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Experimental and Theoretical evaluation of Bending Behavior of Shape Memory Actuator

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ABSTRACT

In this paper, a shape memory actuator that is made by composition of shape memory fibers and elastomer, is studied theoretically and experimentally. First, an initial strain at low temperature is applied to the shape memory fibers, then they are embedded in the outer surface of the beam. Therefore, if a positive gradient temperature is applied, compressive recurrent stress would be produced and as a result, the beam would be deflected. In this work, firstly, stress-strain-temperature relations for shape memory alloys (SMA) are studied. Then, recurrent compressive stress, caused by temperature rising of the shape memory fibers, is evaluated. In follow, beam deflection is calculated and finally the shape memory actuator is tested experimentally. In experimental tests, specimens are deflected by applying a specified voltage which lead to a positive gradient temperature. These specimens have a fast flexibility capability and the beam deflection can be controlled via input current.

KEYWORDS:

Sma, Nitinol, Stress, Deflection, Elastomer

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1- Introduction

In 1986, relation of shape memory alloys is issued by Tanaka [1]. In these relation, martensite ratio is mentioned as an exponential function of stress and temperature. In 1997, Rogers and Liang [2], based on Tanaka's model, proposed a cosine function for martensite ratio. After this year, almost all relevant studies used Rogers's model.

In the theoretical field, a reinforced triangular beam with shape memory fibers is explored by Baz [3]. The fibers be curvy in the martensite mode. Also, a curved composite shell with shape memory alloys is studied numerically by Lee [4]. Marfia [5] probed flexural behavior of an specific triangular composite beam with two shape memory alloys in the inner and outer surface.

In the recent years, many works have been done on impact resistance behavior of composite structures with shape memory fibers [6, 7, 8], but in this work, flexural behavior of an elastomer beam with shape memory fibers is studied. As another difference with previous studies, beam's elastomer material can be expressed. In this work an elastomer with low modules of elasticity and high flexibility characteristics is used, so large deflection and deformation can occur. Also, in this work, shape and speed of flexural deformation are controlled along the beam.

2- Theoretical Study

The temperature effect is different in shape memory alloys with typical materials. Based on Tanaka's model, phase transformation from martensitic phase to austenite one is controlled by total potential energy. Integrating from Tanaka's model leads to another fundamental equation which is issued by Rogers and Liang.

After some mathematical simplifications, stress equations can be expresses via stress (σ), strain (ε) and martensitic ratio (ξ) as:

$$d\sigma = \frac{D}{1 + b_A \Omega\left(\frac{\xi_0}{2}\sin[a_A(T - A_s) + b_A\sigma]\right)} d\varepsilon + \frac{\Theta - a_A\Omega\left(\frac{\xi_0}{2}\right)\sin[a_A(T - A_s) + b_A\sigma]}{1 + b_A\Omega\left(\frac{\xi_0}{2}\right)\sin[a_A(T - A_s) + b_A\sigma]} dT \qquad (1)$$

For analytical analysis, firstly, recurrent stress in shape memory alloys to be computed. Based on the following assumptions, recurrent stress in the mentioned alloys is evaluated:

1. Temperature effects on elastomer beam is neglected.
2. During beam deformation, axial strain is neglected.
3. Stress via temperature is computed according to the Figure 1.

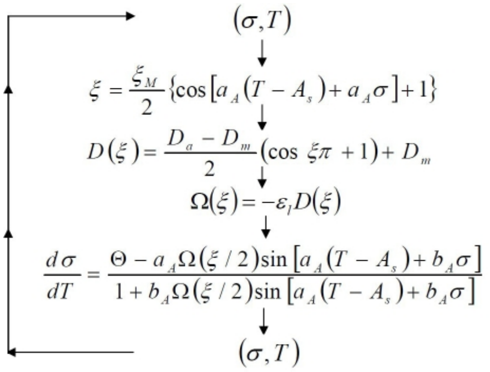

Figure 1. Iteration schema for evaluation of stress-temperature of shape memory fibers

4. Properties of shape memory alloys in either of theoretical and experimental analysis are available in Table 1.

Table 1. Shape memory wire's property

Characteristic	Unit	Value
Diameter	μm	250
Cross Section Area	μm^2	49
Electrical Resistance	Ω/m	20
Austenitic Starting Temp.	ºC	68
Austenitic End Temp.	ºC	78
Martensite Starting Temp.	ºC	52
Martensite End Temp.	ºC	250
Density	Kg/m^3	6450
Young's modulus in Martensite Phase	GPa	28
Young's modulus in Austenite Phase	GPa	75

3- Experimental Study

In experimental study, electrical current produce heat in the wire. For experimental tests, a DC power supply connected to the wire and electrical current is passed through it. An accurate thermocouple device is also used that its sensor is attached to the wire (in one point). Therefore, for each current, a relevant temperature is obtained. Experimental results is plotted in Figure 2. As can be seen wire temperature via electrical current obtained from experimental tests, can be approximated by a line with slope of

m=236.92 .

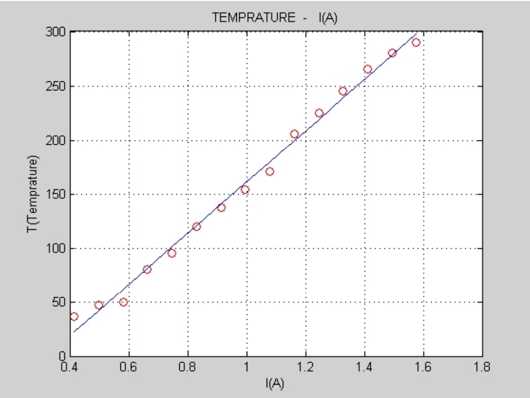

Figure 2. Temperature via current (experimental results)

To create recurrent stress in the shape memory fibers, a primary strain is applied by a bolt mechanism. Shape memory fibers to be placed horizontally. The used elastomer is MAXEAL RTV G23 that is blended by 1 percent hardener, then shed in a wood mold.

4- Theoretical and Experimental Results

5 percent primary strain for shape memory fibers at martensite temperature is considered, then wire is heated to 185 ^{o}C. After computation of recurrent stress, actuator deflection resulted from analytical method is plotted in Figure 3.

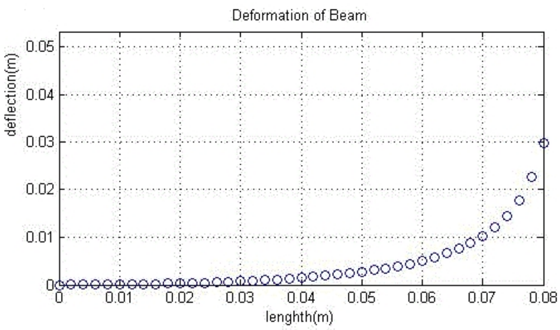

Figure 3. Deflection of shape memory beam (analytical method)

In addition, beam deflection resulted from experimental method is depicted in Figure 4.

5- Conclusion

In this work, deflection of a uniform cantilever shape memory beam is studied. Theoretical and experimental actuator's deformation in three temperature of 142, 185 and 166 ^{o}C is done. In all mentioned temperatures, good agreement between theoretical and experimental results is seen, but far away from its support, a little difference exists. Difference between theoretical an experimental result

Figure 4. Shape memory beam (experimental method)

is increased, as temperature in the shape memory wire increased. If input current is controlled, beam deformation will be controlled too. So, fiber's temperature is proportional to the input current. According to the experimental results and theoretical analysis, it can be concluded that to probe large flexural deformation, selection of elastomer field with shape memory fibers is an appropriate idea.

6- References

[1] Tanaka.K, 1986. "thermomechanical sketch of shape memory effect: one dimensional tensile behavior", *Res. Mech* , 18,251–63.

[2] Liang.C, Rogers.C, 1997. "One-dimensional thermomechanical constitutive relations for shape memory materials", *J.Intel.Mat.Syst.Str*, 8, 285-302.

[3] Baz.A, Chen.T ,2000. "Shape control of NITINOL-reinforced composite beams", *composite*, 31, part B, 631-642.

[4] Lee. H.J, Lee. J.J, Huh. J.S, 1999. "A simulation study on the thermal buckling behavior of laminated composite shells with embedded shape memory alloy (SMA) wires", *Composites*, 47,463–469.

[5] Marfia.S, 2005. "Micro-macro analysis of shape memory alloy composites", *International Journal of Solids and Structures*, 42, 3677-3699.

[6] Roh.j, Kim.j, 2003. "Adaptability of hybrid smart composite plate under low velocity impact", *Composites* , Part B, 34, 117–125.

[7] Meo.M, Marulo.F, Guida. M , Russo. S, 2013. "shape memory alloy hybrid composites for improved impact properties for aeronautical application" *Compos,Struct*, 95 , 756–766.

[8] Kurmar.R.S, Ray.M.C, 2012. "Active constrained layer damping of smart laminated composite sandwich plates using 1-3 piezoelectric composites", *Int. j. mech. mster, des*, 8,197-218.