CHAPTER V

Permethylpolyazine-Ethylene Propylene Diene Elastomer (EPDM) as an Electroactive Actuator

Patcharee Intanoo[1] and A. Sirivat[1*]

[1]The Petroleum and Petrochemical College, Chulalongkorn University,

Bangkok 10330, Thailand

5.1 Abstract

In this work, we investigated electromechanical properties of electroactive polymer blends consisting of dielectric elastomers, EPDM, and a conductive polymer, PAZ, which was synthesized and doped with iodine. The blends were prepared by a solution casting of highly doped PAZ particles with EPDM at various particle volume fractions ranging from 5vol% to 20 vol%. The chemical structures of undoped and doped PAZ were characterized by FT-IR. The electromechanical properties were studied under an oscillatory shear mode in the frequency range of 0.1-100 rad/s with the electric field strength varying from 0 to 1 kV/mm at 27°C. The effects of particle concentration on the storage modulus response, $\Delta G'$, storage modulus sensitivity, $\Delta G'/G'_0$, electrical conductivity, σ, and dielectric constant, ε' at 27°C and 100 rad/s was studied. $\Delta G'$ and $\Delta G'/G'_0$ increase with increasing electric field strength, and particle concentration. The electrical conductivity and dielectric constant monotonically increase with particle concentration.

Keywords: Electroactive polymer, Permethylpolyazine (PAZ), Ethylene Propylene Diene elastomers (EPDM), Electrorheological properties.

[*]Corresponding author, email: anuvat.s@chula.ac.th

5.2 Introduction

Electroactive polymers (EAPs) are a new class of smart material [1] and used in robotic applications, including: biomimetic robot eyes, artificial muscle,

muscle/insect-like actuators, and children toys [1] because they can convert electrical energy to mechanical work. Generally, EAPs are attractive as actuator materials because they are light weight, easy to fabricate to various shape, high energy density, and low cost [2]. For this reasons, EAPs are of considerable interest in the development of next-generation organic actuators [3]. One type EAPs is the elastomer, dielectric materials which can be electric-field-activated. It is capable of fast response, large displacement, and high efficiency [4].

Various elastomers have been widely used as dielectric materials in electroactive polymers, for example, silicone, nitrilic, butyl, natural, ethylene-propylene-diene monomer (EPDM) rubber [5], and acrylic elastomer which has many advantageous characteristics such as high response under applied electric field, good resilience, flexibility, high tensile strength, inexpensiveness, and etc. [5]. These characteristics are desirable to induce large strain when they were under electric field. Thus, ethylene-propylene-diene monomer (EPDM) rubber is an one interesting choice. EPDM is a thermoplastic elastomer from blends of two immiscible polymers. Faez *et al.,* [6] studied a conductive elastomer based on EPDM and polyaniline; the tension at break for all blends increased with doped-polyaniline loading until 30% (w/w).

Recently, the blending of dielectric elastomer with a conductive polymer has been studied, for examples, poly(p-phenylene) and acrylic elastomer blends for electroactive applications [5], a conductive elastomer based on EPDM and polyaniline [6], and etc. Conductive polymers, generally are composed of conjugated monomer units with π-electrons delocalized along the backbone. Conductive polymers have many advantages: simple fabricated techniques, easy to deposit on various substrates, and low material cost [7]. The electrical conductivity of a conductive polymer can be improved by an addition of small molecules known as the p-type dopant or the n-type dopant. Both p-type and n-type have been utilized to induce an insulator–metal transition in conductive polymers.

Bassil M. *et.al.,* [8] found that PMMA hydrogel actuators show large volume changes in response to various stimuli from the surrounding environment and they can be driven by electric field.. Skov A.L. *et.al.,* [9] reported the basic physical

and chemical properties of elastomers that were essential for their use as dielectric elastomer actuators. The elastic modulus, the dielectric constant, and the dielectric breakdown strength determine the ultimate static performance of actuators. The chemical and thermal properties determined the environmental compliance of the actuator including temperature service range and resistance towards various solvents [9]. In 2009, Shankar R. *et.al.*, [10] reported several polymeric materials that can convert electrical energy to mechanical work that were broadly classified as electroactive polymers (EAPs) and typically exhibited considerable stress and/or strain upon electrical stimulation. Due to their light weight, resilience, large actuation strain and toughness, EAPs offer comparatively low actuation stresses.

Feher *et.al,* [11] studied the bending of a TiO_2-loaded polydimethylsiloxane (PDMS) gel measured in a uniform and a non-uniform electric field. The gel cylinder between parallel copper electrodes gradually bent to the cathode. The bending behavior was found to be reversible, when positive and negative electrodes were alternated. As one of the electrodes was modified to create a non-uniform electric field, a metal ball replaced one of the electrodes, the bendings were the same. Watanabe *et.al.,* [12] studied the electromechanical responses of a pure polyurethane with compliant electrodes. The responses were due to the difference in charge densities between the anode and the cathode. Yun *et.al.,* [13] studied the performance of an electroactive paper (EAPap) that had three different samples thickness of 20, 30, and 40 μm. The EAPap actuator showed bending deformation in the presence of electric field which depended on thickness; as the thickness increased the electric field strength and the displacement decreased due to the bending stiffness.

In our work, we are interested in highly doped permethylpolyazine/EPDM NORDEL IP 5565 grade elastomer blends as an electroactive actuator. The electromechanical properties were studied in terms of electric field strength and highly doped permethylpolyazine (PAZ) particle concentration on the storage modulus response ($\Delta G'$), the storage modulus sensitivity ($\Delta G'/G'_0$), the electrical conductivity, and the dielectric constant.

5.3 Experimental

5.3.1 Materials

2,3-butanedione, $OC(CH_3)-CO(CH_3)$ (AR grade, S.M. Chemical Supplied Co., Ltd.), hydrazine sulphate, $H_2NNH_2.H_2SO_4$ (AR grade, ACI Lab Scan) was used as the monomer. Iodine, I_2 (AR grade, S.M. Chemical Supplied Co., Ltd.) was used as received. Sodium carbonate, Na_2CO_3 (AR grade, Sigma-Aldrich) was used as the catalyst. Chloroform, n-butanol, hexane, and ether (AR grade, ACI Lab Scan) were used as the solvents. Ethylene-Propylene Diene elastomer, NORDEL IP 5565 grade (Chemical Innovation Co., Ltd.) was used as the polymer matrices.

5.3.2 Synthesis and doping of permethylpolyazine (PAZ)

Permethylpolyazine (PAZ) was synthesized through the condensation polymerization according to the method of Euler W.B. [14]. Hydrazine sulphate (5.0 g) and sodium carbonate (4.07 g, 0.038 mol) were added into 5 mL of water, and the mixture was stirred at room temperature until CO_2 formation disappeared. Then 40 mL of n-butanol was added. A separate solution of 3.4 mL (0.038 mol) of 2,3-butanedione in 20 mL of n-butanol was prepared and slowly added to the hydrazine solution. The entire solution was stirred and reflux for 22 hours at temperature 80°C. After that the solution was cooled on ice and filtered with ether. The recovered solid was stirred in water to remove sodium sulphate (Na_2SO_4) for 3 hours at room temperature, filtered, washed, and vacuum dried (Euler W.B. [14]). The final obtained product was in the form of yellow solid powder.

The electrical conductivity of permethylpolyazine was improved by the doping process. 0.3 g of PAZ powder was added into a flask, a weight amount of iodine powder was added to the flask, and the flask was corked according to iodine was allowed to saturate for 1 hour. Then 10 mL of chloroform was added [14]. The mole of iodine (N_{iodine}) was varied versus the mole of monomer ($N_{monomer}$). $N_{iodine}/N_{monomer}$ values chosen were 1.00, 0.75, 0.50, and 0.25. The mixture was stirred for 24 hours at room temperature, filtered, washed with chloroform, and vacuum dried. The obtained products were dark brown powder depending on the doping level.

5.3.3 Preparation of polymer blend (D_PAZ/EPDM)

The polymer blends of dielectric elastomer, EPDM and a conductive polymer, PAZ were prepared through a solution casting. 3 cm^3 of EPDM (NORDEL IP 5565) was dissolved in 30 cm^3 of hexane and stirred for 24 hours. Then doped PAZ particles of the highest doping level were added into EPDM solution and the mixture was stirred for 24 hours. The dispersion of particles was quite homogenous. Particle concentration in EPDM NORDEL IP 5565 grade were prepared at 5, 10, 15, and 20vol.%. The films were cast in a mold and left at ambient condition for a slow removal of solvent and vacuum dried to remove solvent residual at 70°C for 24 hours.

5.3.4 Characterization and testing of PAZ, D_PAZ, and polymer blends

The functional groups of undoped and doped permethylpolyazine (De_PAZ, and D_PAZ) were investigated by a Fourier Transform Infrared spectrophotometer, FT-IR (Thermo Nicolet, Nexus 670) operated in absorption mode with 32 scans and a resolution of ± 4 cm^{-1}, covering a wavenumbers range of 4000-400 cm^{-1}, and using a deuterated triglycine sulfate as a detector. Optical grade KBr (Carlo Erba Reagent) was used as the background material. The synthesized De_PAZ and D_PAZ were intimately mixed with dried KBr at a ratio of PAZ: KBr = 1:20.

The thermogravimetric analyzer (Perkin Elmer, TGA7) was used to determine the thermal behavior of polymers. The experiment was carried out by weighting a powder sample of 5-10 mg and placed it in a platinum pan, and then heated it under nitrogen flow, 100 mL/min with the heating rate 10 °C/min from 30-900°C.

Scanning electron micrographs were taken with a scanning electron microscope (Hithachi, S-4800) to determine the morphology of PAZ in powder forms and polymer blends, D_PAZ/EPDM at various particle concentrations. The scanning electron micrographs of PAZ and polymer blends were obtained by using acceleration voltage of 25 kV with magnifications of 1000 times.

The particle sizes of doped-permethylpolyazine (D_PAZ) were determined by using a particle size analyzer (Malvern Instrument Ltd., Masterizer X Version 2.5). The lenses used in this experiment were 45 mm. The sample was

placed in a sample cell across a laser beam. This instrument measured the average particle size and the standard size distribution.

Electrical conductivity of De_PAZ, D_PAZ, and D_PAZ/EPDM blends was measured by a custom-built two-point probe and a resistivity test fixture (Keithley 8009 resistivity test fixture) connected with a source power supplied (Keithley, model 6517A). The specific conductivity, σ (S/cm) of De_PAZ and D_PAZ were obtained from the two point probe using following Eq. (1):

$$\sigma = \frac{1}{\rho} = \frac{1}{R_s \times t} = \frac{I}{K \times V \times t}$$

(1)

where σ is the specific conductivity (S/cm), ρ is the specific resistivity (Ω.cm), R_s is the film resistivity (Ω), t is the film thickness (cm), I is the measured current change (A), V is the applied voltage (voltage drop) (V), and K is the geometric correction factor.

The geometrical correction factor (K) was determined by calibrating the two-point probe with semi-conducting silicon wafer chips of known resistivity values, the geometrical correction factor was investigated by using following Eq. (2):

$$K = \frac{\rho}{R \times t} = \frac{I\rho}{Vt}$$

(2)

where ρ is the known resistivity of silicon wafer chips (Ω.cm), t is film thickness (cm), R is the film resistance (Ω), and I is the measured current (A). The electrical conductivity was obtained using the resistivity testing fixture data and the following Eq. (3):

$$\sigma = \frac{1}{\rho} = \frac{I}{(6.44 \times 10^{-5}) \times V \times t}$$

(3)

where σ is the specific conductivity (S/cm), ρ is the film resistivity (Ω), V is the applied voltage (voltage drop) (V), and t is film thickness (cm).

A melt rheometer (Rheometric Scientific, model ARES) was used to measure rheological properties of highly D_PAZ/EPDM blend films. It was fitted with a copper parallel plate fixture (diameter of 25 mm and the thickness of the prepared elastomers was about 1 mm). A DC voltage was applied with a DC power supply (Instek, GFG 8216A), which can deliver electric field strength to 2 kV/mm. A digital multimeter (Tektronic, CDM 250) used to monitor the voltage input. In these experiments, for temporal responses testing, oscillate shear strain and the dynamic moduli (G′ and G″) were investigated as a functions of time and electric field strength. Dynamic strain sweep tests were first carried out to determine appropriate strain by measure G′ and G″ in the linear viscoelastic regime at 1.0 rad/s frequency. The appropriate strain was determined to be 0.3, and 0.1% for pure EPDM NORDEL IP 5565 grade, and all highly D_PAZ/EPDM blends, respectively. The temporal G′ response of all elastomers was carried out at T=300 K, and 1 kV/mm. Frequency sweep tests were carried out to measure G′ and G″ of each sample as functions of frequency. The deformation frequency was varied from 0.1 to 100 rad/s. In each measurement, pure EPDM NORDEL IP 5565 grade and all highly D_PAZ/EPDM blends samples were presheared by applied electric field for 50 min to ensure the formation of equilibrium polarization before the G′ and G″ measurements. Experiments were repeated at least two or three times. The effect of particle concentration was studied at various electric field strengths varying from 0 to 1 kV/mm on storage modulus response ($\Delta G'$) and storage modulus sensitivity ($\Delta G'/G'_0$).

The dielectric constant of pure EPDM NORDEL IP 5565 grade and all highly D_PAZ/EPDM blends were measured by an LCR meter (HP, model 4284A) connected to the melt rheometer (Rheometric, ARES) with a 25-mm parallel plate with diameter of 25 mm and the thickness of the prepared elastomers was about 1 mm. The top and bottom sides of specimens were coated with silver adhesive to improve electrical contact between specimens and electrodes. The measurements were carried at temperature 300 K.

5.4 Result and discussion

5.4.1 Characterization of undoped and doped permethylpolyazine

A FT-IR spectrum of synthesized undoped and doped permethylpolyazine was recorded to identify characteristic absorption peaks [14]. The absorption peaks of undoped permethylpolyazine are at 1119, 1358, 1437, 1589, and 3000 cm^{-1}. These peaks can be assigned to the N–N stretching; the C-CH$_3$ symmetric stretching; the C-CH$_3$ antisymmetric stretching; the C=N stretching; the C-H vibration, respectively [14]. The absorption peak of doped permethylpolyazine is at 1502 cm^{-1}. This peak is assigned to either the N=N or C=C vibration after doping [14]. The most important peaks are the N–N stretching and the C=N stretching at 1119, and 1589 cm^{-1}, respectively.

The TGA thermogram of undoped permethylpolyazine and highly doped permethylpolyazine shows a degradation peak at 278°C corresponding to the backbone degration. The ethylene propylene diene elastomer, NORDEL IP 5565 thermogram shows a degradation peak at 442° C corresponding to the backbone degradation.

The average particle diameter of highly doped permethylpolyazine is approximately 41.64 μm with standard deviation of 0.55 μm. Highly doped particle microstructures were observed using a scanning electron microscope (SEM). Fig. 5.1 (a) shows the shapes of highly doped permethylpolyazine particles; they are quite irregular in shape. Figures 5.1 (b) and (c) show that the particles are dispersed uniformly within matrix of polymer blends between EPDM NORDEL IP 5565/10vol.% highly doped permethylpolyazine and EPDM NORDEL IP 5565/20vol.% highly doped permethylpolyazine, respectively.

The specific conductivity of undoped, doped permethylpolyazine, and all polymer blends was measured by a custom-built two point probe (Keithley, model 6517A). The specific conductivity of undoped is 4.18×10^{-6} with standard deviation of 3.15×10^{-7} and doped permethylpolyazine at $N_{iodine}/N_{monomer}$ values equal to 0.25, 0.50, 0.75, and 1.00 are 3.01×10^{-4}, 7.07×10^{-3}, 1.66×10^{-1}, and 2.16×10^{-1} S/cm with standard deviations of 2.14×10^{-5}, 1.18×10^{-4}, 1.67×10^{-2}, and 2.29×10^{-2} S/cm, respectively.

5.4.2 Electrorheological properties

5.4.2.1 The temporal response of polymer blend

The temporal responses of all polymer blends films were studied at $E = 1\text{kV/mm}$, $\omega = 100$ rad/s, $T = 300$ K and % strain = 0.1% are shown in Fig. 5.2 All polymer blend samples were presheared at a low frequency, and then the electric field was applied for 50 min to ensure the formation of equilibrium polarization before G' measurement. As can be seen, G' increases with electric field on and remains constant with electric field off. The increase in G' with electric field is due to the induced dipole moments generated on both the unsaturated bond on the side chain of EPDM elastomer and the polar group of highly doped permethylpolyazine. As electric field is turned off, G' does not recover, suggesting that the polymer blends material systems are irreversible, possibly due to residue dipole moments.

An induction time of polymer blends of 0, 5, 10, 15, and 20vol.% highly D_PAZ are 3735, 4167, 4282, 4274, and 4312 sec, respectively in the steady state and a recovery time of all polymer blends are 0 sec in the steady state. The induction times and the recovery times of all polymer blends are thus comparable.

5.4.2.2 Effect of electric field strength

The specific electrical conductivity values of all polymer blends with 0, 5, 10, 15, and 20vol.% highly D_PAZ at temperature of 300 K are 4.69×10^{-7}, 1.50×10^{-6}, 1.96×10^{-6}, 2.16×10^{-6}, and 2.25×10^{-6} S/cm with standard deviations of 7.23×10^{-8}, 4.42×10^{-8}, 6.78×10^{-8}, 2.35×10^{-8}, and 2.76×10^{-8} S/cm, respectively.

The effect of electric field on electromechanical properties of all polymer blend films was studied at $T = 300$ K with the electric field strength varied between 0 and 1 kV/mm. The storage modulus (G') vs. frequency of the polymer blend film (EPDM NORDEL IP 5565/20vol.% of highly doped permethylpolyazine) at %strain = 0.1% is shown in Fig. 5.3. It can be seen that the storage modulus increases with electric field strength at all frequencies examined. As

electric field is applied, both EPDM NORDEL IP 5565 matrix and highly D_PAZ particles become polarized, electrical dipole moments are generated and the electrostatic interaction between the polymer chains is induced leading to an intermolecular interaction. These intermolecular interactions result in an increase in the storage modulus. Figures 5.4, and 5.5 compare the storage modulus response, $\Delta G'$, and sensitivity $\Delta G'/G'_0$, of polymer blends of various electric field strengths. Both $\Delta G'$ and $\Delta G'/G'_0$ generally increase with electric field strength and attain maximum value of 3.14×10^{-5} Pa, and 1.125, respectively at E = 1 kV/mm.

5.4.2.3 Effect of concentration

On the effect of highly D_PAZ particles concentration on electromechanical properties of polymer blend between highly D_PAZ and ethylene propylene diene elastomer (EPDM; NORDEL IP 5565) was investigated in the electric field range between 0 and 1 kV/mm. Fig 5.6 shows the storage modulus response, $\Delta G'$, and sensitivity, $\Delta G'/G'_0$ versus particle volume fraction at electric field 1 kV/mm, %strain = 0.1%, and ω = 100 rad/s. $\Delta G'$ and $\Delta G'/G'_0$ increase with increasing particle concentration and attain a maximum value of 3.17×10^{-5} Pa, and 1.125, respectively at particle concentration of 20vol.%. As particle concentration increases, induced dipole moments are more generated under applied electric field as more dispersing particle dipole moments are aligned to electric field. Table 5.1 summarizes the data and the findings with respect to the effects of particle concentration. The electromechanical effect is caused by alignment of electrically polarized particles between electrodes [15]. At low concentration, the number of particles is too small and the distance between particles (dipole dipole distance) are too large and allow weaker interparticle interaction than that of at high concentration since the distances between particles are smaller.

Liu and Shaw et.al., [16] found that the enhancement of shear modulus for silica/silicon system was negligible below 8.0vol.%, but increased dramatically above this threshold concentration. At volume fraction above 55vol.%, the shear modulus decreased since the interparticle force decreased with the steric hindrance effect. Li et.al., [17] reported the bending strength of TiN–Al_2O_3

nanocomposites increased with various TiN contents and the highest bending strength was achieved at 20vol.% TiN. Puvanatvattana *et.al.*, [18] showed the storage modulus response ($\Delta G'$) of polythiophene/polyisoprene blends increased linearly with particle volume fraction below 0.10, and it increased nonlinearly when particle volume fraction was above 0.10. Kunanuruksapong *et.al.*, [19] reported the storage modulus sensitivity ($\Delta G'_{2kV/mm}/G'_0$) of the polymer blends with the concentrations of 0, 5, 10, 20, and 25 increased linearly with electric field strength 0 kV/mm and the maximum value was about 97% for the AR71:30_un system at electric field strength 2 kV/mm. Chotpattananont *et.al.*, [20] found the storage modulus (G') of polymer blend between polythiophene and polyisoprene increased with increasing polythiophene concentration.

5.4.2.4 The dielectric constant of polymer blends

The dielectric constant of polymer blends at T = 300 K and at the frequency of 100 Hz, are 1.92, 2.11, 2.31, 2.37, and 2.86 for 0, 5, 10, 15, and 20vol.% of highly D_PAZ, respectively. The dielectric constants vs. frequency of all polymer blends are shown in Figure 5.7 The dielectric constants are independent of frequency. From the data tabulated in Table 5.1, it can be seen that the dielectric constant increases with particle concentration; as more conductive polymer are available to create greater dipole moments or to store more charges.

5.5 Conclusion

In this study, electromechanical properties of EPDM NORDEL IP 5565 grade/ highly D_PAZ blends were investigated through examining the effect of electric field strength varying from 0 to 1 kV/mm in frequency sweep test modes and highly D_PAZ particle concentration varying from 0 to 20vol.% on the dynamic storage modulus (G') under oscillatory shear mode. In our polymer blends, the storage modulus (G') increases with electric field. The storage modulus response ($\Delta G'$) and sensitivity ($\Delta G'/G'_0$) also increase with electric field and attain a maximum value of 3.14×10^{-5} Pa, and 1.125, respectively as electric field strength is applied, the alignment of electrically polarized particles between electrodes were generated

leading to the induced dipole moments. For the latter effect, $\Delta G'$ and $\Delta G'/G'_0$ increase with particle volume fraction and attain a maximum value of 3.14×10^{-5} Pa, and 1.125, respectively at particle concentration of 20vol.% highly D_PAZ. The mechanism for the storage modulus response is the interaction between electrically polarized particles which induced electrostatic force. The dielectric constant of polymer blend that have 20vol.% of particle volume fraction is the highest because there are more content of dispersed particles on EPDM NORDEL IP 5565 matrix which can generate more dipole moments and the interaction become strong as the dipole moments are close to each other.

5.6 Acknowledgements

5.7 References

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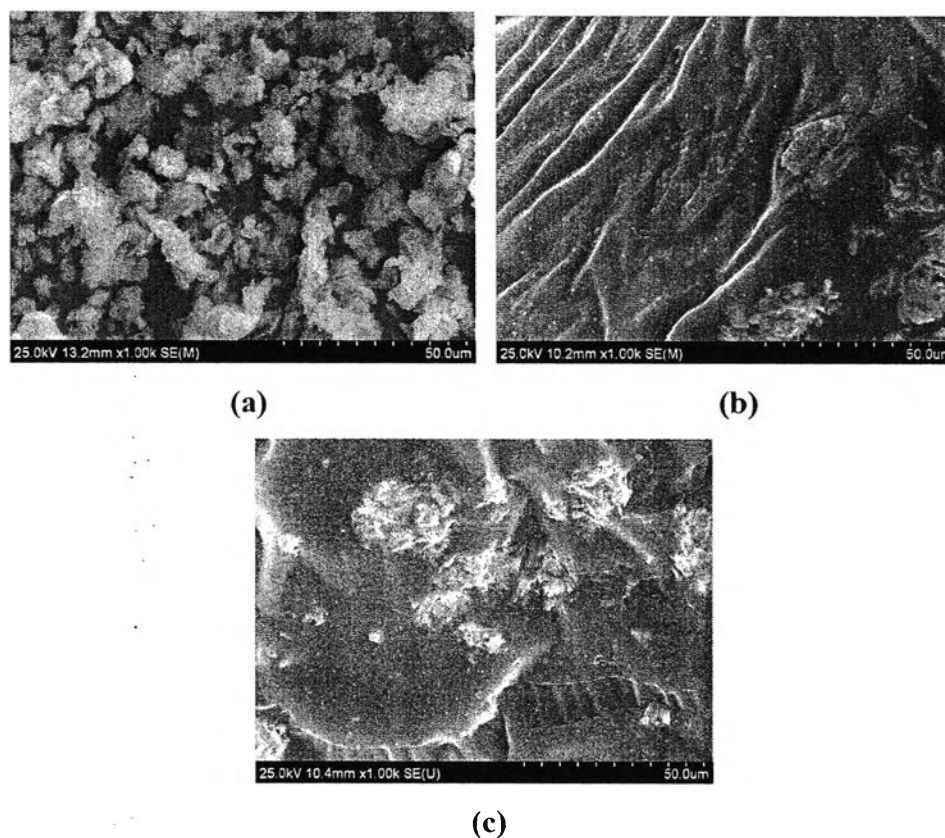
(a)

(b)

(c)

Figure 5.1 The morphology of doped permethylpolyazine particles and the doped permethylpolyazine/NORDEL IP 5565: (a) synthesized doped permethylpolyazine at $N_{iodine}/N_{monomer}$ = 1.00:1, and at magnification of 1000; (b) 10vol.% D_PAZ/NORDEL IP 5565 blend at magnification of 1000; (c) 20vol.% D_PAZ/NORDEL IP 5565 blend at magnification of 1000.
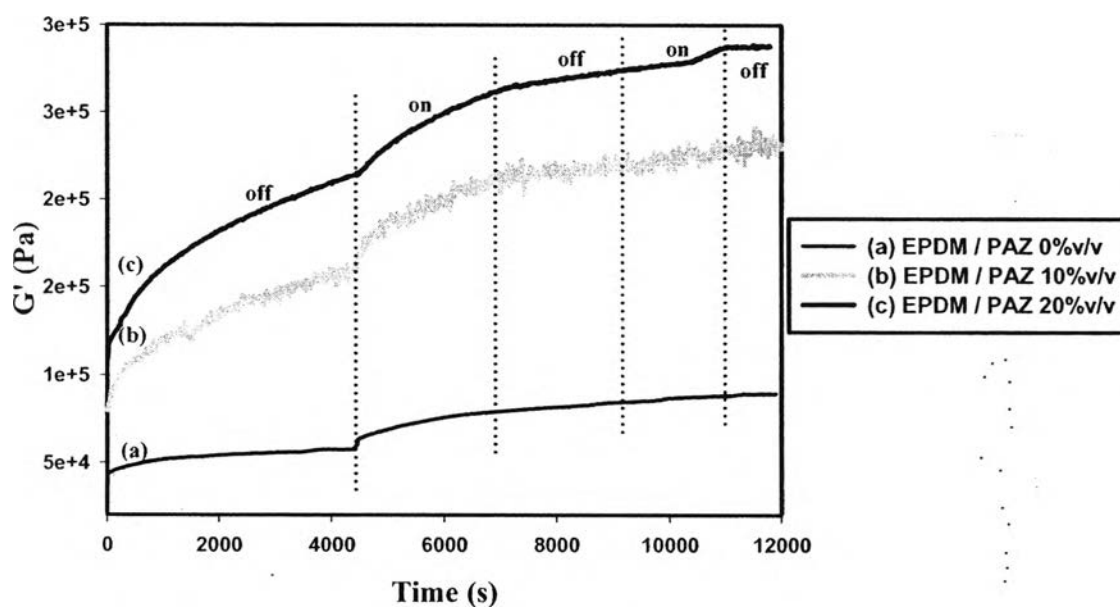
Figure 5.2 Storage modulus, G′, at 100 rad/s, 1kV/mm: vs. time of polymer blends of: (a) NORDEL IP 5565/D_PAZ 20vol.%; (b) NORDEL IP 5565/D_PAZ 10vol.%; and (c) NORDEL IP 5565/D_PAZ 0vol.%.
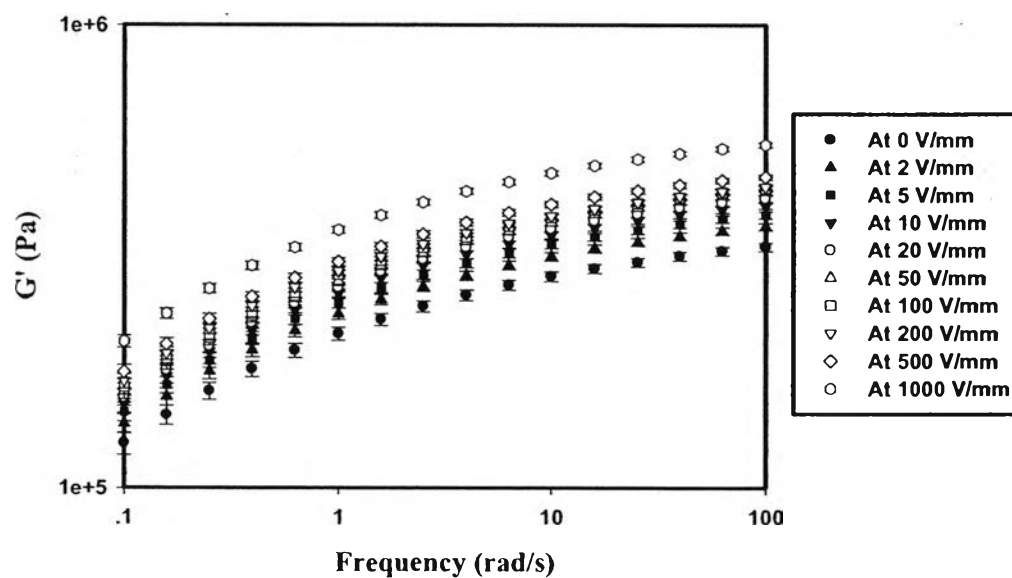
Figure 5.3 Storage modulus, G′, at T = 300 K, and % strain = 0.1%, vs. frequency of 20vol.% D_PAZ/NORDEL IP 5565 blend at various electric field strengths.
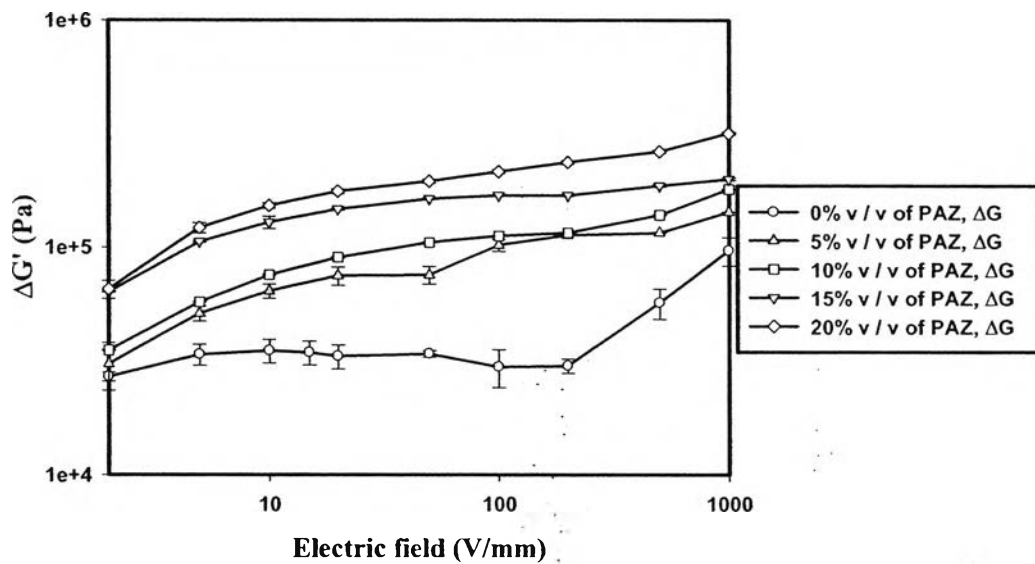
Figure 5.4 Storage modulus response, ΔG, at T = 300 K, and % strain = 0.1%, of polymer blends of different particle concentration vs. electric field strength.
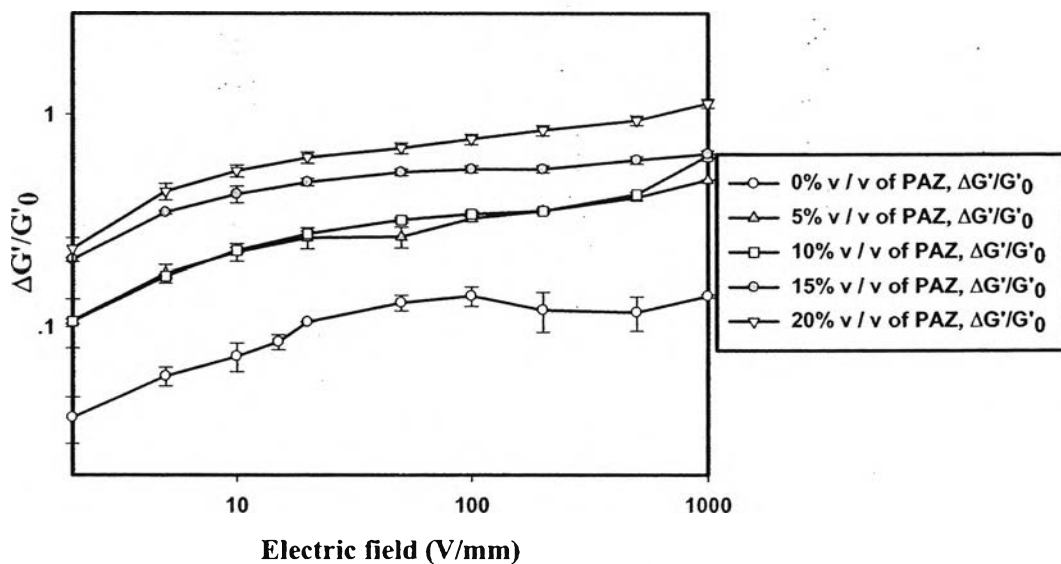

Figure 5.5 Storage modulus sensitivity, $\Delta G'/G'_0$, at T = 300 K, and % strain = 0.1%, of polymer blends of different particle concentration vs. electric field strength.
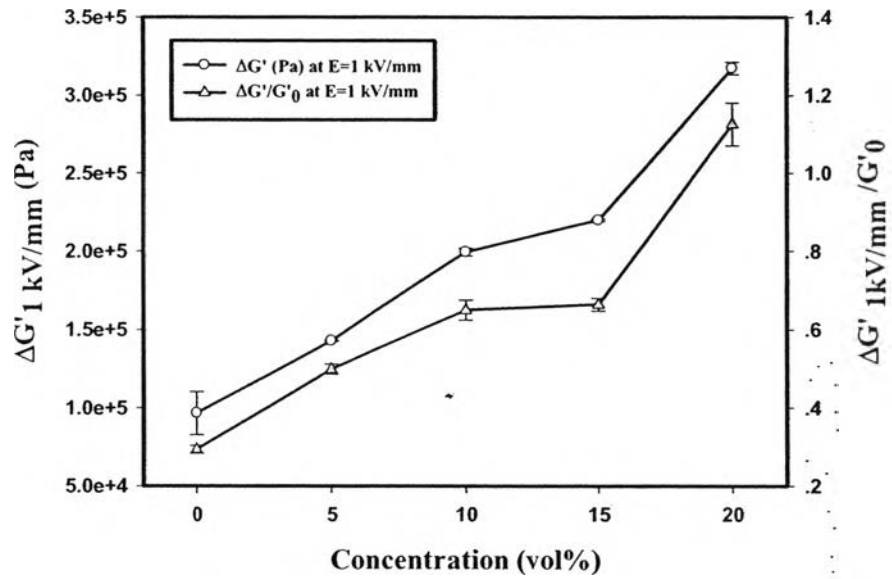
Figure 5.6 Effect of particle concentration on storage modulus response, $\Delta G'$, and sensitivity, $\Delta G'/G'_0$
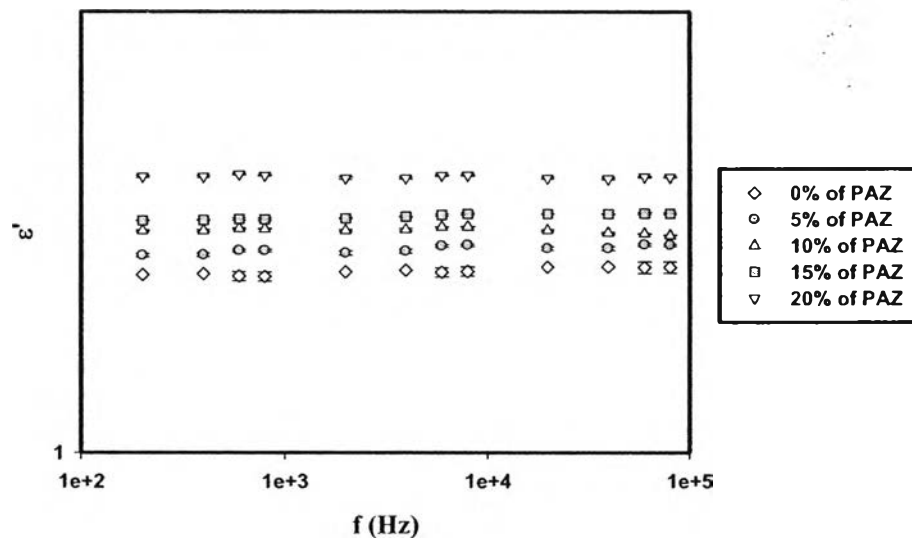

Figure 5.7 Relative dielectric constant (ε') vs. frequency of polymer blends of different particle concentration at temperature of 300 K.

Table 5.1 Comparison of storage modulus responses and sensitivity of pure polymer, and polymer blends.

Material	%v/v of PAZ	Electric field (V/mm)	Frequency (rad/s)	Temperature (K)	Storage modulus response ($\Delta G'$). Pa	Sensitivity of storage modulus ($\Delta G'/G°$)	Relative dielectric constant (ε') at low frequency	Electrical conductivity (σ). S/cm	Induction time (τ_{ind}). s	Recovery time (τ_{rec}). s
EPDM/PAZ	0	1000	100	300	9.65×10^4	0.140	1.91	4.69×10^{-7}	3735	0
EPDM/PAZ	5	1000	100	300	1.43×10^5	0.489	2.11	1.50×10^{-6}	4167	0
EPDM/PAZ	10	1000	100	300	1.79×10^5	0.634	2.31	1.96×10^{-6}	4282	0
EPDM/PAZ	15	1000	100	300	1.99×10^5	0.649	2.37	2.16×10^{-6}	4274	0
EPDM/PAZ	20	1000	100	300	3.17×10^5	1.125	2.86	2.25×10^{-6}	4312	0