PERFORMANCE OF ACTIVE POLYMER-MATRIX COMPOSITE USING SHAPE MEMORY ALLOY WOVEN LAMINATES

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Abstract

An active structure enables interaction with the external environment has been investigated to meet a requirement for use in shape changeable applications via the adaptation of its shape. In this study, to provide a variety of deformation behaviors of the morphing structure, the polymer-matrix composite using Shape Memory Alloy (SMA) woven laminates was investigated. To generate a bending deformation, the SMA wires which were woven with the glass fibers were heated by applying current. Different configurations of the morphing structure were tested by changing the number of the additional layered glass-fiber lamina to modify the principle of the deformation quantity of the morphing structure. Also, the blocking force which generates an out-of-plane deformation caused by the axial shrinkage of the SMA wires was measured using load cell with different configuration of the woven composites.

1. Introduction

Morphing is the proposed technology intended to achieve the ability to adapt its shape to a diversity of operational condition without discrete parts [1]. In general, morphing technology has been applied to aerospace applications which affected by fluidic forces since it can reduce the efficiency loss of a fluid by continuous shape change. Not limited to aerospace application, nowadays, biomimetic robot applications such as inch worm robot, robot fish, etc. are developed using the advantages of morphable structure [2].

Morphing skin is a type of the morphing technology to make a surface-area changes which covered on the moving/non-moving parts. It could be categorized as the passive skin with mounted actuation source and active surface morphing with passive structure. The type of the passive skin with mounted actuation source shows deformation by inducing external forces such as the actuation of the smart materials and the other type shows a self-actuation by integrating the skin with actuation sources [3].

As a passive morphing, composite corrugated structures having an anisotropic properties were used for the morphing trailing edge of the airfoil to amplify the aerodynamic improvement by adjusting the environment. Its skin is transformed and locked with mechanical elements. And the skin is actuated by the induced force from outside of the structure [4]. Also, a passive 1D morphing skin consisted of honeycomb composite with Pneumatic Artificial Muscle (PAM) has been presented to apply the wing span morphing. The wing span morphed by PAM actuator that push and pull the scissor frame connected with the honeycomb structure [5].

Non-traditional methods such as tendon mechanism were used for shape change. A tendon-actuated compliant cellular truss was developed for local wing deformation. Tendon actuator such as wires and SMA wires could be applied for controlling its shape by pulling and releasing tensions [6]. Morphing skin technology is used in biomimetic robot as well as morphing wing. A bat-like micro aerial vehicle

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inspired by bat flapping mechanism was proposed to control the wing motion enables the retraction and the extension of the wing using SMA wires [7]. To realize own advantages of traditional /non-traditional actuator, hybrid actuation was presented as a robotic manipulator. Tendon-driven and pneumatic actuated systems are integrated in a soft manipulator [8].

Self-actuated skin using pneumatic muscle fibers embedded in a silicone matrix was developed to reduce the complicating auxiliary parts assisting transforming the structure [9]. Also, inflatable wing which can be packed into much smaller than their deployed volume without damaging was developed. Using the inflatable wing, the nominal airfoil shape was demonstrated and flexible skin is attached on the wing surface [10].

To achieve the bend-twist motion in a single structure, Smart Soft Composite (SSC) was presented. The SSC consists of smart actuator, anisotropic material, and polymeric matrix which can generate the coupling effect for in-plane/bending/twisting deformations. Self-contained structure, which combining an actuator and structure, has benefit to build a concise and lightweight structure since it doesn't need to secure extra space for mechanical subsidiary parts [11-16].

This paper aims to introduce a soft morphing skin using SMA embedded woven fabric. The soft morphing skin consists of SMA wires embedded woven fabric and the woven fabric was weaved in a plain weaving method. The woven fabric is made of dissimilar fibers including SMA wires with anisotropic materials. The characterization of the fabricated soft morphing skin was examined by changing the number of additional fabric layers. Its maximum end-edge deflection and blocking force were measured in an acting condition of SMA wires.

2. Design & Fabrication

In a previous study, a woven type SSC actuator was presented to apply soft morphing structures. SMA wires and glass fibers were weaved in a plain weaving method and they were designed to be used for the morphing wings [14]. However, the woven actuator has not enough frictional force to maintain its fabric composition to use as it is intactly. To narrow the gaps and increase frictional force among woven fibers, the nylon fibers added as a warp thread between SMA wires. The nylon has much larger elongation properties and can withstand the acting environment by SMA wires.

3. Experiment

3.1. Deformation

To observe the characteristic of the soft morphing skin, beam type actuator was prepared. Its dimension is 84 mm x 11 mm, and one SMA wire is embedded in the middle of the actuator. To study for the deformation quantity of the actuator with various number of layered glass fiber fabrics, from one to two glass fiber fabric layers were stacked onto the woven fabric. And then, liquid polymer (Polydimethylsiloxane, PDMS, Sylgard 184, Dow Corning) was poured to the fixed fabrics.

Figure 1 shows the maximum deformed shape of the beam actuator at each layering condition. The beam was fixed at a fixture in a vertically. Maximum end-edge deflection of the beam was 170° with one glass fiber fabric. The results of the deformation test is shown in Table 1.

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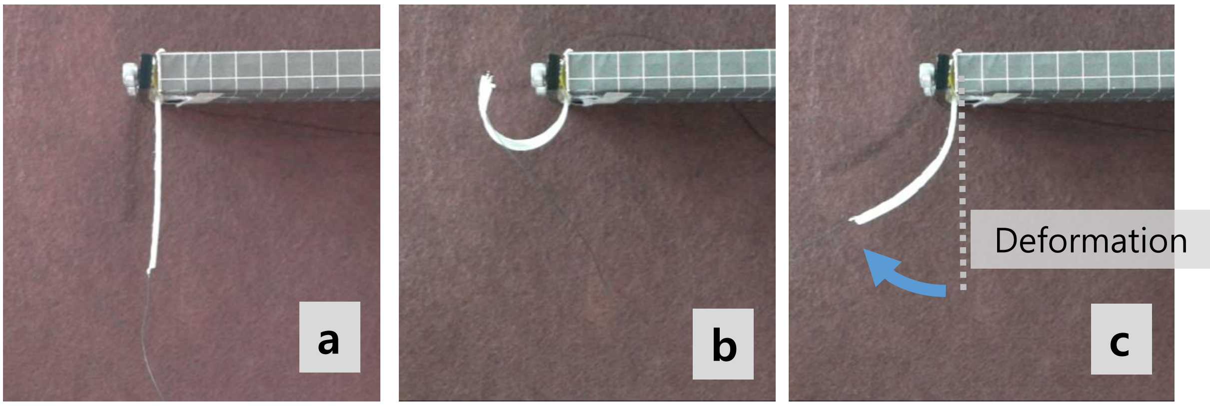

Figure 1. Deformation experiments using beam type actuator; (a) Before actuation. Captured images of maximum end-edge deflection with (b) one glass fiber fabric, (c) two glass fiber fabric

3.2. Blocking force

Blocking force of the actuator was measured using the dynamometer (Kistler, type 9256C1). The actuator was fixed on the fixture using acrylic plate and bolts according to the horizontal plane. The actuator was placed with a negligible gap between acrylic plate and force measurement sensor. Experimental set-up for the force measurement is shown in Figure 2. When the actuator was bended, the end-edge of the actuator pushed the dynamometer. The maximum blocking force was 0.53 N with one glass fiber fabric. With increasing the number of glass fiber fabric, the blocking force was decreased. The results of the test is shown in Table 1.

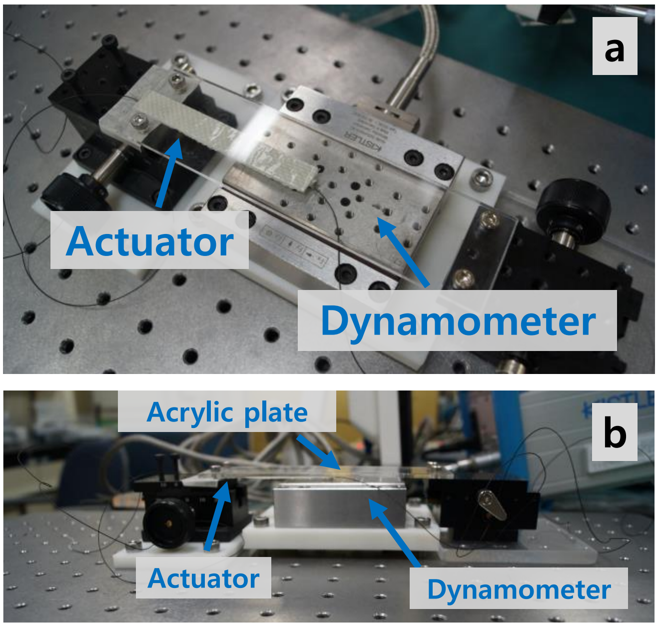

Figure 2. Experimetal set-up for measuring blocking force using dynamometer;
(a) Top view, (b) Side view.

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Table 1. Results of the experiments

Specimen Type	*Number of the layered glass fiber fabric*	*Max. end-edge deflection (degree)*	*Blocking force (N)*
A	1	170	0.53
B	2	55	0.22

4. Conclusions

A soft morphing skin using SMA wires embedded woven fabric was fabricated to generate large surface morphing. The woven fabric consists with SMA wire as a warp threads, and glass fibers as a weft threads. Beam shaped actuator which contains only one SMA wire was fabricated and its actuation characteristic was observed in terms of end-edge deflection and blocking force by changing the number of glass fiber fabric from one to three layers. The maximum end-edge deflection was 170° and the maximum blocking force was 0.53 N with one glass fiber fabric. Although the proposed soft morphing skin should be improved to generate large deformation with large area, it gives promise of morphing technology using fabric type actuator.

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