Effect of Temperature on The Electromechanical Properties of Elastomers

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Acrylic elastomers, SAR, SBR and SIS thin sheets were fabricated through solvent casting and electrorheological properties were measured and tested towards electroactive applications such as artificial muscle and/or MEMS devices. Experiments were carried under the oscillatory shear mode with applied electric field strength varying from 0 to 2 kV/mm. The effect of temperature on the storage and loss modulus (G' and G"), storage modulus sensitivity ($\Delta G'/G'_0$), and dielectric permittivity of acrylic elastomers (AR70, AR71, and AR72), SAR, SBR and SIS D1112P were studied between 300-370 K. AR71 has the highest dielectric permittivity (ε') of 55.98 pF/m, whereas SIS D1112P has the lowest dielectric permittivity of about 24.28 pF/m. From our data, we can classify the elastomers into two types. Acrylic group has positive storage modulus sensitivity with increasing temperature and dielectric constant, and the styrene copolymer group has negative storage modulus sensitivity.

1. Introduction

Electroactive polymer (EAP) is the polymer which can respond under applied electric field. One type of electroactive polymers is the dielectric elastomer (Wissler and Mazza, 2005, p.184).Dielectric elastomers have been known to generate both stress and strain responses towards applied electric field. When the electric field is applied, the repulsion force between like charges on the same electrode generates tensile stresses in the length and the width directions. The unlike charges on the opposite electrodes generates the attractive force in the thickness direction (Pelrine *et al*., 1998, p.77 and Butkewitsch *et al*., 2006, p. 8277). There has been much recent interest in dielectric elastomer to be used as electroactive materials (Pelrine *et al*., 2002, p.89). The important relation which is used to indicate the degree of electromechanical response of a dielectric elastomer is the effective pressure:

$$p = \varepsilon\varepsilon_0 E^2 \tag{1}$$

where p is the effective pressure, ε is the dielectric permittivity of the material, ε_0 is the dielectric constant of free space (8.85 pF/m), and E is the electric field strength (V/m) (Pelrine *et al*., 2002, p.89). From equation (1), the elastomers which have higher dielectric permittivity can and are expected to generate the same pressure at a lower applied voltage (Soares *et al*., 2006, p. 676) Since the dielectric permittivity depends on both frequency and temperature (Rubinstein *et al*., 2003, p. 258), it appears that we can vary the electrorheologial response by merely changing operation temperature at a fixed frequency.

In our work, we are interested in investigating various types of elastomers as the suitable electroactive polymer. The effect of elastomer types was examined. In particular, the effect of temperature on the storage modulus respond ($\Delta G'_{2kV/mm}$) and the storage modulus sensitivity ($\Delta G'_{2kV/mm}/G'_0$) were considered and will be shown to be correlated with the dielectric permittivity of elastomers at various temperatures.

2. Methodology

2.1 Materials

Nipole AR71 and AR72HF are acrylic elastomers produced by Nippon Zeon Polymix Advance Co., Ltd. Acrylic elastomer AR7018 (AR70), Styrene-Butadiene rubber (SBR) and Styrene-Acrylic-copolymer (SAR) were produced and provided by Dow chemical. Styrene-isoprene-styrene triblock copolymer (Kraton D1112P) was obtained From Shell in Thailand Co., Ltd.

2.2 Preparation of specimen

All elastomer specimens were fabricated through solution casting. AR70, SAR, and SBR specimens were formed by water evaporation; SIS D1112P, AR71, and AR72 specimens were dissolved by toluene at 30 % vol/vol. The solutions were cast on to a mold (diameter 25 mm, thickness 1 mm) and the solvent was eliminated out under a vacuum atmosphere at 27ºC for 48 hours.

2.3 Characterizations

2.3.1 The specific conductivity of polymer sheet were measured by a meter which consists of a melt rheometer (Rheometric Scientific, ARES) with parallel plate fixture making contact on a surface of specimens. The melt rheometer was connected to a source meter (Keithley, Model 6517A) for a constant voltage source and for reading current.

2.3.2 The dielectric permittivity values were measured by a LCR meter (HP, model 4284A) connected with and controlled by the melt rheometer (Rheometric Scientific, ARES) which was fitted with a 25 mm parallel plate fixture. The thickness of specimen is 1 mm and diameter is 25 mm.

2.3.3 The eletromechanical properties were measured by the melt rheometer (Rheometric Scientific, ARES). It was fitted with a custom-built copper parallel plates fixture (diameter of 25 mm). A DC voltage was applied with a DC power supply (Instek, GFG 8216A), which can deliver electric field upto 4 kV. A digital multimeter (Tektronix, CDM 250) was used to monitor the voltage input. In these experiments, the oscillatory shear strain was applied and the dynamic moduli (G' and G") were measured as functions of frequency and electric field strength.

3. Results and Discussions

3.1 The dielectric permittivity measurement

The dielectric permittivity measurements were measured by using a HP model 4284A. The results of all elastomers at various temperatures are shown in Table 1.

Table 1 The dielectric permittivity of all elastomer at various temperatures**.**

Temperature (K)	Dielectric permittivity of various types of elastomer (pF/m)					
	AR70	AR71	AR72	SAR	SIS D1112P	SBR
300	53.97	55.98	36.66	34.97	24.28	28.86
310	56.47	56.19	37.45	37.23	25.56	30.12
320	60.92	58.61	39.63	45.04	25.67	30.79
330	94.49	59.11	40.48	49.88	25.75	30.55
340	103.3	59.25	47.56	61.29	26.55	30.54
350	111.8	59.46	53.59	62.51	26.89	28.81
360	-	-	71.34	-	26.92	28.45
370	-	-	73.37	-	27.39	-

3.2 The specific conductivity measurement

The specific conductivity of elastomers were measured by a source meter (Keithley, Model 6517A) which consists of melt rheometer (Rheometric Scientific, ARES) with parallel plate fixture making contact on a surface of specimens. The specific conductivity results of all elastomers at various temperatures are shown in Table 2.

Table 2 The specific conductivity of all elastomer at various temperatures**.**

Temperature (K)	**Conductivity of various types of elastomer (S/cm)**					
	AR70	**AR71**	**AR72**	**SAR**	**SIS D1112**	**SBR**
300	1.17E-12	4.39E-12	2.87E-12	1.27E-10	2.05E-18	1.47E-15
310	1.26E-12	4.58E-12	2.96E-12	1.45E-10	2.27E-18	1.93E-15
320	1.30E-12	5.44E-12	3.02E-12	1.63E-10	2.66E-18	1.98E-15
330	1.35E-12	7.19E-12	3.04E-12	2.18E-10	2.51E-18	1.99E-15
340	1.49E-12	7.21E-12	3.03E-12	3.85E-10	2.42E-18	2.01E-15
350	2.17E-12	1.01E-11	3.04E-12	7.24E-10	2.30E-18	2.03E-15
360	-	-	2.91E-12	-	2.34E-18	2.03E-15
370	-	-	2.85E-12	-	-	-

3.3 The rheological properties of the elastomers

3.3.1 The effect of temperature on the rheological properties of the elastomers was investigated at electric field strengths of 0 and 2 kV/mm with the temperature range between 300-370 K. Fig. 1 shows G'_o and $G'_{2kV/mm}$ vs. temperature of all acrylic elastomers. We can see that the storage moduli increase linearly with temperature, in conformation with the classical network theory (Sato *et al.*, 1996, p. 6231):

$$G' = \nu k_B T \tag{2}$$

where k_B is Boltzmann's constant, T is the absolute temperature (K), and ν is number of strands per unit volume ($1/cm^3$). As temperature increases, the entropy of the elastomer also increases. This leads to a stronger retractive force and an increase in the storage modulii. G′ at 2 kV/mm is higher than that without electric field at any temperature investigated, as a result of the dipole-dipole interactions between charges created by the electric field. Fig. 2 shows G'_o and $G'_{2kV/mm}$ vs. temperature of SAR, SIS D1112P and SBR. In the SAR case, we can see that the storage modulii decrease linearly with temperature. When temperature increases above T_g of polystyrene segment, the styrene segment becomes soften and with less friction, and the free volume increases; the material changes its behavior from the rubbery like to the plastic like behavior (Sato *et al.*, 1996, p. 6231).

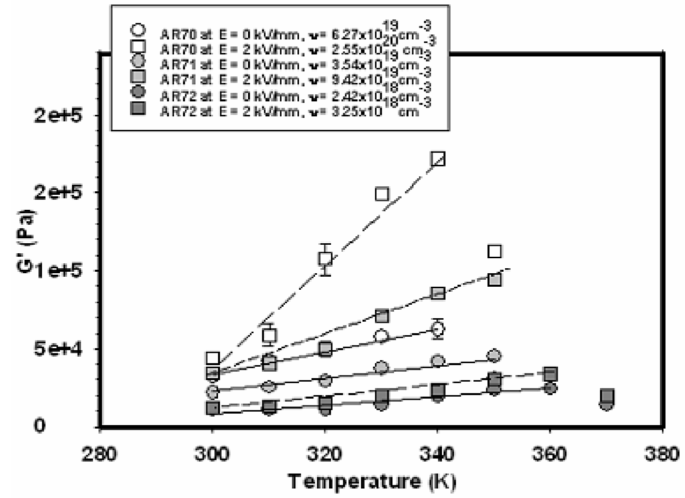

Fig.1 Effect of temperature on G′(ω = 1 rad/s) for the all acrylic elastomers (AR70, AR71, and AR72) onthe storage modulus (G') at E = 0 and 2 kV/mm vs. Temperature.

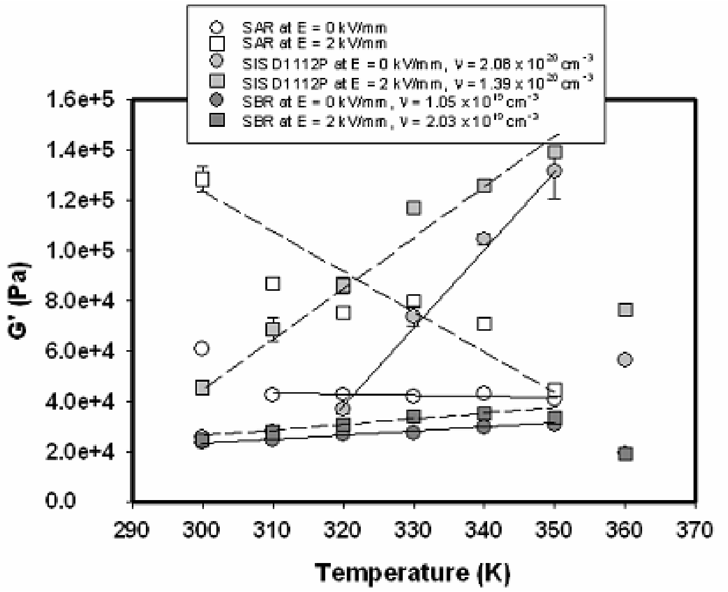

Fig. 2 Effect of temperature on G′(ω = 1 rad/s) for the all styrene copolymer elastomers (SAR, SIS D1112P, and SBR) onthe storage modulus (G’) at E = 0 and 2 kV/mm vs. Temperature.

3.3.2 The dielectric permittivity that influences the rheological properties of the elastomers was investigated at electric field strengths of 0 and 2 kV/mm within the temperature range between 300-370 K. The data are shown in Fig. 3 This figure shows that the storage modulus sensitivities of all acrylic elastomer increase with permittivity but the storage modulus sensitivities of all styrene copolymer decrease with increasing permittivity.

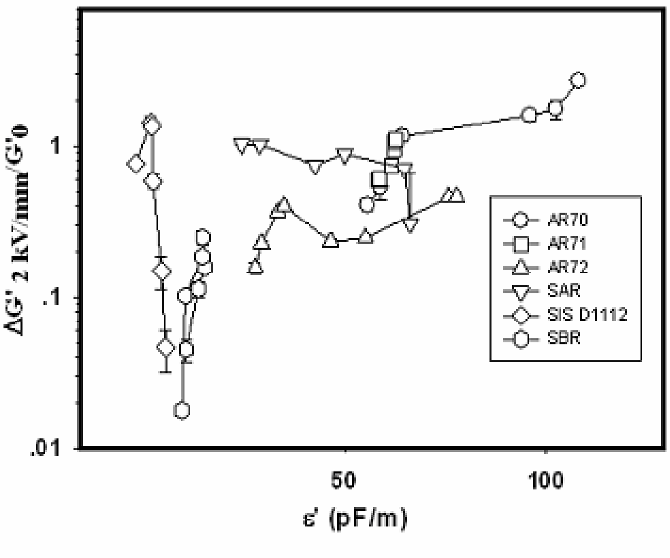

Fig.3 The storage modulus sensitivity ($\Delta G'_{2kV/mm}/G'_0$) of all elastomers vs. dielectric permittivity (ε').

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