10th International Conference on Composite Science and Technology ICCST/10 A.L. Araújo, J.R. Correia, C.M. Mota Soares, et al. (Editors) © IDMEC 2015

# **Electroactive Polymer Film**

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### Key words: Electroactive, Polyurethane, Thickness

**Summary:** Although their experimental errors can be observed, pure polyurethane (PU) elastomers are one of the most important class of polymers due to some remarkable electromechanical characteristics such as large electric field induced strain, high specific energy and fast speed of response. To get the large strain at low electric field, a dependence of the solidification condition on electrostriction was investigated for PU with carbon nano-filled film. The starting point of the convergence occurred at a lower electric field for the solidification to get thick film as opposed to for the optimum condition to obtain the thin film. Based on the prediction and experimental results, the electrostriction of composite films depended on its solidification condition.

## **1 INTRODUCTION**

Polymer actuators demonstrate numerous advantages, such as soft actuation, easy manufacturing, being lightweight and, especially, presenting a large deformation. In general, a high driving energy is required. [1] The strain level of piezoelectric materials, which are the most conventional actuator materials, is quite small (< 0.2 %), but they require only a low electric driving field (< 5 MV/m). Large strains can be generated in dielectric polymer actuators since electric dipoles are assumed to be present within the polymer. In many research investigations, large electroactive strains up to 10-100 % have been readily observed. [2, 3] Since the strain of human muscles is limited to around 20 %, these materials would be quite interesting for fabricating artificial muscles. Electroactive strain values up to 380 % have even been obtained when a silicone rubber was utilized as the matrix material. [1] Although such extraordinary results have drastically increased the potential of EAPs, it should be noted that these data were obtained under quite high values of the driving electric field, i.e., 120 MV/m. This limits the use of EAPs since few portable electric components can stand to be used together at such high electrical input. A reduction of the required energy is thus desired for a widespread use of EAPs.

Dielectric EAPs are able to generate a large electroactive strain (> 30 %) while requiring only a low electric field (< 20 MV/m). [4] Polyurethane (PU) is one of the most versatile materials in the world today. Their many uses range from flexible foam in upholstered

furniture, to rigid foam as insulation in walls, roofs and appliances to thermoplastic pure PU used in medical devices and footwear, to coatings, adhesives, sealants and elastomers used on floors and automotive interiors. Over the last two decades, the field of electrically controllable polymer actuators has developed significantly because their performances are comparable to those of natural muscles. However, their experimental errors can be observed. Pure PU elastomers are one of the most important class of polymers due to some remarkable electromechanical characteristics such as large electric field induced strain, high specific energy and fast speed of response. [5-9] This makes the material very attractive for many electromechanical applications. Many electroactive strain properties of the PU were investigated but the fundamental mechanisms which are responsible for the electrostriction have not been yet well understood. [10]

We found that the thermal absorption on melting of differential scanning calorimetry (DSC) analysis often corresponds to data of electrostriction. [11] Crystalline volume fraction may contribute to the electrostriction. If the volume fraction of surface crystallization on solidification is controlled by solidification thickness, the experimental error can be explained to obtain the reproducible data. The purpose of the present paper is to report the influence of solidification controlling on electrostriction of the composite films.

#### **2 EXPERIMENTAL PROCEDURE**

PU was chosen with conductive particles of carbon black (CB). The electric field induced into the CB/PU composite was assumed not to pass through the CB nanoparticles. Rather, the electrons were believed to remain on the filler surfaces. This mechanism is thought to be more efficient to obtain the electroactive strain than that in ferroelectric filled composite films. Pure PU films as well as composite films comprising a nanoink were prepared by a simple solution cast method. [11-13] One gram of PU granules (Noveon Estane 58888 NAT021, Lubrizol Corporation, Wickliffe, OH, USA) was dissolved in approximately 20 ml of N,N-dimethylformamide (DMF) at 85 °C for 45 min. The solution was poured onto a glass plate and dried at 60 °C at atmospheric pressure for 1 day. The obtained films were removed from the plate with ethanol. Subsequently, they were placed in a ventilated oven at 130 °C for 4 h in order to eliminate residual solvent. The thicknesses of the films varied from 19 to 150  $\mu$ m. For the electromechanical characterization measurements, metal electrodes were placed on both sides of disc-shaped specimens (25 mm in diameter).

The field-induced thickness strain was measured by a laser interferometer (Agilent 5519A) with a precision on the order of 5 nm. The induced electric field was a sawtooth wave for 2-cycles at 0.1 Hz. Its maximum was varied with an upper limit at 20 MV/m. The film samples were placed on a horizontal brass disc (20 mm in diameter) in order to avoid measuring a parasitic flexural motion, and a second brass disc placed on the upper side of the film rendered it possible to apply a bipolar electric field. A function generator (Agilent 33220A) delivered the corresponding bipolar voltage amplified by a factor of 1000 through a high-voltage lock-in amplifier (Trek 10/10B). The ground current between the sample holder and the ground was measured using a current amplifier (Stanford Research Systems SR570).

### **3 RESULTS**

Micelle form of CB nanoparticles obtained from nanoink was selected as conductive particle. In general, aggregation problem is a big issue when nanoparticles are dispersed in polymer. To confirm the micelle form, the composite was observed by Scanning Electron Microscope (SEM: Supra 55 vp, ZEISS) and Transmission Electron Microscope (TEM: HF-2200TU, HITACHI). The dispersed conditions of CB nanoparticles were observed by SEM. In this case, samples are not coated to prevent the charge. Consequently, accelerating voltage is selected at 0.5 kV. The sample is frozen with liquid nitrogen. After fracture, the surface is observed by SEM. According to SEM micrograph, the composite film exhibits a rather good CB nanoparticles dispersion within the matrix. However, few aggregates were found, as well as individualized CB nanoparticles of about 30 nm. TEM result confirms well dispersed CB nanoparticles in PU matrix.

The starting point of the convergence occurred at a lower electric field for the thick composite films as opposed to for the thin composite films. Optimum solidified thin composite film does not have convergence until 20 MV/m. Although the thin composite film shows the high strain value, the strain saturation cannot be found until 20 MV/m. The thin composite film enhances the strain at high electric field, although the thick composite films reduce the strain at high electric field. On the contrary, thinning the composite films reduce the strain at low electric field, whereas thick composite films remarkably enhance the large strain at high electric field of 20 MV/m, whereas thick composite films apparently exhibit the higher strain at low electric field of less than 4 MV/m. The strain saturation occurs at low electric field for thick composite film. We conclude that thinning the composite film thickness is a useful tool to obtain the large strain at low electric field.

#### 4 DISCUSSION

The strain of thin composite film was generally higher than that of pure PU at each solidification thickness. Therefore, micelle form of CB doping effect was confirmed. Thinning PU films remarkably enhanced the strain at 20 MV/m. Thick films apparently exhibited the higher strain at low electric field of less than 5 MV/m. X-ray diffraction (XRD: D8 ADVANCE, BRUKER) was used to confirm the internal structures of periodicity of composite films with different thicknesses. The peak width corresponds to the periodicity perfection of hard and soft segments. Differential scanning calorimetry (DSC: 131Evo, SETARAM, France) analysis was used to confirm the volume fraction of crystalline of composite films with different thicknesses. The endothermic heat is usually generated by transformation from crystal to liquid on melting. It corresponds thus to volume fraction of crystalline form in material. The fusion enthalpy values were obtained by area of endothermic peak. Considering with crystalline volume fraction and crystalline periodicity, the solidification thickness dependent strain was explained. Effects of making composites on strain were probably contributed by the polarization enhancement induced by increasing the capacitance.

#### **5** CONCLUSIONS

In order to obtain the large strain at low electric field, a dependence of the solidification thickness on strain was investigated for polyurethane with carbon nano-filled films.

Optimum solidified thin composite films remarkably enhanced the strain at high electric field at 20 MV/m. Thick composite films apparently exhibited the higher strain at low electric field of less than 4 MV/m. The starting point of the convergence occurred at a lower electric field for the thick composite films as opposed to for the thin composite film, which does not have convergence until 20 MV/m. Based on results of crystalline volume fraction and crystalline periodicity, the solidification thickness dependent strain was explained. Effects of making composite on strain were probably contributed by the polarization enhancement induced by increasing the capacitance.

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