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Electromechanical Strain Responses of SEBS/Carbon Composite

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Electromechanical strain response of poly (styrene-b-ethylene-co-butylene-b-styrene) (SEBS)/carbon black(C) composite has been investigated by using laser displacement sensors. The composite consisting of neat SEBS, mineral oil and carbon powder was prepared by internal mixer. Compliant carbon paste electrodes were coated on both sides of the composite films. The SEBS and SEBS/C composite showed very fast electromechanical strain responses to the electric stimulation. The residual strain was rarely observed during the cyclic actuation tests. The SEBS/C composite with a small amount of carbon black had much higher electromechanical strain than the SEBS.

Keywords Composite; dielectric; electromechanical strain

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Introduction

Electroactive dielectric elastomers have been paid great attention as a potential candidate for the compact transducers, flat-panel speakers, and artificial muscles, because they have many merits such as high electromechanical strain, fast response, high power to mass ratio and low cost, compared to other electroactive polymers. However, the high performance of the dielectric elastomer has been achieved at very high applied electric field, which is considered as the biggest obstacle for the real application [1].

When an external electric field applied, the dielectric elastomer films are compressed in thickness direction and expended in lateral direction due to electrostatic force between oppositely charged compliant electrodes, called as Maxwell stress [2]. The electric field-induced strain along the thickness direction, S_z is

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expressed according to Eq. (1).

$$S_z = -\frac{\varepsilon_0 \varepsilon_r E^2}{Y}, \quad (1)$$

where ε_0 and ε_r are the vacuum dielectric permittivity and the dielectric constant of the sample. E and Y are the electric field and a compressive modulus, respectively. Hence, many composites systems filled with high dielectric constant organic or inorganic fillers have been investigated in order to reduce operational voltage of the dielectric elastomer [3,4,6]. Petit *et al.* reported that polyurethane(PU)/carbon nanopowder composite showed higher strain than pure PU [3]. Dang *et al.* reported that poly(vinylidene fluoride) (PVDF) composites with ceramic particle such as LTNO, $BaTiO_3$ showed the enhanced electromechanical strain response [4]. Such performance enhancement was attributed to higher dielectric constant of the composites than that of matrix polymers.

Shankar *et al.* reported that poly (styrene-*b*-ethyle-*co*-butylene-*b*-styrene) (SEBS) gel had not only unexpected high electromechanical strain response, but also easy performance tenability via addition of a plasticizer. The results were attributed to the strong surface polarization of styrene micelles in the multiphase system [5].

In this paper, the SEBS/C composite is demonstrated in order to investigate the carbon filler effects in the electromechanical properties of the multiphase SEBS dielectric elastomer.

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Experimental

SEBS (G1650) triblock copolymer was purchased from KRATON. It is a thermoplastic elastomer with 30 wt% styrene hard end blocks and 70 wt% ethylbutylene soft mid blocks. White mineral oil (T-150) was obtained by Michang Oil Ind. Co. in Korea. Carbon powder was purchased from DENKA. Carbon paste (FTU-20) for compliant electrode was purchased from ASAHI CHEMICAL. It included carbon powders with average particle diameter of 36 nm and specific surface area of 65 m^2/g. The SEBS gel was consisting of 20 wt% neat SEBS and 80 wt% mineral oil. The SEBS/carbon composite contained 0.2 wt% carbon powders in the SEBS gel. The SEBS/carbon composite was prepared by using ball milling with zirconium balls. Mixture of a SEBS, carbon powder, oil and toluene in bowl was milled at 400 rpm for 1 hour. After ball-milling, it was dried at vacuum oven. The sample films 0.5 mm thick were prepared by using hot pressing molding. Compliant carbon paste electrodes were coated on both sides of the composite films. The dielectric constant was measured by Impedence Analyzer (HP1492A).The dielectric constants of SEBS and SEBS/C were 2.37 and 2.41 at 100 Hz to 10 kHz at room temperature, respectively. The compressive modulus was obtained by Instron 5883. SEBS and SEBS/C had compressive modulus of 0.18 MPa and 0.19 MPa, respectively. Electric voltage was applied by a function generator (Agilent 33250A) with a high voltage amplifier (Trek 10/10B). The electromechanical thickness strain was measured by using two laser displacement sensors (Keyence LK-G80). The advantage of the laser sensing systems was previously published [7].

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Results and Discussions

Figure 1 describes that thickness strain measurement by using two laser sensors. The incident laser beam was exposed vertically to the sample surface. The positions of the two sensors were fixed. The sample was located in between fixed two laser sensors. The laser displacement sensor measured the distance between the sensor and the sample. The film thickness was denoted as D_0 without and electric field and D under an electric field, respectively. The distance between a sensor, S_A and the film was expressed as L_{A0} without and electric field and L_A with an electric field. It was assumed that a flexure motion occurred as long as Δf. The dimension change of the film, $-\Delta D$ was obtained by the sum of ΔL_A and ΔL_B, the distance changes between each sensor and the film, as described in Eq. (2). The measured dimension change did not depend on the flexure movement. Hence, a true thickness strain of the dielectric elastomer can be measured by the combination of the two laser displacement sensors [7].

$$\begin{aligned} &L_{A_0} + L_{B_0} + D_0 = L_A + L_B + D \\ &(L_A - L_{A_0}) + (L_B - L_{B_0}) = -(D - D_0) \\ &\Delta L_A + \Delta L_B = -\Delta D \end{aligned} \tag{2}$$

Figure 2 shows the electric field induced strain responses of SEBS and SEBS/C. SEBS/C composite was including 0.2 wt% carbon powder in the SEBS gel. The strain was measured by using two laser sensors.

The DC electric field of 22 V/μm was delivered to the electrodes in the form of step function. Both SEBS and SEBS/C composite showed fast contraction and fast recovery response in thickness dimension to the input electric stimulation. The residual strain was rarely observed after removing the electric field. The SEBS/C composite showed much high electromechanical strain response than the SEBS.

Figure 3 shows the thickness strain of the SEBS and SEBS/C composite as a function of an electric filed. In both samples, the thickness strain, S_z quadratically

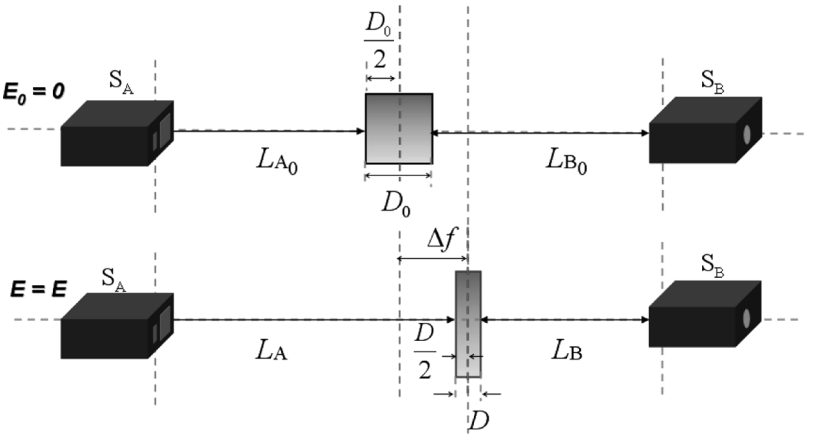

Figure 1. A schematic diagram of thickness strain measurement by using two laser displacement sensors.

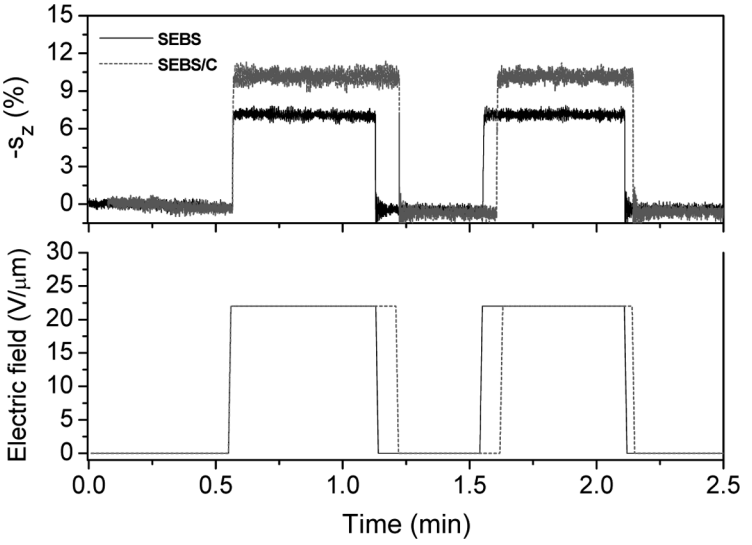

Figure 2. The thickness strain responses of the SEBS and SEBS/C to the applied DC electric signal.

increased with the applied electric field strength as expected in Eq. (1). SEBS/C had much higher thickness strain than SEBS at the same electric field level. The electromechanical strain enhancement of the SEBS/C composite can be attributed to the space charge effect. Space charges injected from the electrodes under an electric field might be trapped at the SEBS/C interface due to large dielectric difference between SEBS and C. It causes to develop an inhomogeneous electric field across the film thickness [2,5,8,9]. The nonuniform field distribution can enhance the strain response, because the strain is proportional to the square of electric field in a dielectric elastomer described in Eq. (1). Therefore, the SEBS/C composite has much larger strain response at the same applied electric field strength than the SEBS.

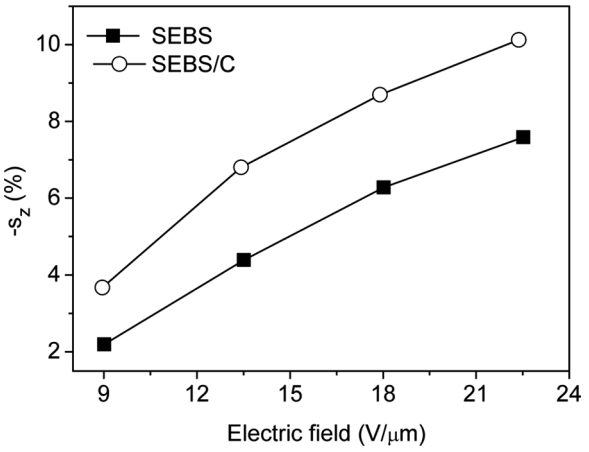

Figure 3. The electromechanical thickness strains, S_z of the SEBS and SEBS/C as a function of an applied electric field.

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Conclusion

Electromechanical strain response of poly (styrene-*b*-ethylene-*co*-butylene-*b*-styrene) (SEBS)/carbon (C) composite has been investigated by using laser displacement sensors. The SEBS and SEBS/C composite showed very fast strain responses zwithout significant cyclic hysteresis to the electric simulation. The SEBS/C composite with 0.2 wt% carbon loading had much higher electromechanical strain than the SEBS. The electromechanical strain enhancement of the SEBS/C composite can be attributed to the space charge effect.

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