order to put it into the biomedical application.

INTRODUCTION

Many work have been done on contractile behavior of polymers in contact electric fields [1-3], which is called electromechanochemical (EMC) behavior, but few have been studied on the EMC phenomena in non-contact electric fields. In this paper, we focused on bending behavior of the complex forming hydrogel synthesized on the basis of poly(ethylene glycol-co-propylene glycol), P(EG-co-PG), chain extended with acrylamide (AAm) and crosslinked acrylic acid (AA). In addition to salt solution, such as Na_2SO_4 and Na_2CO_3 aqueous solution, we also observed the polymer's bending in distilled water under different voltages. Devices based on these phenomena have important applications in the field of artificial organs. For examples, muscle like

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*Corresponding author

actuators for artificial sphincters, limb prostheses, pulsatile pumps and circulatory assist devices [4].

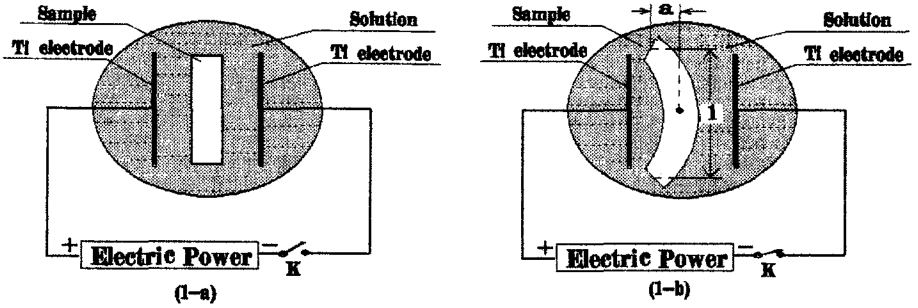
EXPERIMENTAL

Materials syntheses

Complex forming hydrogels were prepared following such a procedure: first, 10^{-4}mol 4-hydroxyl terminated P(EG-co-PG) (the average number molecular weight of 2400) was dissolved in 100ml 1.0M AAm aqueous solution, then 0.4ml 1.0M $Ce(NH_4)_2(NO_3)_6$ (initiator) in 1.0M nitric acid solution was added. The polymerization was carried out at $40^\circ C$ for 1.5 hours to obtain the graft polymer. Second, the graft polymer was swollen with 1.0M AA monomer solution in which 5.0wt% crosslink agent N,N-methylene bisacrylamide and 1.0 mol% $k_2S_2O_8$were contained. The absorbed AA mixture was allowed to react in situ at $80^\circ C$ for 7 hours, yielding PAA second network which interpenetrated with P(EG-co-PG)-g-PAAm. And last, the P(EG-co-PG)-g-PAAm:cr-PAA complex forming IPN gel samples were washed with distilled water, and cut to a square with section sizing in $3.0 \times 1.0 \times 0.5cm^3$.

Bending behaviors

A rectangular sample of P(EG-co-PG)-g-PAAm:cr-PAA complex forming hydrogel was placed between two non-contact titanium electrode, and it's center was fixed. All of them were in a solution contained in a glass vessel (see Fig.1-a). D.C. potential was applied across the flat electrodes which were 6 cm apart. When the switch was on, we could observed that the sample bend to the anode while swell on the side to the cathode (see Fig.1-b).



(1-a)

(1-b)

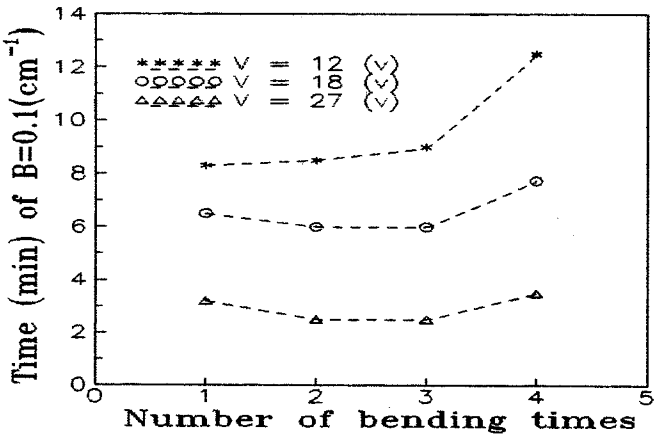
1. **Figure 1. Schematic drawing of the EMC experiment (1-a), and the EMC phenomenon under D.C. electric field in polar a.q. solution (1-b).**

The bending degree (B) could be calculated according to the following equation.

$$B = \frac{8a}{l^2 + 4a^2}$$

RESULTS AND DISCUSSION

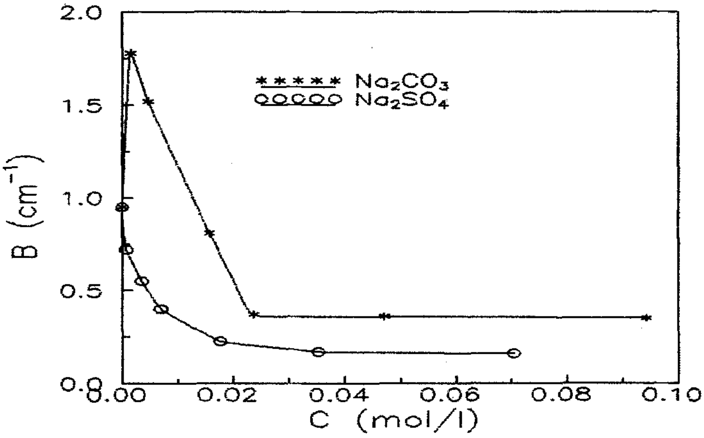
P(EG-co-PG)-g-PAAm:cr-PAA is a kind of polyelectrolyte hydrogel. Not only is it able to bend in non-contact D.C. electric filed, but also this behavior is reversible when the positive and negative electrodes change each other (cf. Fig.2).



2. **Figure 2. The influence of voltage on the time for the desired B ($B = 0.1cm^{-1}$) on the different bending times.**

Many experiments showed that polyelectrolyte polymers were able to contractile on the anode side in contact electric field due to pH changes, ions movements in solution and volume phase changes [5-6] in the polymers. Similar to these, but not the quite same, the reversible ability of complex formation and dissociation of the hydrogen bonds between P(EG-co-PG)-g-PAAm:cr-PAA. As it can strongly influence the swelling degrees of the polymer samples, the bending behavior may be a result of the imbalance of the equilibrium swelling pressure in the samples. Addition to that, spatio-temporal pH ionic strength gradients created by electrochemical reactions in the electric field, which are influential factors of swelling equilibrium, can also affect the bending of the samples.

Figure 3 shows bending vs concentration of Na_2SO_4 and Na_2CO_3 aqueous solution at constant electric strength E=3.0v/cm. Different between these two electrolytes, in Na_2SO_4 solution , the B decreased with the increasing of Na_2SO_4 concentration, therefore showed that ionic strength had influence on the bending behavior. But in Na_2CO_3 a.q. solution , there was a sharp value B in the curve, and on the same condition, all of the B in Na_2CO_3 a. q. solution were higher than that in the Na_2SO_4 a.q. solution. That showed bending behavior was not only related to ionic strength, but also to pH, as pH in Na_2CO_3 solution was above 7.0.



3. **Figure 3. Relationship between the bending degree and concentration of the electrolyte solution at time t=6min.**

In different from the others, we observed the bending of P(EG-co-PG)-g-PAAm:cr-PAA complex forming hydrogel in water under a D.C. electric field. The result (cf. Fig. 4) shows that the higher the voltage is, the faster the sample reach the desired bending degree B. Because H_2O was resolved into hydrogen and and oxygen in the electric field, hydrogen was released at cathode where OH^- was left simultaneously and pH was high, while oxygen was released at anode where H^+ was left and pH was low. That resulted in a pH and ionic strength gradient between the anode and cathode, and in the sample, the swelling pressure on the side to the cathode was higher than that to the anode, and made the sample bend to the anode while swell on the other side.

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