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Electrostrictivity Study of Some Polymers as Potential Actuators

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ABSTRACT

Dielectric elastomer EAPs are polymers with low elastic stiffness and high dielectric breakdown strength that can be used to produce a large actuation strain by subjecting them to an electrostatic field. Silicone (based on poly(dimethyl siloxane)-PDMS) and acrylic based polymers are most widely used as dielectric elastomers in actuator configuration, due to their excellent elastic and electro-active properties.

The goal of this paper is to compare the electromechanical response of some dielectric elastomers based on silicone films (PDMS/silica and PDMS/cellulose). All samples show thickness strain under electric field. The field-induced strain due to electrostriction effect present in silicone based polymers was measured using a displacement sensor and a high voltage supply. Field-induced strains up to 25% was obtained at 50MV/m.

This make him to be available in applications like actuators or sensor.

INTRODUCTION

In the last decade the interest in "smart materials", which respond to external stimuli like temperature, pH, light, magnetic or electric fields by changing their shape or size, has incrased. Among the deformable polymers, electroactive polymers (EAP) showing a mechanical effect (force, deformation) when electrically stimulated were strongly focused on as smart materials during the last years [1].

Generally, EAP materials can generate strains that are as high as two orders of magnitude greater than the striction-limited, rigid, and fragile piezoelectric ceramics. Further, EAP materials are superior to shape memory alloys (SMA) in higher response speed, lower density, and greater resilience [2].

EAP can be divided into two major groups based on their activation mechanism: ionic (involving mobility or diffusion of ions) and electronic (driven by electric field or Coulomb forces).

Dielectric elastomer actuators are known for their unique properties, such as providing an excellent overall performance, combining large elongation (free area strains of over 380%), high specific elastic energy density of 3,4J/g (resp. $3,4 J/cm^3$), good efficiency and high speed of response in the order of milliseconds. Several applications have envisaged for dielectric elastomer actuators such as mobile mini- and micro-robots, micro-pumps and micro-valves, micro air vehicles, prosthetic devices and flat panel loudspeakers.

The above characteristic allows the production of linear actuators using dielectric elastomer films that appear to act similar to biological muscles, therefore, dielectric EAP actuators are often referred to as "artificial muscles" [1,3,4].

The strain response is based on two effects. If the response is dominated by the field-induced reorientation of a crystalline or semicrystalline structure, then the polymer is said to be "electrostrictive" (in this case, the permittivity is dependent on the electric field). If the response is dominated by the interaction of the electrostatic charges on the electrodes (often called Maxwell stress), then the polymer is called a "dielectric elastomer" (or "electrostatically stricted") type of EAP.

A dielectric elastomer actuator consists basically of a capacitor with a thin elastomer film sandwiched between two compliant electrodes as shown in Figure 1. When a voltage is applied across a polymer film, the unlike charges on the opposing electrodes will attract each other and tend to squeeze the film in thickness while the like charges on each electrode will tend to repel each other and expand the film in area [5].

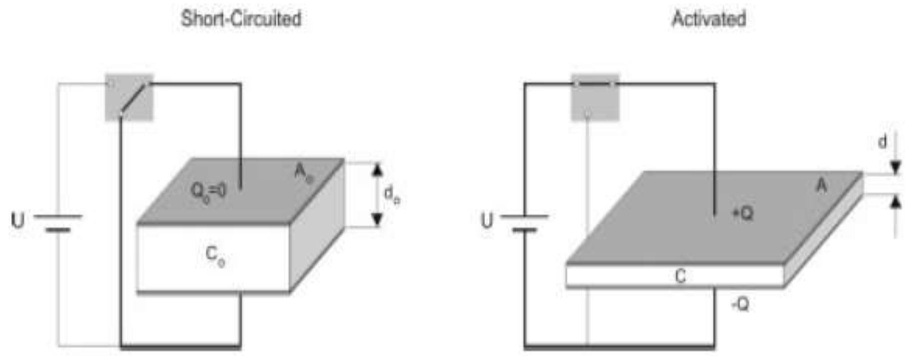


Figure 1 : The working principle of dielectric elastomer actuators in inactive or short-circuited state (left) and under activation (right) [1]

The electrostatic pressure p_{el} acting on the insulating elastomer film for a given applied voltage U and film thickness (d) is shown in Eq. (1):

$$p_{eq} = \varepsilon_0 \varepsilon_r \left(\frac{U}{d} \right)^2 \tag{1}$$

where ε_0 is the free-space permittivity (8,85*10^{-12} F/m) and ε_r is the relative dielectric constant of the elastomer.

The electrodes have to behave as very compliant layers in order to oppose minimum resistance to the deformation. Graphite based electrodes like carbon grease (graphite particles suspended in silicone oil based grease), graphite spray and graphite powder are widely used as electrode materials in dielectric actuators due to their good compliance properties and easy application.

There are three types of polymer materials used as dielectric elastomer in actuator configuration: polyurethan, silicone (based on poly(dimethyl siloxane)-PDMS) polymers and acrylic polymers.

While acrylic based elastomers have shown good performance as actuator materials by producing large strains, high forces and high energy density, silicone reveal fast response, broad temperature stability and are in general less viscous [1].

In this study we compare the field induced thickness strains of PDMS/silica and PDMS/cellulose films.

MATERIALS AND METHOD

Materials

First type of materials used were copolymers synthesized with different contents in diphenylsiloxane units, expressed as %DP= 100y/(x+y), were mixed in different ratio with tetraethyl-ortosilica (TEOS) as cross-linked agent and precursor for in situ generating silica network, in the presence of organometallic-dibutyl in diluted catalyst.

Figure 2 shows interconnection of poly(dimethyl diphenylsiloxane)/silica interpenetrate networks. They were processed as films, with thickness between 0,05 and 0,235 mm, by pouring the reaction mixture on a substrate, before cross-link finish.

Second type of materials were PDMS with different contents of cellulose.

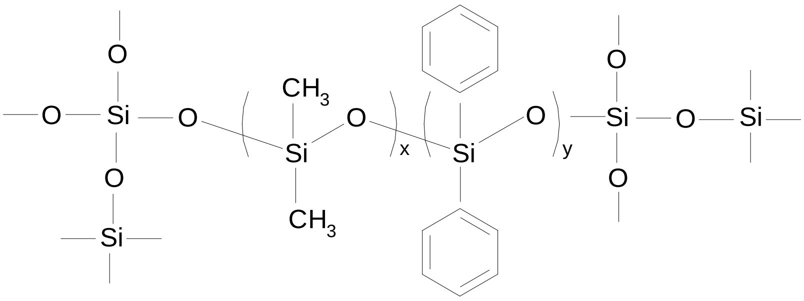


Figure 2: Poly(dimethyldiphenylsiloxane)/silica interpenetrated networks

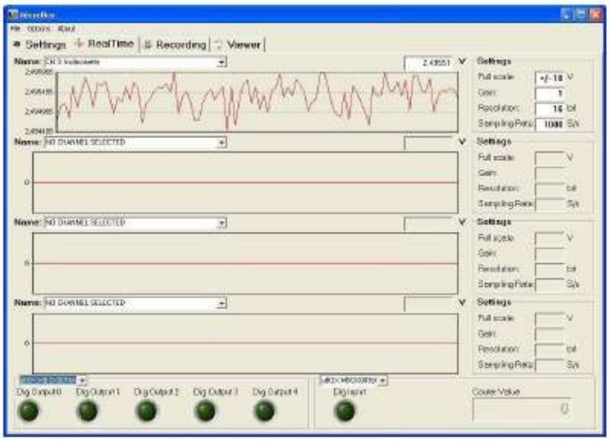
Equipment

A displacement sensor (MTN/EP080 by Monitran) with a sensitivity of 8mV/µm was used to feel the sample deformations. Output signals from the sensor go to sensor terminal connector (Figure 3) into a system data acquisition (microBox series by Disynet – Figure 4) which is connected via USB to a computer.

Figure 3: Sensor terminal connector

Figure 4: System data acquisition

A software allows the real-time visualization of sensor signals, recording them and viewing records (Figure 5). Also, an additional driver makes possible the use of module and basic functions of LabView program, thus ensuring the adaptation of the basic functions of the program for laboratory work that requires any processing signals.



Full scale +/-10 V
Gain 1
Resolution 16 bit
Sampling Rate 1000 S/s

Figure 5: Real-time visualization signals

The electric field applied between electrodes was provided by a high voltage supply (Treck 610E, 0-10kV). Sensors were also fed by a DC voltage supply 0-24V.

Method

Measurements were made under static conditions using increased voltage. Experiment was made in a room relatively distant from noise or vibrations sources. To avoid influence on the results of air currents or any interference with the electric fields, a plexiglass cage that protects the sensor and the polymer sample was used. Because we use rigid electrodes, to ensure their compliance, we put a thin layer of carbohydrate liquid between they and sample. Temperature in room was remains relatively constant (19^0C – 20^0C).

RESULTS

Electrostriction effect was observed in all samples. They present an electric field-strain dependence common to all dielectric elastomers (Figure 6). Reversal of the electric field does not reverse the direction of the deformation.

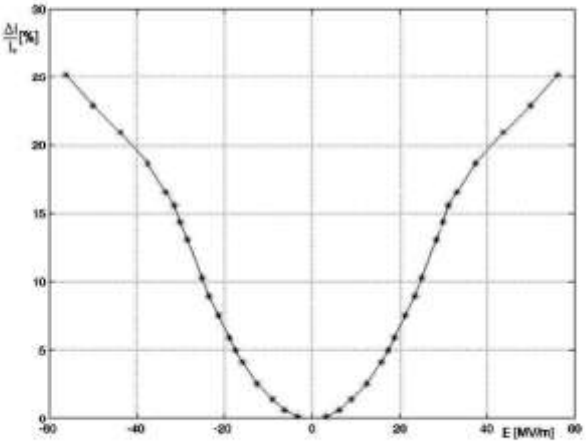


Figure 6: Strain-electric field dependence

The thickness strain presents a quadratic dependence on electric field (Figure 7). This dependence shows the electrostriction effect present in sample.

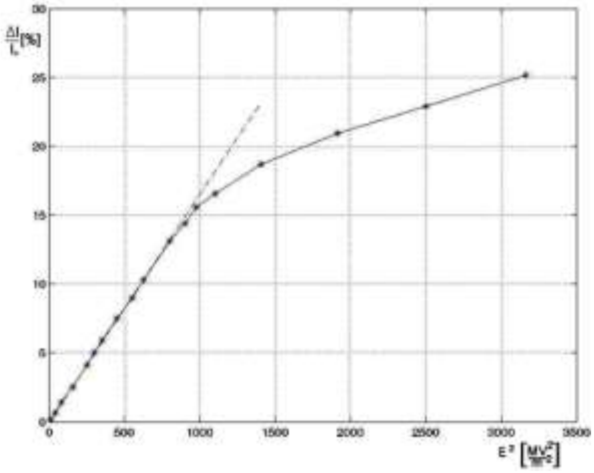


Figure 7: Strain-square electric field dependence

Strains up to 25% were obtained at fields of about 50MV/m for PDMS/silica films, while strains up to 27% were obtained in the case of PDMS/cellulose films when a voltage of 1kV was applied.

CONCLUSIONS

The investigate PDMS films show remarkable electromechanical parameters such as thickness strain, apparent electrostrictive coefficient and response time.

Strain-electric field variation shows linearity on a part of the domain, allowing to use these materials as actuators and sensors.

Further research is now developing to determine other parameters (effective compressive pressure, mechanical energy density and efficiency) and to synthesize new siloxane/silica networks in order to establish correlations between structure and properties so as to produce actuators with higher forces, motions, energy density, speed of response and stability.

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