Design and characterization of electrically driven-bioinspired soft actuator based on silicon- ethanol composite

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1- Introduction

Composite actuators based on silicone and ethanol were first introduced in 2016 as phase change material, and variety of analyses have been done to identify their behavior. Despite the ability of tolerating high strain and forces, the proposed actuators degrade after a limited number of working cycles (7 working cycles) due to the escape of ethanol from the material. In this study, silicon and an optimized value of ethanol were used to fabricate a soft and robust artificial muscle. The effect of relaxation time on the temperature-displacement characteristic of the actuator was investigated. Also, the microstructure and weight loss of composite during multiple actuation experiments were evaluated.

2- Experimental

2-1 Material. In this research, silicone elastomer (silicon and hardener) as a matrix and ethanol (>99.5%) as a phase change fluid (Merck) were used. Nickel-chromium resistance wire with a diameter of 0.25 mm was used for electrically-driven actuation.

2-2 Composite fabrication. The composite was fabricated by hand-mixing of silicon with ethanol. Hardener was added to the mixture after mixing the silicone with the optimized value of ethanol for about 5 minutes. The composite was cured after 4 hours. The molding process was performed by using polymethyl methacrylate (PMMA) mold with dimensions of 90 × 15 × 15 mm and installing 75 cm Ni-Cr spiral wire as seen in Figure 10.

2-3 Data recording hardware. The microstructure of the composite was observed by a field-emission scanning electron microscope (FESEM, MIRA3 TESCAN). Digital power supply (Rohde & Schwarz) was used for electrical actuation of the soft actuator. Voltage (20v) and current 0.6A (12W) were applied to the samples in each actuation cycle. A pt1000 (Japan) was used as a temperature sensor. A digital camera (Canon-Japan) was also used to record the dynamic behavior of the soft robot.

3- Result and Discussion

3-1- Determining the optimized value of ethanol. In order to select the optimal value of ethanol, silicone matrix composites with 10, 20, 30, 40, 50 V. % of ethanol, were prepared. The preparation of the composite with more than 30. %V of ethanol cause to the difficulty in the mixing process, and phase separation. According to Table 1, composite samples with 10% and 30V.% of ethanol have the maximum rate of loss and storage of ethanol, respectively. Then, three composite samples with 20, 30, and 40 V.% ethanol, by embedding 75 cm of nickel-chromium wire, were subjected to similar electrical actuation conditions (W12 = V20 × 0.6) (Figure 2). A 30 V. % ethanol was selected as the optimal percentage due to: 1- Optimal fluid storage capability, 2- Low fluid loss rate, 3- an expansion strain equal to 20%.

3-2-Temperature and displacement behavior of soft actuator. Fig.3 shows the variation of temperature-displacement of composite samples for 15 working cycles. Relaxation time after each actuation cycle was considered 100 and 200 seconds for samples 1 and 2, respectively (Fig.A). This was followed by keeping the actuation time equal to 110s for all samples to apply the similar energy to soft robots in all working cycles. The temperature response and weight loss of the samples were investigated.

According to Fig.3-A and 4-B, the maximum and minimum value of displacement and temperature of sample 1 are higher than sample 2. Sample 1 has less time to transfer thermal energy to the outer layers of the composite due to the shorter relaxation time. The temperature of ethanol located in microcapsules is close to phase transition (78.3°C) due to the pre-heating of sample 1. This effect has two results: 1- Ethanol vapor pressure inside the microcapsules is higher than the sample 2 and prevents the complete recovery of the muscle to its original shape, 2-Sample 1 has more displacement during the same actuation time (110s) compare to sample 2.

3-3- Weight loss variation of silicone-ethanol composite. Fig.4 shows the weight loss of composite samples after a prolonged electrical excitation period (15 cycles). As shown in Fig.4, slope of weight loss versus temperature for sample 1 is more severe than sample 2, which can be attributed to the higher internal temperature of sample 1 compared to sample 2, at least 10°C(Fig.3).

3-4- Microstructural observation. Figure 5 shows the distribution of microcapsules with smooth surfaces in micron size (5-A) and large air cavities(5-B). Air cavities with a diameter of 50 to 100μm along with small cavities with a diameter of 20μm were observed.

4- Conclusion

The kinematic and temperature response of the soft actuator revealed more energy storage in sample 1 (relaxation time=100s) than the sample 2 (relaxation time 200s), as 10°C higher internal temperature. The higher internal temperature of sample 1 increased the ethanol escape, which caused 45 wt.% of the ethanol in the structure after 15 actuation cycles. In contrast, sample 2 loses only 33 wt.% of ethanol. Microstructure observation revealed a homogeneous distribution of ethanol inside spherical microcapsules with 20μm diameter and air

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cavities (50-100µm).

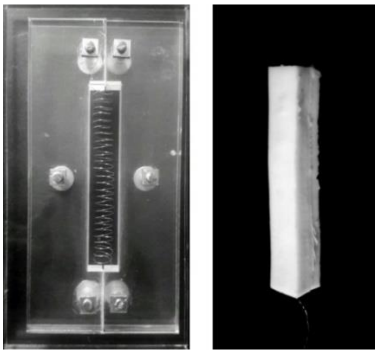


Figure 1- Images of mold and cured muscle.

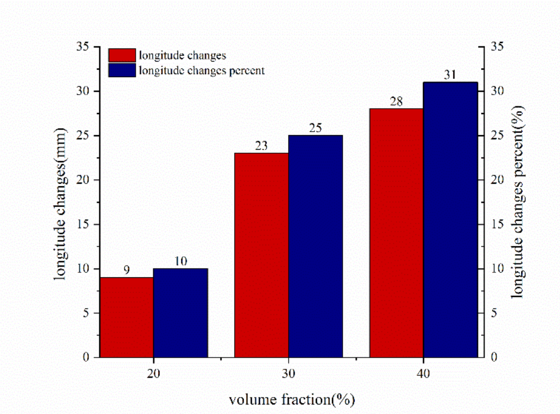
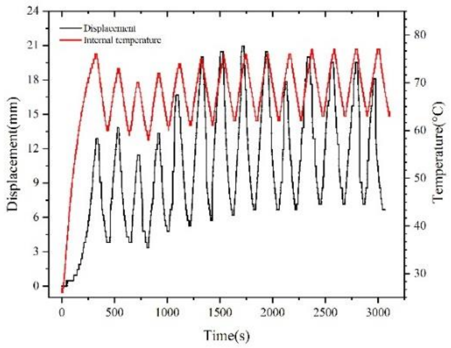
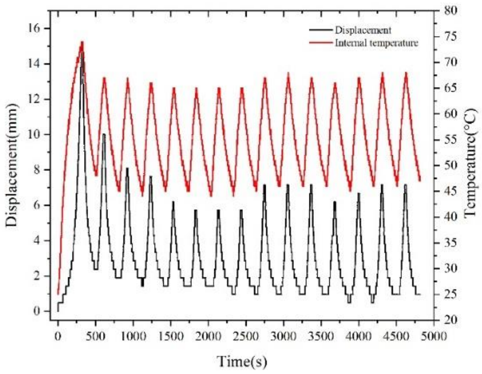


Figure 2 – variation of actuator elongation as a function of ethanol volume.



A: Sample 1 with relaxation time of 100s .



B: Sample 2 with relaxation time of 200s

Figure 3 – Displacement versus temperature for silicone-ethanol composites with different relaxation time .

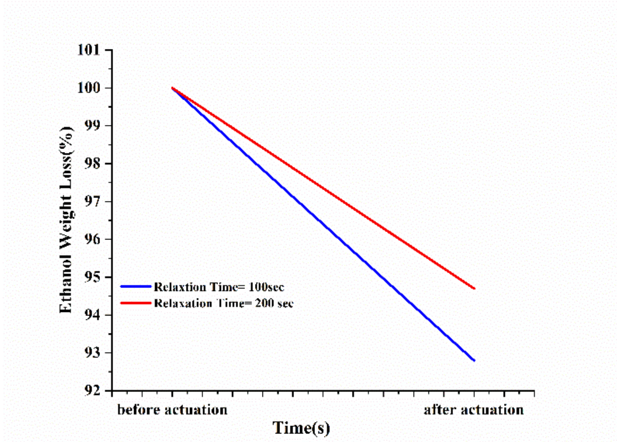
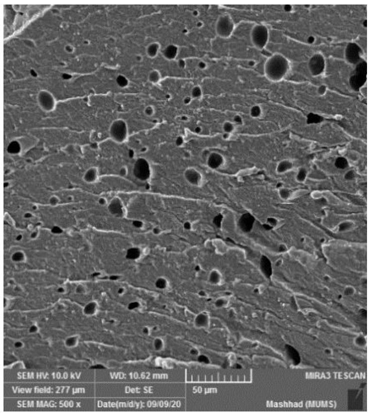


Figure 4: Ethanol weight loss of composite samples after 15 cycles.

A



B

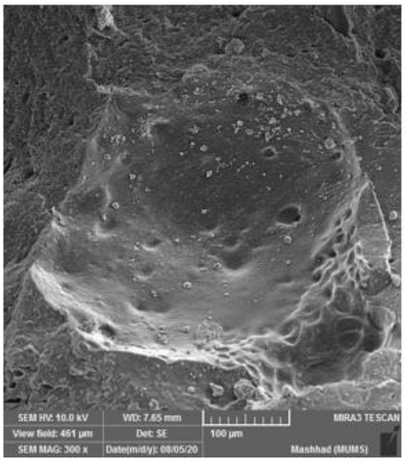


Figure 5: FESEM images of composites after 15 actuation cycles.