Characterization of IPMC actuators using standard testing methods

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ABSTRACT

In response to a clear need, the research community on EAP (Electroactive Polymer) has just started to work on a standard test methodology to characterize EAP actuators. A very general test methodology for EAPs, covering the characterization procedures for extensional and bending actuators was recently presented.

In the present work, well known IPMC samples are characterized following such test methodology. Also, additional tests, not covered by the preliminary standard are included. These tests are conducted using the EAP Unit Tester, a test bench specifically designed for the characterization of EAP actuators. Rather than presenting new material's results, the paper focuses on the instrumentation, procedures and form of presenting results.

Although the paper is focused on IPMC the method can be extrapolated to other bending actuators.

Introduction

Some Electroactive Polymer (EAP) actuators such as Ionic Polymer Conductor Composites (IPCCs) are low level intelligent materials. IPCCs are polymers that respond to electrical stimulation with a significant shape or size change while also can be used as sensors.

Industrial sectors such as aerospace, biomedical, defence, construction or automotive are keeping an eye on EAP based devices. Unfortunately, comparing published results from different materials becomes a complex task, since every research group uses their own instrumentation and also their own test methods. This is delaying the transfer of EAP technology to industrial applications.

In response to a clear need, the EAP (Electroactive Polymer) research community has just started to work on a standard test methodology to characterize EAP actuators. A very general test methodology for EAPs, covering the characterization procedures for extensional and bending actuators was recently presented [1].

In the present paper the test methodology is applied to IPMC actuator material characterization. Also, two tests not included in the standard are applied, this is the outgassing test, and the maximum voltage test, which are key to characterize ionic EAPs in general [2]. The document is organized in a timely fashion. This is, the first test to be conducted is the physical characterization of the samples. After that the stability test and maximum voltage test are conducted to determine the maximum operating voltage and also the stability of the material when operated in air. Finally, the Free deflection test and Blocked force tests are conducted to retrieve the electromechanical properties of the sample.

Physical characterization

Ionic Polymer Metal Composite (IPMC) samples were prepared using the Impregnation Reduction technique [3]. The IPMC was based on Nafion and platinum electrodes. Water was selected as solvent, and Li+ as mobile ion.

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IPMC Composition	
Base material	Nafion 117
Electrode material	Pt
Mobile ion	Li+
Solvent	water

Table 1. IPMC composition

IPMC sheets were cut in strips and attached to fixed electrode clamp as defined in figure 1. No flexible electrode was used. Following the test standard [1] We use a coordinate system in which the '3' direction is defined as the direction of the gradient of the electric potential caused by the application of an electric potential. The '2' direction is defined with an axis that is orthogonal to the other two directions in which the '3' direction follows the right-hand rule.

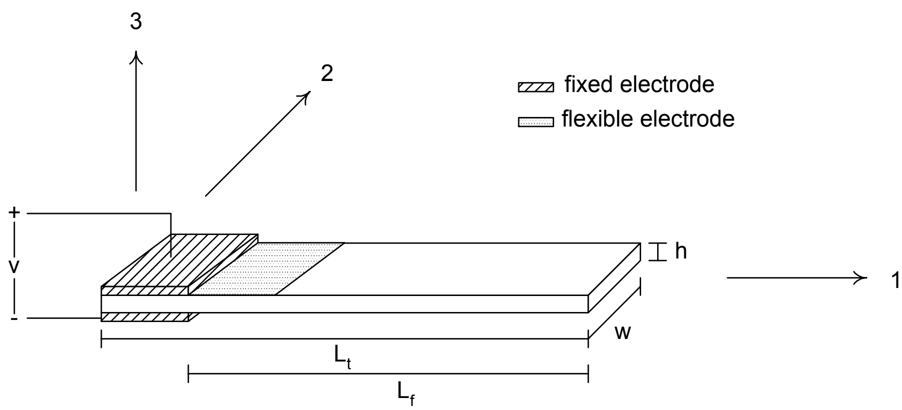


Figure 1. Coordinate system and sample dimension

Thickness of the sample is characterized by SEM imaging. Although a micrometer might also be used, SEM imaging is useful to identify morphological features associated to the manufacturing process such as the thickness of the electrodes. Since SEM imaging is a destructive measuring method, it should be conducted on a piece of material from the same manufacturing batch as the sample under test. Since thickness measuring through SEM imaging involves vacuum, it is not valid to characterize the thickness of the sample in humid state, where a micrometer is required.

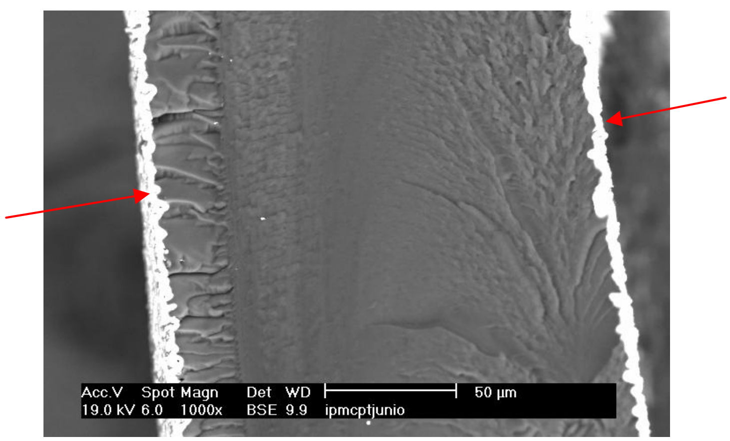


Figure 2.Cross-section SEM Image of the sample

Due to IPMCs hygroscopic nature the sample shall shrink when humid. Prior to measuring the length and width of the sample, the sample must be humidified. The procedure shall be as follows:

The sample shall be soaked into its appropriate salt solution to absorb the required solvent and then both sides of the sample shall be dried using lab paper until the sample stops soaking. Once this is done, the sample shall be humid but not soaking wet, and measurement of the sample length and width dimensions can begin.

In order to measure the width, micrometer measurements are taken at three locations. Specified width is the mean of the three measurements. In order to measure the length of the sample, a similar method is used. In order to test the surface conductivity of the sample a precision ohmmeter is used.
Mass of the sample is taken by hanging the sample prior to measurement in a precision load cell.

Physical characteristics				
Measurement	**Variable**	**Value**	**Accuracy**	**Measuring Method**
Thickness	h	175 µm	5 µm	SEM imaging on a twin sample (from the same manufacturing lot)
Width	W	0,5 cm	0,1 cm	Micrometer measurements at three locations along the sample. Specified width is the mean of the three measurements.
Total Length	L_t	3 cm	0,1 cm	Micrometer
Free Length	L_f	2,7 cm	0,2 cm	Micrometer
Length to measurement point	L_m	2,5 cm	0,2 cm	Micrometer
Mass (humid)	M	140 mg	10 mg	Precision Balance
Surface Resisitivity	R	16 Ω/cm	2 Ω-cm	

Table 2 . Sample physical characterization

Test Environment				
Measurement	**Variable**	**Value**	**Accuracy**	**Notes**
Humidity	R_H	45%RH	5%RH	Humidity uncontrolled
Temperature	T	25,7ºC	0,5ºC	Temperature uncontrolled

Table 3. Environmental conditions of the test

Outgassing test

Stability of IPMC in air is currently one of the limiting factors of the technology. Many IPMC samples operate in air during a limited period of time due to evaporation of its solvent. Therefore, for this type of materials, it is very important to quantify the amount of solvent inside the sample before, during, and after electroactivation. The procedure for monitoring this quantity is measuring the mass of the specimen with accurate methods and instrumentation. Since the solvent is delivered to the ambient in the form of gass, the test can be considered an outgassing test.

Outgassing test can be conducted by means of measuring the mass of the specimen in its dry state (see previous section) and after solvent swelling. If a reduction of the specimen mass takes place during any of the tests, this will indicate that the specimen is loosing mass due to solvent evaporation (outgassing).

Also, previous to sample characterization it is recommended to conduct an outgassing test of the sample operating at ambient pressure and temperature in order to determine the stability of the samples with time when operated in air. Outgassing tests of the material with time are required to demonstrate stability of the material.

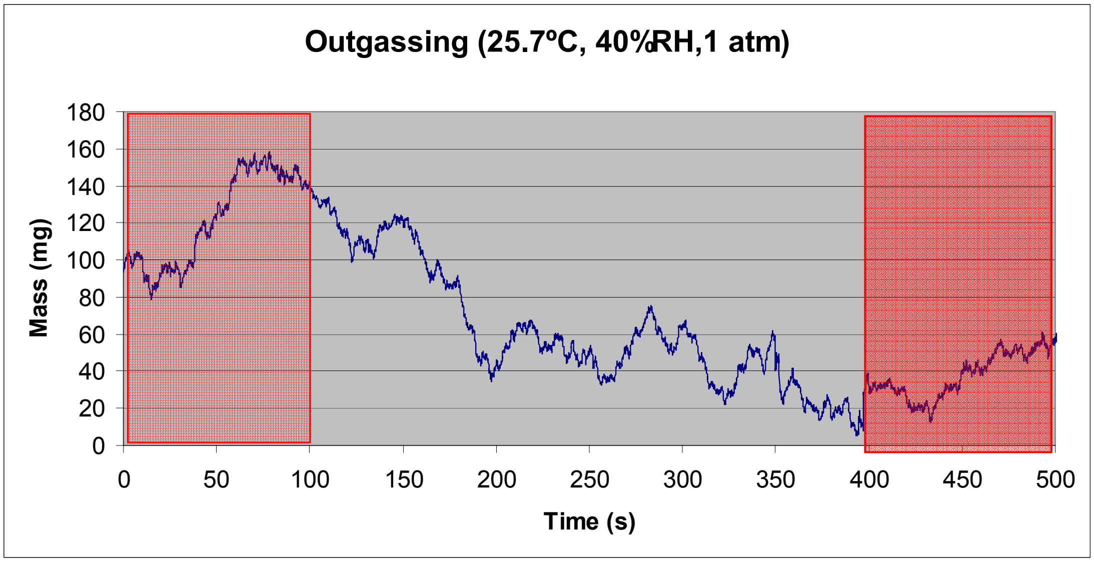


Figure 3. Loss of mass, or outgassing test, with the sample exposed to air indicates the stability of the sample in air.

In addition, maximum voltage applicable to IPMC might be determined using outgassing test. The voltage that causes electrolysis of the solvent and therefore accelerates the loss of mass in the specimen should be considered the maximum voltage.

Although solvent introduced in these IPMCs is water, the electrolysis voltage might not necessary be that of pure water since salt residues in the material will change the electrolysis point. It is therefore recommended to characterize the maximum applicable voltage to the material prior to electromechanical tests, since this voltage shall not be exceeded during practical applications of the material as actuator. A voltage ramp at a minimum rate of 1v/min should be applied to the sample until the mass of the specimen starts to decay dramatically, indicating the electrolysis voltage threshold and therefore the maximum applicable voltage to the specimen.

The maximum voltage of the current IPMC samples using these techniques was identified as 1,45V +-0,25V.

Free Deflection test

The free deflection test for a bending actuator consists of applying a voltage to the actuator and measuring the deflection of the measurement point located at a distance L_m from the fixed end. This tests is required to determine the maximum strain delivered by the actuator material

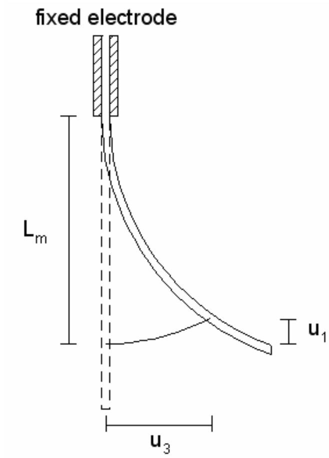


Figure 4. Free deflection test configuration and coordinate system as defined in [1]

Free deflection is measured by artificial vision techniques that detect both the angle of deflection, the tip deformation in the u3 direction, and also the radius of curvature[2]

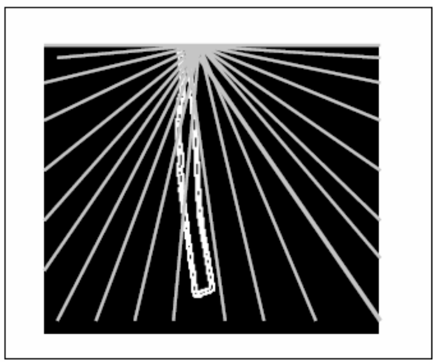


Figure 5. Free displacement is measured by a CCD camera and artificial vision techniques. [2]

According to the proposed standard [1], the displacement at the measurement point is defined by the displacement in the direction, u3, and the displacement in the '1' direction, u1, as shown in Figure 3.
Deflection of the sample can be expressed in terms of linear deformation in the u_3 direction or in terms of the radius of curvature $\rho = \frac{(L_m - u_1)^2 + u_3^2}{2u_3}$. For small deformations ($u_1/L_{m<<}\ u_3/L_m$) it is more appropriate to present the linear deflection in the u_3 direction. In other cases the radius of curvature better expresses the deformation of the sample, but cautions in the fabrication of the sample shall be taken, since non uniformities in the sample electrodes (more dominant in larger test samples) will affect the uniformity of the material deformation.

Strain of the material is derived from the maximum deformation obtained either from the radius of curvature $\varepsilon_1 = \frac{h}{2\rho}$ or the linear deformation in the u_3 direction $\varepsilon_1 = \frac{hu_3}{L_m^2}$. Note this last expression assumes the deformation is small comparing to the length of the sample ($u_1/L_m << 1$ and $u_3/L_m << 1$)

The sample under characterization does not deform in a curvature shape. This implies that the radio of curvature is not valid as a measurement of large deformation. In this case, the angle of deflection of the sample with respect to the clump axis is most appropriate-

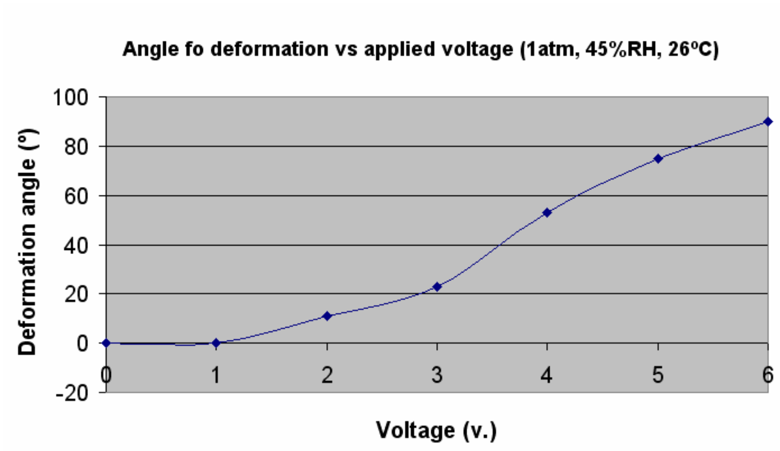


Figure 6.Angle of deformation of the sample w.r.t to the resting position axis vs. applied voltage. [2]

Blocked Force Test

The force produced by a bending cantilever sample when the displacement of the measurement point is constrained to be zero is called the blocked force. Blocked force test is required in order to obtain the stress produced by the actuator material.

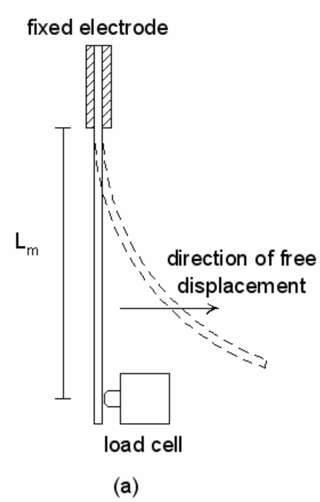
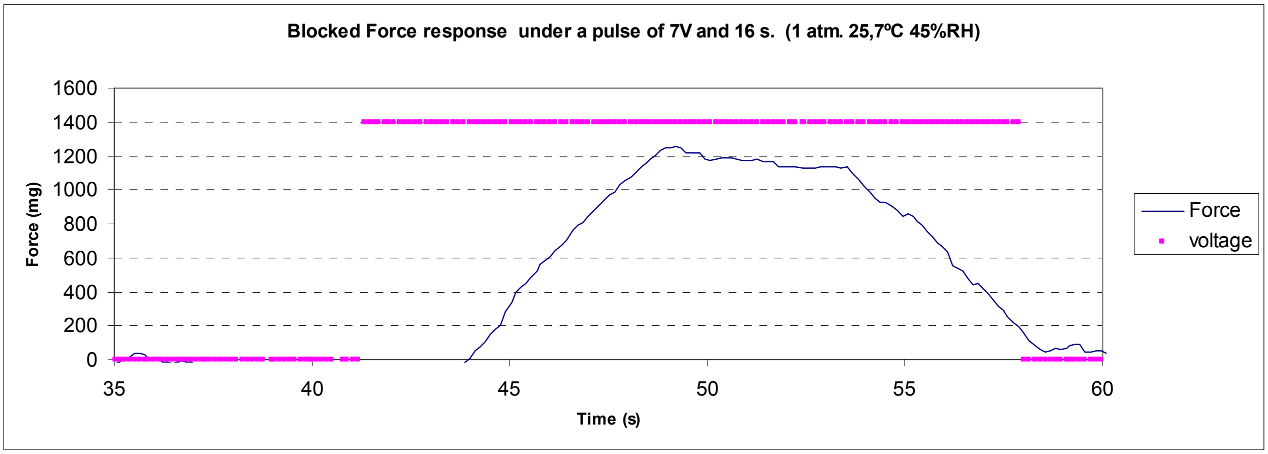


Figure 7. Blocked force Test configuration [1]



Conclusions

Basic actuator tests on well-known IPMC samples were conducted following the recently published test standard for bending and extensional actuators.
Outgassing tests, and maximum voltage test, not mentioned in the standard, were added to determine stability and maximum operating voltage of the sample
This paper illustrates basic tests to be conducted onto IPMC actuator samples. Many other tests such as dynamic tests, transducing characterization by Impedance measuring, thermal power dissipation, vibration absorbing or close-loop controllability tests have not been included in this study but might be included in the set of tests that characterize an IPMC actuator..
Following the current characterization procedure it is clear that this type of IPMC material allows practical use of it as an actuator material, understanding practical as controllable, when used below 1,45V (the maximum operating voltage) and therefore the strain of the actuator material should remain below $\varepsilon = 0,00112$ and the force produced by the actuator material under such conditions is negligible.
Also, the properties of the material are guaranteed for only 50 seconds when operated in air, since the loss of solvent rate is too high.

Reference

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