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Electrode Effects on Polyurethane Soft Actuator

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Abstract

A polymer soft actuator is under investigation using a poly urethane elastomer film that bends by means of an applied voltage, which is based on the electrostriction. Bending experiments were performed under different metal electrodes deposited the both sides of the film. Even if the thickness of the both electrodes is the same, the metal of the both electrodes is desirable to be the same to bend more. It is suggested that the balance of the physical properties of the both metal is critical for larger bending.

Keywords

Poly Urethane Elastomer, Soft Actuator, Fullerenol, Metal Electrode

1. Introduction

A polymer soft actuator of polyurethane elastomer is now under investigation. The soft actuator is quite attractive because the structure is so simple as to be prepared at low cost. Actually the device consists of a polyurethane film with a thickness of several hundred micrometers equipped with two metal electrodes on the both sides. Other advantages of the device are soundless action, high energy efficiency and only use of environment-friendly materials [1] [2]. The technology is now expected to be the one that is developed to robotic fingers [3]. It will also proceed to the fascinating artificial muscle technologies [4]. Some other research histories are in the literature cited in our previous article [5].

Although the soft actuator is promisingly an interesting device, there are several problems unfortunately. The biggest problem among them is that the applied voltage is required to be above 1 kV even to bend several centimeters. Obviously this voltage is too high from the aspect of artificial muscle applications. Some breakthrough to the lower driving voltage will be needed.

This article reports the effect of electrode materials on bending characteristic. The role of the metal electrodes is to supply the applied voltage over the surface.

This actuator acts to bend, so the mechanical properties of the electrode metal may affect the bending performance. The obtained results will be discussed in relation to the Young's modulus of the metal used in the electrodes.

2. Experimental

First described is the way to form a polyurethane elastomer film. Before the formation of the film, fullerenol was synthesized, that was added to enhance the amount of bending. The synthesizing step of fullerenol is that fullerene is sulfonated and then hydrolyzed. Actually, fullerene (3 g) and oleum (25 ml) were mixed for 7 days to obtain multivalent sulfonated fullerene. By controlling the time and temperature of this mixing determines the degree of sulfonation. The sulfonated fullerene (3 g) was mixed with distilled water (60 ml) for 4 days for hydrolyzing. More detailed conditions can be referred to the literature [5]. This fullerenol was added in the process of a polyurethane film described later.

For the synthesis of polyurethane, prepolymer was prepared in such a way that a certain amount of polyol (P-3010 by Kuraray Co. Ltd.) was reacted with para-phenylene diisocyanate to replace the hydroxyl group to the isocyanate group. The number of para-phenylene diisocyanate moles should be the same as that of –OH group moles for the replacement of all –OH groups. The mixture of the two substances was heated up to around 100˚C in vacuum for the elimination of water in the mixture and even in the air.

The obtained prepolymer was blended with extenders that are actually diol and triol: 1,2-propanediol (1,2-PD) and trimethylolpropane (TMP). We were quite careful to degas thoroughly before and after the mixing at 80˚C in vacuum. The fullerenol was added together at this stage. The ratio of the fullerenol was 0.25% that gives the best performance as reported [5]. When prepolymer and extenders were mixed together, the coupling reaction between –OH and –NCO groups started spontaneously. The mixture was rapidly put into a mold of stainless steel and cured for 18 hours after it was well mixed and degassed. The thickness of the film was 400 μm, which was determined by a spacer put between a pair of two molds.

After curing, the film was taken out and cut into a rectangular form of 15 by 50 mm. Afterwards metal electrodes were deposited by means of an ion-assisted vacuum deposition method. The film thickness was under 0.5 μm. Four kinds of combinations were tried using Al and Au metals.

The actuation of bending was performed using a laser displacement meter (LB-1000 by Keyence Corp.) at the bottom end of the film while the film was clipped at the upper end as shown in **Figure 1**. The displacement meter measures the forward or backward movement of the film at the laser-irradiated point.

3. Results and Discussion

Figure 2 shows the displacement depending on the applied voltage. The displacement was about 7 mm at most. It is supposed to bend more if the film thickness is less than 400 μm [6]. It is because the electric field induced in the

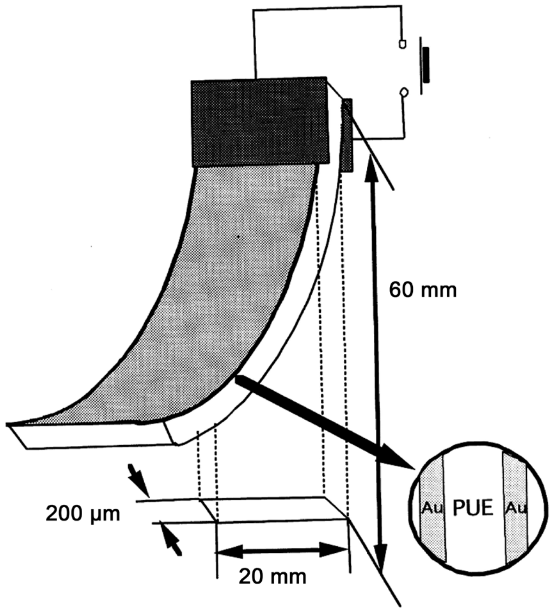

Figure 1. Dimension of polyurethane elastomer and its external appearance of bending action.

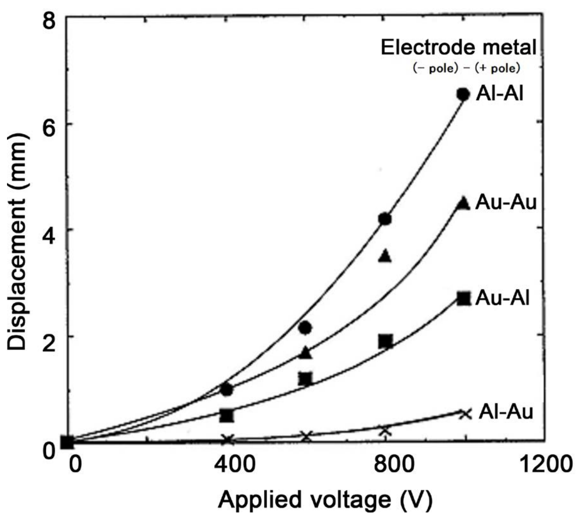

Figure 2. The bending displacement of the film as a function of applied voltage. Four kinds of combinations of metal were shown.

film is inversely proportional to the film thickness.

The interesting feature of the results is that the characteristic is quite different depending on what metal is used as an electrode. We remind here the thickness of the electrodes was controlled to be the same. The electrode only provides the electric voltage to the film, and it needs no chemical reaction between the film and the electrode required to bend. **Figure 2** shows that the sample with Al (cathode) - Al (anode) electrodes bended most, the one with Au - Au electrodes was the second, and then Au - Al, Al - Au successively. It can be said that when the same metal is used in the both sides it is easier to bend. In the case of using Al and Au metals are used, bending displacement was quite small when Al was used as a cathode.

We pay attention to the Young's modulus of the metal. The Young's moduli of aluminum and gold are 70.3 and 78.0 GPa, respectively. From the point of view, gold is harder than aluminum to bend by about 10%. It can well explain the Al - Al and Au - Au samples qualitatively. However, the Young's modulus cannot explain the Au - Al and Al - Au cases at the same time. The discrepancy between Au - Al and Al - Au samples is meaningfully large. It was concluded that the unknown effect was triggered when the kinds of metal is different in an anode and a cathode.

Take the Al - Au case to consider further. Figure 3 shows other experimental results of Al - Au samples. The "thick" indicated in the figure means the thickness of the film was about three times thicker. When the Au anode was thickened the characteristic was not apparently changed. On the other hand, when the Al cathode was thickened, the bending direction was reversed while the bending amount was not so varied. From the facts above, the cathode among the two electrodes, have an effect on bending mechanism. The effect was not clearly recognized at this stage. It is interesting to pursue the effect thoroughly because it may possibly unveil the closer mechanism of bending.

Another difference between the two metals is resistivity. Aluminum and gold have the resistivity of 27.5 and 24.0 nΩm, respectively. The resistivity of aluminum has about 20% larger than that of gold. However the difference may not contribute to the change in bending characteristics because the polyurethane film is an insulator and the electric current does not play an important role for the actuation.

J. Kyokane *et al.* have reported the interesting results that both positive and negative electric charges were accumulated near a cathode when the voltage was applied [7]. It is unlikely to the fact that negative and positive charges were accumulated near the cathode and the anode, respectively, in case of polyethylene terephthalate that does not shows electrostriction. The cathode side shrinks and the anode side expands so that the film always bends in the direction of the ca-

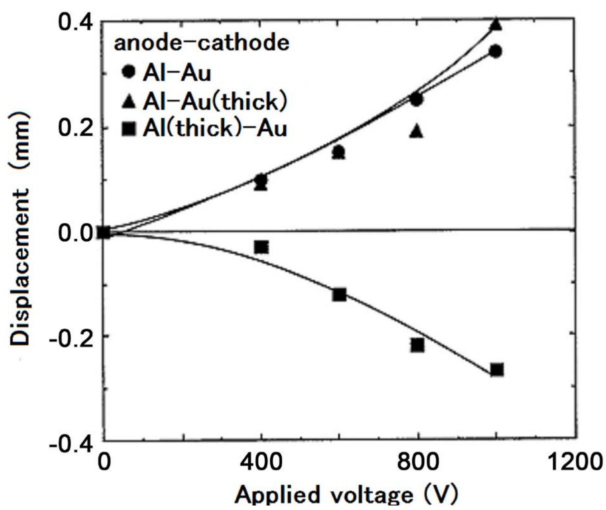

Figure 3. The bending displacement of the film as a function of applied voltage. Three kinds of combination of metals were shown.

thode. Since this result was when carbon nanotube was included in the film, it is too rough to apply this idea to our experimental results directly.

On the basis of the unaccountable phenomena shown in Figure 2, it is speculated that fine particles of the anode and the cathode permeated into the film and partly mixed in the film when the electrodes were deposited. In order to clarify the phenomena, it is needed to investigate more closely, even including a physical structure in the film, in the future.

4. Conclusions

Polyurethane elastomer films were fabricated with two metal electrodes on the both sides. Aluminum and gold were used as a metal material and so four kinds of combination were considered for the two electrodes. The effect of metal material of the electrodes on the bending characteristics was investigated.

When the both two electrodes of front and back sides are composed by the same material, bending displacement is comparatively large. In this case, aluminum, which has a Young's modulus smaller than gold by about 10%, bended more. When the two electrodes were made of two different metals, the bending displacement became small. It is more noticeable when aluminum was used for a cathode. In this case, the results cannot be explained on the basis of the Young's modulus alone.

Another interesting feature was found in the case of aluminum in cathode and gold in cathode. The characteristic was not changed when the thickness of the gold thickened three times larger. But if the thickness of the aluminum was three times larger, the bending direction turned into the opposite side.

Further studies were expected including the physical structure inside the film. It will help us understand the mechanism of this fascinating phenomenon of electro-bending action more closely in the future.

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