Bending Deformation of Monolayer Polyurethane Film Induced by an Electric Field

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The bending deformation of a polyurethane film induced by an applied electric field was examined under free electrode conditions. We showed that the deformation was due to bending electrostriction.

In previous papers,[1-3] we reported that some kinds of polyurethanes can contract due to an applied electric field. The thickness strain was proportional to the square of the applied electric field. This property is termed electrostriction. B. A. Newman et al. also reported the electrostrictive property of polyurethane.[4] T. Furukawa et al. studied this property using poly(vinylidene fluoride).[5] In these reports, only the change in thickness induced by an electric field was measured.

There are few studies of the bending deformation of monolayer polymer films by an applied electric field. The bending due to piezoelectricity has also been reported,[6-11] but the studies of the bending electrostriction in polymers have been restricted to only a few reports. H. Kawai reported the bending electrostriction of polarized poly(vinylidene fluoride) and nylon 11.[12-13]

In this report, we investigated the bending deformation induced by an electric field of a monolayer polyurethane film, which was not polarized.

The polyurethane film was synthesized using the prepolymer method.[14] The soft segment was poly(3-methyl-1,5-pentane adipate) (PMPA). The hard segment was composed of 1,6-diisocyanohexane (HDI) and 1,4-buthanediol (BD). The composition of the polyurethane was PMPA/HDI/BD=6.7/10.0/3.5 in mole ratio. Using an ion-sputtering method, the prepared film (0.5 mm in thickness) was coated with a thin gold layer on each surface that served as electrodes. The film was cut into 5 X 30 mm pieces.

The experimental setup for the measurement of the bending deformation is shown in Figure 1. The film was vertically suspended in air, and the top of the film was fixed. The measurements were carried out at room temperature. By applying a d.c. voltage, the displacement of the free bottom end of the film was measured using a laser displacement meter (Keyence Corporation, LB-62).

By applying an electric field (2 MV/m) to the polyurthane film (sample A), which was at equilibrium under the absence of an electric field, it gradually bent toward the anode side (Figure 2). The displacement value was 0.18 mm. Another sample (sample B) was cut from the same sheet. One side of the sheet was defined as the front face, while the other side was the back face. In the case of sample A, the anode side was the front face and it bent toward the anode side (0.18 mm). In the case of sample B, the anode side was the back face, but it also bent toward the anode side (0.15 mm). This indicates that the bending motion was caused by the asymmetrical deformation induced by an electric field, not by the difference between the front face and the back face of the sheet.

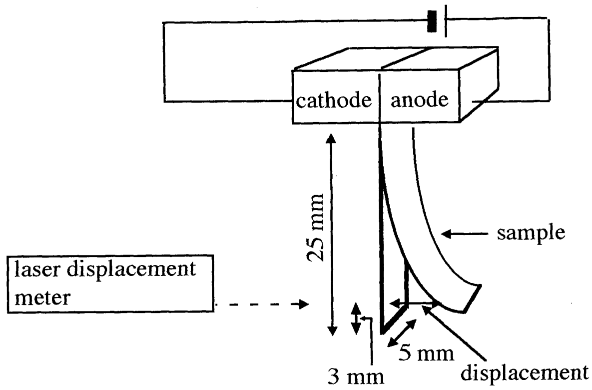

Figure 1. Experimental set up for the measurement of deformation of the polyurethane films.

Application of an electric field (2 MV/m) was repeated twice. In Figure 2, the direction of the electric field in the second application was in the same direction as the first application. In

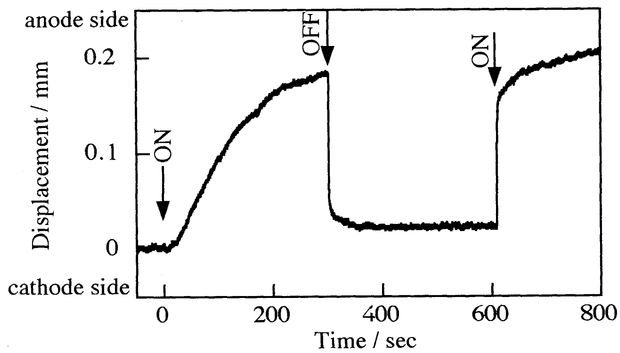

Figure 2. The course of bending deformation.

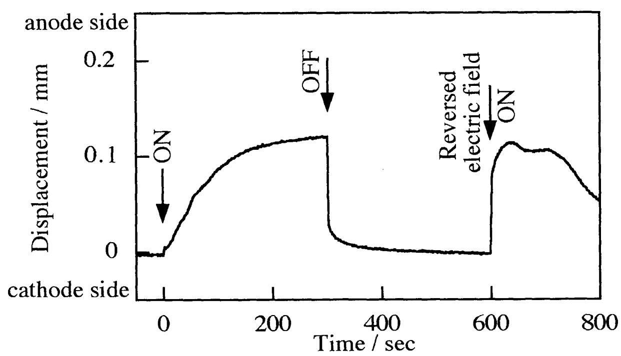

Figure 3. The course of bending deformation when the second applied electric field was opposite to the direction in the first application.

Figure 3, the direction in the second application was opposite to the direction in the first application, but it bent in the same direction. This suggests that the bending deformation of the polyurethane film polarized by the first application was caused by electrostriction.

The variation in displacement due to an applied electric field was also examined. To measure the displacement of the film polarized by the first application, the measurement was carried out after applying an electric field of 2 MV/m for 30 minutes. To keep the state of polarization constant, the application pattern was followed as in Figure 4.

The variation in displacement due to the applied electric field is shown in Figure 5. The displacement was proportional to the square of the applied electric field.

To examine the expansion of the each surface, the displacement was measured, sticking adhesive tape on the anode or cathode surface. The adhesive tape is inert to the electric field and

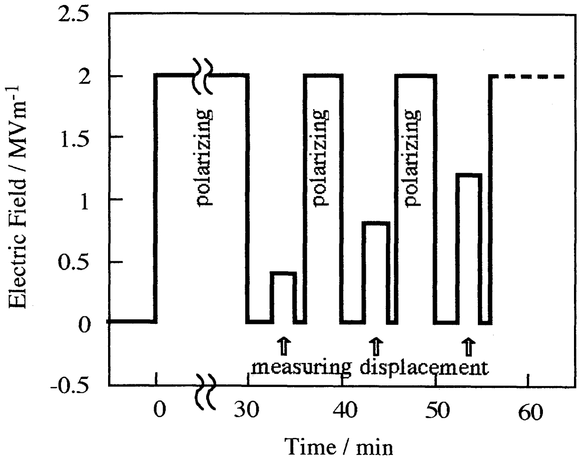

Figure 4. The application pattern of the electric field.

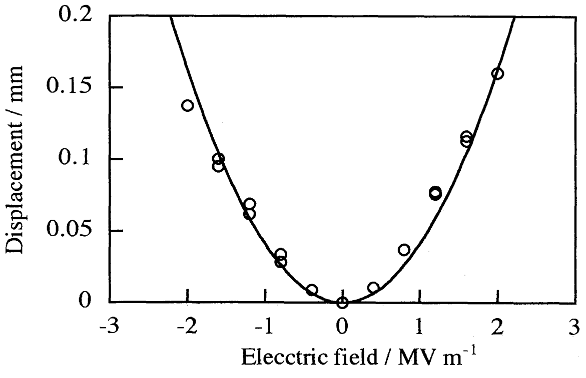

Figure 5. The variation of displacement with an applied electric field.

prevents the striction by sticking to the surface. As a result, both surfaces were expanded in proportion to the square of the applied electric field. But the expansion of the cathode surface was much greater than that of the anode surface. This difference generates the electrostrictive bending deformation.

In Figure 1, the displacement gradually increased during the first application but bent rapidly during the second application. As already stated, the rapid second deformation was caused by electrostriction. During the first application of an electric field, at any time, once the electric field was interrupted then applied shortly thereafter, the value of the displacement diminished to about 0 mm then quickly recovered to the same position before the interruption. This indicates that the gradually increasing displacement was also caused by electrostriction but the degree of electrostriction, which was defined by the degree of polarization, gradually increased with the increase in polarization.

In conclusion, the polyurethane film can bend using an applied electric field. We showed that the bending deformation was caused by the electrostriction which was asymmetric to the polarity.

The polyurethane film was one layer and homogenous but can bend like bimorph actuators. This material can offer great promise in applications as artificial muscles and actuator devices.

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