Chapter 20
Electromechanical Characterization of Bucky Gel Actuator Based on Polymer Composite PCL-PU-CNT for Artificial Muscle

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Abstract Artificial Muscle is a common term for material that able to actuate because of external stimulus such as electric. The Artificial Musclehas promising future in application of medical and robotic disciplines. Bucky Gel Actuator is one example of Artificial Muscle which consists of electrolyte layers sandwiched with electrode layers. In this paper, we proposed an alternative material for electrode and electrolyte layers. The electrolyte layer was synthesized from Polycaprolactone-Polyurethane copolymer (PCL-PU). On the other hand, the electrode layer was composited between PCL-PU and carbon nanotube (CNT) in percentage of 0.5, 1.5, and 2.4 wt%. Furthermore, we measured electrode conductivity and elastic modulus as key physical properties for our artificial muscle. Our results have shown that the polymer electrode starts to be conducting at a mixture of 2.4 wt% CNT. At this concentration, the elastic modulus is 6.2 MPa and its conductivity is 1.6 Sm^{-1}.

Keywords Artificial muscle · Bucky gel actuator · Electrode layer · Electrolyte layer · CNT

20.1 Introduction

Research about artificial muscle as an actuator has already reached certain point where people realized all of its potentials. Artificial muscle held high potential due to its high flexibility and power-to-weight ratio. Artificial muscle commonly has contraction and relaxation movement as normal muscle does [1].

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Bucky gel actuator is an example of artificial muscle which mainly consists of ionic liquid, polymer, and carbon nanotube. The actuator movement is produced by different electric potential of its electrolyte and electrode layers. Electrolyte layer is made by polymerizing ionic liquid and polymer [2, 3]. On the other hand, electrode layer is made by mixing electrolyte layer with carbon nanotube [4–7]. The high electrical conductivity of carbon nanotube creates certain amount of electric discharge that ultimately able to move this muscle [8, 9].

Nowadays, the application of artificial muscle includes robotics, biomedical, and electronics areas. In medical fields, artificial muscle is utilized as prosthetic limbic which function as close as possible to actual muscle of human beings. Furthermore, artificial muscle is also engineered as a micro sensor and micro actuator in implanted device in human body. These applications bring hope to handicapped person to live normally. Robotic application is using artificial muscle for certain activity in production line. Moreover with the increasing popularity of rapid prototyping, artificial muscle will be likely to have a high potential to be mass production [10].

However, many obstacles are still eminent so that artificial muscle is not ready to be fully utilized. Characterization of such material is not plausible enough to be used in above corresponding areas. The required energy activation of artificial muscle is currently too high to be used safely. Additionally, there were no significant research about durability and lifetime of artificial muscle. Therefore, our research is aimed to investigate new material to be used as artificial muscle with relatively low voltage activation i.e. less than 10 VDC.

20.2 Experimental

20.2.1 Artificial Muscle Preparation

Basically, artificial muscle is composed of electrolyte layer and electrode layers. Firstly, ionic solution salt is being prepared by mixing two salts i.e. aluminum chloride ($AlCl_3$) and Urea ($CO\ (NH_2)_2$) with molar ratio of 1:2. This mixing salt was then dissolved into Dimethyl Sulfoxide (DMSO) with molar ratio of 1:3 to have the ionic solution.

Secondly, electrolyte layer was prepared by mixing the ionic solution with Polycaprolactone-Polyurethane copolymer (PCL-PU). The mixture was arranged to have 50 % w/w of salts to polymer. Later, the mixture was mixed in ultrasonic vibration for 2 min and dried by heating to 50 °C for about 10 min.

Thirdly, electrode layer was prepared by mixing carbon nanotube with ionic solution and PCL-PU polymer. The CNT content in electrolyte layer was arranged to have various concentration i.e. 0.5, 1.5 and 2.5 % w/w. The solution mixture was mixed thoroughly in ultrasonic vibration and heated with the same condition as above to realize electrode layer.

Lastly, artificial muscle is assembled by hot pressing electrolyte layer that sandwiched with two electrode layers. The temperature was kept at 70 °C for 2 min.

20.2.2 Material Testing and Measurement

20.2.2.1 Conductivity Measurement

Artificial muscle specimen was prepared into a dimension of 2 cm x 1 cm in length and width. The thickness was also measured using micrometer. A two point probe is employed to measure sample's resistivity using digital multimeter.

20.2.2.2 Elastic Modulus Measurement

Elastic modulus measurement is done by using ASTM D1708 micro tensile testing method. Four specimens with a dimension of 2 and 1 mm were prepared. The deformation rate was set to 0.5 mm/min.

20.3 Results and Discussion

20.3.1 Image Acquisition

Figure 20.1 shows stereomicoscope images of electrode layer of artificial muscle from various concentration of CNT. Obviously, the more CNT concentration it has, the higher intensity of the image. Here, a higher intensity of an image represents a darker colour of image. However, at 2.4 wt%, it can be seen that the CNT agglomeration is evident. This agglomerate indicates a low dispersion quality of CNT throughout the polymer electrode. Intuitively, dispersion quality of CNT shall affect the mechanical and electrical properties of electrode layer.

20.3.2 Mechanical Property Measurement

Stress-strain curve is acquired after the elastic modulus test as shown in Figs. 20.2 and 20.3. Figure 20.2 represents the result from electrolyte layer that mainly is a mixture of polymer and salts. Here, the control specimen is composed of polymer PCL-PU layer. The addition of 50 % w/w salts results in lower tensile strength and later also elastic modulus. It can be seen that at 15 % of elongation, the tensile is lowered by 50 %. It can be indicated that the salts left more micropores during the drying process to realize the electrolyte layer. A further addition of salt (66 %) brings a lower tensile strength as shown in Fig. 20.2. However, a statistical analysis shows that the difference is not significant.

Figure 20.3 shows the result of mechanical testing from electrode layer specimens. With respect to control specimen, the addition of CNT is not showing any significant difference of tensile strength property until the 2.4 % CNT

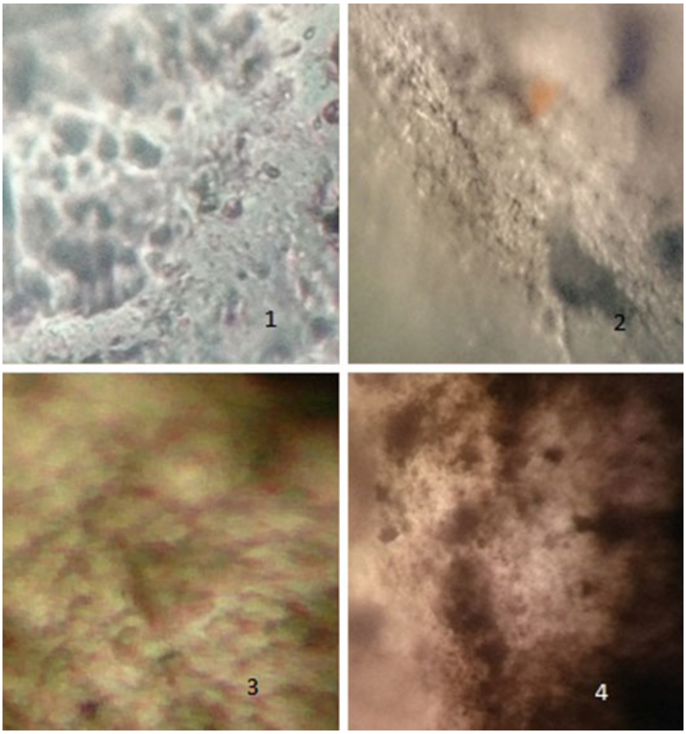


Fig. 20.1 Stereomicroscope images from electrode layer at various CNT concentration: (*1*) 0%, (*2*) 0.5%, (*3*) 1.5% and (*4*) 2.4%

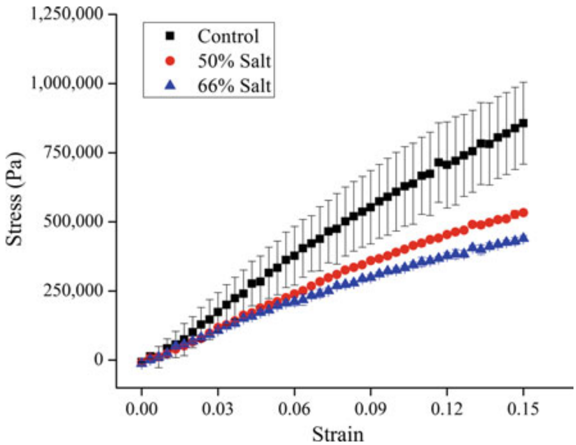


Fig. 20.2 Stress-strain curve of electrolyte polymer layer at various salt concentrations

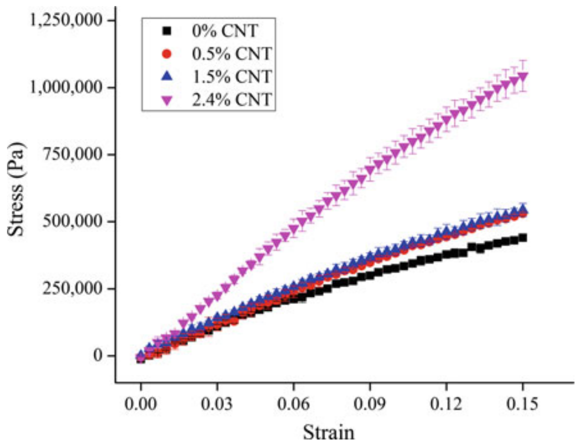


Fig. 20.3 Stress-strain curve of electrode layer at various CNT concentrations

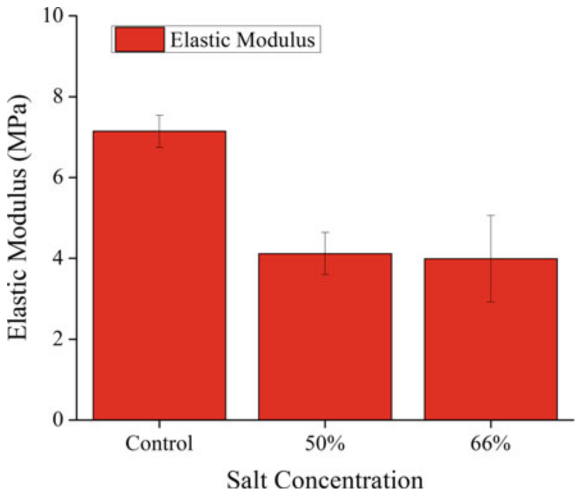


Fig. 20.4 Result of elastic modulus measurement from electrolyte layer at various salt concentrations

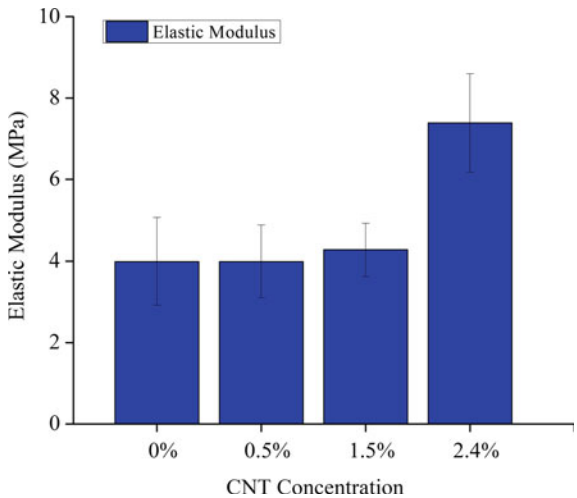


Fig. 20.5 Result of elastic modulus measurement from electrode layer at various CNT concentrations

concentration. Intuitively, this increasing tensile strength is correspondingly with the amount of carbon nanotube in the electrode layer.

Furthermore, the measurement of elastic modulus is depicted in Figs. 20.4 and 20.5 for electrolyte and electrode layer respectively. Similarly to the strength property, the stiffness of electrolyte layer is decreasing as the salt was added in Fig. 20.4. In addition, Fig. 20.5 confirms that the addition of CNT bring a much higher elastic modulus of polymer membrane.

20.3.3 Conductivity Measurement

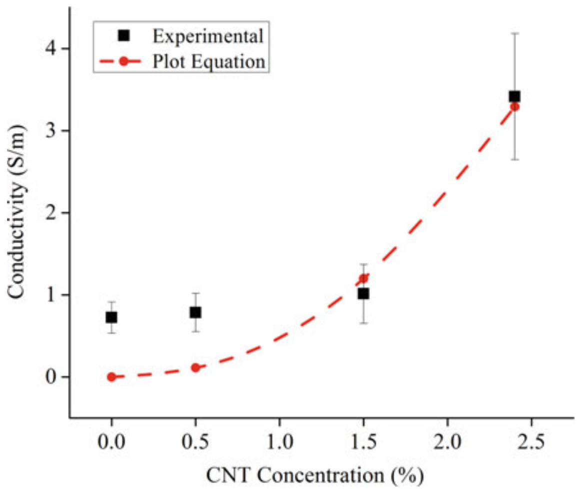
The conductivity result of electrolyte and electrode layer is reported in Fig. 20.6. Here, specimens with 50 % salt were taken into account as control for electrode layer. Note that the electrode layers are a mixing between electrolyte material and carbon nanotube as conductive filler. The conductivity results show that the electrical property corresponded positively with mechanical properties. It can be concluded that the micropores by salts and CNT affect the electrical property as much as mechanical properties.

Furthermore, Fig. 20.6 shows a small improvement of conductivity is shown at the 1.5 wt%. Later, an abrupt conductivity value at 2.4 wt% is evident. This can be explained that the percolation threshold of electrode is reached at near 1.5 % w/w CNT addition. The conductivity measurement at 2.4 wt% is comparable to those of germanium (2.17 s/m 20 °C). This substance is widely used as a semiconductor material. Thus, PCL-PU CNT might be used as a flexible electrode in electrical field.

A simple plot line as suggested by below equation was applied.

$$\sigma \propto (p - p_c)^t \tag{20.1}$$

Fig. 20.6 Conductivity measurement result of electrolyte and electrode layers



The equation is employed to predict the value of conductivity (ρ) at any concentration of conductive substance (p) as the conductive threshold concentration (pc) is known from experimental. Our previous result gives the value of conductive threshold to be near 1.5 % w/w carbon nanotube. By inputting the power value (t) of 2.15 at Eq. 20.1, we shall have a prediction line of conductive as plotted in Fig. 20.6. This result is interesting in that the power constant is similar to that theoretically predicted for a 3D percolation model. The percolation theory suggests that a substance has a power constant to be about 2 in order to behave as conducting material.

20.4 Conclusion

The main material for artificial muscle is realized and characterised completely. This paper shows the strong relation between mechanical property and electrical property that driven by the particle contents. The anion salt and carbon nanotube affect the microstructure of polymer which evident in the electromechanical properties. The experiment shows that the percolation threshold occurred between 1.9 and 2.4 wt% CNT concentrations for electrode layer. Modulus elastic value at percolation point has a value of 7 MPa. Conductivity value at percolation point is around 1.6 S/m.

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