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Ratnesh Kumar Singh
National Institute of Technology Karnataka

S. M. Murigendrappa
National Institute of Technology Karnataka

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Ratnesh Kumar Singh, S. M. Murigendrappa, and S. Kattimani

Experimental Investigation on Free Vibration of Composite Beams Implanted Ni-Ti Shape Memory Alloy Wires

Ratnesh Kumar Singh[1], S. M. Murigendrappa[1, a)] and S. Kattimani[1]

[1] Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal 575025, India.

[a)]Corresponding author: smm@nitk.ac.in

Abstract. The paper presents free vibration of shape memory alloy hybrid composite beams by experimentally. The hybrid composite beams are fabricated using glass fiber with epoxy resin matrix implanted with the Ni-Ti SMA wires with diameter 0.47mm. The rectangular cross-section of beams with sizes, thickness, 3mm, width, 20mm and length 250mm are considered in the investigation. Free vibration test has been performed for the cantilever beams to investigate the effect on the fundamental natural frequency shift by changing the current as well as increasing the number of SMA wires. The fundamental natural frequency of the beam has shifted on higher side, 12.82% for single wire and 35.48% for two wires implant under the influence of current in comparison with no current state. Further, as supplied current increases in the SMA wire the natural frequency of beam increases helps in improving the stiffness and encourages to avoid resonance state.

INTRODUCTION

Smart material are the material which can change the shape as well as position, natural frequency and mechanical properties [1]. Change in these properties achieved by providing an additional source such as temperature, stress, electrical field, magnetic field, etc. There are variety of smart materials available, e.g., piezoelectric, Magnetorheological, Photovoltaic, shape memory alloy (SMA), etc. [2]. These types of smart materials can be used as actuator, sensor, and logic and control system by embedding it into the structure such as bridge, composite aircraft wing, robotics [3]. The shape memory alloy (SMH) is a type of unique smart material, make it smart namely: shape memory effect and superelasticity [4]. When the structure is mechanically loaded below the Martensite finish temperature, M_f and remain strained after removal of load, but once heated above the austenite finish temperature, A_f regain its original shape known as shape memory effect. The superelasticity is the reversible response to the load caused by phase transformation. The SMA is a light weight material, solid to solid state transformation and also alternative to convention actuator e.g. hydraulic type, pneumatic and motor type system.

Different types of SMAs are available e.g., Ni-Ti-X, Cu based and Iron based alloys. However, Ni-Ti based and Cu based SMA have very good shape memory properties. Ni-Ti-X SMA is the widely used alloy due to its stability and good thermo-mechanical performance [5]. Hebda et al. [6] reports that SMAs wire works as actuator into graphite/epoxy matrix and discussed the effect of training condition, bias stress and extended thermal cycling on the transformation behavior for wire, which contain Ni55 % rest Ti wire of diameter 0.19mm. Duan et al. [7], presented FEM for calculating critical temperature and post buckling displacement for composite plates implanted with pre-strained SMA wires. In 2002, Lau et al. [8], investigated analytically to calculate the natural frequencies of glass fiber composite with implanted SMA wire (Ni-Ti-Cu 0.5mm). Lau et al. [9] have introduced composite beam with embedded SMA non pre-strained and pre-strained Wires. The dynamic response of SMA composite beam was determined theoretically and experimentally for clamped-clamped beam, simply supported beam and clamp free beam. It was observed that natural frequency was less significant for non-pre-strained wires. The damping ratio of SMA composite beam increases with increase in temperature of implanted SMA wires with and without being pre-strained. It was observed that even small change in natural frequency, the damping properties were significantly improved. Aoki [10] fabricated epoxy matrix composite beam with embedded Ti-Ni SMA Fiber (0.4mm) and studied its

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mechanical properties. Yamashita and Shimamoto [11], have presented the shape recovery force of Ti-Ni fiber reinforced composite beam by electric heating. The research paper deals with reinforced composite material, which was implanted with polymer matrix and laminated with Ni-Ti SMA fiber. The experimental approach was consisting of single axis tensile test machine having thermostatic bath in the center. The specimens were electrically heated for tensile axial load of 6 MPa. Based on experimental results, graph of displacement vs. heating time and temperature vs. heating time were plotted for all three specimens. Finally, the author concludes that best composite material can be made by using electric heating and shape recovery is maximum for maximum number of SMA fibers. Diodati et al.[12], have focused on design of fiber glass laminated structural element with implanting SMA wires. The dependence of dynamic behavior with respect to number of SMA wires and different initial stress conditions were presented. He presented numerical simulated result through MSC/NASTRAN code. He had shown the effect of frequency variation for single wire and increase in number of SMA wires. With increasing weight of wires, the natural frequencies were shifted significantly. During validation, he found 2.5% of error in numerical and theoretical model for 110N. Zhou and Lloyd [13], have done experimental study on shape memory alloy hybrid composite (SMAHC) beam, for the fabrication of beam per-strained Ni-Ti wires used. It observed that the end deflection (up to 41 mm were easily attained) for the E-glass/epoxy was higher than the carbon/epoxy. And the longer length composite beam exhibited higher actuation rate and took short time to reach the same state of deflection. Faiella et al.[14], have presented the manufacturing and shape control ability of glass fiber/Polyester resin beam by embedding SMA wire experimentally and the vacuum infusion technique was used for the fabrication of SMAHC beam. The mechanical and calorimetric characterization of SMA have been done and correlated with the thermo-mechanical behavior. Barzegari et al.[15], were find out the analytically relationship to evaluate exact solution for natural frequency and mode shape of SMAHC beam with different end conditions and prepared by Euler-Bernoulli, Timoshenko and Reddy theory. Also they were find out the relationship to predict the effect of axial load generated by the per-strained SMA wire and modules of elasticity on the stiffness and natural frequency. More and Chavan [16], Have taken Ni56.2% and rest Ti in the form of wire and inserted into the sandwich beam which was made by copper plate. By embedding the different numbers SMA wires into the sandwich beam the natural frequency and damping factor were examined. Then Noolvi et al. [17], have made the SMAHC by glass fiber which reduces the overall weight and increase the actuating speed of the structure. Finite element analysis was done in the MSC Nastran to obtained displacement, stress, strain and Normal mode analysis and validated with experimental results. From the above literature, it is clear that numerous works have been done in the area of SMA for vibration and mechanical characterization with and without embedding into different types of matrix composite. Also, researchers have been used different diameters of SMA wire, composition, different environment condition etc. However, there is scope for investigation on improvisation of SMA properties with structure by experimental, numerical and/or analytical techniques. In the present, the experimental work has been carried out on the SMAHC beams to investigate the effect of different current and different numbers of wires on the fundamental natural frequency.

FABRICATION OF SMAHC BEAMS AND VIBRATION TEST

Shape memory alloy is a type of smart material is used as an actuator in the present investigation. The SMA is available in the form of wire, round bar, coil etc. The composite beam was fabricated by embedding the SMA wire into the structure, and this structure is called shape memory alloy hybrid composite beam. To use SMA wire as an actuator, it need to pre-strain before embedding into the structure. Once the current passes through the pre-strained SMA wire, it tries to regain original shape. However, due to strong bonding between the wire and composite matrix SMA wire cannot regain its original shape. The induced axial tensile force makes the beam stiffer compare to the normal composite beam. For pre-straining wire, in-house developed mold as shown in Figure 1 has been used to obtain sufficient strain in the SMA wire during the layup procedure.

Initially, Ni-Ti SMA wire of diameter 0.47mm was trained at 500 ^{o}C for two minutes in the muffle furnace with argon gas controlled environment. For the training purpose, a frame was prepared according to the required dimensions for proper seating the wire straight and finally SMA wire quenched into the normal water at room temperature. By quenching it into the water, crystal structure change takes place in the shape memory alloy from higher temperature austenite phase to lower temperature martensite phase. To fabricated hybrid composite plate, the trained wire is fully tightened at one end of the mold and two layers of Glass fiber was made in the zero direction. For the composite layup, epoxy resin, L12 and suitable proportion (10:1) of hardener K6 was mixed. The wire was fixed on the other end in the direction of the fiber ensuring with 6% of pre-strained in the wire. Then remain two layers were applied in the same zero-direction. The prepared composite plate was allowed to cure for a duration of 24 hrs at atmospheric condition.

Finally, the hybrid composite plate was cut to extract the beam configuration with dimension, 250×20×3 mm. Figure 2 depicts the fabricated single wire and two wires hybrid composite beams.

FIGURE 1. In-house developed mold assembly.

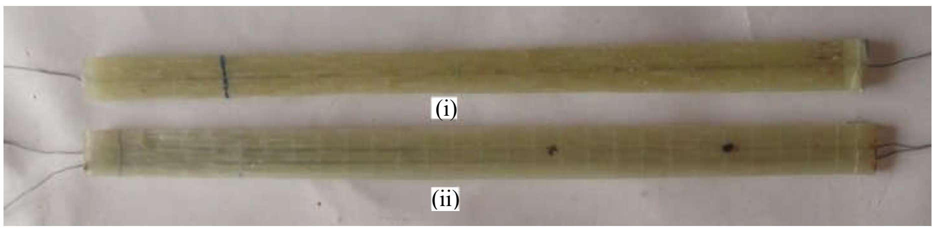

FIGURE 2. Shape memory alloy hybrid composite beams: (i) single wire and (ii) two wire.

In this study, the free vibration testing was performed on single and two wire implanted SMAHC beams to examine the effect of SMA wire as well as the different current input on fundamental natural frequency. The vibration setup is as shown in Figure 3. A cantilever SMAHC beam was mounted on a fixture support and accelerometer glued to it. The sensitivity of accelerometer is 9.82mV/g. The setup has components such as fixture, current supply unit and Data Acquisition System (DAQ) supported by NI LabVIEW software.

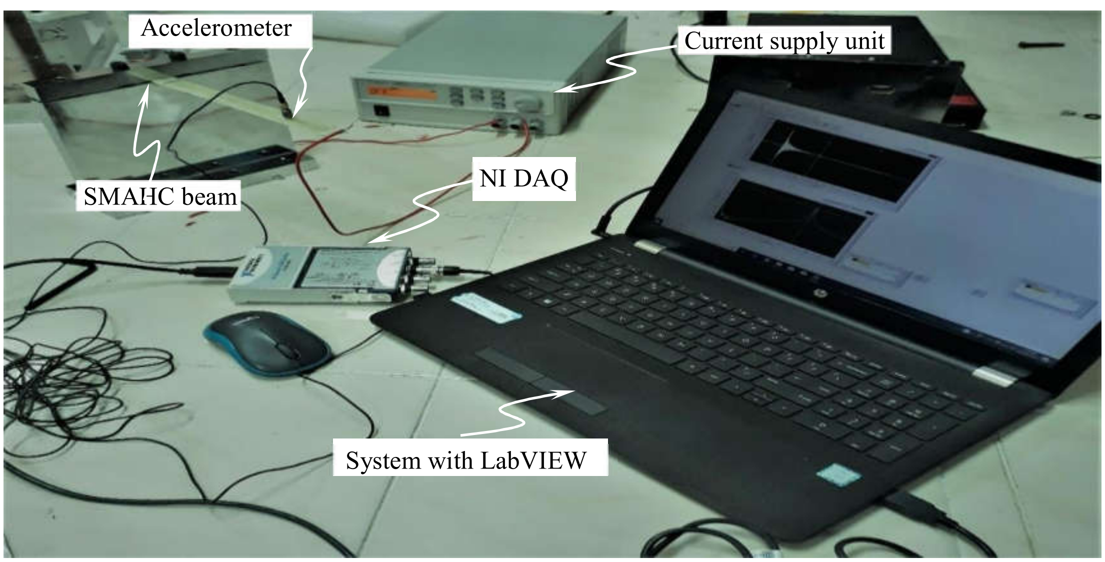

FIGURE 3. Experimental Setup.

RESULTS AND DISCUSSION

The frequency response as shown in Figure 4 obtained for single wire SMAHC beam. The Table 1 presents fundamental natural frequency of single and two wire SMAHC beams. It is observed that as the current increases from 0.8 to 1.0A the fundamental natural frequency of single wire SMAHC beam increases from 40 to 44 Hz, respectively. Further, it is observed that fundamental natural frequency of the beam is influenced with current input in the wire. That is, the fundamental natural frequency of the beam increased by 12.82% with supply current in the wire as compared to the without current supply. For two wires SHAHC beam, the fundamental natural frequency increased by 35.48% under the influence of current in comparison with no current state. It is evident that in the case of two wire SMAHC beam, the fundamental natural frequency increases sooner for current pass more than 0.8A as compared to the single wire SMAHC beam.

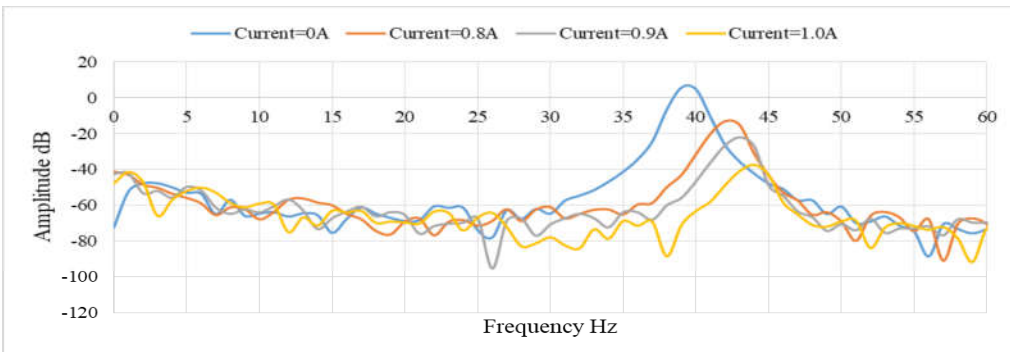

FIGURE 4. Frequency response of SMAHC beam with single wire.

In the case of two wire SMAHC beam, the parallel connection was set to get the same current in both the wires. Figure 5 depict the plot of fundamental natural frequency with respect to the current of single and two wire SMAHC beams. The decrease in the fundamental natural frequency in two wire SMAHC beam is due to increase in overall mass of the beam by increasing the number of SMA wires. However, as frequency of the SMAHC beam increases, make the structure stiffer as compared to the normal composite beam. Moreover, the main part of this study is by embedding the SMA into the structure, resonance can be avoided by frequency shift under the influence of current.

TABLE 1. Comparison of fundamental natural frequency of hybrid composite beams with one and two wires.

Sl. No.	Current per wire (Amp)	Fundamental natural frequency (Hz)		
		Single wire	Two wires	% Decrease
1	0	39	31	-20.51
2	0.80	42	34	-19.04
3	0.90	43	38	-11.62
4	1.00	44	42	-4.54

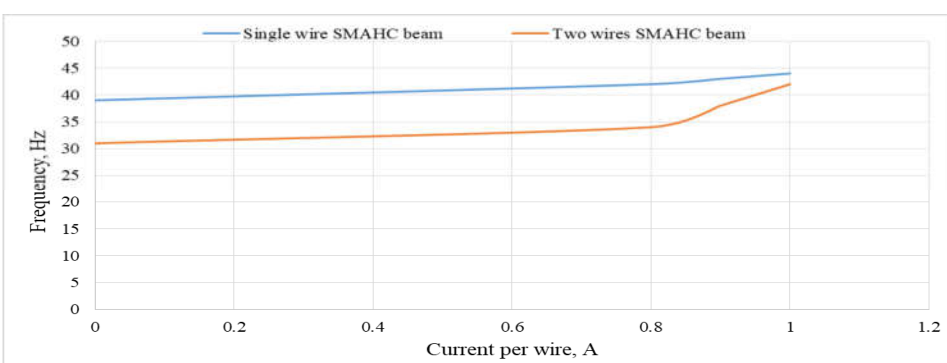

FIGURE 5. Fundamental natural frequency vs. current plot of single and two wire SMAHC beams.

CONCLUSION

Investigation has been carried out for free vibration of shape memory alloy hybrid composite beams by experimentally. The hybrid composite beams were fabricated using glass fiber with epoxy resin matrix implanted with the Ni-Ti SMA wires with diameter 0.47mm. The rectangular cross-section beams with thickness, 3mm, width, 20mm and length 250mm were considered. The free vibration test was performed on cantilever beams. The fundamental natural frequency of the SMAHC beam has shifted on higher side, 12.82% for single wire and 35.48% for two wires implant under the influence of current in comparison with no current state. Further, as supplied current increases in the SMA wire the natural frequency of beam increases helps in improving the stiffness and encourages to avoid resonance state.

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REFERENCES

[1] Town C. Smart Materials and Structures Cape Peninsula University of Technology. 2017;

[2] Mishra J. Smart Materials-Types Ss and Their Application : a Review. 2017;2320–2322.

[3] Mohd J, Leary M, Subic A, et al. A review of shape memory alloy research , applications and opportunities. Mater. Des. 2014;56:1078–1113.

[4] Pheerawong P, Plienthaisong B. Outcome of recombinant tissue plasminogen activator in ST-segment elevation myocardial infarction in Buriram hospital. J. Med. Assoc. Thail. 2014;97:804–811.

[5] Article R. A concise review of the applications of NiTi.pdf. 2014;110:5–9.

[6] Library U. from the SAGE Social Science Collections . All Rights Reserved . 2015;

[7] Tawfika M, Goek SN. shape memory alloy at elevated temperatures. 2000;3991:366–376.

[8] Lau K. Control of natural frequencies of a clamped – clamped composite beam with embedded shape memory alloy wires. 2002;58:39–47.

[9] Lau K. Vibration characteristics of SMA composite beams with different boundary conditions. 2002;23:741–749.

[10] Aoki T. ACTIVE VIBRATION CONTROL OF EPOXY MATRIX COMPOSITE BEAMS WITH EMBEDDED SHAPE MEMORY ALLOY TiNi FIBERS . Introduction Modern high-rise buildings and bridges are designed so that they can minimize the damage from earthquakes and natural disasters . By detec. 2003;17:1744–1749.

[11] Yamashita K, Shimamoto A. Shape Recovery Force of TiNi Fiber Reinforced Composite by Electric Heating. 2004;45:1646–1652.

[12] Concilio A. ADAPTIVE VIBRATION CONTROL THROUGH A SMA. 2007;919–930.

[13] Zhou G, Lloyd P. Design , manufacture and evaluation of bending behaviour of composite beams embedded with SMA wires. 2009;69:2034–2041.

[14] Aiella GAF, Ntonucci VIA, Aghia FED, et al. of a Shape Memory Alloy Hybrid Composite. 2011;22:245–252.

[15] Barzegari MM, Dardel M, Fathi A. VIBRATION ANALYSIS OF A BEAM WITH. Acta Mech. Solida Sin. 2013;26:536–550.

[16] More DJ, Chavan SA. Frequency Response of Sandwich Beam Embedded With Shape Memory Alloy Wires. Procedia Mater. Sci. 2015;10:638–643.

[17] Noolvi B, Raja S, Nagaraj S, et al. Fabrication and Testing Of SMA Composite Beam with Shape Control. 2017;020055.