Experimental study of a dielectric elastomer (artificial muscle)

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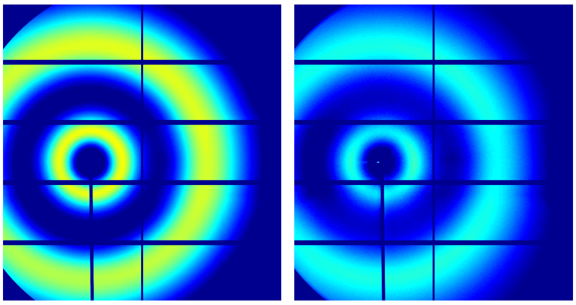
May 12, 2015

Dielectric elastomers belong to the group of electroactive polymers (EAP), which are polymers that deform when exposed to electric stimuli. Dielectric elastomers were discovered in the early 1990s and have been under great interest during the last two decades. They have been found to show the largest actuation strains among EAP, areal strain as large as 1692% has been reported. In this thesis, different types of experiments were conducted on VHB™ 4910 from 3M™, an acrylic elastomer that has been found to have good electromechanical properties. The aim was to better understand the electromechanical behaviour of dielectric elastomers and contribute in the development of accurate models. Two types of experiments were performed: X-ray scattering measurements during mechanical loading and digital image correlation (DIC) with simultaneous force measurements on electrically loaded samples. The force measurements were performed using a novel method that allows the force distribution around a circular boundary to be measured.

Small and wide angle X-ray scattering (SAXS/WAXS) are methods that are used to probe the structure of material at the micro and nano-scale. X-rays are electromechanical waves that have wavelengths of 10^{-8} to 10^{-11}m. When a sample is illuminated by an X-ray beam the structures inside the material will scatter the incident beam in different directions. The scattered X-rays may then interfere with each other and produce a diffraction pattern. This pattern can then used to determine the internal structure of the material. One way of doing so is by using Bragg's law, $2dsin\theta = n\lambda$, where d is the particle spacing (d-spacing), θ is half the angle between the incident and scattered beam, n is a positive integer and λ is the wavelength of the X-rays. Bragg's law states at what directions, given by θ, the diffraction will have constructive interference. Thus, by studying the intensity of the pattern as a function of θ, it is possible to determine structural distances. The difference between SAXS and WAXS is the angle at which the scattered rays are recorded, with WAXS the scattering is recorded at wider angles, which allows the detection of smaller structures than SAXS.

WAXS measurements were performed on a VHB 4910 sample subjected to a displacement controlled tensile load. The diffraction patterns are shown in Figure 1, with one image when the sample is unstrained and one image when the sample is at 780% strain.

From the initial diffraction pattern it can be concluded that VHB 4910 is an amorphous material, i.e. there is no smallest repeating unit that can represent the structure. This can be concluded due to the highly diffuse pattern, in crystalline material the diffraction pattern will produce small spots or thin rings. The two rings seen in the images reveals that the spacings occur in all orientations. In single crystal or polycrystalline material the diffraction pattern does not have rings but rather spots at certain angles that correspond to differently oriented spacings. The images also revealed that the sample was slightly anisotropic, both when it was unstrained and at 780% strain. The average d-spacings of the two rings are 1.76 nm and 0.49 nm when it is unstrained. At 780% strain, the average d-spacings are 1.78 nm and 0.49 nm, which indicate change in the polymer structure at the nano-scale due to the mechanical loading.



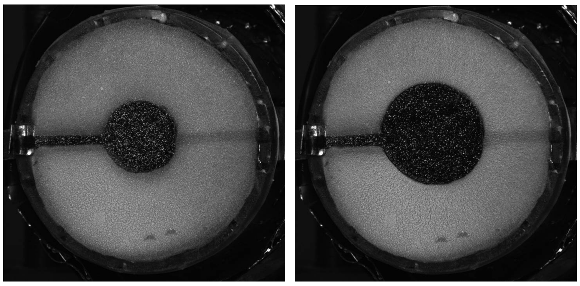
(a) 0 % (b) 780 %

Figure 1: WAXS images for the VHB 4910 unstrained and strained.

DIC is a method that allows the measurements of the full displacement field of deforming samples. By dividing images into small segments, the DIC algorithm is able to identify segments between two different images and thus, the displacements between points can be retrieved. In this thesis 3D-surface DIC was used, which can measure in-plane and out of plane deformation. This is accomplished using two cameras taking simultaneous images of the sample. Like human vision, the two cameras allow the perception of all three spatial dimensions.

The DIC measurements where performed on electrically loaded circular samples. Simultaneous with the DIC measurements, the forces around the boundary of the circular sample were measured using a technique developed in this thesis.

In Figure 2 we see two photos of a sample when it is unloaded and when 6.5 kV is applied. The black area shows the active part, where the elastomer film is sandwiched between two electrodes. Applying voltage creates an electric field over the elastomer film, which causes it to contract in thickness and expand in the planar directions.



(a) 0 kV (b) 6.5 kV

Figure 2: Photos before and after application of voltage.

From the displacement given by the DIC algorithm, the strain field can be mapped, which is vital in the development of models that describe the mechanical behaviour. In Figure 3 we can see the magnitude and direction of the two principal in-plane strains.

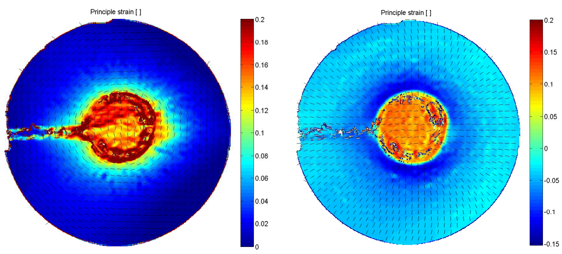
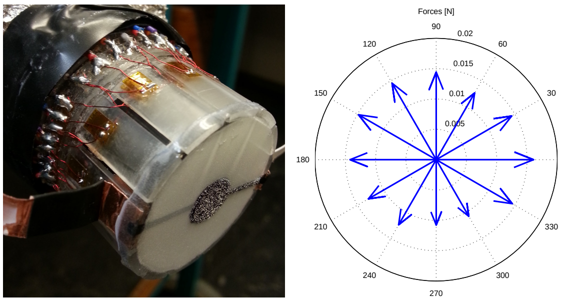


Figure 3: Principal strains and principal strain directions.

The device that measures the force distribution was build from a plexi cylinder were one end was cut into twelve arms. Each arm works as a force gauge that measures the forces locally in the radial direction of the sample. Figure 4 shows a photo of the device and the forces that was measured.



(a) (b)

Figure 4: a) The device that measures the forces around a circular boundary. b) The measured forces at the twelve directions.

In conclusion, we have seen results from the WAXS measurements that can help us understand the mechanical behaviour of VHB 4910 at the nano-scale. Also, a new method has been developed in this thesis, which allows the measurements of strains and forces simultaneously on a circular sample. This method can be used to characterize the electromechanical behaviour of dielectric elastomers and has several advantages over existing methods found in the literature.