

## Static Analysis of the Effect of Shape Memory Alloy in Laminated Beam

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**Abstract:** This study deals with the effect of shape memory alloy in carbon/epoxy laminated beam. In this study we analyses static response of laminated beam under the load of 10 KN at the mid span of the beam. In this study a cantilevered beam of dimension 1000mm length, 100mm width and 30mm height which is divided in 3 layers of 10mm each is considered. The study includes three cases. In first case all the 3 layers of beam is laminated with carbon/epoxy. In second case the top and the bottom layers are laminated with carbon/epoxy and middle layer is 2qw laminated with shape memory alloy. In the third case the top and the bottom layers are laminated with shape memory alloy while the middle with carbon/epoxy. Loading and boundary conditions are same for all the three cases. All the analysis is done using ANSYS workbench 15.0

**Keywords:** Shape memory alloy, Carbon/Epoxy, Laminated beam, Static response, ANSYS workbench 15.0

### 1. Introduction

Shape memory alloy is a material, which keeps its shape in memory and can be made to return to its actual shape after getting deformation if subjected to an appropriate thermal process[1]. The phase change occurs in SMA's over a range of temperature[2]. The recovery of strains imparts to the material at a low temperature, as a result of heating is called Shape Memory Effect and the formation of stress induced (at higher temperature) Martensite from Austenite (at low temperature) phase result in a phenomenon called pseudo-elasticity[3]. In the past few decades SMA is receiving more attention in research area. Many researchers have been working on the application of unique properties of SMA like shape memory effect and pseudo elasticity in various engineering applications[4]. Many researchers have contributed to the wide accessible literature on the study of experimental and observational behavior of SMA[5]. There are many approaches that have been evolved to mark the constitutive behavior of these materials[6]. Beams are important element of structures and are widely used in machinery, aerospace and in light weight structures. In their service life they are subjected to various static as well as dynamic loads of certain frequency of vibrations which leads to their failure[7]. Vibration analysis has become important in the design and development of such engineering systems[8]. This study deals with the effect of shape memory alloy in carbon/epoxy laminated beam. In this study we analyses the static response of laminated beam under the load of 10 KN at the mid span of the beam[9].

### 2. Materials and Methods

The properties of shape memory alloy and carbon/epoxy are given in the Table 1 below[10]

**Table 1.** Properties of shape memory alloy

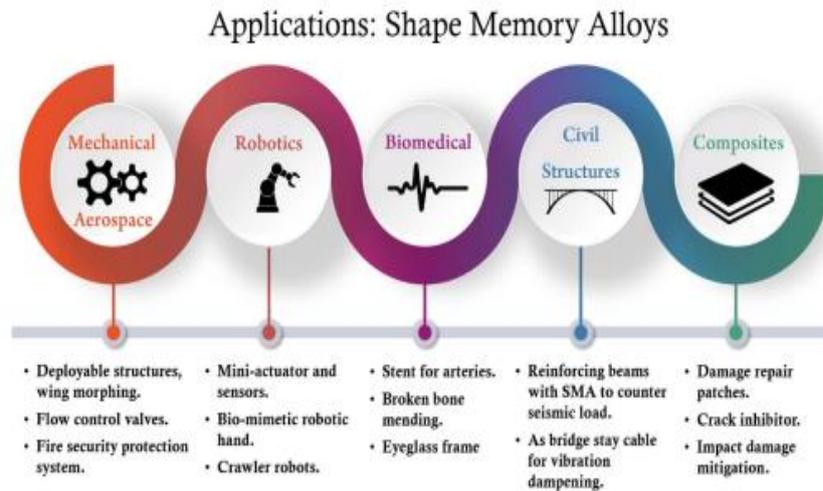
Density (kg/m <sup>3</sup> )	6450
Young modulus (Pa)	6.7E+10
Poisson's ratio	0.33
Sigma SAS(MPA)	100
Sigma FAS(MPA)	170
Sigma SSA(MPA)	239
Sigma FSA(MPA)	170
Epsilon(mm <sup>-1</sup> )	0.067
alpha	0

**Table 2.** Properties of Carbon/Epoxy

E <sub>1</sub> (N/M <sup>2</sup> )	144.8e <sup>9</sup>
E <sub>2</sub> (N/M <sup>2</sup> )	9.65e <sup>9</sup>
E <sub>3</sub> (N/M <sup>2</sup> )	9.65e <sup>9</sup>
G <sub>11</sub> (N/M <sup>2</sup> )	4.14e <sup>9</sup>
G <sub>12</sub> (N/M <sup>2</sup> )	3.45e <sup>9</sup>
G <sub>13</sub> (N/M <sup>2</sup> )	4.14e <sup>9</sup>

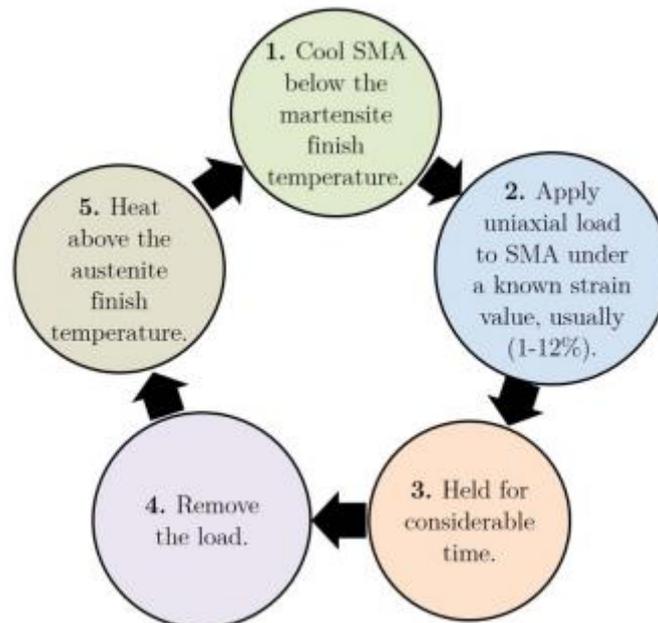
$\mu_{12}$	0.3
$\rho$ (KG/M <sup>3</sup> )	1389.23

Properties of Carbon/Epoxy are given in Table 2. Shape memory alloys are extensively used in several domains of engineering to handle a set of applications, which are given in figure 1. These alloys can be utilized either as independent or as a reinforcement in composites based on the application. The SMAs are commercially available in sets of geometries like wires, rods, ribbon, springs, foils, and also as foams. The sintered NiTi alloy foam of high porosity (71–87%) are being examined to be comparable with the intended performance of human bone. Application domain of shape memory alloys are shown in Figure 1.



**Figure 1.** Application domain of shape memory alloys

Usually, pre-strained SMAs are used in such a way that on heating more than the austenite finish temperature, the material changes back to its actual dimensions resulting from restoration. A rise in pre-strain leads to a parallel increase in stress related to the slip and dislocation motion. According to ASTM E3098, the process adopted for pre-straining the SMA has been briefly given in Figure 2.



**Figure 2.** Process for pre-straining the shape memory alloys

### 3. Modeling and Simulation

For modeling and analysis of laminated beam with SMA and carbon-epoxy, ANSYS Workbench 15.0 version is to be used which is based on Finite Element Method (FEM). ANSYS 15.0 has innovative features for composites, bolted connections and improved mesh tools. The ANSYS Workbench platform provides a comprehensive and integrated system. ANSYS workbench provides higher productivity in product development simulation because it has an in-built application and access to Multiphysics and system level application. The equation of motion of Composite laminated plate with and with no cutouts is resolved employing FEM tool (ANSYS) in the form of the equation of motion for a laminate with cutouts is hard to be visualized and hence any FEM tool is the only probable solution for the analysis of the vibration features of laminate with cutouts. The ANSYS 15 finite element program was considered for free vibration of the orthotropic (Composite) Laminated plate. To this end, the key points were first generated and later line segments were created. Multiple layers are specified along with the Orientation and thickness. The lines were merged to form an area. At last, this area was shaped to model the laminated plate. Schematic of static analysis is shown in Figure 3.

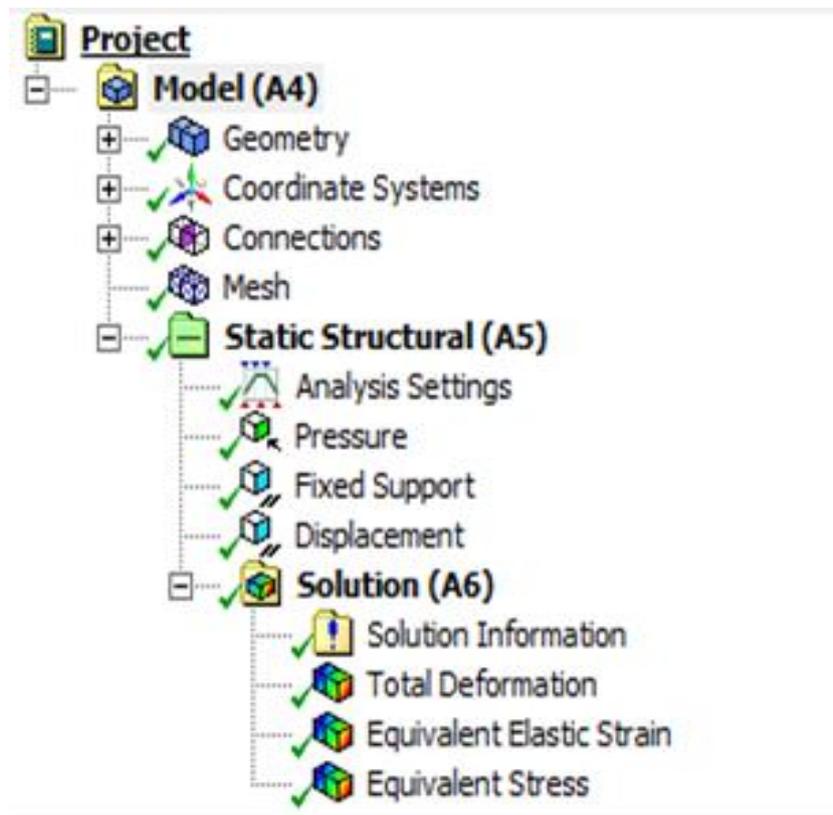


Figure 3. Schematic of static analysis

### 3.1. Geometry

In this work a cantilevered beam of dimension 1000mm length, 100mm width and 30mm height which is divided in 3 layers of 10mm each is considered. The figures below show the geometry of the beam.

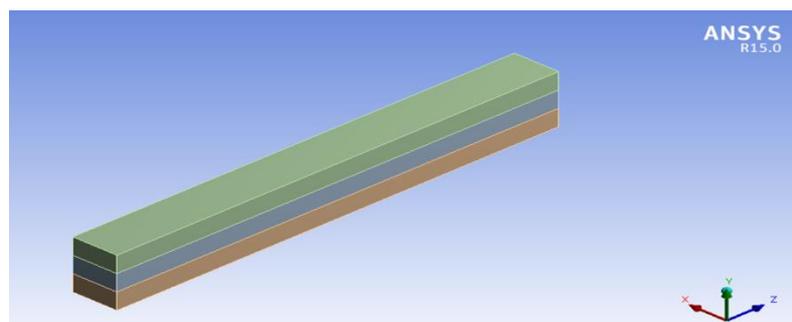
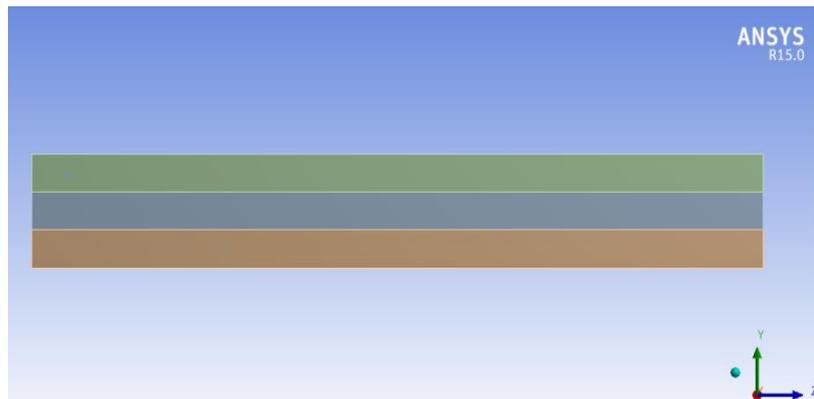


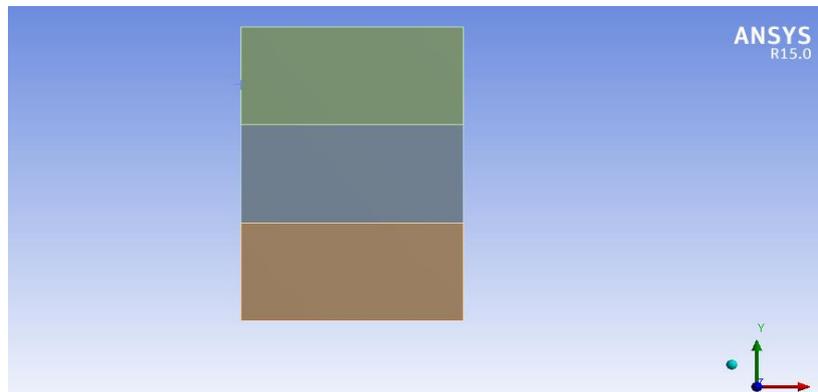
Figure 4. Isometric View

Figure 4 shows the Isometric view of the geometry of the beam. Isometric projection is a technique used for visually defining 3-D objects in 2-D in technical and engineering drawings. It is an axonometric projection in which the three coordinate axes seem to be equally contracted and the angle between any two of them is 120 degrees.



**Figure 5.** Side View

Figure 5 shows the side view of the geometry of the beam.

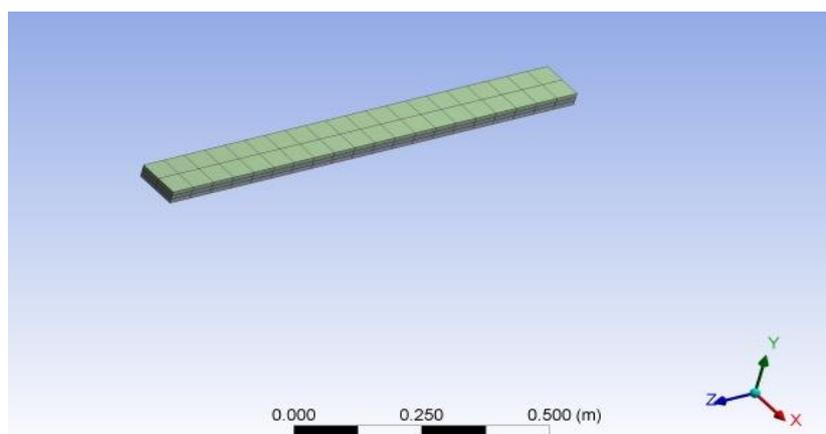


**Figure 6.** Elevation View

Figure 6 shows the Elevation view of a 3-D object from the view of a vertical plane along an object. Otherwise said, an elevation is a side view as seen from the front, back, left or right sides.

### 3.2. Meshing

The figure 7below shows the meshing of the laminated beam. Here rectangular mechanical mashing is done for both static as well as harmonic analysis.



**Figure 7.** Meshing

### 3.3. Loading and boundary conditions

Loading Condition is shown in figure 8. The loading and boundary conditions used for all 3 cases are given as below:

1. In static analysis a concentrated load of 10 KN at the mid of the beam is considered.
2. Boundary conditions are one end is fixed and another end free.

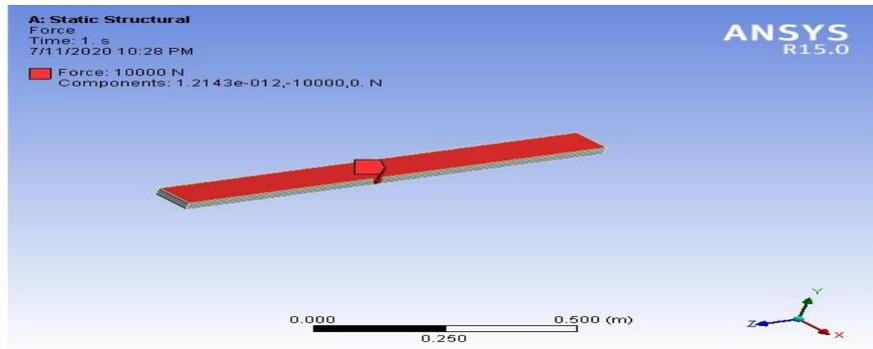


Figure 8. Loading Condition

## 4. Analysis

### Case.1

In case-1 all the three layers of beam is laminated with carbon/epoxy for both static as well as harmonic response analysis.

### Case.2

In second case the top and the bottom layers are laminated with carbon/epoxy and middle layer is laminated with shape memory alloy.

### Case.3

In the third case the top and the bottom layers are laminated with shape memory alloy while the middle with carbon/epoxy.

## 5. Results and Discussion

Following figures and graphs shows the maximum total deformation, maximum stress, and maximum strain for all three cases full carbon/epoxy laminated beam, with SMA at Centre, and with carbon-epoxy at Centre

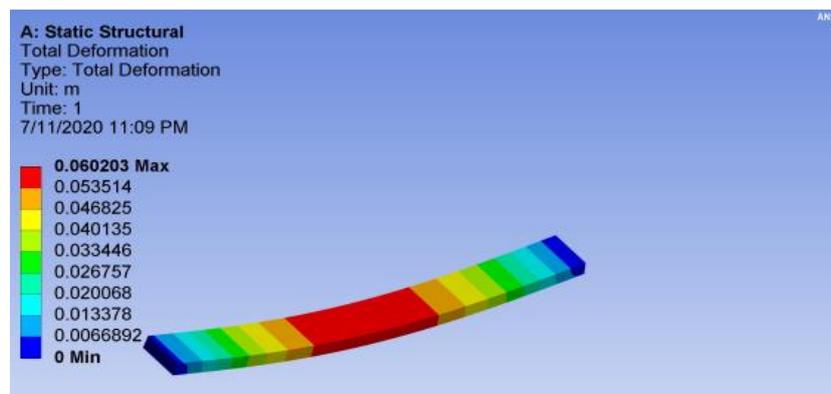
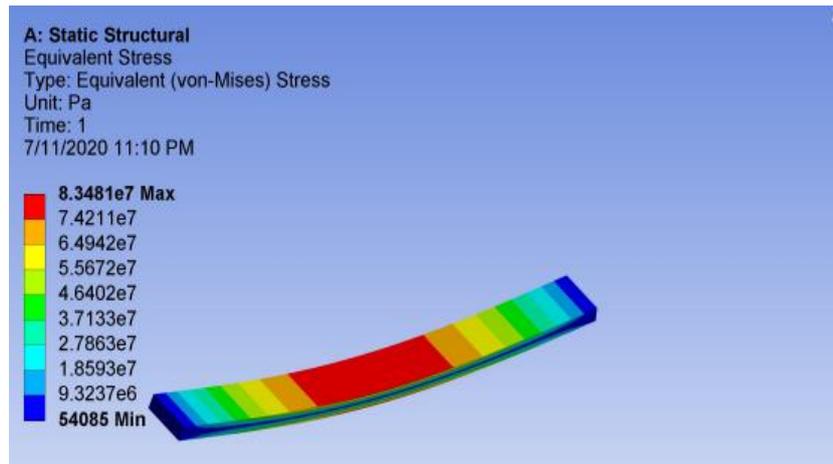


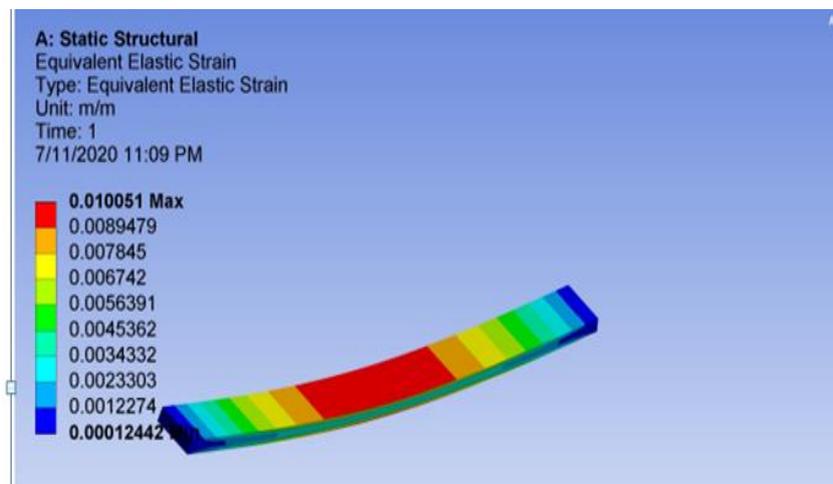
Figure 9. Total deformation when full beam is laminated with carbon/epoxy

Figure 9 shows the Total deformation when full beam is laminated with carbon/epoxy.



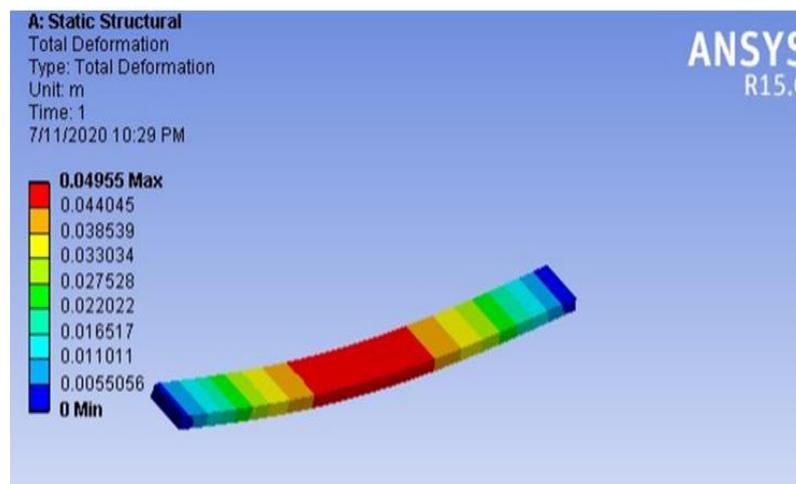
**Figure 10.** Equivalent Stress when full beam is laminated with carbon/epoxy

Figure 10 shows the Equivalent Stress when full beam is laminated with carbon/epoxy. The colors of the full beam denote the minimum to maximum values of iterations.



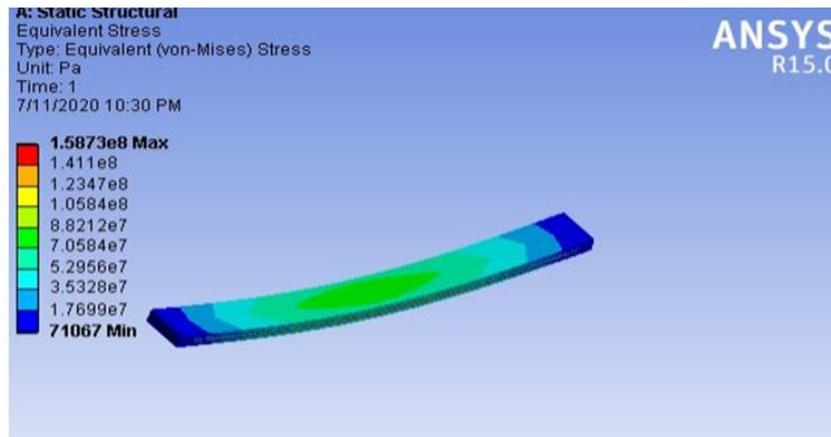
**Figure 11.** Equivalent Strain when full beam is laminated with carbon/epoxy

Figure 11 shows the Equivalent Strain when full beam is laminated with carbon/epoxy.



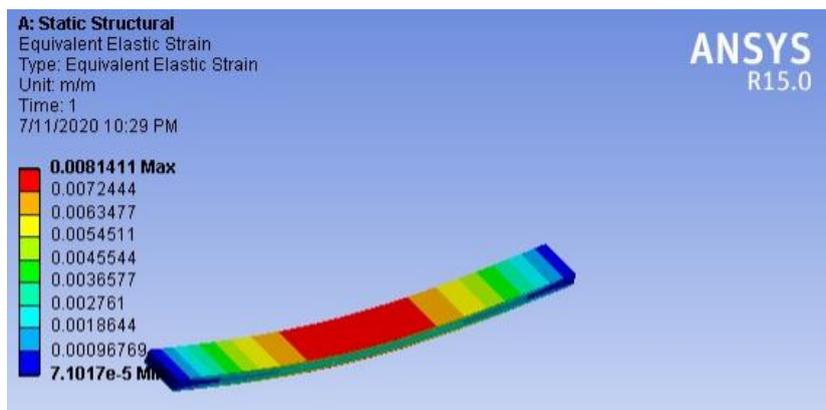
**Figure 12.** Total deformation when SMA at centre

Figure 12 shows the Total deformation when SMA at centre of the beam.



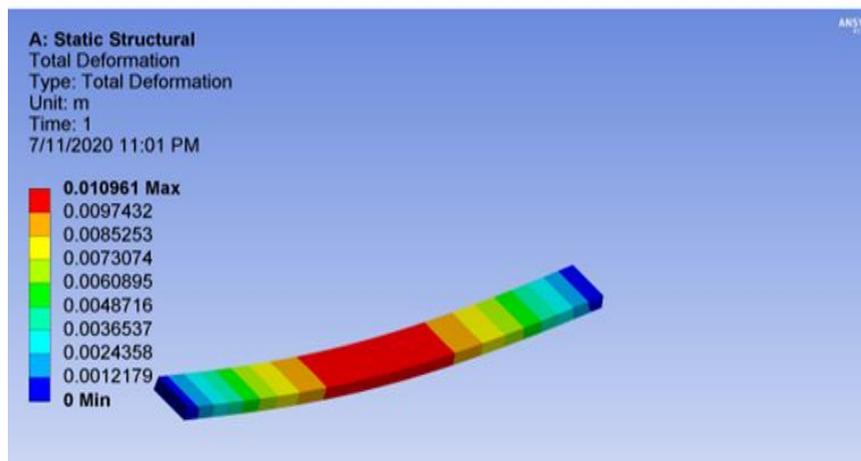
**Figure 13.** Equivalent Stress when SMA at centre

Figure 13 shows the Equivalent Stress when SMA at centre



**Figure 14.** Equivalent strain when SMA at centre

Figure 14 shows the Equivalent strain when SMA at centre



**Figure 15.**Total deformation when carbon/epoxy at centre

Figure 15 shows the Total deformation when carbon/epoxy at centre

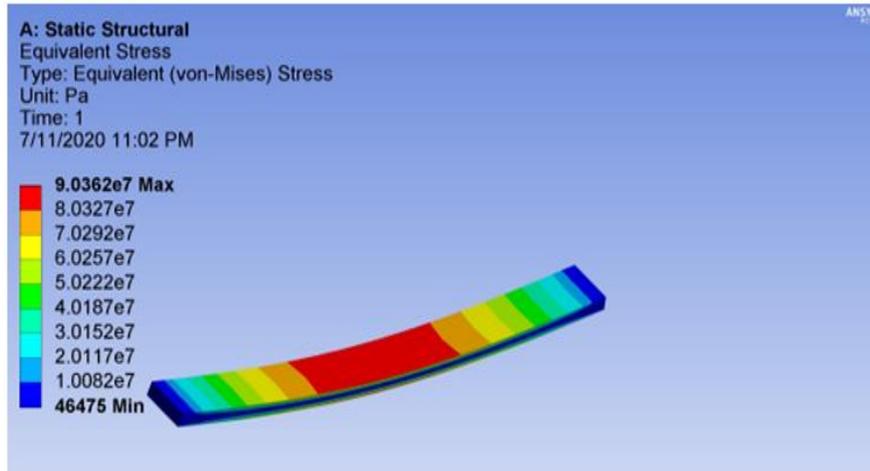


Figure 16. Equivalent Stress when carbon/epoxy at centre

Figure 16 shows the Equivalent Stress when carbon/epoxy at centre

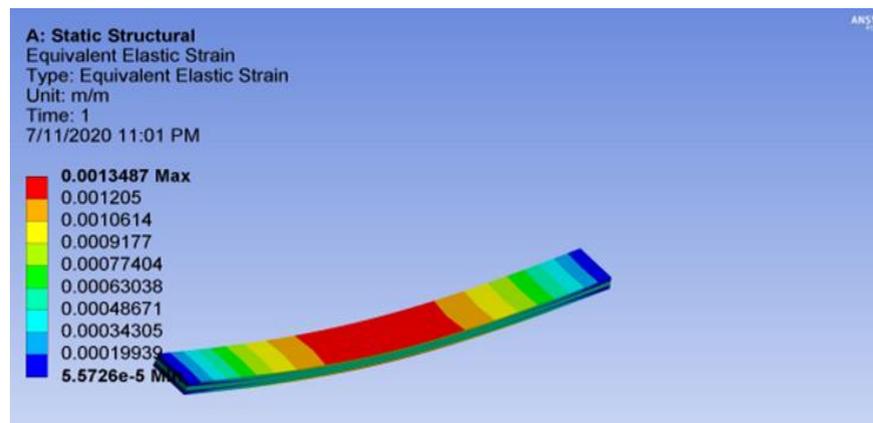


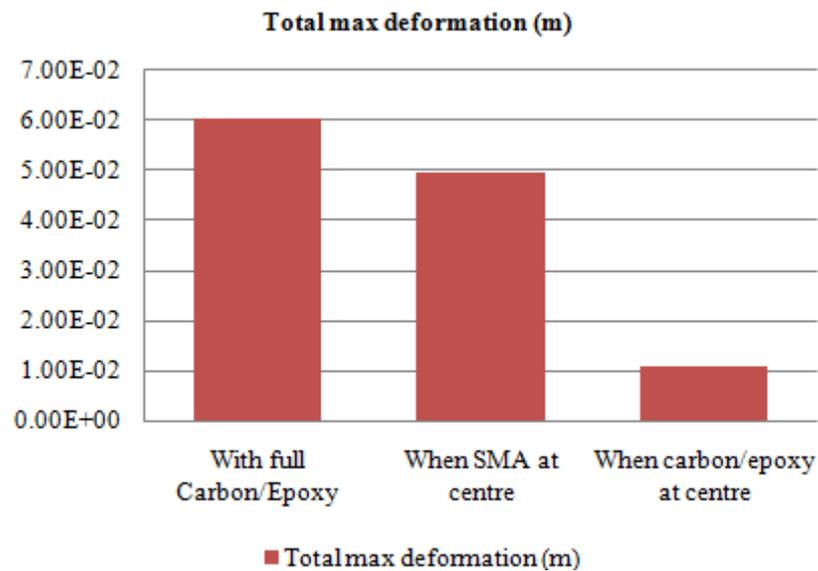
Figure 17. Equivalent Strain when carbon/epoxy at center

Figure 17 shows the Equivalent Strain when carbon/epoxy at center

Table 3 shows the Maximum deformation, Maximum Equivalent von-mises stress and maximum Equivalent von-mises strain in all the three cases.

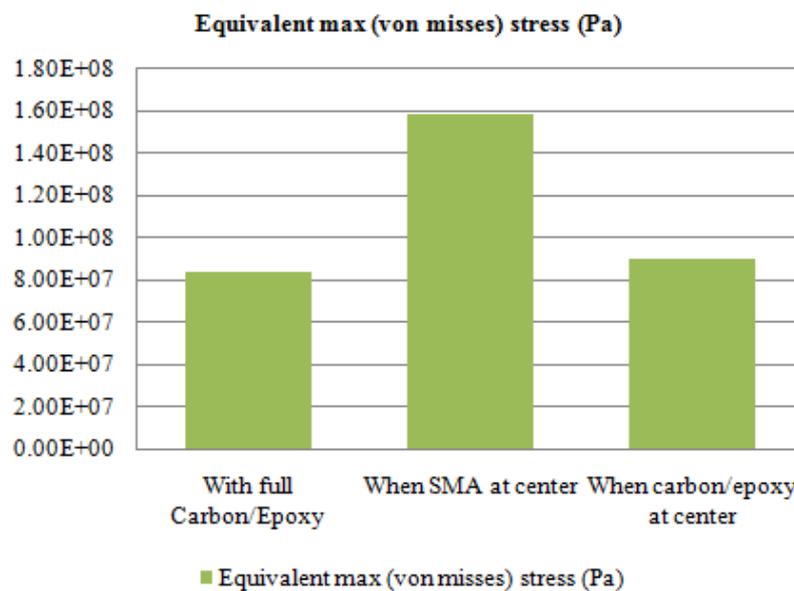
Table 3. Maximum deformation, Maximum Equivalent von-mises stress and maximum Equivalent von-mises strain in all the three cases.

Properties	With full Carbon/Epoxy	When SMA at Centre	When carbon/epoxy at Centre
Force (KN)	10	10	10
Total max deformation (m)	6.0202E-002	4.955e-002	1.0961e-002
Equivalent max (von misses) stress (Pa)	8.3481e+007	1.5873e+008	9.0362e+007
Equivalent max elastic strain (m/m)	1.0051e-002	8.1411e-003	1.3487e-003



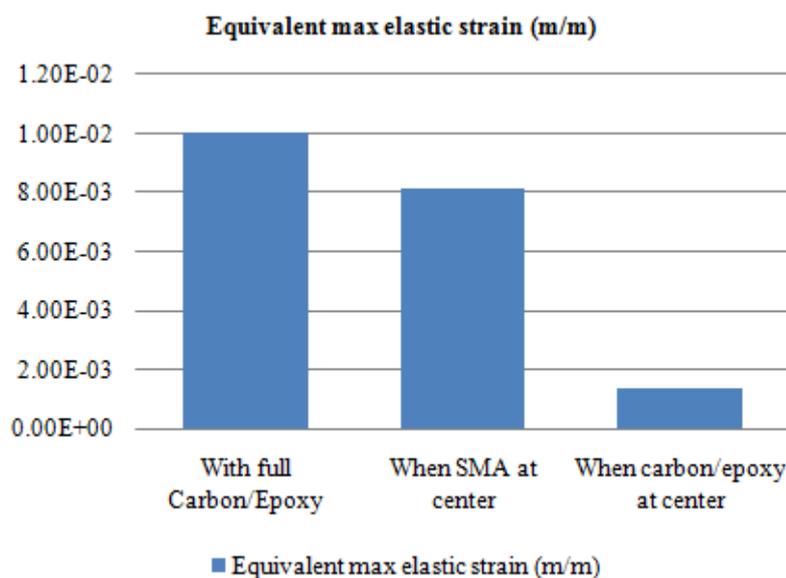
**Figure 18.** Max total deformation when full beam is laminated with carbon/epoxy, when SMA at Centre and when carbon/epoxy at Centre

Figure 18 shows the Max total deformation when full beam is laminated with carbon/epoxy



**Figure 19.** Max stress when full beam is laminated with carbon/epoxy, when SMA at Centre and when carbon/epoxy at Centre

Figure 19 shows the Max stress when full beam is laminated with carbon/epoxy, when SMA at Centre and when carbon/epoxy at centre



**Figure 20.** Max strain when full beam is laminated with carbon/epoxy, when SMA at Centre and when carbon/epoxy at Centre.

Figure 20 shows the max strain when full beam is laminated with carbon/epoxy, when SMA at Centre and when carbon/epoxy at Centre

## 6. Conclusions

When we use SMA at Centre there is decrease in deformation by 17.7%, increase in stress by 90.13 %, decrease in strain by 19 %, as compared to full carbon/epoxy laminated beam. When we use carbon epoxy at center there is decrease in deformation by 81.79%, increase in stress by 8.2429 %, decrease in strain by 86.58 %, decrease in deformation by 77.77 % as compared to full carbon/epoxy laminated beam. When we use carbon/epoxy at Centre there is decrease in stress by 43.07 %, decrease in strain by 83.433 % as compared to SMA at Centre. From the above observation we can conclude that shape memory alloy increases the strength

## 7. Future Scope

In future we can use other fiber materials to enhance the properties of the laminate and we can perform Fatigue as well as free and forced vibration analysis using same composite.

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