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Free Vibration Analysis of Composite Beam Considering Different Boundary Conditions using Finite Element Method

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Abstract: Vibration analysis of a beam is crucial and peculiar subject of study in engineering. All real physical structures, when subjected to loads behave dynamically. Composite is a material consisting of two or more constituents are combined at a ratio of matrix and fiber. Composites are using in most of areas especially in engineering field, in automobile, mechanical, aviation and marine industries. design of components are made with the help of software and experimental analysis because this composite material has high strength to weight ratio. In this study, free vibration of steel beams is investigated analytically under two different boundary conditions: Clamped-Free (C-F), Clamped-Clamped (C-C), Analytical solution is carried out using Euler-Bernoulli beam theory. Then, solutions including the effects of the geometric characteristics, and boundary conditions are obtained and discussed for the natural frequencies of the first five modes. and also analyze the free vibration of beam for the composite as well as steel material are carried out. Natural frequency and mode shape of the beam has been determined using ANSYS 18.1. Also comparative study of Steel, E-glass epoxy and Epoxy Carbon under two different boundary conditions. These materials are used for vibration analysis to observe the effect of a modal parameters of beam subjected to free vibration. analytical and results obtained from the finite-element-method (FEM) based software called ANSYS, are compared. It is concluded that analytical and Numerical results are found to be good agreement.
Keywords: Free Vibration, Composite, , Natural Frequency, Boundary Conditions, finite element method.

I. INTRODUCTION

A composite may be a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is known as the reinforcing phase and the one in which it is embedded is known as the matrix. The reinforcing phase material could also be in the form of fibers, particles, or flakes . The foremost common fibers used are glass, graphite, and Kevlar. Glass fibre reinforced composite laminates have gained significant importance in aerospace and defence applications due to their high specific strength, damage tolerance and maturity in processing. They have also been recognized as an alternate energy absorbing materials for replacing steel and light weight alloy armour materials. The “E” in E-glass stands for electrical because it had been designed for electrical applications. However, it's used for several other purposes now, like decorations and structural applications. The 'S' in S-glass stands for high content of silica. It retains its strength at higher temperatures compared to E-glass and has higher fatigue strength. It's used mainly for aerospace applications.

This paper is cares with obtaining the natural frequencies and mode shapes of composite beam. These vibration characteristics are of great and fundamental importance in structural dynamic analyses. Fiber reinforced polymer composites (FRPCs) are utilized in most kind of advanced engineering structures like aircraft, helicopters, boats, ships and off-shore platforms, automobiles, sports equipments, chemical processing equipment etc. A key factor driving the increased applications of composites over the recent years is that the development of latest advanced sorts of FRPCs. These appreciate of developments in high performance resin systems and wide variety of fabric reinforcement.

II. LITERATURE SURVEY

Yogita U. Medhane [1] Comparative Analysis of Composite Materials, In this paper author studied and analysed the free vibration analysis of only cantilever beam for the composite. Here the author works on comparing the natural frequencies of different materials. and they carried out the analysis of natural frequencies of different materials by using the FEM software ANSYS 17.1

Shubham Singh, Nilotpal Acharya and Bijit Mazumdar [2] Free Vibration Analysis of Beams, they studied to determine the natural frequencies and mode shapes of the beams of various cross-sections, material properties & support conditions with the help of mathematical models. they used only metallic materials not composite. however the present work carried out on composite materials.

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Gawali A.L [3] VIBRATION ANALYSIS OF BEAMS, he studied vibration analysis of beam by numerical discretisation scheme such as finite element method, Composite Element Method (CEM), Differential Quadrature Method (DQM).and also he reported the crack depth for different modes.

Y. N. V. Santhosh Kumar & M. Vimal Teja [4] in this paper the Design and Analysis of Composite Leaf Spring is studied. The composite material has many advantages as high strength and stiffness. Here the author works on replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. This paper deals with the replacement of conventional steel leaf spring with a Mono Composite leaf spring using E-Glass/Epoxy. The design parameters were selected and analyzed with the target of minimizing weight of the composite leaf spring as compared to the steel leaf spring. The leaf spring was modeled in Pro/E and therefore the analysis was done using ANSYS Metaphysics software.

M. Raghavedra &Syed Altaf Hussain [5] Modeling and Analysis of Laminated Composite Leaf Spring under the Static Load Condition by using FEA, In this present work, the dimensions of mono steel leaf spring of a Maruti 800 vehicle is taken for modeling and analysis of a laminated composite mono leaf spring with three different composite materials namely, Eglass/Epoxy, S-glass/Epoxy and Carbon/Epoxy subjected to an equivalent load as that of a steel spring. The design constraints were stresses and deflections. There are 3 different composite mono leaf springs are modeled by taking in to consideration of uniform cross-section, with unidirectional fiber orientation angle for every lamina of a laminate. Static analysis of a 3-D model has been performed using ANSYS 10.0.

Mehmet Avcar [6] In this paper author studied about the free vibration of square cross section of aluminium beams are investigated analytically and numerically under 4 different boundary conditions. Clamped-Clamped (C-C), Clamped-Free (C-F), Clamped-Simply Supported (C-SS) and Simply Supported-Simply Supported (SS-SS). during this study analytical solution is carried out by using Euler-Bernoulli beam theory and Newton Raphson Method. First, the equations of motion are provided.

From literature review, we summarized work done by various researchers and engineers in field of vibration analysis mainly on composite materials. It includes different sort of methods, software analysis and Experimental techniques are used for analysis. some researcher used different materials and boundary conditions. According to some researcher changes in dynamics characteristics are often used as an information source for detecting of vibrating beam. In this paper mainly considering on comparing the natural frequency of composite materials with steel under different boundary conditions.

III.THEORY AND FORMULATION

A. Geometry and Material Modeling of Specimen

In this paper following materials are selected for analysis.

Material Used: Steel, E-glass epoxy and Epoxy carbon with cross ply [0/90/0/90/0]. According to testing of the steel beam its mechanical properties are taken from literature. A thin flat strip of specimen having a uniform rectangular cross section was prepared in all cases. The dimension of the specimen was taken as given in Table No. I

Table I. Dimensions of specimens

Sl. No	Length(mm)	Width(mm)	Thickness(mm)
01	850	50	5

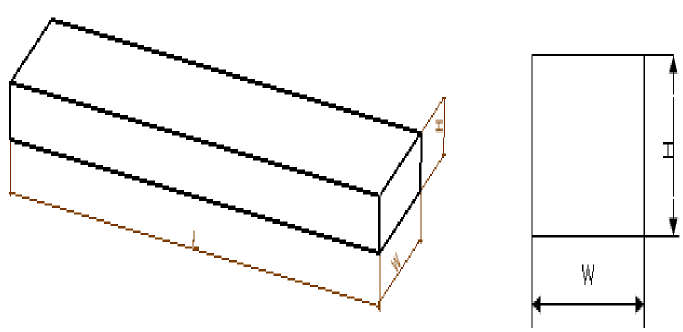

Fig 1. Geometry and cross-sectional view of beam

B. Equation of Lateral Vibration of Beam

Consider an elastic beam of length L, Width W, and Thickness H, with uniform cross section A, as shown in Figure 1. and the beam dimensions are given in Table I.

The equation for lateral vibration of an Euler-Bernoulli beam is given by the following,

EI[(d^4 y)/(dx^4)] - ρω2y = 0 (1)

where, ρ= is mass per unit length of the beam

by defining,

β = (ρω^2)/EI

Equation is rearranged as a fourth order differential equation as follows,

(d^4 y)/(dx^4) - β2y = 0 (2)

The general solution to the equation is,

y = Acoshβx+Bsinhβx+Ccosβx+Dsinβx (3)

where A, B, C, D are constants, and sinh & cosh are the hyperbolic and sin & cos functions.

From Euler's Beam theory theoretical formula for natural frequency of vibration for beam given as follows

ωn = 〖(βn l)〗^2 √(EI/(ρl^4)) (4)

where, 〖(βn*l)〗^2 is constant depends on the boundary conditions and n=1,2,3..... are frequency corresponding to each mode. numerical values of 〖(βn* l)〗^2 for Clamped-Free and Clamped-Clamped as given in below Table No. II

The relation between angular frequency(rad/sec) and the natural frequency(Hz) is given as below,

fn = ω/(2π) (5)

Table II. Values of (βn* l)〗^2

Beam configuration	mode1	mode2	mode3	mode4	mode5
Clamped-Free	3.52	22.0	61.7	121	200
Clamped-Clamped	22.4	61.7	121	200	298.6

According to Euler's Beam theory calculated frequency values for each mode for different boundary conditions as follows,

Table III. Analytical results for natural frequencies at different mode shapes

Material	Mode Shape	Natural frequency (Hz) Camped-Free (C-F)	Natural frequency (Hz) Camped-Clamped (C-C)
Steel	1	5.644	38.348
	2	35.279	98.941
	3	98.941	194.034
	4	194.037	320.718
	5	320.718	478.832

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IV. SOFTWARE SIMULATION

In the present work, for steel analyses rectangular beam is modeled. For modeling the beam Catia-V5 is used. The solid model prepared in Catia-V5 is imported in workbench ANSYS 18.1 to perform static analysis and modal analysis. for analysis of E-glass epoxy and Epoxy carbon are prepared by using ANSYS ACP(Pre) with cross ply [0/90/0/90/0].The dimensions of the beams are same for both that are 850mm length, 50mm width, and 5mm thickness.

A. Modelling in Catia-V5

For the analysis of Steel we prepared the solid model With the help of design software here, used Catia-V5 software to model a beam as shown in following figure, the modeling of beam as it is same in geometry for all materials which is used in this project.

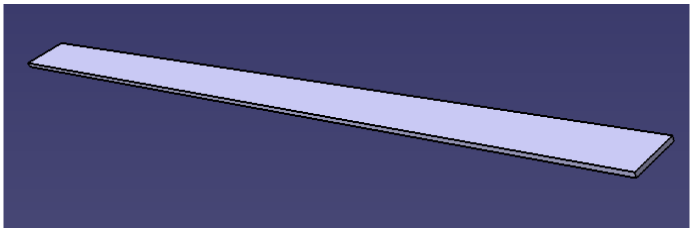

Fig 2. 3D Design in Catia-V5

B. ANSYS ACP(Pre)

For analysis of E-glass epoxy and Epoxy carbon are prepared by using ANSYS ACP(Pre) with cross ply [0/90/0/90/0].for calculating the natural frequency of composite materials and the composite material preparation steps by using ACP(Pre) as shown below figure.

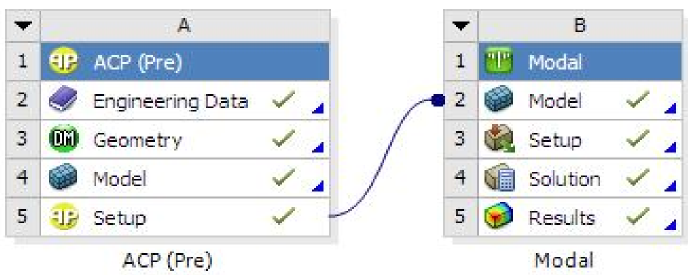

Fig 3. ANSYS ACP(Pre)

C. Meshing

The meshing of rectangular beam is carried out in ANSYS software. The finite element standard quality criteria considered in meshing of rectangular beam component. Total number of elements and nodes used to create the FE model of beam is 345 elements and 2788 nodes.

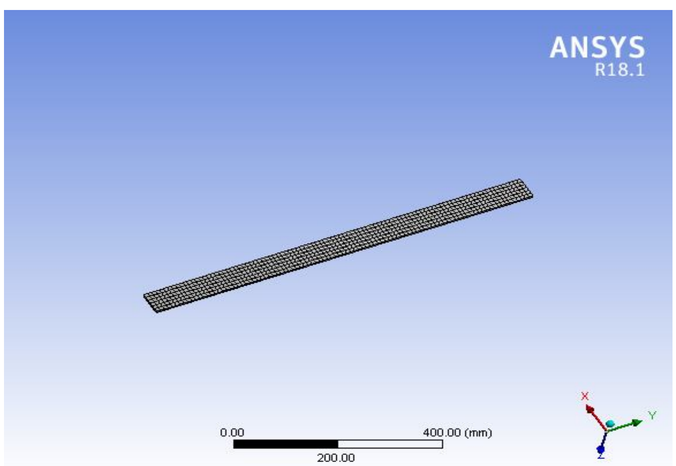

Fig 4. Finite Element Model of the Beam with Meshing.

D. Boundary Conditions

The finite element modeling of the beam with applying boundary conditions is as shown in Fig. No. 4. for the modal analysis of beam for Clamped-Free & Clamped-Clamed there are two boundary conditions are shown below.

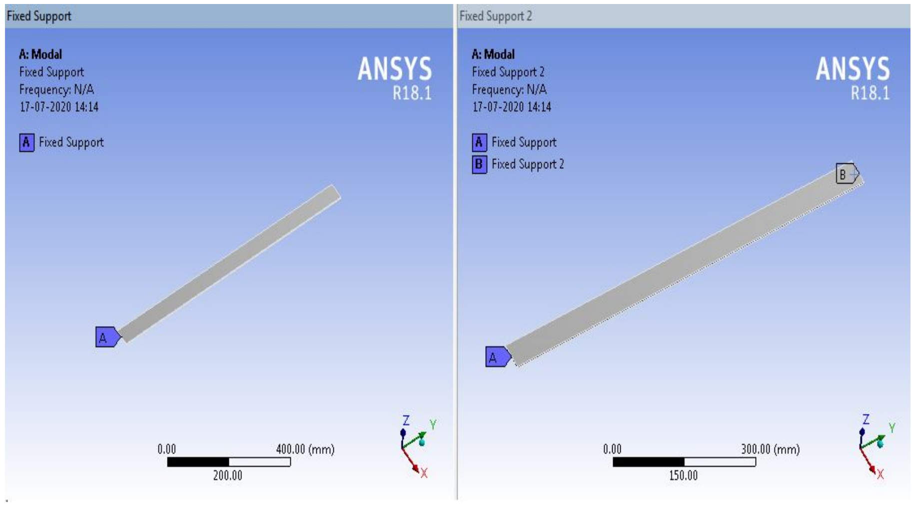

Fig5. Beam with Camped-Free & Camped-Clamped Boundary Conditions.

E. Modal Analysis

Modes are inherent properties of a structure. Resonances are determined by the material properties and boundary conditions of the structure. Each mode of the material is defined by a natural frequency, modal damping, and a mode shape. If the material properties or the boundary conditions of a structure change, its modes will change. basically, modal analysis is that the study of the natural characteristics of structures. Understanding together the natural frequency and mode shape helps to design my structural system for noise and vibration applications. We use modal analysis to assist design all kinds of structures including automotive structures, aircraft structures, spacecraft, computers, and tennis rackets, golf clubs etc.

Once we defined the boundary conditions than, modal analysis is performed for 3 different materials which are utilized in this paper for comparison. When an elastic system vibrates due to natural forces, this state of system is known as free vibration. In state of free vibration, system vibrates at its natural frequency. The natural frequency and mode shapes are both two important modal parameters in free vibration. The natural frequency is controlled by geometric and material properties. FEA analysis was used for free vibration analysis. The natural frequency and mode shapes for steel and E glass epoxy, Epoxy Carbon which different composite materials were obtained. The finite element analysis using ANSYS18.1 software was utilized in modal analysis to get the natural frequencies for steel and E glass epoxy, Epoxy Carbon composite materials.

F. Modal Analysis for Selected Materials

1) Material: Steel

For Clamped-Free boundary condition of beam, Modal analysis has been carried out for Steel material.

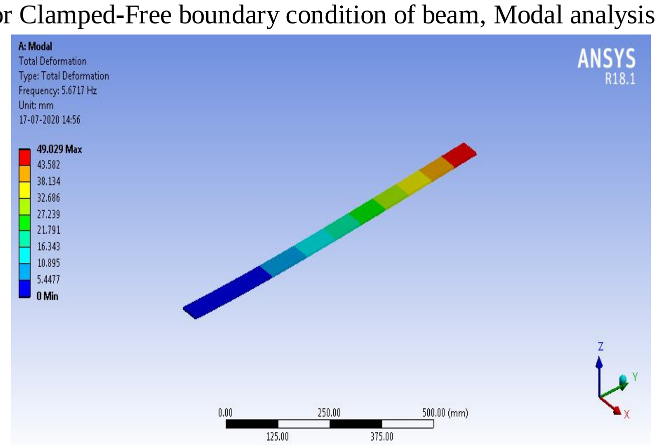

Fig 6. mode1

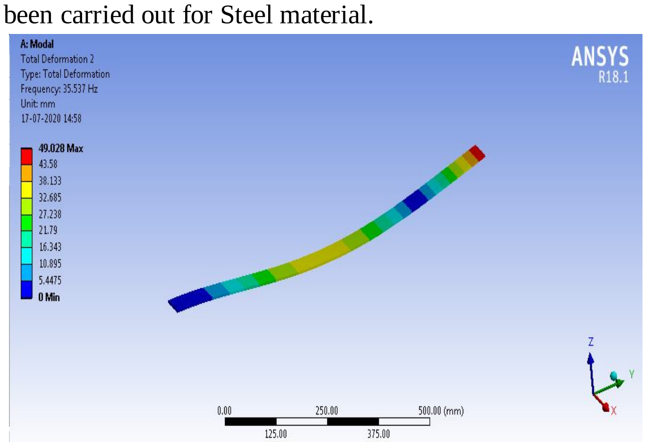

Fig 7. mode2

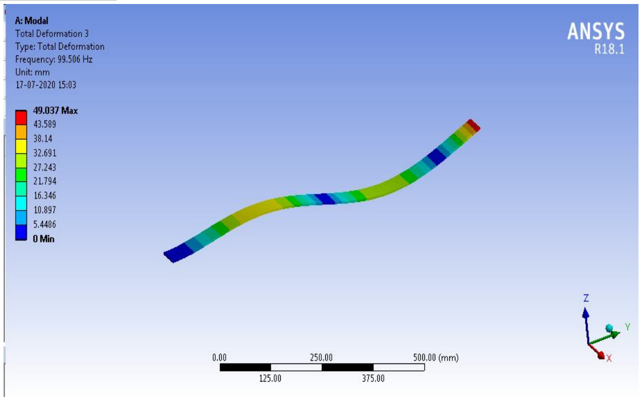

Fig 8. mode3

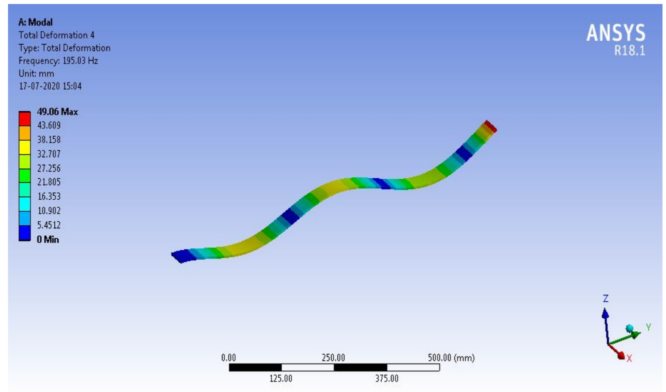

Fig 9. mode4

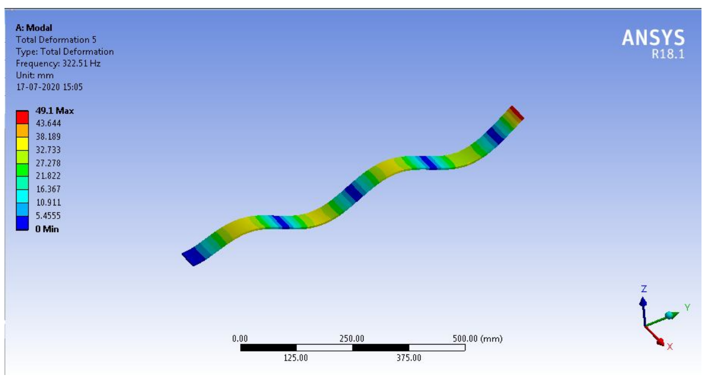

Fig 10. mode5

2) *Material:* Steel

For Clamped-Clamped boundary condition of beam, Modal analysis has been carried out for Steel material.

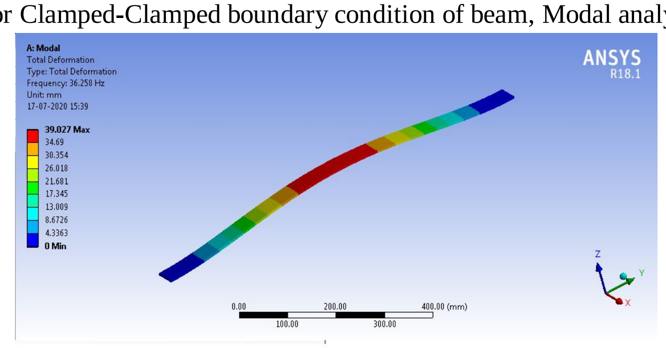

Fig 11. mode1

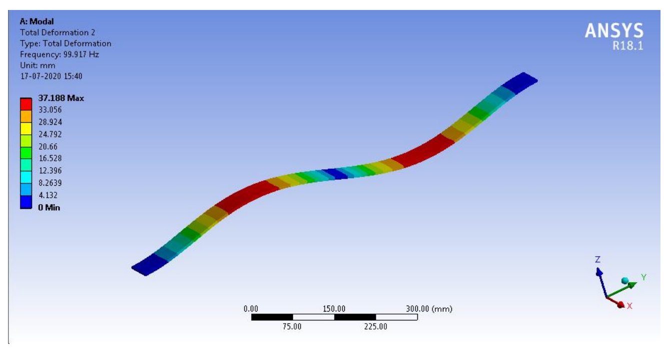

Fig 12. mode2

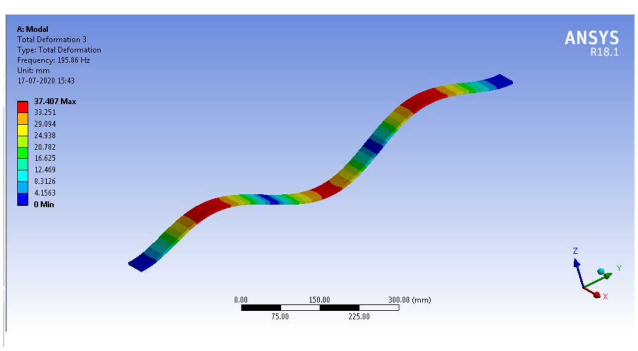

Fig 13. mode3

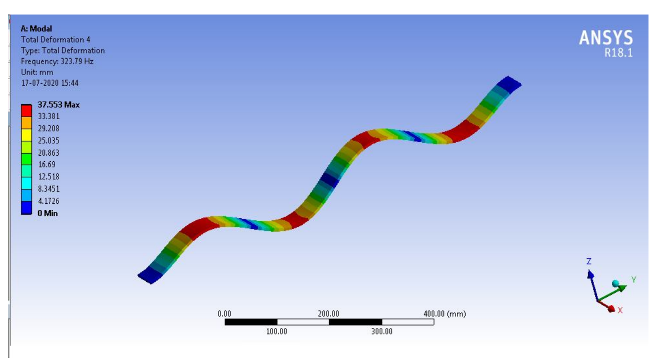

Fig 14. mode4

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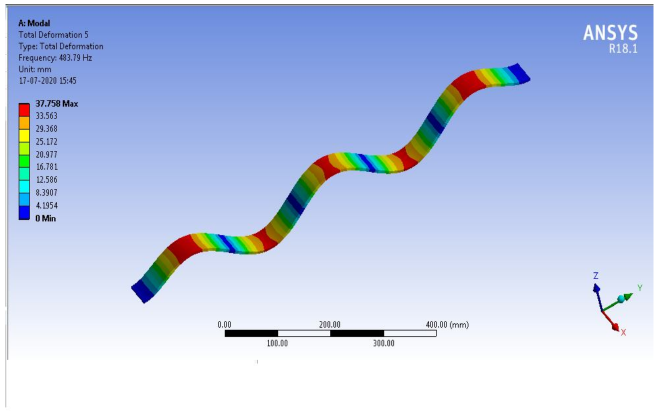

Fig 15. mode5

3) Material: E-Glass Epoxy

For Clamped-Free boundary condition of beam, Modal analysis has been carried out for E-Glass Epoxy material.

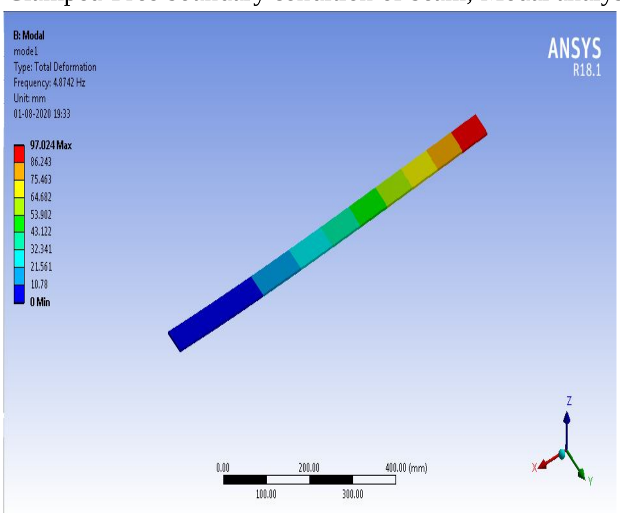

Fig 16. mode1

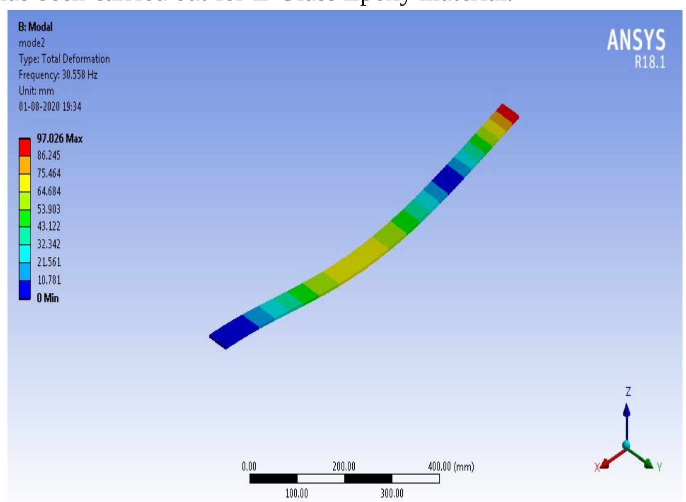

Fig 17. mode2

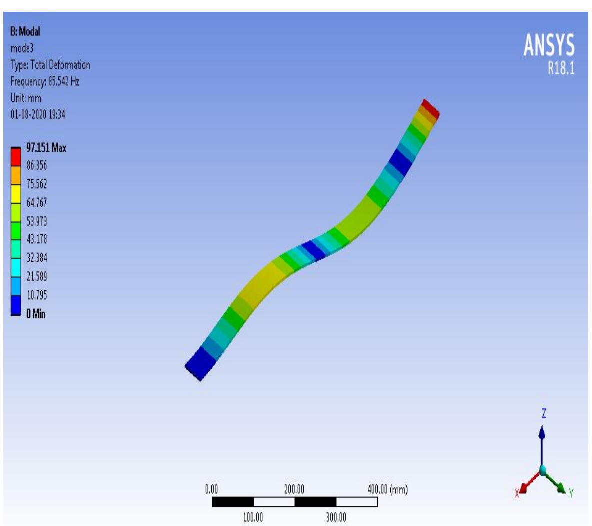

Fig 18. mode3

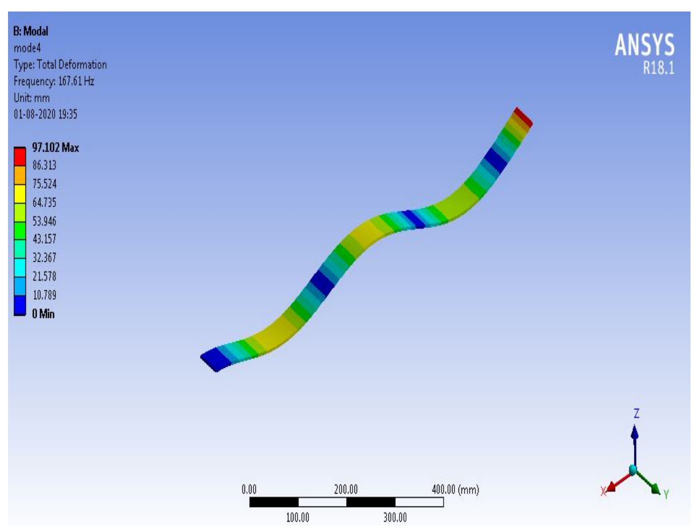

Fig 19. mode4

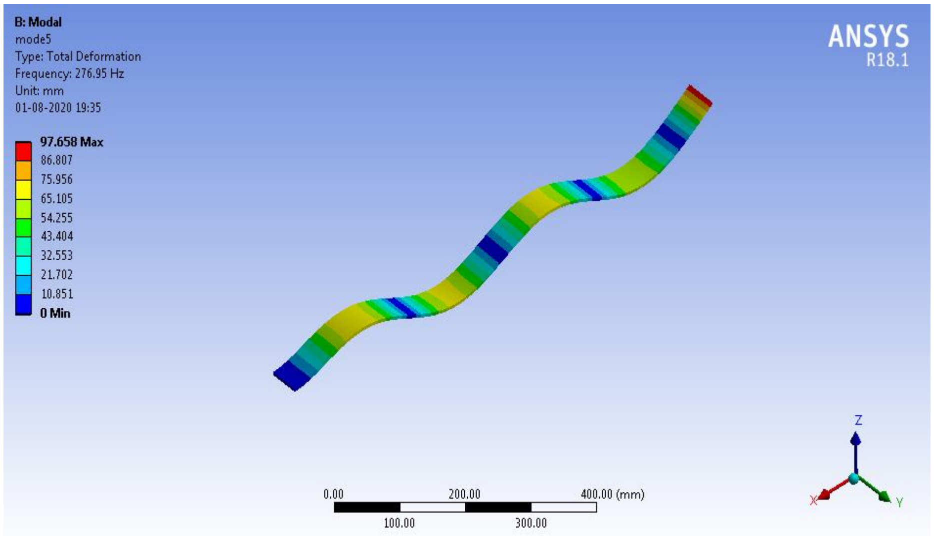

Fig 20. mode5

4) *Material:* E-Glass Epoxy

For Clamped-Clamped boundary condition of beam, Modal analysis has been carried out for E-Glass Epoxy material

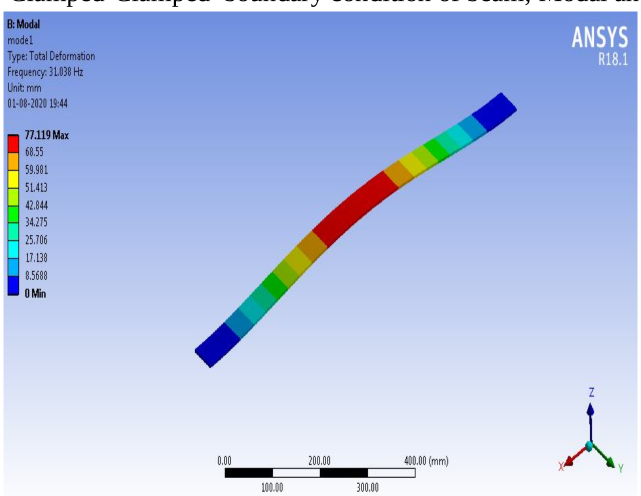

Fig 21. mode1

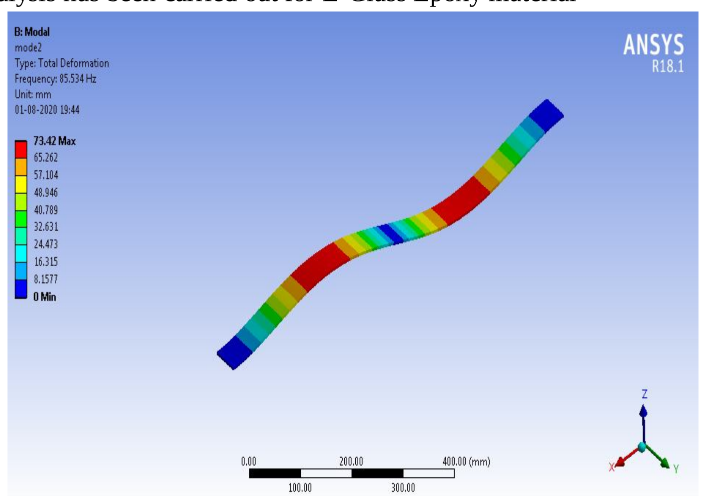

Fig 22. mode2

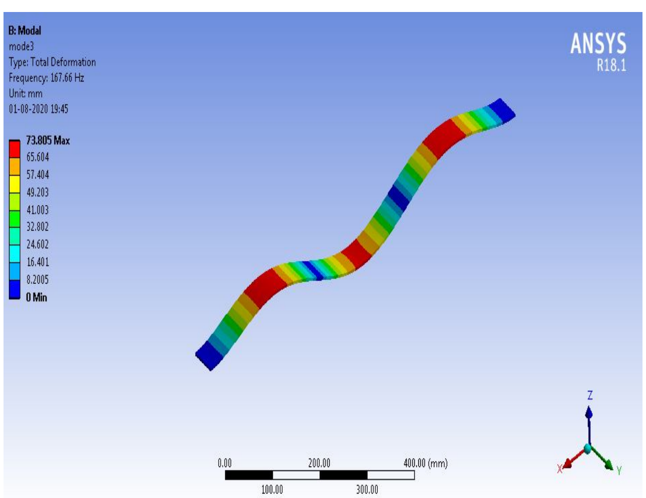

Fig 23. mode3

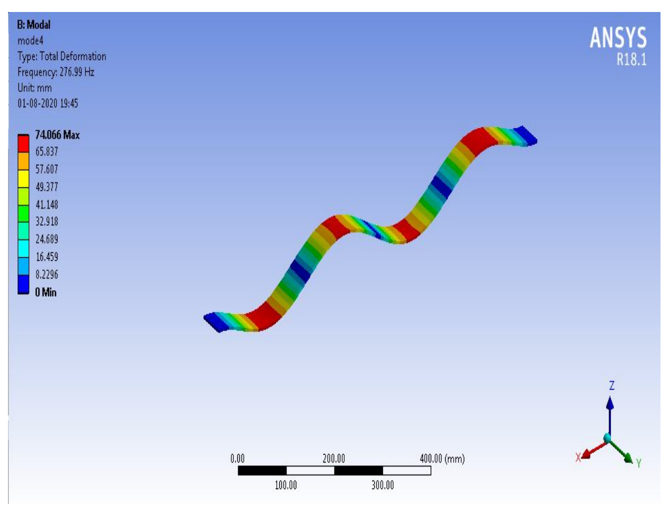

Fig 24. mode4

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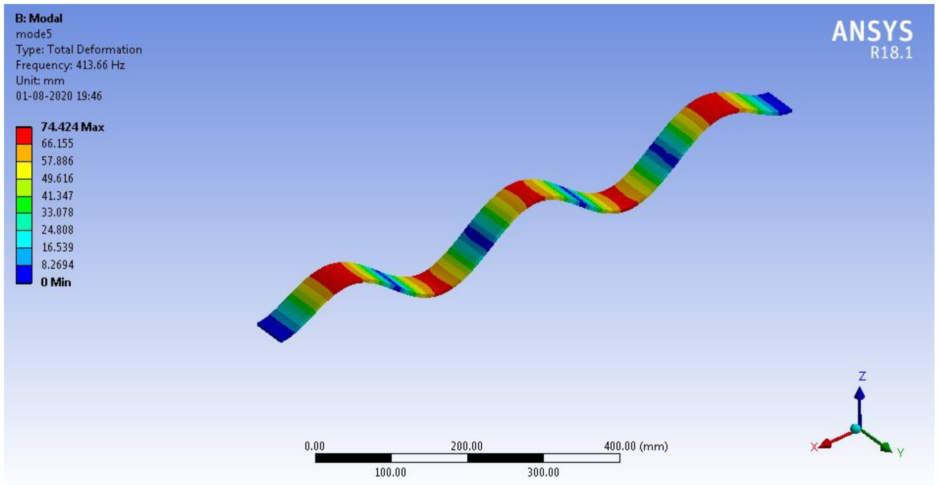

Fig 25. mode5

5) Material: Epoxy Carbon

For Clamped-Free boundary condition of beam Modal analysis has been carried out for Epoxy Carbon material,

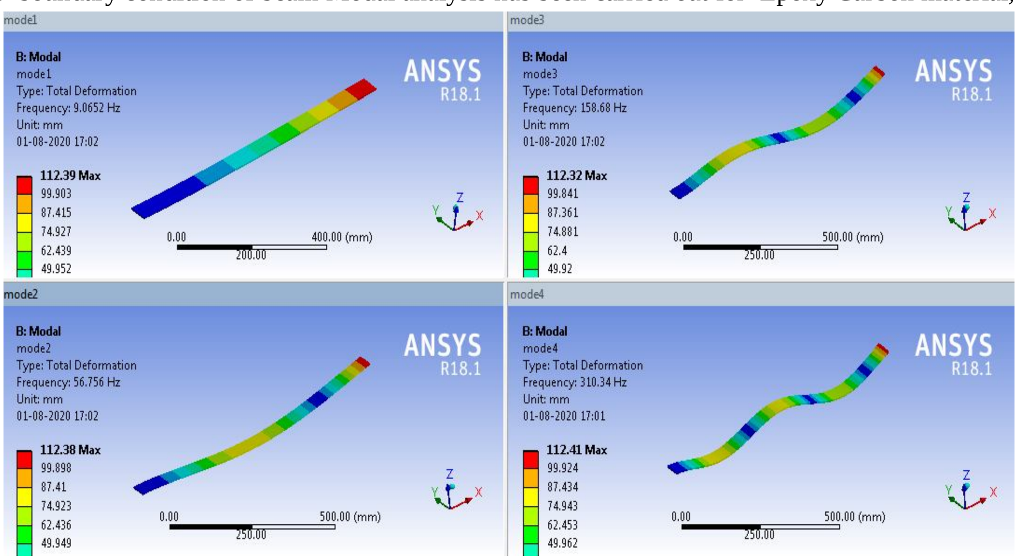

Fig 26. mode1-4

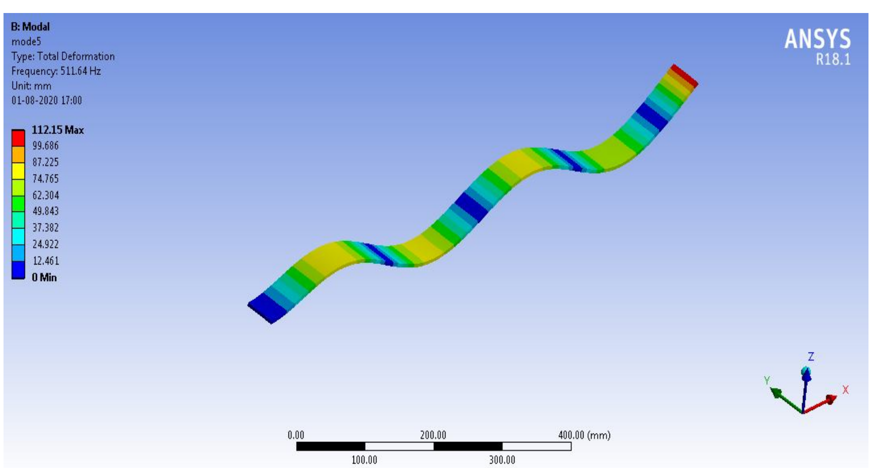

Fig 27. mode5

6) Material: Epoxy Carbon

For Clamped-Clamped boundary condition of beam, Modal analysis has been carried out for Epoxy Carbon material.

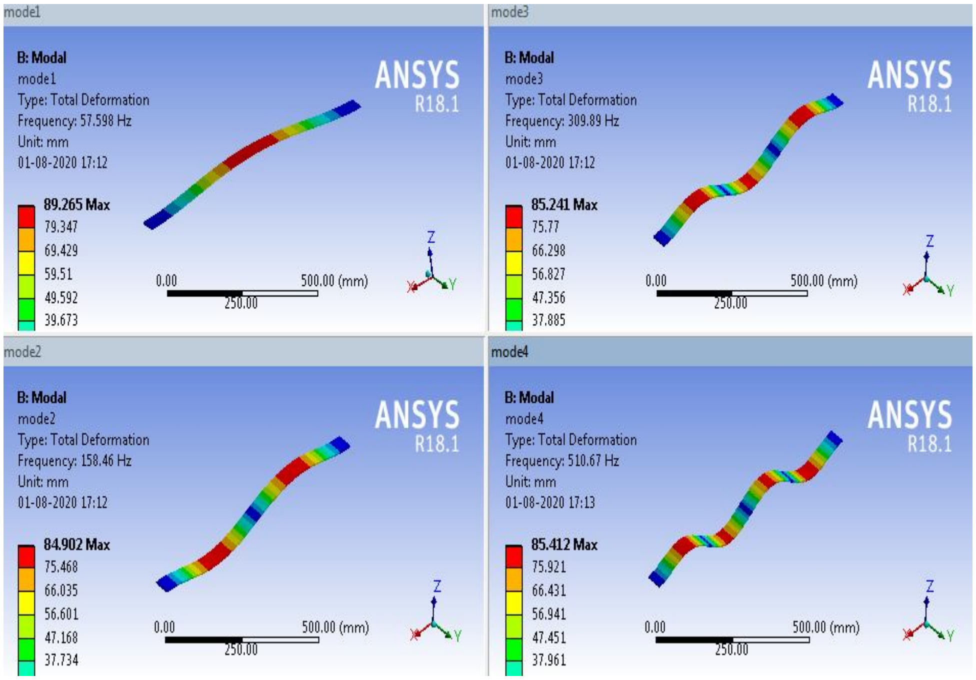

Fig 28. mode1-4

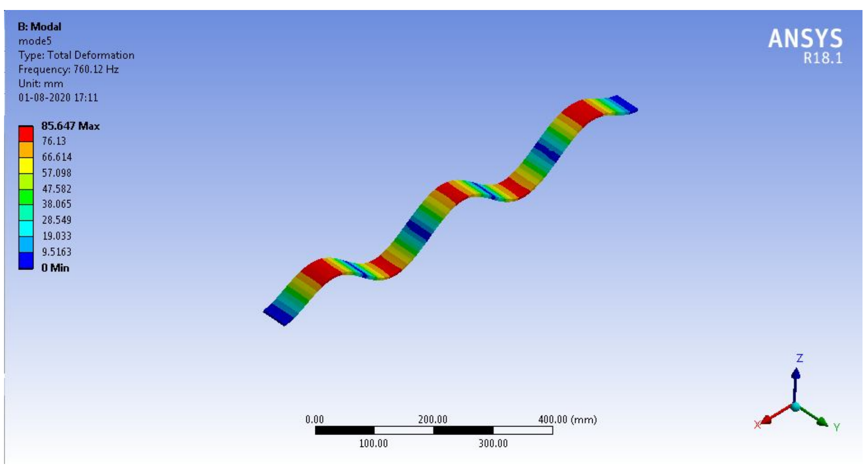

Fig 29. mode5

V. RESULTS AND DISCUSSION

In this section, comparative study was performed to validate the present numerical results. The analytical results were compared with the results of the FEM -based software ANSYS. The basic concept behind this is the software that is theoretical and the experimental results were compared and found out the better results. The results and discussion were based on the observation so for drawing the conclusion the results are very important. Natural frequencies were extracted for steel from ANSYS18.1 and compared with analytical results. and also Natural frequencies were extracted and compared for Steel, and E-glass epoxy, Epoxy Carbon. Since the results are in good agreement, the finite element analysis can be used to generate many sets of input-output data for comparison with experimental data from which we can make the conclusions are in last part of this paper, from the finite element analysis by using ANSYS 18.1 following results are obtained for frequencies at different mode shapes under different boundary conditions.

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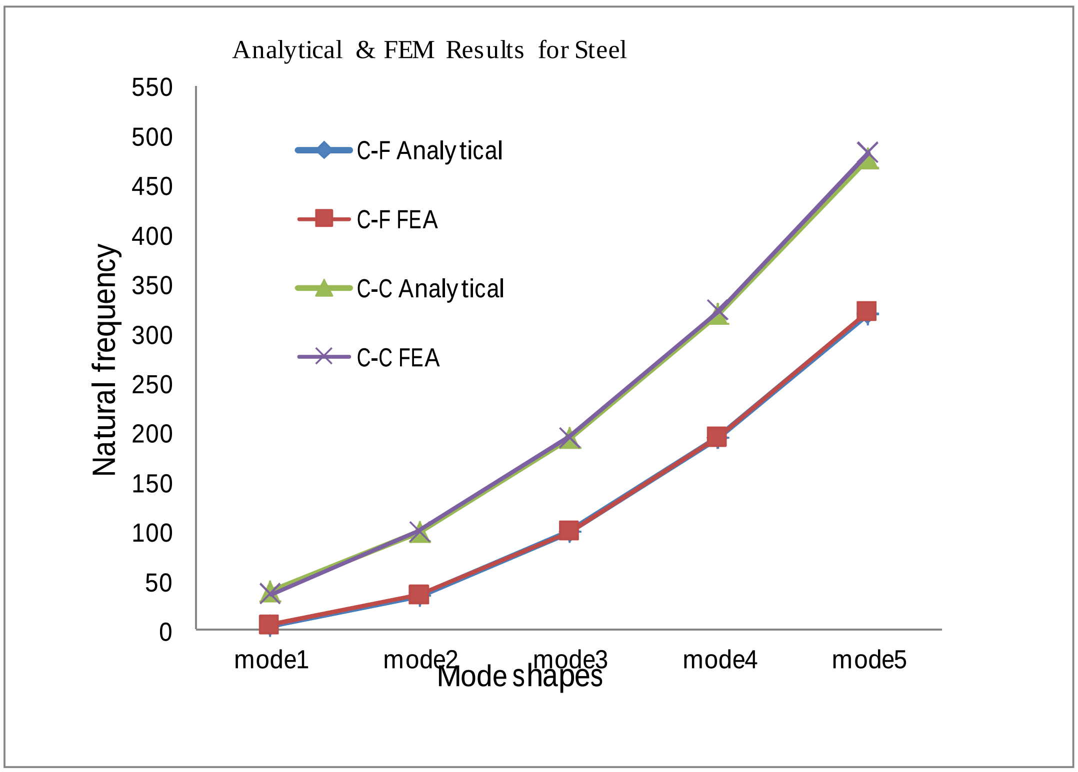
1) *Study 1:* The results of simulation by using ANSYS 18.1 software for Steel under different boundary conditions is given in Table IV. In Graph I. the various natural frequencies(Hz) of Steel beam obtained from analytical and numerical method versus the mode shapes under Clamped-Free & Clamped-Clamped boundary conditions are plotted.

Table IV. Comparison Between Analytical Natural Frequency of Steel and Those Obtained From FEM(ANSYS) at Different mode Shapes.

Material	Mode Shape	Analytical Natural frequency (Hz) Camped-Free (C-F)	FEA Natural frequency (Hz) for Camped-Free (C-F)	Analytical Natural frequency (Hz) Camped-Clamped (C-C)	FEA Natural frequency (Hz) Camped-Clamped (C-C)
Steel	1	5.644	5.671	38.348	36.258
	2	35.279	35.537	98.941	99.917
	3	98.941	99.506	194.034	195.86
	4	194.037	195.03	320.718	323.79
	5	320.718	322.51	478.832	483.79

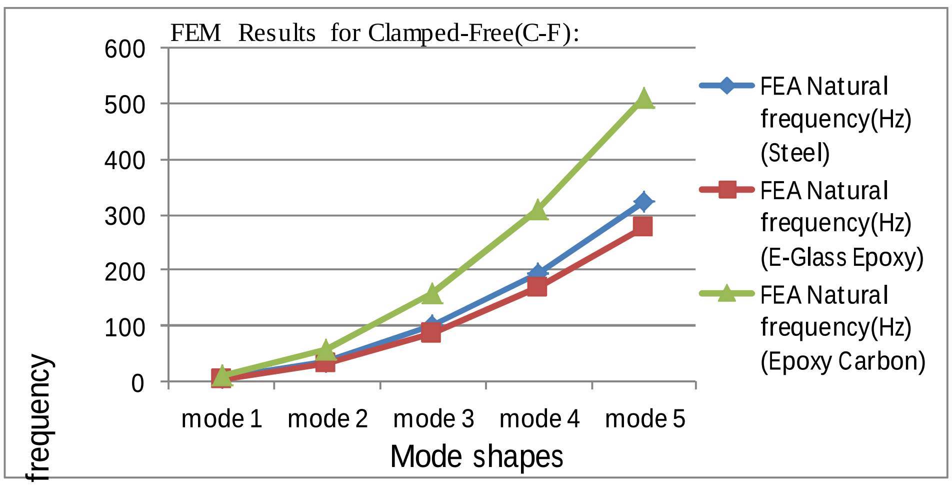


Graph I. Comparison between Analytical Natural frequency of Steel and those obtained from FEM At different mode shapes under different boundary conditions.

2) *Study 2:* The results of simulation by using ANSYS 18.1 software for Steel, E-Glass Epoxy and Epoxy Carbon under Clamped-Free boundary condition is given in Table V. In Graph II, the various natural frequencies(Hz) of Steel, E-Glass Epoxy and Epoxy Carbon beam obtained from FEM versus the at different mode shapes under Clamped-Free boundary condition are plotted.

Table v. Comparison of Natural Frequency Obtained From FEM for CLAMPED-FREE(C-F)

Mode Shape	FEA Natural frequency (Hz) for (Steel)	FEA Natural frequency (Hz) for (E-Glass Epoxy)	FEA Natural frequency (Hz) for (Epoxy Carbon)
1	5.671	4.874	9.0652
2	35.537	30.558	56.756
3	99.506	85.542	158.68
4	195.03	167.61	310.34
5	322.51	276.95	511.64

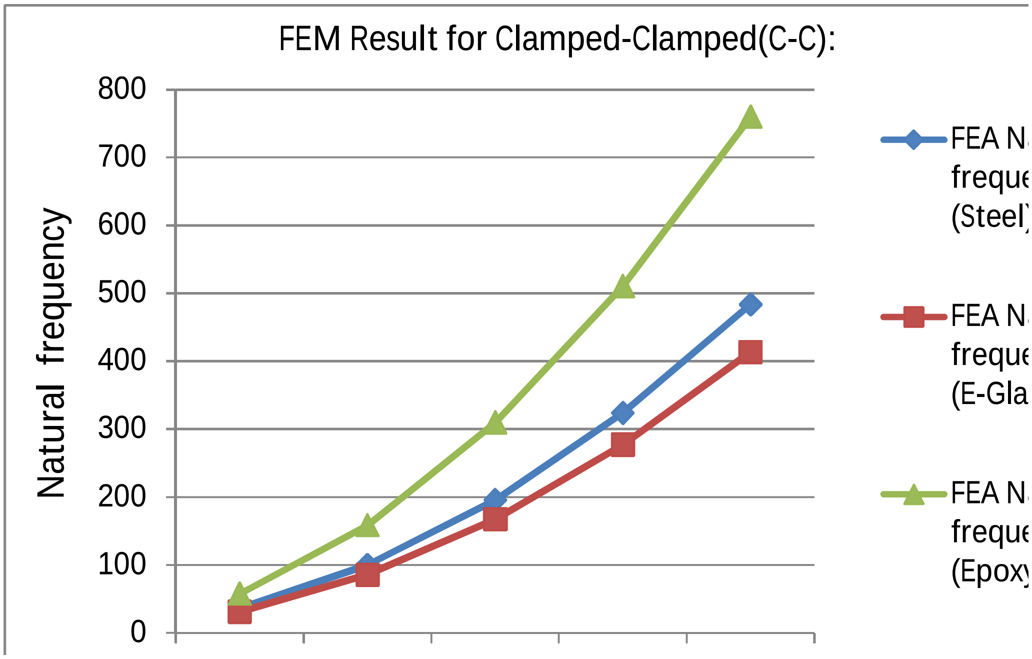


Graph II. Comparison of Natural frequency of Steel, E-glass Epoxy, Epoxy Carbon obtained from FEM for Clamped-Free(C-F)

3) *Study 3:* The results of simulation by using ANSYS 18.1 software for Steel, E-Glass Epoxy and Epoxy Carbon under Clamped-Clamped boundary condition is given in Table VI. In Graph.III , the various natural frequencies(Hz) of Steel, E-Glass Epoxy and Epoxy Carbon beam obtained from FEM versus the at different mode shapes under Clamped-Clamped boundary condition are plotted.

Table VI. Comparison of natural frequency obtained from fem for clamped-clamped(C-C)

Mode Shape	FEA Natural frequency (Hz) for (Steel)	FEA Natural frequency (Hz) for (E-Glass Epoxy)	FEA Natural frequency (Hz) for (Epoxy Carbon)
1	36.258	31.038	57.598
2	99.917	85.534	158.46
3	195.86	167.66	309.89
4	323.79	276.99	510.67
5	483.79	413.66	760.12



Graph III. Comparison of Natural frequency of Steel, E-glass Epoxy, Epoxy Carbon obtained from FEM for Clamped-Clamped(C-C)

VI. CONCLUSIONS

In this study, the free vibration of rectangular beam is investigated analytically and numerically under Two different boundary conditions. Analytical solution is carried out by using Euler-Bernoulli beam theory. From results and discussion we can made some conclusions as analytical and FEM results are in good agreement. We can see that Epoxy Carbon material gives higher natural frequencies by comparing it with Steel and E-Glass Epoxy.

We depict sets of data natural frequencies corresponding to analytical and FEM analysis. Natural frequencies for Epoxy Carbon are higher as compared to Steel and E Glass Epoxy material at different modes. and also we found that The beam has the highest natural frequencies under Clamped-Clamped boundary condition. we can predict the behaviour of that particular material at a particular natural frequency. Natural frequencies of Epoxy Carbon material are high so By doing the comparative study we came to a final conclusion that Epoxy Carbon is more stiffer as compared to steel and E-Glass Epoxy.

VII. ACKNOWLEDGEMENT

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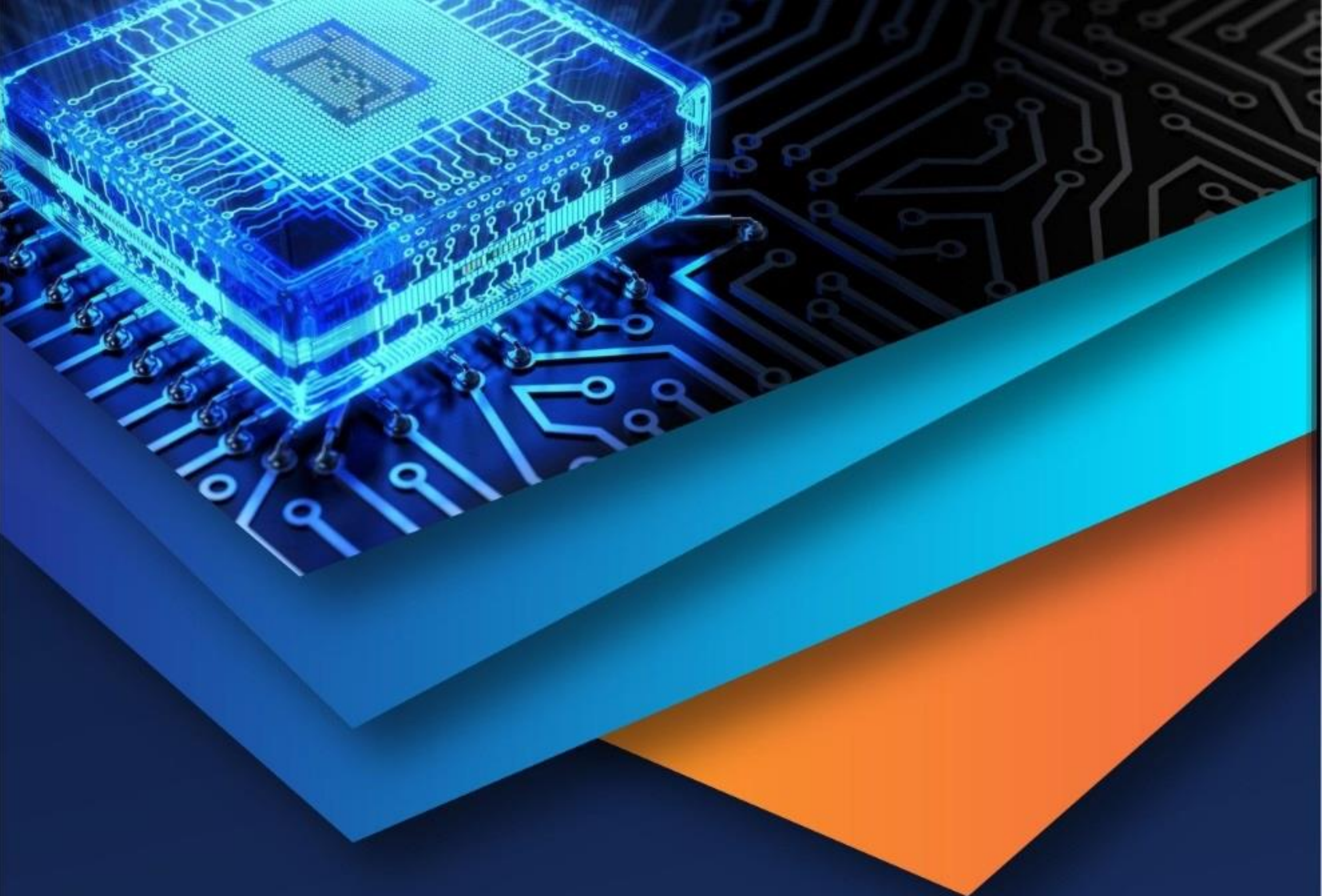

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