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Numerical and Experimental Vibration Analysis of Laminated Composite Beam at Different Boundary Conditions

Cheekatla Sathish Kumar[1], Dr.D. Srinivasa Rao[2]

[1] Post Graduate Student, Department Of Mechanical Engineering, DMSSVH College Of Engineering, Machilipatnam, India
[2]Professor, Department Of Mechanical Engineering, DMSSVH College Of Engineering, Machilipatnam, India

ABSTRACT: In the present work E-glass fiber reinforced composite beams were fabricated by hand lay-up method having three layers with orientations (0 0 , 30 0 , -45 0). The first three natural frequencies of these beams ware evaluated experimentally using accelerometer, impact hammer and FFT analyzer, which is being operated by DEWESOFT software. The dimensions of the beams are 200mmX40mmX9mm. The first three natural frequencies were obtained for different boundary conditions like Cantilever, Simply supported, Fixed-Simply supported and Fixed-Ended conditions. The numerical analysis was also carried out to find the first three natural frequencies of the beam for the above boundary conditions using Euler beam equation.

The process of find the first three natural frequencies was repeated by simulating the composite beam using ANSYS 16.2.The Results thus obtained in three methods were compared.

Keywords: ANSYS, FFT analyzer, Numerical analysis, Fiber reinforced composite beam and Natural frequencies.

• INTRODUCTION

Composite materials are used in many years ago and now days they are very use full. Since 4000 B.C straw was added soil to increase the resistance of the bricks. Although the benefits brought by the composite materials are known for thousands of years, just some years ago the right understanding of material behavior as well as the technology for designing composites war started to be developed. F111 airplane is the first model to incorporate this technology. Another example, of an airplane Boeing 767 has 2 tons in composite materials. The main possibility of material to combine with high strength and stiffness with low weight has also got the attention of the automobile industry. The Ford device or motor Company was developed a car in 1979 with some components made from composite materials. The type of modal was simply 570 kg lighter than the version in steel, only the transmission shaft had a reduction of 57% of its original weight. Since then Recently, Chrysler developed a car which was completely based on composite materials, and it's known as CCV (Composite Concept Vehicle).

Laminated composite materials are, generally lighter and stiffer than other structural materials. It consists of several layers of a composite mixture combination of matrix and fibers. Each and every layer can have similar (or) dissimilar material properties with having different fiber orientations under varying stacking sequence. Because of composite materials are produced in many several combinations and forms, the design engineer must consider many design alternatives. The structural components can made of composite materials such as different aircraft wings, helicopter blades, vehicle axles and turbine blades. This type of materials are used widely in structural applications where high strength-to weight and stiffness-to-weight ratios are required. In the composite's fiber orientations by altering lay-up, composite beam material can be tailored to meet the particular requirements of stiffness and strength .The ability to manufacture a composite material are due to high strength of the material, low weight ratio, resistance in fatigue and low damping factor. The composite materials have wide range of applications in car and aircraft industries. Research work in the design of mechanical, aerospace and civil structure and development of composite materials has grown tremendously in few decades. The main thing is designing and modeling of industrial products for finding the free vibration characteristics of Laminated Composite Beam (LBC). Composites beam analysis is main important in mechanical and civil structural design such as railways, car suspension system and structural foundation.

V. Tita, J. de Carvalho and J. Lirani [1] contributed for better understanding of the dynamic behavior of components made from fiber reinforced composite materials, specifically for the case of beams. In order to investigate the influence of the stacking sequence on the dynamic behavior of the components, using the Finite Element work has been carried out by experimental and numerical analysis and then results are presented and discussed. Subramanian [2] has investigated free vibration analysis of LCBs by using two higher order displacement primarily based on shear deformation theories and finite elements. Each theory is assumed as quantic and quartic variation of in-plane and transverse displacements within the thickness coordinates of the beam respectively. Results are indicating that application of those theories and finite element model leads to natural frequencies with higher accuracy. Banerjee [3] has investigated the free vibration of axially laminated composite Timoshenko beams using dynamic stiffness matrix technique. L Santosh Sreekanth, and m kumaraswamy [4] used to two different fibers analyze the critical buckling loads at relative cracked and non-cracked beam including crack depth.

In this present work the fabrication of E-glass fiber reinforced beam dimensions 200mmX40mmX9mm was carried out by hand lay-up technique. The natural frequencies of these beams ware evaluated for different boundary conditions like Cantilever, Simply supported, Fixed-Simply supported and Fixed-Ended. The evolution of the natural frequencies for above conditions was carried out using accelerometer, impact hammer and FFT analyser which been operated using DEVESOFT software. The numerical evolution the first three natural frequencies for above boundary conditions was also carried out using Euler beam equation. The evolution was also carried out by simulating the composite beam using ANSYS 16.2 the natural frequencies those obtained ware compared and necessary graphs are adopted.

• NUMERICAL ANALYSIS

2.1 Laminate code

A composite Beam consists of three layers orientations they are 0^o, 30^o,-45^o. Every layer can be identified as it's an angle of orientation and position of laminate can be placed with respect to a reference co-ordinate axis.

0
30
-45

2.2 Determination of Reduced Stiffness Unidirectional Lamina

To determine the reduced stiffness matrix, longitudinal elastic modulus, Transverse elastic modulus, Major poisons ratio, Minor poison ratio and Shear modulus are required for the given composite materials. Formulas used for determining reduced stiffness matrix are following below.

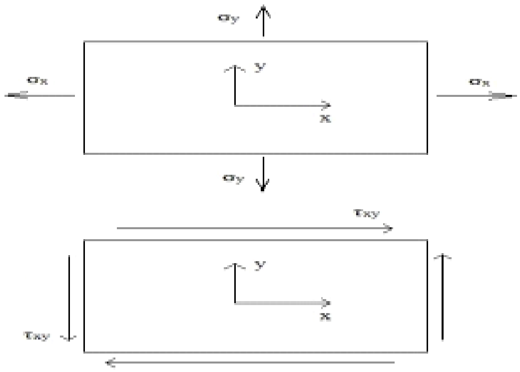

Figure 1: Application of stresses in angle of lamina

Therefore the application of stresses to find out the engineering constants of a unidirectional lamina

………..(2.1)

.............(2.2)

………..(2.3)

……………(2.4)

Since normal stresses are applied in the 1–2 direction do not result in any shearing strains in the 1–2 plane because $Q_{16} = Q_{26} = 0$ therefore unidirectional lamina is an especially orthotropic lamina. Also, the shearing stresses applied in the 1–2 plane do not result in any normal strains in the 1 and 2 directions because $Q_{16} = Q_{26} = 0$. A woven composite with its weaves perpendicular to each other and short fiber composites with fibers arranged in perpendicularly to each other or aligned in one direction also are especially orthotropic.

2.3 Determination of D_{11} Matrix

2.3.1 Hooke's Law for a Two-Dimensional Angle Lamina

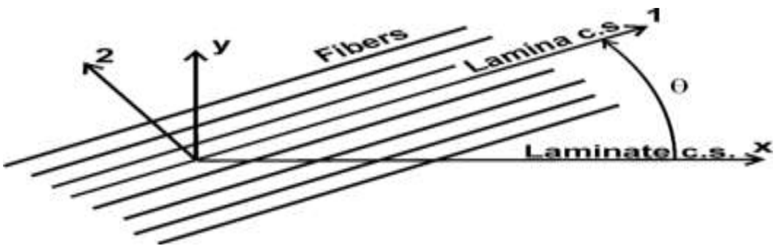

Figure 2: local and Global axes of an angle lamina

Direction of 1 is parallel and the direction 2 is perpendicular to the fibers. In some literature, direction 1 is also called the longitudinal direction L, and the direction 2 is also called the transverse direction T. The axes of the x–y coordinate system are called the global axe (or) the off-axes. The angle between the two axes is denoted by an angle θ. The stress–strain relationship in between the 1–2 coordinate systems is defined as

………….(2.5)

Where [T] is called the transformation matrix and is defined as

……………(2.6)

C=Cos (θ),

S=Cos (θ).

Therefore the stress-strain equation, global and local strains are to be written as

……………..(2.7)

Where

[R] =…………. (2.8)

Therefore after the multiplication of stress- strain transformed reduced stiffens matrix is

……………(2.9)

Where

2.3.2 Stress and Strain in a Laminate

The reduced transformed stiffness matrix [corresponds to that of the ply located at the point along the thickness of the laminate. The laminate can be expressed as

………..(2.10)

Know equation (2.9) can be written as

………..(2.11)

2.3.3 Force and moment resultants related to mid-plane strains and curvatures.

From the strain equation (2.10) we can find the stress and strains. The relationship between applied loads, mid-plain strains and curvatures is developed in this theory. Know the thickness of beam in mid-plane so the "n" number of plies and the each play thickness is "t_k" total thickness of laminate 'h' is

Integrate the global stresses in each lamina and it gives the resultant forces, and resulting moments per unit length, consider x-y plane as on mid-plane of laminate thickness as

Where

N_x N_y is normal force per unit length.

N_{xy} Is shear force per unit length.

M_x M_y Is bending moments per unit length.

M_{xy} Is twisting moments per unit length.

Therefore the equation (2.11) is substitute in equation (2.12) the mid plain stains and beam curvatures are independent of Z-coordinate. The transformed reduced stiffness matrix [is constant in each play. So, the equations can be written as

(2.13a)

(2.13b)

We know that

Equation (2.14) is substituting in Equation (2.13) gives

………..(2.15a)

………..(2.15b)

Where

Similarly where i, j = 1, 2, 6.

The [A], [B], and [D] matrices are called the extensional, coupling, and bending stiffness matrices respectively.

2.3.4 Natural frequency

Is natural frequency in radians per unit time for the n^{th} term of vibrational mode. In this case is n=1, 2, 3... etc.

Where

= n^2 (Constant)

l = Length of the beam

b = width of the beam

=Density of the composite material

Value of is given in following table 1 for all types of support i.e. cantilever, simply supported, fixed-simply supported and fixed-ended.

Table 1

n	Cantilever	Simply supported	Fixed-Simply supported	Fixed-Ended
1	3.516	9.870	15.42	22.37
2	22.03	39.48	49.96	61.67
3	61.70	88.83	104.25	120.90

The natural frequencies of composite beam can determine by using

- **EXPERIMENTAL ANALYSIS**

3.1 Manufacturing of composite beam

E-Glass fiber reinforced composite beam is fabricated by using hand lay-up method. The composite beam consists of three layers each layer has different fiber orientations 0^o 30^o-45^o with respect to the reference axis. In the fabrication process E-glass fiber, Epoxy (GY-257) and hardener (HY-140) are used to fabricate the composite beams. Measure the weight of E-glass fiber, it is in 50% of epoxy and the hardener is taking in 30% of epoxy. Epoxy and hardener are mixed continuously, now take polishing cover and it is placed with smooth surface then apply the epoxy on the polishing cover with the help of brash. In the first layer Fibers are arranged in 0^o orientation and apply the epoxy on the fibers. For second layer the fibers are arranged in 30^o orientation and apply the epoxy on the fibers. Similarly, the third layer fibers are arranged in -45^o orientation. Then apply the epoxy on the E-glass fibers and place the polishing cover on the surface of the composite beam. Now remove the air baubles from the composite material by using squeegees on the surface and it is solidified for 24 hours, after solidification the composite material is cut in to the required dimensions of the beam.

Figure 3: E-glass fiber

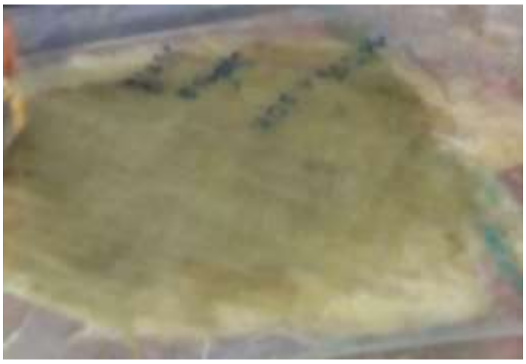

Figure 4: Composite plate

Figure 5: composite beams

3.2 Experimentation

In the present experimentation work natural frequencies are calculated at different boundary conditions of composite beam like cantilever beam, simply supported beam, fixed-simply supported beam and fixed-ended beam as shown in fig 6. Mainly the requirements of an experimentation work

-
- Composite Beams,
- C-Clamped Fixers,
- Impact Hammer (2000LBF)
- Connectors.
- Accelerometer (50G),
- Data acquisition system, `
- DEWE Software,

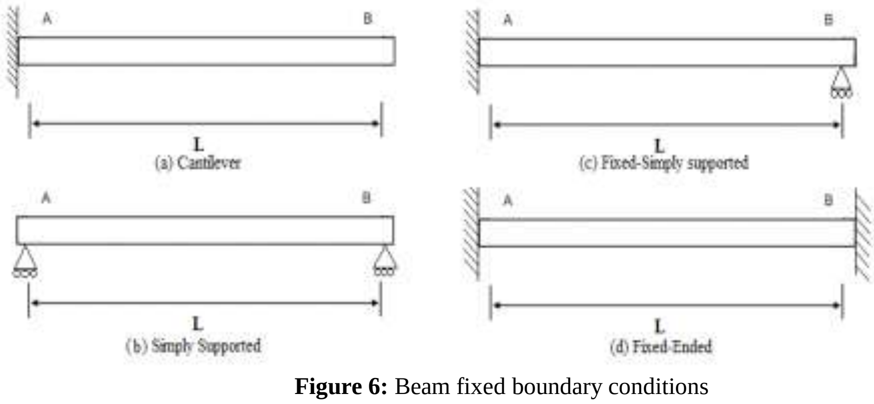

Figure 6: Beam fixed boundary conditions

The C-clamped fixers are used to fix at the different fixed boundary conditions of composite beam. Connect the accelerometer and impact hammer to the data accusation system (DAQ) using connectors. DAQ is mainly used for measuring the vibration with help of DEVESOFT. The accelerometer is placed on the composite beam with the help of wax; the experimental setup is shown in fig-7. Now the excitation is created on the composite beam with the help of impact hammer. After the excitation the beam was fluctuated, now open FFT graph in the DEWESOFT software and measure the natural frequencies of the composite beam.

Similarly the experimentation is carried out on E-glass fiber reinforced composite beam at different boundary conditions like cantilever, simply supported, fixed-simply supported and fixed-ended boundary conditions.

Figure 7: Experimental Setup

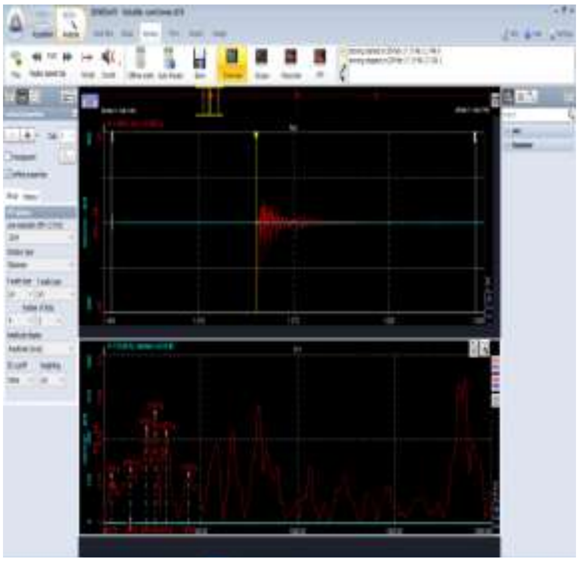

Figure 8: Frequency variation graph in DEWE Software

- **SIMULATION**

Composite beam is created by using ANSYS 16.2. In this analysis two conditions are consider, first one is fiber orientations and the second one is different boundary conditions of beam. The beam consists of three layers orientations 0^o, 30^o,-45^o. Every layer can be identified as their angles of fiber orientation with respect to the reference co-ordinate axis. Orthotropic material properties of composite beam as mentioned in table 2.

Table 2: Properties of Composite Beam Material

Length (l)	0.2m
Width (w)	0.04m
Thickness (t)	$0.009x10^{-3}$m
Area (A)	3.6X
Density (ρ)	1413.06 kg/
Moment of inertia (I)	2.43X
Young's modules (E_{xx})	16.3744 Gpa
Young's modules (E_{yy}= E_{zz})	4.0125 Gpa
Poisons ration's (υ_{yz})	0.52908
Poisons ration's ($\upsilon_{xy} = \upsilon_{xz}$)	0.2841`
Shear modules (G_{yz})	1.562 Gpa
Shear modules (G_{xy} =G_{xz})	1.5432 Gpa

4.1 Simulation Procedure

In the ANSYS modal generation is very important in this they are three stages preprocessor, solution and General post processor. In preprocessor stage the element type, material properties and real constants are specified. Next solutions stage the boundary conditions and loads are specified and the general post processor stage regarding the best results are considered. Modal is generated by selecting the area option and enter the dimensions of the beam, then go to extrude option and enter the extruded length. Now the boundary conditions are applied at one end of the composite beam then it is cantilever beam. In the modal analysis is carried out by using Block Lonczos method the natural frequencies are calculated at the boundary conditions of composite beam.

Similarly the same procedure was repeated on the composite beam at different boundary conditions like cantilever, simply supported, fixed-simply supported and fixed-ended boundary conditions.

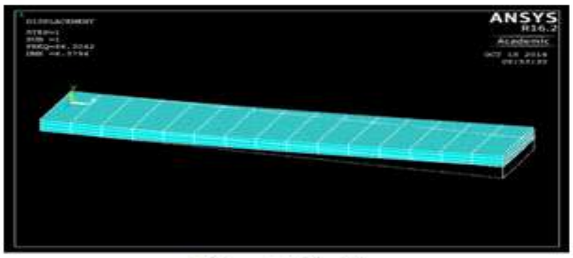

Figure 9: Cantilever

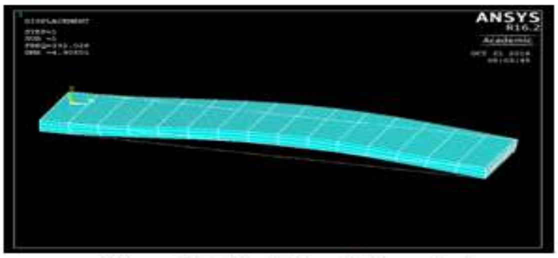

Figure 10: Fixed-Simply Supported

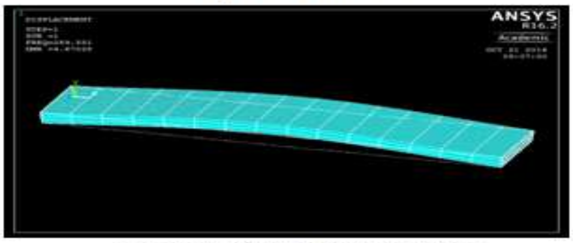

Figure 11: Simply Supported beam

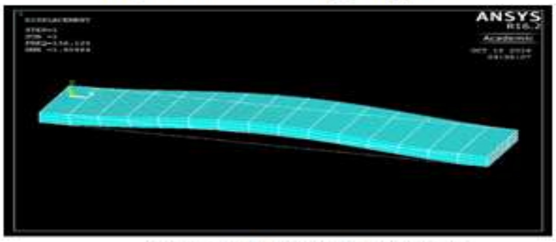

Figure 12: Fixed-Ended Beam

- **RESULTS AND DISCUSSIONS**

The Young's modulus, Shear modulus, Poisson's ratio and Density of composite beam were calculated from weight fractions and volume fractions considered for fabrication of beams.. In the numerical analysis the mechanical properties are used to calculate the natural frequencies at different boundary conditions. Experimentation and simulation were carried out at different boundary conditions of composite beam using FFT analyzer and ANSYS.

The numerical results obtained for different boundary conditions of the composite beam were compared in figure 13, the experimental and simulation results were compared in figure 14 to 15. The overall results are shown in figure 16. The three natural frequencies obtained cantilever beam are less than that of to simply supported beam condition which are further less than to fixed supported beam. The natural frequencies obtained for the fixed - ended beam condition are greater than to the remaining boundary conditions of composite beam. The same phenomenon is also observed in experimental as well as simulation results. The numerical, experimental and simulation comparisons of first three natural frequencies are shown in graphs from figure 17 to figure 20 for different boundary conditions of the composite beams. The reason for variation in the first three natural frequencies of the composite beams for different boundary conditions is due to the change in the stiffness of the beams in each condition.

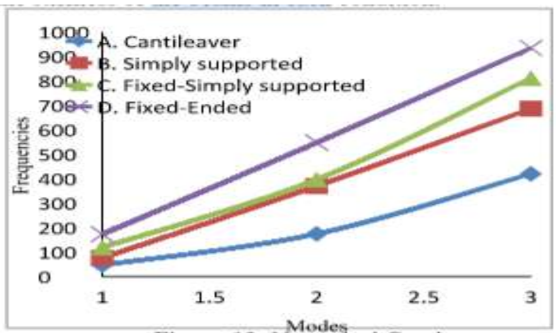

Figure 13: Numerical Graph

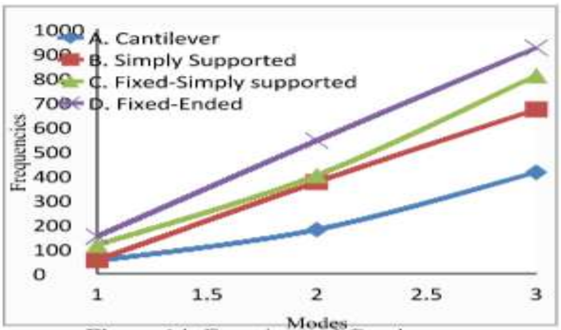

Figure 14: Experimental Graph

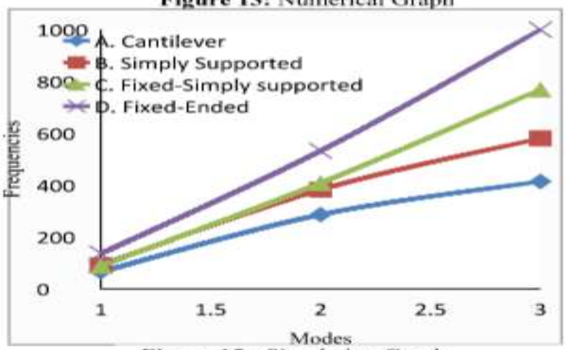

Figure 15: Simulation Graph

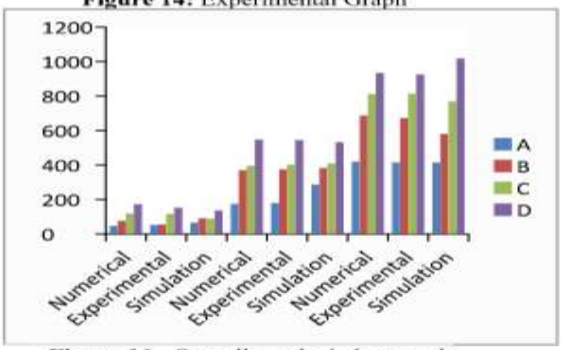

Figure 16: Overall results in bar graph

Theoretical, Experimental and Simulation Results are Comparing at different boundary conditions of beam

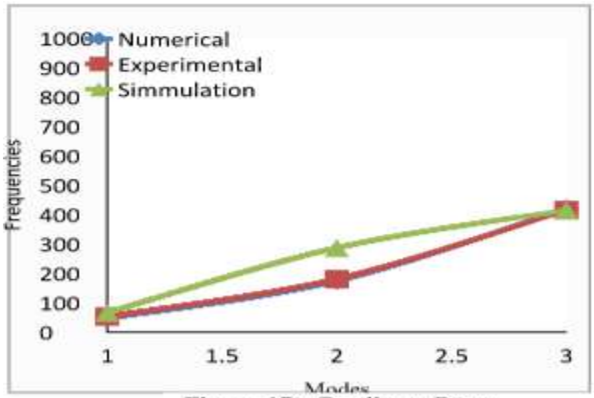

Figure 17: Cantilever Beam

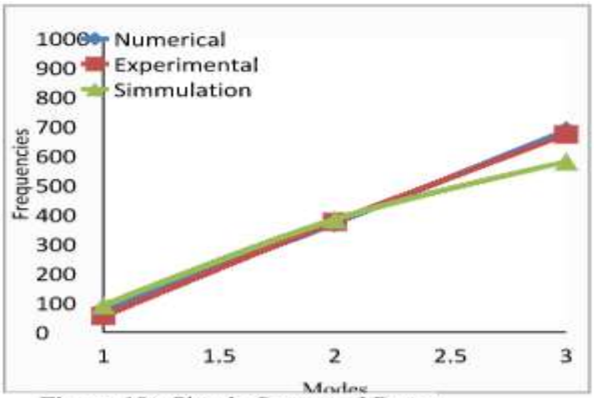

Figure 18: Simply Supported Beam

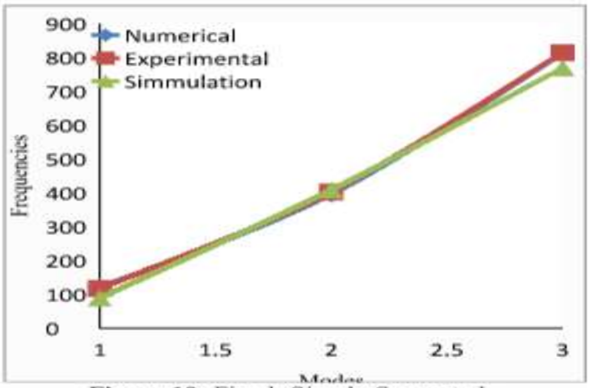

Figure 19: Fixed- Simply Supported

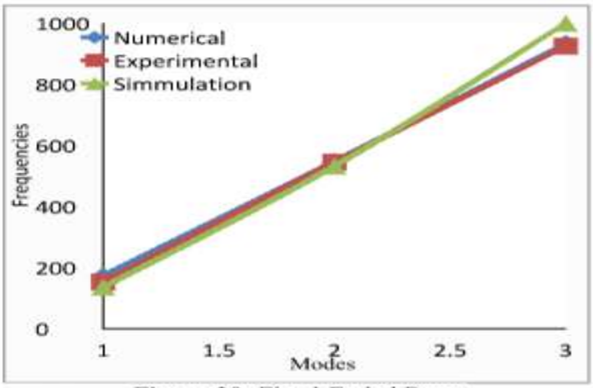

Figure 20: Fixed-Ended Beam

• CONCLUSIONS

In the present work the free vibration analysis of E-Glass fiber reinforced composite beams are investigated numerically, experimentally and by simulation using ANSYS. The results are well corroborated. In each of the above procedures the first three natural frequencies at different boundary conditions like cantilever, simply supported, fixed-simply supported and fixed-ended conditions of the composite beams are evaluated and also compared. The process can be repeated for composite beams having other layer orientations with different volume fractions. The work can also be carried out by harmonic analysis. The simulation can also be done using MATLAB.

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