Investigation on dynamic behaviour of shape memory alloy (SMA) wire embedded composite

Ranjit A. Patil¹, Santosh B Rane¹ and Samir B Kumbhar²

¹ Sardar Patel college of Engineering, Andheri Mumbai, India
² Rajarambapu Institute of Technology, Rajaramnagar, India

E-mail: ranjit6044@gmail.com

Abstract. Smart Material are responsive and intelligent materials. Shape memory alloy (SMA) are subset of a broad class of smart material. The functionalities arise from their underlying microstructural changes when subjected to external non-mechanical stimuli like temperature or magnetic field changes. The study of SMA uses and applications has been done because recently use of shape memory alloy used in the field of the automobile, robotics, medical, Aerospace, Biomedical domain etc. Shape memory alloy can be used for an actuator, sensor, stiffness changer, and damper. The extensive literature survey has been conducted to explore the potential and research scope in this project. This research will help industry to use SMA embedded composite for vibration isolation and damping.

Keywords: Shape memory alloy, composite, SMA damper

1. Introduction

Smart materials are responsive and intelligent materials. The properties of smart material are changed in controlled fashion by changing stress, electric and magnetic field, moisture, temperature etc. Piezoelectric materials, Shape Memory alloy (SMA), Magnetostriective, Electroactive Polymers these are examples of smart materials. Shape memory alloys are a subdivision of a broad class of smart materials. Functionalities arise from their basic microstructural changes when exposed to external non-mechanical stimuli like magnetic field or temperature changes. Shape memory alloy has wide applications in automotive, medical, robotics and aerospace industry. Shape memory alloy can be used as an actuator, sensor, stiffness changer and damper. New research has shown that SMA can be used as actuator to replace Electrical Motors, pneumatics and hydraulic due to their capability and unique characteristics to respond directly to environmental stimuli. Normally, designers make use of the engineering effects of SMA to design their applications. SMA has advantages in dampening vibrations due to pseudoelastic behaviour, hysteresis behaviour. Biological organisms have ability to repair themselves, even if they are complex one. Self-healing materials are having property to heal themselves. Many researchers have used SMA embedded composites for damping purpose. Very few researchers have used SMA wires for self-healing. Based on this SMA embedded can be used for damping and shape recovery in automotive applications.

1.1. Context

Mechanical, civil and aerospace engineering are facing vibration problems frequently. If component is subjected to vibration near to natural frequency, resonance occur and lead to extreme load or deformation of component. Due to resonance there are chances of catastrophic failures. In design of bridges and aircraft wings, we must eliminate chances of resonance. Some shape memory alloys like...
Nitinol present high damping property. They are able to dissipate the energy of a mechanical system, resulting from the energy conversion from mechanical to thermal energy. However, shape memory alloys still lack of enough attentions for commercial applications so far. Presently many researchers are working on minimize the vibration by damping. Many researchers have used SMA as vibration damper. Still there is scope for improvement. There is wide scope in development of SMA composite which will act as damper and which will recover deformed shape.

1.2. Need of research
The vibration phenomenon is a very key issue for aerospace and automobile industry. The difficulties caused by vibration are: increases in fuel consumption, damages elements of vehicle. It is more important if we consider the passengers transport because the comfort of transport service is evaluated by this. Driving safety and comfortably depend on vibration parameters. The character of the car vibration transferred from road to car body is very important. As a need of new era is to find new material which minimize the vibration as well as have less weight.

1.3. Motivation
Looking at the mechanical engineering industries like Aerospace and automobile companies, we find a lot of scope of vibration damping and shape recovery. To overcome this issues of vibration SMA wire embedded composite could best solution. SMA can respond to change in stiffness by changing its temperature consequently dynamic behaviour. Also SMA could recover deformed shape by heating above austenite finish temperature. This properties of SMA may be used for applications in Automobile and aerospace industries to control behaviour as well as self-healing and shape recovery of deformed component.

1.4. Problem Statement
In automobile and aeronautical fields, systems are subjected to continuous undesired vibrations. In order to control these vibrations, it is essential to know modal parameters of the system and different methods to alter these parameters. Also in applications like aerospace, automobile resonance as well as vibration amplitude is required to monitor and control continuously during their working period to avoid serious damage and accidents. Therefore there is need of investigation of adaptive, lightweight composite structural members which are capable of altering real time dynamic behaviour in response to external stimuli. The smart material like SMA is proved to be good candidate as adaptive stiffness changer in view of necessary change in dynamic behaviour.

1.5. Research Objectives
1. To complete detailed literature survey in order to find the impact of smart materials like SMA on adaptive control of vibration behaviour of composite structural member.
2. To design and develop SMA embedded composite structural member.
3. To investigate experimentally modal parameters of designed composite.
4. To analyse adaptivity of the designed composite by using suitable numerical method.
5. Explore potential applications based on the numerical results obtained.

2. Literature survey

| Primary Keywords     | Secondary Keywords    | Search Engines used     | Time Span       |
|----------------------|-----------------------|-------------------------|-----------------|
| SMA as damper        | SMA composites        | Google Scholar          | 2005-2020       |
|                      | SMA Applications      | Google book             |                 |
|                      |                       | Science direct          |                 |

2.1. Literature review on Applications of SMA
JaronieMohdJani et al 2014 have done study on research opportunities and applications of shape memory alloy. Author highlighted the different areas like Biomedical, Automobile, Aerospace, and robotics. This review shows that SMA is having wide scope in different sectors and there is need of research in these areas [1]. S Khan et al 2018 presented work on aerodynamic flapper. The active control of the SMA composite with E- glass woven structure is discussed in this paper [2]. JarodnieMohdJaniem et al 2014 presented different applications of SMA in automotive field. Thermally responsive control valve for automatic transmission and smooth gear shifting are the major application of SMA in automotive field [3]. Jin-Feng Li et al 2009 presented work on TiNi SMA with composite of low thermal expansion copper. Author suggested applications like packaging materials of electronic devices [4]. Christopher Storya et al 2007 used SMA/glass seal in fuel cells and solid oxide electrolyzer [5]. YuanchangLianga, et al 2004 developed diaphragm actuator by using SMA. Based of FEM results new membrane is designed for Jet actuator [6]. S. Jayachandrana, et al 2019 compared performance of different SMA kapton composites for actuator application [7].

2.2. Literature review on SMA composite
Schrooten J, et al 2002 discussed the manufacturing strategies for SMA embedded smart composite. In this experimentation NiTi Wires with diameter of 0.15 mm and epoxy resin as matrix was used. Reinforcement type was Kevlar prepregs. SMA position was in between kelvarprepregs layer. To prepare this composite Autoclave curing method was used [8]. Pappadà S, et al 2009 developed composite of Carbon fibre fabric, Glass fibre fabric, SMA wires and Vinyl ester resin for transportation and aerospace method. Super elastic SMA wires were positioned between four layers of SMA wires and fixed into laminates at different distances from the neutral axis. To fabricate this composite vacuum-assisted resin infusion process was preferred [9]. Aurrekoetxea J, et al 2011, fabricated composite structure of 3.2 mm thick. SMA wires were inserted between carbon fibre by using Vacuum assisted RTM method [10]. Zhao S, Et al 2018, fabricated composite of SMA fiber and Glass fibre cloth by using Vacuum-assisted resin injection process. For this composite Epoxy resin was used as matrix and positioned Symmetric (centre) and asymmetric SMA [11]. Wang Z, Et al 2017 fabricated composite of Glass fibre cloth and SMA wires with Epoxy vinyl resin for Aerospace, civil, automobile industries applications. This composite was developed by using Vacuum-assisted resin injection method. SMA wire were sandwiched between layers of glass fabric cloth [12]. Kang KW Et al 2009 fabricated composite of epoxy/ Glass laminates and SMA wires by using Autoclave curing method. 0.4 mm diameter Ni–Ti SMA wire and Epoxy resin was used in this composite [13]. Jung BS, et al 2010 fabricated composite of Silicon rubber, Glass fabric, and SMA wires. To prepare composite SMA wires and glass fabric were located on an n-shaped mould and then this assembly was cured for 72 hours at 25°C in a vacuum. Nitinol wires (50.4 percent Ni content by weight) with diameter of 0.4mm (Mf = 17.4°C, Af = 96.9°C) were used with epoxy resin [14]. Zhou G et al 2009 fabricated composite of Carbon/ epoxy laminates and SMA wires by using Autoclave curing method [15]. Dawood M, Et al 2015 fabricated composite of SMA wires and Carbon fibre fabric with epoxy resin as matrix by using Hand lay-up method. The superelastic SMA with nickelwere sandwiched between carbon fiber fabric two layers [16]. Daghash SM Et al 2016 fabricated composite of ER3 epoxy resin with Ti–Ni alloy short fibres. Fibres and SMA particles were well dispersed into epoxy resin [17].

2.3. Literature review on SMA damper
Mohammad HadiEnferadi et al 2019, controlled vibration of offshore jacket platforms by using SMA dampers. Author concluded that, use of SMA damper improves dynamic behaviour of jacket platform and shifting of natural frequencies away from excitation is possible [18]. LamineDieng et al 2013, used SMA damper to diminish vibration amplitudes of bridge cables. The tests suggests that effective reduction in oscillation time and amplitude is possible [19]. Weikang Feng et al 2019, investigated behaviour SMA ring spring dampers. The test results shows hysteric behavior with satisfactory energy dissipation [20]. Shih-Hang Chang et al 2011, investigated Damping characteristics of epoxy resin with reinforcing of TiNi shape memory alloy wires. Experimental results shows increase in higher storage modulus value and higher damping capacity [21]. Mohammad Nejati et al 2019 did
analysis on thermal vibration of SMA hybrid composite double curved sandwich panels. Their research work concluded that DCSPs with SMA wires exhibit higher thermal frequencies, compared to the ones obtained for ordinary DCSPs without SMAs. By embedding SMA wires in a composite structure yields higher natural frequencies. This means that DCSP structures could represent the best choice in terms of structural performances in thermal environment. An increased pre-strain leads to an increased natural frequency, due to an increased stiffness in the structure [22]. M. Karimi et al. 2019 presented an approach of adapting cohesive for crack-healing analysis in SMA fiber-reinforced composites. Authors also developed FEM model for comparison of result [23]. Fengfeng Li et al. 2018 investigated thermo-mechanical properties of unidirectional carbon fibre reinforced epoxy-based shape memory polymer (SMP) composites. The fibre mass fractions of 16%, 23%, 30%, 37% are examined with the help of three-point bending tests. Flexural modulus and strength of SMP composite shows temperature dependency [24]. Jani, J et al. 2014 highlighted the applications of SMA in different fields such as Automotive, biomedical, robotics, aerospace. Also author suggest areas for research like SMA composites, improving reliability, computational models of SMA behaviour [3]. Xu, R., Bouby et al. 2018 proposed a method for modelling and the pseudo elasticity. The method was based on 3D generic multi scale finite element [25]. Wang, E., et al. 2017 presented composite of SMAPE laminates. This composite was prepared by using vacuum hot pressing process. The tensile behaviour and compressive properties were studied during this experimentation [12]. Ni, Q. Q., Zhang et al. 2007 experimented on SMA fibres embedded epoxy to investigate temperature dependent vibration characteristics. The results recommend that by the addition of small amounts of SMA short fibers the vibrational characteristics of SMA composites can be improved [26]. Kumbhar, S. B. et al. 2018 studied dynamic response of system in which SMA and magnetorheological elastomer (MRE) are combined together. Author validated analytical result of stiffness change with experimental result. The result showed that initial vibration level of primary system reduced by significantly by tuning of the absorber system [27]. Feng, N. et al. 2015 was designed, fabricated and investigated a multifunctional composite using elastomer embedded with thermally responsive Shape Memory Alloy (SMA) wires. Experimentally author concluded that SMA-elastomer composites vary stiffness by varying temperature. Also SMA-elastomer composites can recover its deformed shape [28]. Cohades, A., et al. 2018 reviewed current applications of SMA wire embedded polymer composites. Shape memory alloys in the form of thin wires have successfully been integrated in composite structures to provide a variety of potential effects such as damping, shape morphing, crack closure [29].

3. Research Gap
It is found that there is inadequate research in SMA embedded composite with different geometrical configurations in order to achieve adaptive dynamic performance of composite so that the results could be used in applications like aerospace structure, where adaptive vibration control is absolutely essential.

4. Research methodology

The flowchart shows the different activities planned for the successful completion of the project.
4.1. **Step 1**-
Step 1 involves the detailed literature survey of the selected keywords. Objective of literature survey is to find the combination of materials in composite.

4.2. **Step 2**-
Step 2 involves the dynamic and static structural analysis of the selected composite. After the analysis the composite plate of desired materials will be manufactured.

4.3. **Step 3**-
Step 3 involves the experimentation. The manufactured composite will be tested to find different vibration parameter.

4.4. **Step 4**-
After the result analysis of the experimentation, suitable application will be selected. By using developed composite comparison of application with existing and new material will be done.

5. **Resources needed**
5.1. Tools that may be used
The following tools may be required for the research work

Table 2. Essential tools.

| Sr. No | Tools               |
|--------|---------------------|
| 1      | Experimentation     |
| 2      | 3D Modeling         |
| 3      | Analysis software   |
| 4      | Design Analysis     |

5.2. Expertise
The guidance of following experts will be needed to complete the research work
1. Vibration analyst
2. Material Analyst
3. FEA Software expert
4. Analytical tool expert

5.3. Applications and software
The list of software’s needed for the project are as follows

Table 3. List of software’s.

| Domain       | Software    |
|--------------|-------------|
| Vibration    | ANSYS, ABAQUS |
| Data Processing | Minitab, Matlab, Excel |
| Modeling     | CATIA, Solidworks, ProE |

6. Feasibility of research deliverables
As a part of this research work, following are the list of titles that could be published.
1. Investigation of dynamic behaviour of SMA embedded composite.
2. Investigation of shape recovery behaviour of SMA embedded composite.
3. Investigation of dynamic and shape recovery behaviour of SMA embedded composite for an automotive application.
4. Patent on new material

7. Technical Feasibility Check
Following are the points will show that our research would be technically feasible:
1. Vibration tools will be purchased and learned to use them effectively in our research.
2. FEA software tools will be purchased and learned to use them effectively in our research.
3. To develop technical competency, if required for some specific task; training will be taken for the same.
4. The time frame of further two years will be sufficient to achieve the desired goal.
5. Validation of the model will be achieved by using various relevant tools.
6. If a particular Skill set or expertise is required that is out of our technical reach, then we shall also hire to achieve the same.

7. **Economic Viability Check**

To undergo these research activities, a huge amount of capital would be required to conduct experiments, surveys, industries visit, attend national and international conferences, purchase software, attend training programs, develop infrastructure, hire resources, travel, and accommodation etc. All the mentioned activities can be successfully achieved by the research grant that is made available by various sponsoring bodies, following are few of such sponsoring committees: SPCE TEQIP, Ph.D. funding, University Funding, AICTE Funding, Ministry of Human Resource, Industrial funding, etc.

9. **Expenses**

9.1. **Recurring Expenses**

Following are the recurring expenses that will be associated with the project.

| Sr. No | Activity                                | Expected cost | Frequency during research | Total cost  |
|--------|-----------------------------------------|---------------|----------------------------|-------------|
| 1.     | Software license/subscription           | 5,00,000/-    | 3                          | 15,00,000/- |
| 2.     | International Conference                | 3,00,000/-    | 3                          | 9,00,000/-  |
| 3.     | International Conference                | 50,000/-      | 5                          | 2,50,000/-  |

9.2. **Non-Recurring Expenses**

Following are the non-recurring expenses that will be associated with the project.

| Sr. No | Activity                                         | Total Cost   |
|--------|--------------------------------------------------|--------------|
| 1.     | Purchase of Material                             | 1,00,000/-   |
| 2.     | Purchase of FFT Analyser                         | 9,00,000/-   |
| 3.     | Purchase of Vibration exciter                    | 3,00,000/-   |
| 4.     | Short term training programs                     | 50,000/-     |
| 5.     | Purchasing articles, journals, books and other literature | 50,000/-     |
| 6.     | Interviews, travel, experimentation              | 70,000,00/-  |
| 7.     | Misc.                                            | 20,000/-     |

10. **Data collection procedure**

Data will be collected from various sources of literature, experimentation etc.

11. **Experimentation overview**

Experimentation will be carried out on SMA composite to collect the data of different parameter of vibration. The setup for the experimentation is shown in
The FFT analyser is used to investigate different parameters of vibration. The dimmerstat is used to control the current in the SMA wires. By changing the current the tuning of the wire can be done. The expected observations are shown in table. Following table shows the expected result format.

**Table 6.** Expected observation table 1 of Experimentation.

| Sr. No | Experimental results | Analytical Results |
|--------|----------------------|--------------------|
|        | Natural Frequency    | Damping Factor     |
|        |                      | Natural Frequency  |
|        |                      | Damping Factor     |

| 1   |                      |                |
| 2   |                      |                |
| 3   |                      |                |

**Table 7.** Expected observation table 2 of Experimentation.

| Sr. No | Experimental results | Volume fraction of SMA in Composite |
|--------|----------------------|-------------------------------------|
|        | Natural Frequency    | Temperature Natural Frequency       |
|        |                      |                                     |

| 1   |                      |                                      |
| 2   |                      |                                      |
| 3   |                      |                                      |

Graphical representation of experimental results and its interpretations will be completed for parameters given below:

1. Damping Factor and Temperature
2. Percentage recovery and Composite type
3. Natural Frequency and Composite type
4. Natural Frequency and Volume fraction of SMA in Composite
5. Natural frequency and temperature
   6. Damping Factor and SMA Volume fraction in Composite

12. Data processing and analysis
Based on the data collected from various sources the data shall be converted from linguistic and unstructured form to numerically analysable and structured form. Various tools and techniques shall be applied to derive meaning out of the same.
Few of the following steps can be used in this
   1. Sort the data
   2. Compare the data of composite material to conventional material.
   3. Identify data processing and analysis tools.
   4. Learn the tool functionality.
   5. Derive the final conclusions.

13. Expected Results
Results that are expected to be extracted from this research are as follows
   1. Design and Development of SMA embedded composite.
   2. Dynamic behaviour of SMA embedded composite.
   3. Application of research to automotive domain.

The different parameter of vibrations are used to analyse the dynamic behaviour of the composite. The proposed composite is expected to capable of altering real time dynamic behaviour in response to external stimuli.

14. Validation of Results
The experimentation will be simulated by using analytical software’s like Ansys. The values of different parameters obtained from analytical methods will be validated by using experimental data. Based on comparison conclusion can be made.

15. Project deliverables

15.1. Industry
This research will provide new SMA reinforced composite material for,
   1. Vibrations control.
   2. Shape recovery
   3. Control dynamic behaviour.

15.2. Academics
This research provides a new dimension to academic institutes which will help in modelling their teaching aligned with the requirement of the industry. This nurtures the learning of their product as key assets in the industry.

15.3. Market
This research will help industries to,
   1. Improve vibration control techniques.
   2. Recover deformed shape
   3. Control dynamic behaviour.

This will help to improve performance of products, this intern will help industries to secure a key position in the market.
16. Impact of Research

16.1. Impact on technology
1. New technique/system for vibration control,
2. New composite to recover deformed shape.

16.2. Impact on industry
1. Design of adaptive, light weight composite.
2. Intelligent system to control vibration.
3. Shape recovery of deformed parts.

16.3. Impact on research institutes
1. New research areas and opportunities to students, faculties and researchers.
2. Good research publications and patents.
3. More research grant to research institutes from the industry

16.4. Impact on society
Savings to the company based on this research will in turn benefit the society in the following ways
1. Vibrations failures will be minimized for better safety of society.
2. Damage and accident risk will be reduced, it will save the cost.
3. More employment opportunities.

16.5. Impact on environment
Proper damping of vibration will reduce power consumption of asset less combustion of petrol, diesel, coal and other conventional sources of energy. This, in turn, will reduce pollution, save fossil fuel for future use and reduce the operating cost of assets.

17. Research product deliverables
1. To design and develop SMA embedded composite
2. To investigate experimentally modal parameters of designed composite.
3. To analyse adaptivity of the designed composite by using suitable numerical method.
4. Explore potential applications based on the numerical results obtained.

18. Expected Conclusion
The expected conclusions are as follows,
1. Design and Development of SMA embedded composite.
2. Experimental Investigation on modal parameters of designed components.
3. Adaptivity analysis of the designed composite.
4. Discussion on potential applications of designed composite.
References

[1] Jani JM, Leary M, Subic A and Gibson MA 2014 Materials & Design (1980-2015) Apr 1;56:1078-113.
[2] Khan S., Sai, Y., SS, M.P., Palani, I.A., Umarikar, A.C. and Singh, P. 2018 Procedia computer science, 133, pp.134-140.
[3] JaniJ.M., Leary M. and Subic A. 2014 Applied Mechanics and Materials 663 248-253
[4] Li J.F., Zhong, Z.Q. Li X.W. and PengZ.W. 2009 Materials & Design, 30(2) 314-318.
[5] Story C., Lu, K., Reynolds Jr, W.T. and Brown, D. 2008 International journal of hydrogen energy.33(14)3970-3975.
[6] Liang Y., Taya, M. and Kuga, Y 2004 In Smart Structures and Materials 2004: Smart Structures and Integrated Systems 5390 268-275
[7] Jayachandran, S., Akash, K., Prabu, S.M., Manikandan, M., Muralidharan, M., Brolin, A. and Palani, I.A. 2019 Composites Part B: Engineering, 176107182.
[8] Schroten J., Michaud V., Parthenios J., Psarras G.C., Galiotis C., GotthardtR., Mánson, J.A. and Van Humbeeck, J. 2002 Materials Transactions, 43(5) 961-73.
[9] Pappada S, RamettaR, Toia L, Coda A, Fumagalli L and Maffezzoli A. 2009 Journal of Materials Engineering and Performance 18(5) 522-30.
[10] Aurrekoetxea J., Zurbitu J., De Mendibil I.O., Agirregomezkorta A., Sánchez-Soto M. and Sarrionandia, M. 2011 Materials Letters 65(5) 863-65.
[11] Zhao S., TengJ., Wang Z., Sun X. and Yang, B 2018 Materials 11(2) 246.
[12] Wang Z., XuL., Sun X., Shi M. and Liu J 2017 Composite Structures 178 311-19.
[13] Kang K.W. and Kim J.K., 2009 Composite Structures 48(3) 455-60.
[14] Jung B.S., Kim M.S., Kim Y.M. and Ahn, S.H. 2010 Materialwissenschaft und Werkstofftechnik, 41(5) 320-24.
[15] Zhou G. and Lloyd P 2009 Composites Science and Technology 69(13) 2034-41.
[16] El-Tahan M., DawoodM. and Song, G 2015 Smart Materials and Structures 24(6) 065035.
[17] Daghsh S.M. and OzbulutO.E., 2016 Materials & Design 111 504-12.
[18] Enferadi M.H., Ghasemi M.R. and ShabakhtyN 2019 Applied Ocean Research 90 101848.
[19] Dieng L., Helbert G., Chirani S.A., Lecompte T. and Pilvin P 2013 Engineering Structures 561547-1556.
[20] Feng W., Fang C and Wang W 2019 Journal of Constructional Steel Research 159 315-29.
[21] Chang S.H and Lee CY 2011 Journal of reinforced plastics and composites 30(23) 1931-38.
[22] Nejati M., Ghasemi-Ghalebahman A., Soltanamaleki A., Dimitri R. and Tornabene F 2019 Composite Structures, 224111035.
[23] Karimi M., Bayesteh H and Mohammadi S. 2019 Computer Methods in Applied Mechanics and Engineering 349 550-75.
[24] Li F., Scarpa, F, Lan, X., Liu, L, Liu, Y. and Leng J., 2019 Composites Part A: Applied Science and Manufacturing 116169-79.
[25] Xu R., Bouby C., Zahrouni H., Zineb T.B., Hu H. and Potier-Ferry M., 2018 Composite Structures 200 408-19.
[26] Ni, Q.Q Zhang, C.S., Fu, Y., Dai, G. and Kimura T 2007 Composite Structures 81(2) 176-184.
[27] Kumbhar S.B., Chavan S.P. and Gawade S.S 2018 Mechanical Systems and Signal Processing 100 208-223.
[28] Feng N., Liu L., Liu Y. and Leng J 2015 Materials & design 88 75-81.
[29] Cohades A., Branfoot C., Rae S., Bond I. and Michaud V 2018 Advanced Materials Interfaces 5(17) 1800177.