

# Deflection of elastic beam with SMA wires eccentrically inserted

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**Abstract.** This research is intended to investigate the ability of shape memory alloys (SMA), through its activation, in generating loads to control beam deflection. An elastic beam is formed by sandwiching eccentrically SMA wires between two elastic plates. SMA wires are activated by electrical current from the power supply. Laser displacement meter (LDM) is used to measure deflection of sample. Results show that the deflection of the beam is dependent on the temperature change. The temperature-deflection response also shows the existence of hysteresis.

## 1. Introduction

SMA hybrid composite structures have functional and adaptive characteristics. Due to the actuation and sensing abilities of SMA, SMA elements have been embedded in polymer and metal matrix composites to aid in controlling the material's structural properties [1]. SMA hybrid composite materials have demonstrated varying success in applications such as vibration and shape control, creep resistance in structures, strain sensing and active damage control.

SMA fiber actuators are embedded in adaptive hybrid composites to generate large induced strains and high actuation forces to control their host composite structures. The performance of the embedded actuators is dependent on the transfer of strain between the host material structure and the actuator. The interface between host composite and actuator must be strong enough to accurately and consistently transfer this strain. Residual stress generated in composite during fabrication process [2] are utilized for certain application. Saunder et al. [3] demonstrated the use of SMA composite structures for structural acoustic control. The unique behavior of the SMA reinforced composites was utilized to allow minimization of radiated sound for harmonic beam vibration and placement of peak radiation response at specified frequencies within a controllable range. Anders et al. [4] studied the structural acoustic behaviour of locally activated SMA hybrid adaptive composite panels. Localized panel activation enhances the structural acoustic control capabilities in the low frequency range.

Choi et al. [5] performed an experimental study on the buckling and postbuckling control of a laminated composite beam with eccentrically embedded SMA wires. The results show that the buckling control can be extended to the postbuckling of the structure with the proper reactive moment. However the proper embedding SMA wires in composite usually give small deflection of the SMA



based structure which are not desired for actuator application, sometimes. Therefore in this work we are investigating the deflection of SMA based structure fabricated using sandwiching technique. This technique able to produce large deflection of the SMA based structure during activation.

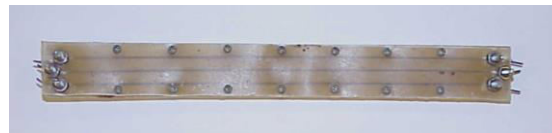
In the present paper, the bending behaviour of a structure composed of an elastic beam and SMA wires is investigated experimentally. SMA wires are sandwiched eccentrically in a polypropylene-natural rubber composite matrix. The activation of SMA wires will generate axial and moment forces which induce stiffening of the structure.

## 2. Experimental Setup

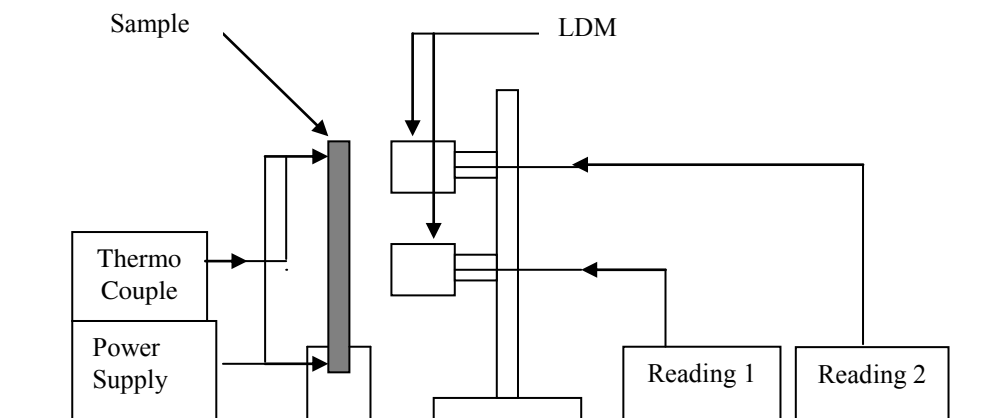
The beams are fabricated with a mixture of 70% polypropylene and 30% natural rubber. It is very difficult to embed SMA wires inside these material composites because of the high operation temperature. The fabrication of this composite using a hot press machine will involve operation temperature of up to 190°C. This will effect the SMA wires pre-strain because its transformation temperature is much lower than the operation temperature. Due to this problem, many researcher such as De Santis et al. [6], Jonnalagadda et al. [7] and Song et al. [8] used glass fiber/epoxy matrix because the embedding process can be done at low temperatures.

SMA wires used is NiTiCu and supplied by Advanced Material and Technologies, Belgium with code number of NTC0113-03-01. The main element are Ni and Ti. Small composition of Cu is added to reduce the hysteresis and lower the martensite transformation stress (Moberly & Melton 1990). Each SMA wire is strain up to four percent. The technique used in pre-straining SMA wire is explained in Tan et al [10]

In this work, the columns are fabricated by ‘sandwiching’ SMA wires between two plates of different thickness. The two plates with 20 mm in width, 170 mm in length and different thickness of 1 mm and 2 mm are formed by hot press machine. Three grooves were made on the plate with 2 mm thickness. Later, three SMA wires are inserted separately into the three grooves and closed by the other plate of thickness 1 mm to give 0.145 mm offset distance of wires from the neutral axis of the specimens. Three SMA wires with diameter size of 0.71 mm are fixed between the plates using screws and nuts as shown in Figure 1. Number of screws and nuts used determine the number of beam segmented. In this work, the beams with four, six and eight segments are prepared.



**Figure 1:** Beam with 8 segments



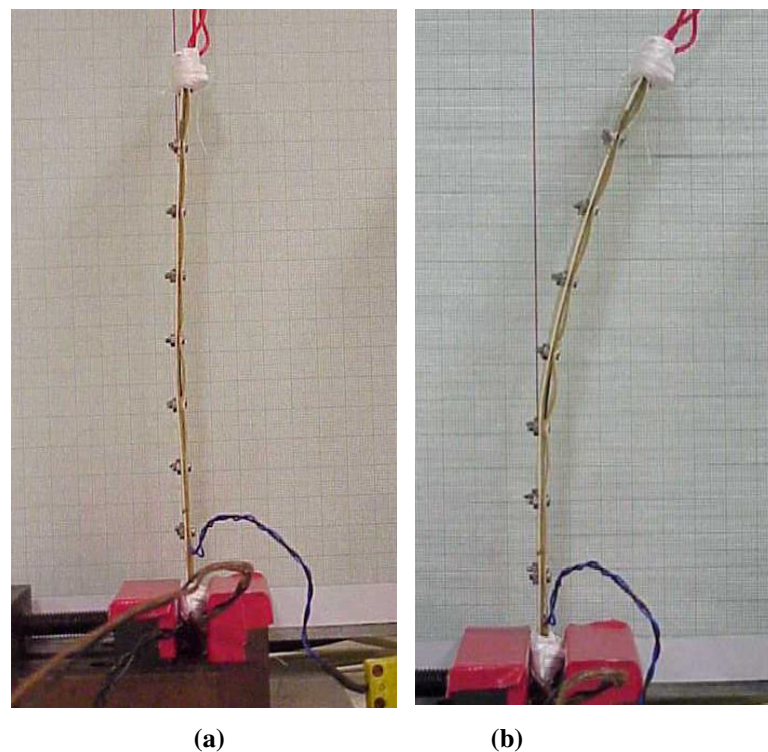
**Figure 2:** Shape control test rig.

Test rig for the shape control analysis is shown in Figure 2. SMA wires are activated by electrical current from the power supply. The current generates heat in the SMA wires because of the wire's resistance. The details on researches about the effect of electric current on SMA wire could be referred to Faulkner et al. [11]. Laser displacement meter (LDM) is used to measure deflection of sample.

### 3. Results and Discussion

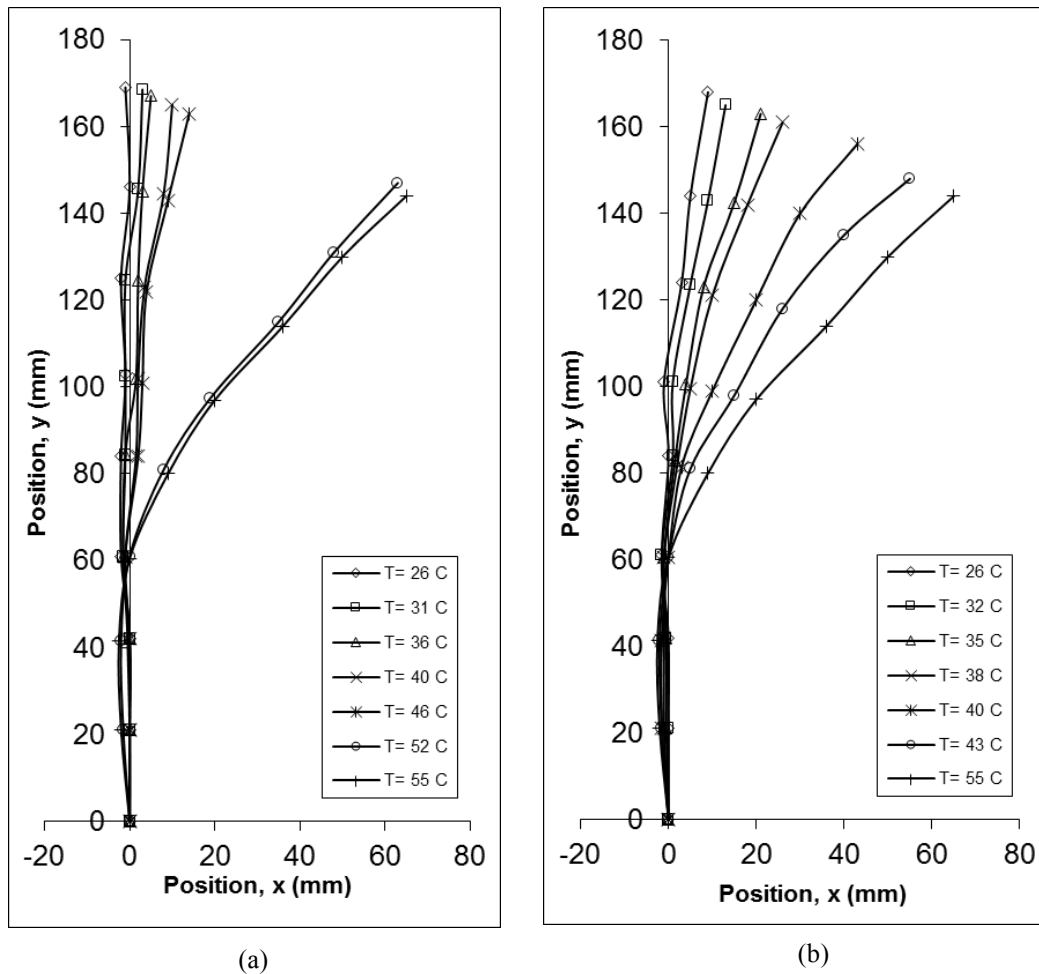
Heating of SMA wire would generate axial force on the beam. Due to the positioning of the SMA wires away from the neutral axis, moments are also applied on the structure. Generation of these loads causes the beam to deflect. The elasticity of the beam would result in the beam trying to return to its original position when cooled. Loss of heat in the SMA wire causes reduction in load generated. SMA wire in the austenite phase would gradually transform to martensite phase.

The initial position is set as in Figure 3(a). After heating by allowing current pass through the SMA wires the sample deflected due to axial force and moment generated as shown in Figure 3(b). Figures 4 shows the segments of the beam position during heating and cooling. During heating the small interval of deflection occur at the beginning and then increase drastically towards the end of temperature increment. The different deflection changes observed during cooling process. The deflection changes almost similar for the temperature decrement interval. The figure indicates the existence of hysteresis where the heating and cooling process undergo different paths.

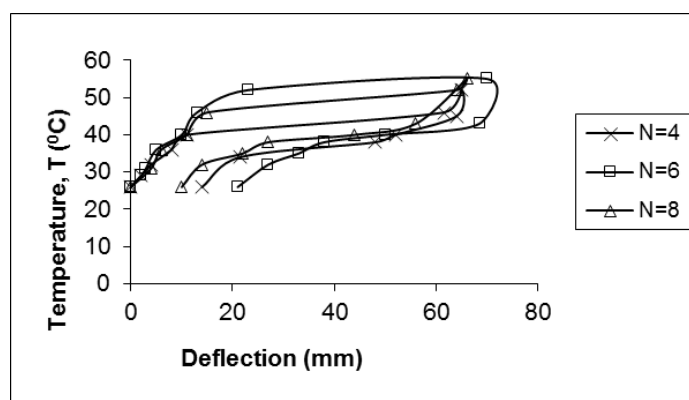


**Figure 3:** Beam deflection: (a) initial position, (b) during heating.

To investigate further the path of the beam deflected during heating and cooling, the relationship between temperature and deflection and axial displacement of the free end point of the beam are plotted as shown in Figures 5 and 6, respectively. Deflection and axial displacement of the column is dependant on the load generated from the change in temperature. Similarly, the hysteresis in the load-temperature response curve is also evident from the plots of temperature-deflection curves.



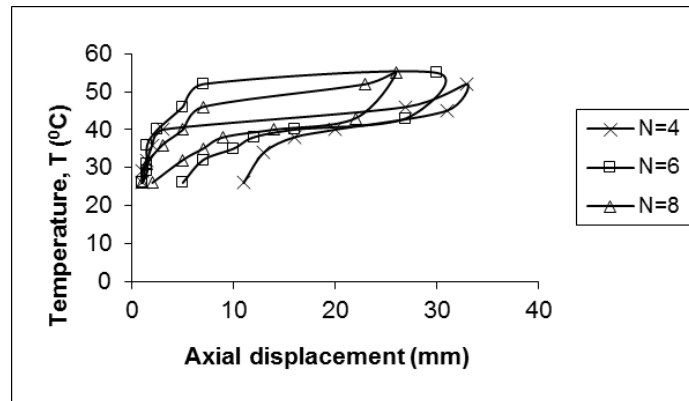
**Figure 4:** Position of beam with eight segment during (a) heating and (b) cooling



**Figure 5:** Temperature versus deflection of the free end point of the beam

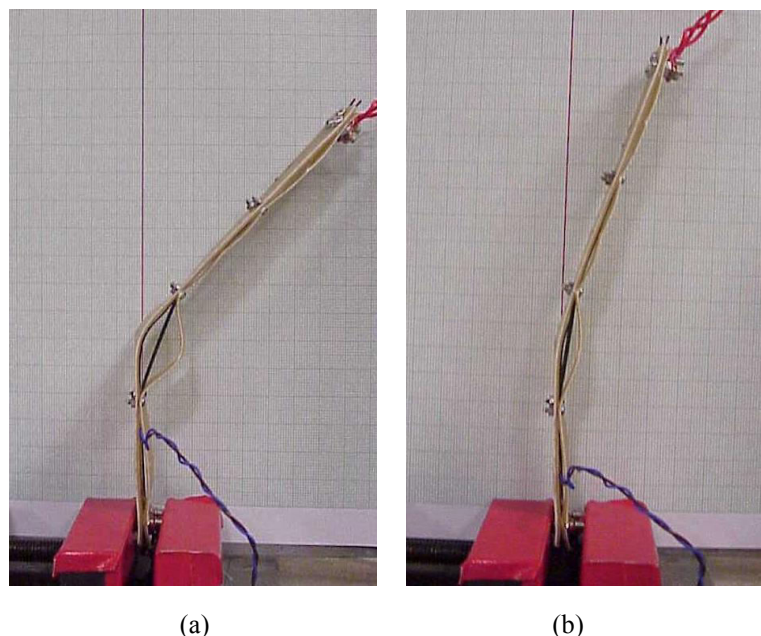
It can be observed in Figures 5 and 6 that the deflections and axial displacements of the beam with different number of segments are different. The variation is attributed to the different stiffness of the beam. The deflection is reducing with the increases of segments. The similar pattern is observed for the temperature-axial displacement of the end point of the beam. The large deflection with the

temperature changes is caused by the stiffness of the column. With the additional segments, more fixed contact points exists between two plates which increase the resistance to deflect. During heating, the SMA wire tends to return to its original shape, which is vertically straight. The increase in temperature also leads to an increase in the SMA Young modulus, where the Young modulus for the SMA in full austenite is, in general, three times greater compared to when it's in full martensite. This tendency to return to its original condition coupled with the increase in Young modulus; increase the stiffness of the beam.



**Figure 6:** Temperature versus axial displacement of the free end point of the beam

From the test done, it can be clearly observed that delamination occur at almost the middle of column with four segments. It can be seen in Figure 7. The large delamination of four segments beam is larger than the eight segment beam (Figure 2(b)). The delamination is a main problem of the sandwiching technique compare to the embedding technique which need to be further investigated.



**Figure 7:** Beam with four segments position (a) during heating (b) during cooling



#### 4. Conclusion

From the results, it could be observed that heating and cooling process of SMA wires could control the deformation of structures. The large deflection of SMA based structure can be produced using sandwiching technique. It is very convenient to be functional as actuator.

#### Acknowledgement

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