ISSN XXXX XXXX © 2019 IJESC

Research Article Volume 9 Issue No.1

Modal Analysis of Composite Beam using MATLAB

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Abstract:
Modal analysis is a method to describe the dynamic properties of a structure such as natural frequency, mode shape and damping ratio. These properties are important for the design and analysis of structures in a dynamic condition. MATLAB is a high-performance numerical computation and visualization software package. It provides an interactive environment with hundreds of built-in functions for technical computation, graphics, and animation. In the present analysis, free vibrational characteristics of a structure made of composite materials were analysed using MATLAB software. The study involves finding the natural frequencies and mode shape of structure made of Glass-epoxy, Carbon-epoxy and Graphite fibre reinforced polyimide materials. Euler's-Bernoulli beam theory is used for an analytical solution and to construct MATLAB codes. The structure considered here is a beam with fixed-free, fixed-fixed, boundary conditions, also ANSYS software used to calculate the mode shapes and corresponding natural frequencies. The modal parameters of different composite materials with different boundaries conditions were analysed with different densities.

Keywords: Modal analysis, Modal parameters, Composite beam, Natural frequency, Mode shape Stiffness, MATLAB, Ansys, Resonance.

I. INTRODUCTION:

Composite material made from two or more constituent to form single material they are two constituent one is matrix another one is reinforcement. Matrix provides protective cover from environmental or moisture and it is also providing the same load can transfer to reinforcement and reinforcement is surrounded by matrix. The main function of reinforcement is to increased strength and stiffness of composite some examples of composite materials are glass-epoxy, carbon-epoxy both are composite materials glass and carbon are reinforcement and epoxy is matrix material. In both glass and carbon reinforcement carbon has high strength and stiffness compared to the glass but carbon is expensive than glass fibre [1].

The present development of new structure depends on advanced materials because of conventional materials not meet physical properties like high strength high, wear resistance and high-temperature resistance. The most advanced design of turbine blades, aircraft fuselage etc.no use if adequate materials to bear the service loads and conditions are not available then structure undergoes fail. Whichever the field may be final limitations on to developed new materials.The idea of composite materials is not a recent one. In ancient people, they used composite materials some of the examples are clay pots and ceramics things. Some naturally available composite is wood is a fibrous composite cellulose fibre and lignin is a matrix material. Cellulose fibres have high tensile strength but they are very flexible in nature then lignin matrix combined with fibres to increase the stiffness. Another example is a human body is also made up of some composite materials example is bone and it also made up of two materials they are short and soft collagen fibres this fibre enclosed with mineral matrix called apatite. Present era there has been an increasing demand for materials that are better overall performance such as high strength, high stiffness, high fatigue life, less corrosion resistance; low wear resistance, low weight.

II. LITERATURE REVIEW:

Tarun K Mehta, Rakshith, Gowda D et.al [1] presented the modal analysis of organic-matrix composite with different percentage of Si_3N_4. In this paper taken two different composites i.e. epoxy composite, and carbon epoxy composite by varying the percentage of Si_3N_4 (0%,6%,10%). It was observed that the inclusion of 0 to 10% of Si_3N_4 in a structure, the natural frequency increases due to the increases the modulus of elasticity (E). By the help of Analytical and ANSYS, the solution was found out and an answer was correlated.

Md. Shumon Mia, Md. Shahidul Islam et.al [2] described the vibration analysis of a cantilever beam. FEM analysis is done on a proposed beam by introducing crack in it in this paper calculated the natural frequencies of the both cracked and un-cracked cantilever beam. In this journal Abaqus, FEM software is used for vibration analysis. And included the effect of mesh elements, crack opening size, and effect of crack depth of beam analysed by using Abaqus software.

M. Rastgaar Aagaah, M. Mahinfalah et.al [3] determining the natural frequencies of laminated composites structure using third-order shear deformation theory. The structure was square plates and analysed these with different fly angles. The results obtained from analytical as well as FEM method were in good agreement.

The paperentitles "Analysis of composite beam using Ansys software" was presented by Jayalin.D, Prince Arulraj.G et.al [4] shown that in this paper analysis of composite beam with the inclusion of small opening was analysed. Author has taken Carbon fibre reinforced polymer and glass fibre reinforced

polymer and also studied the flexural effect of a beam by changing the load on an opening zone and material properties.
Mahmoud Yassin Osman, Osama Mohammed Elmardi Suleiman [5], presented a paper on "To study free vibration of rectangle laminated composite beams by using first-order shear deformation theory". In this paper formulated the mathematical equations and verified with the FEM method for Graphite epoxy composite structure. In this paper performed free vibration analysis of rectangle laminated beam with different boundaries conditions. The results obtained were compared with the results of previous work papers and it was found that the results are good agreements.
The Vibration attenuation place a very important in many electromechanical structures from the health point of structure M. R. Siddiqui, I. Ahmad et.al [6] were studied about the electromagnetic damping utilized for cantilever beam which is made of ferromagnetic material. Author has studied the vibration control of the structure experimentally. And also performed theoretical and FEM analysis. The results obtained by all methods were found to be a good agreement.
G.Rajeshkumar, V.Hariharan [7] in this paper "The free vibration analysis of hybrid-composite beams, analysed composite beam made of carbon-epoxy and glass-epoxy" also studied about the effect of fibre orientation ranges from 0 to 90 with aspect ratio ranges from 45 to 120 with different boundaries conditions.

III. OBJECTIVES:

1)The main goal of the present work is to determine the dynamic behaviour or modal characteristics of the composite beam.
2)Development of MATLAB codes for the dynamic analysis of a composite beam
3)To find out the natural frequency and mode shape of the composite beam. Using ANSYS and MATLAB software.
4)To find out the parameters affecting the natural frequency by using ANSYS and MATLAB software.

IV. PROBLEM STATEMENT:

From the literature survey, it was found that the dynamic analyses of a structure place a very important role in designing the components. The present work involves the evaluation of dynamic properties of a composite structure made of three different materials with different configurations. Initially, MATLAB codes will be developed to find the natural frequencies and mode shape using Euler's beam theory. Using Finite Element (FE) analysis it is planned to validate the result obtained from the MATLAB for correlation.

V. METHODOLOGY:

The following are the steps followed for analysisof composite beam with help of MATLAB and Ansys.

1) Mathematical formulation using Beam theory
2) Development of MATLAB codes
3) Validation of FEM solution
4) Comparison of results

Modal analysis of composite beam with different boundary conditions. To develop mathematical formulation by using Euler Bernoulli beam theory. Further beam theory is used to derive equations for calculating the natural frequencies corresponding to its mode shapes. Then these equations are further used for developing MATLAB codes. Then MATLAB results are compared with FEM (ANSYS). The given below equation derived from Euler's beam theory. It is used to find out the natural frequency. And βl value will changes according to boundaries conditions i.e. given Table II.

$$\omega = \beta^2\sqrt{\frac{EI}{\rho A}} \quad = (\beta l)^2\sqrt{\frac{EI}{\rho A l^4}}$$

ω is the natural frequency βl is constant it can be determined by different boundary conditions of beams. A is an area of the beam, E is Young's modulus, ρ is a density of material l is a length of the beam.

VI. RESULTS:

Figure.I. Physical model of beam

From above FigI show a physical model of the beam then dimensions are given as follows.
Length (L)= 250mm,
Width (b)= 25mm,
Thickness (t)= 1.5mm

Table.1. Material properties of Composites

Glass-Epoxy Composite	Carbon-Epoxy Composite	Graphite fiber Reinforced polyimide
E_x =40.59 Gpa	E_x =144.8 Gpa	E_x =129 Gpa
E_y =13.96 Gpa	E_y =9.65 Gpa	E_y =9.4 Gpa
E_z =13.96 Gpa	E_z =9.65 Gpa	E_z =9.4 Gpa
μ_{xy} = 0.22	μ_{xy} = 0.3	μ_{xy} = 0.3
μ_{yz} = 0.11	μ_{yz} =0.3	μ_{yz} =0.3
μ_{zx} = 0.11	μ_{zx} =0.3	μ_{zx} =0.3
ρ =1830 Kg/m^3	ρ =1389 Kg/m^3	ρ =1550Kg/m^3
G_{xy} =3.1 Gpa	G_{xy} =4.14 Gpa	G_{xy} =5.1Gpa
G_{yz} =1.55 Gpa	G_{yz} =3.45 Gpa	G_{yz} =2.5 Gpa
G_{zx} =3.1 Gpa	G_{zx} =4.14 Gpa	G_{zx} =4.3 Gpa

From the above Table, I show it is different composite materials properties. And boundary conditions and βl value is given below Table II.

Table.II. βl Value for different boundary conditions

Boundary conditions	Mode 1	Mode 2	Mode 3
Fixed-Free	1.875	4.693	7.854
Fixed-Free	4.729	7.853	10.995

- **MATLAB results:**

1) Glass-Epoxy Composite beam in Cantilever condition

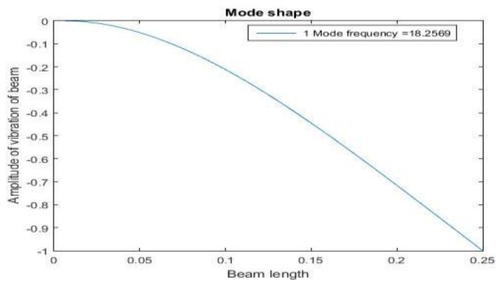

Figure. II – 1 Mode

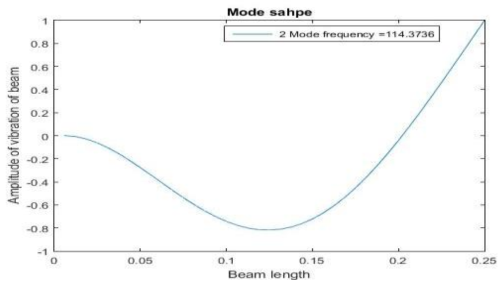

Figure. III – 2 Mode

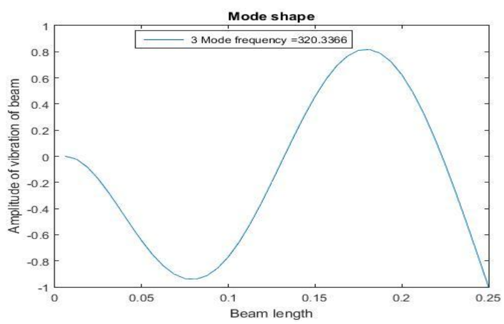

Figure. IV– 3 Mode

From Fig II to IV shows the first three mode shapes and its corresponding natural frequencies for a Carbon-Epoxy composite beam in Fixed-free condition

2)Glass-Epoxy Composite beam in fixed-fixed condition:

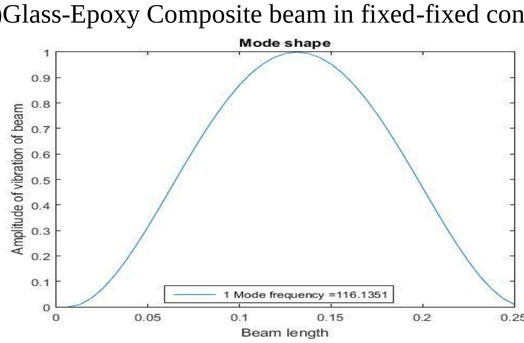

Figure.V – 1 Mode

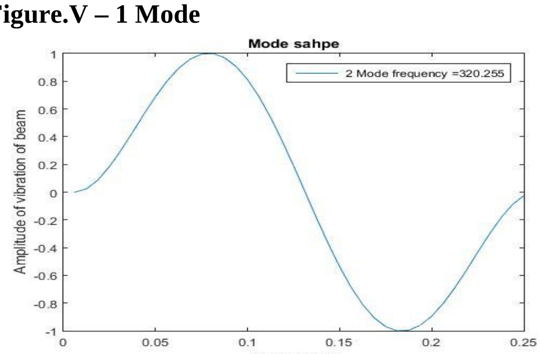

Figure.VI – 2 Mode

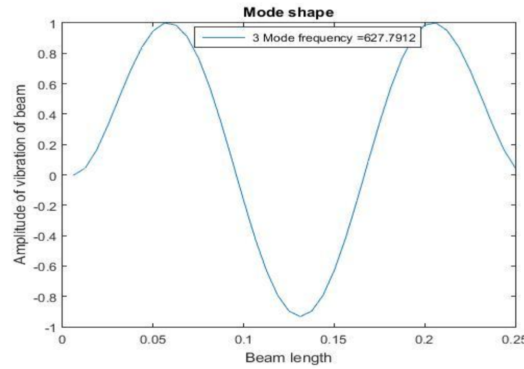

Figure.VII – 3 Mode

From Fig V to VII shows the first three mode shapes and its corresponding natural frequencies for a Carbon-Epoxy composite beam in Fixed-fixed condition and same procedure has to follow to obtained mode shape and natural frequency for other two composite materials.

Finite element Procedure:

ANSYS (APDL) version 11 is used for the numerical simulation. Any finite element tool comprises three main steps namely Pre-processor, processing, and Post-Processing.

Pre-processing: In this phase or a step, a finite element model is developed using 2D elastic beam element as a basic entity. This beam element has 3 DOF at each node i.e. two translation and one rotation. Also, the beam material properties and other parameters related to the beam namely, area, height and moment of inertia are assigned to the FE model.

Processing: In this phase essential and natural boundary conditions are applied. Finally, the problem is solved to obtain the primary unknown quantities.

Post processing: At this stage, results are listed and the mode shapes are visualized. The mode shapes obtained from the analysis are as shown in below figures for different materials as well as different boundary conditions of the beam.

- **ANSYS results:**

Glass-Epoxy Cantilever beam:

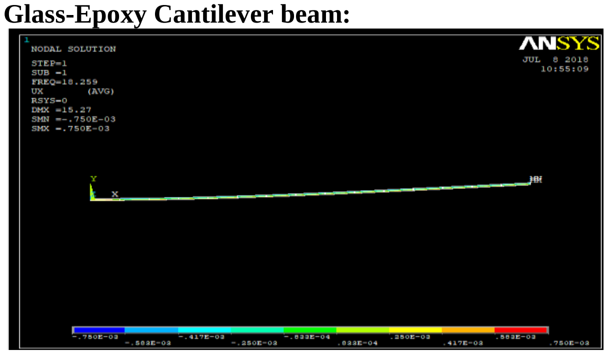

Figure. VIII – 1 Mode

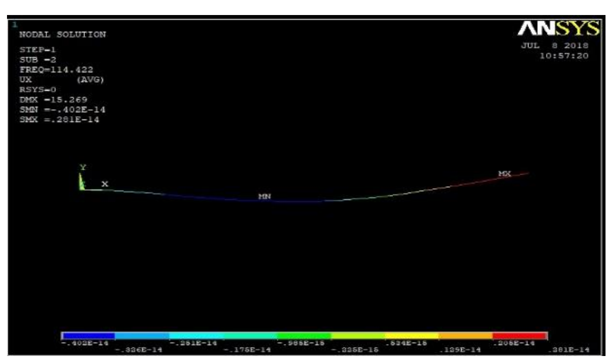

Figure. IX – 2 Mode

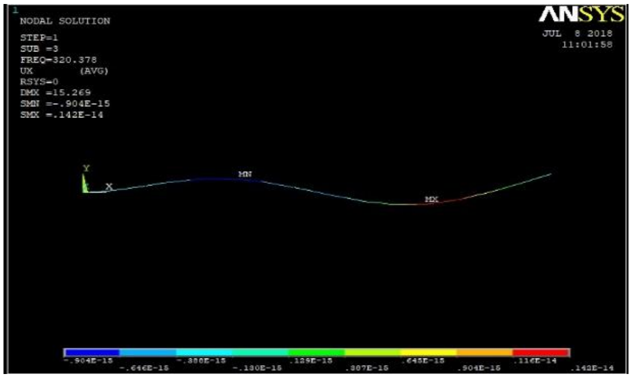

Figure. X – 3 Mode

From Fig VIII to X shows the first three mode shapes and its corresponding natural frequencies for a Carbon-Epoxy composite beam in Fixed-free condition

Glass-Epoxy Composite beam in fixed-fixed condition:

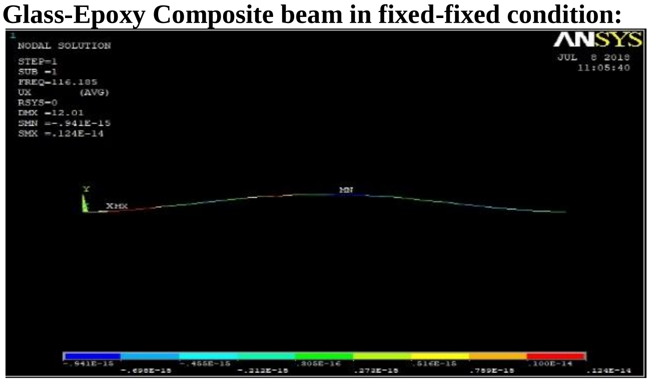

Figure. XI– 1 Mode

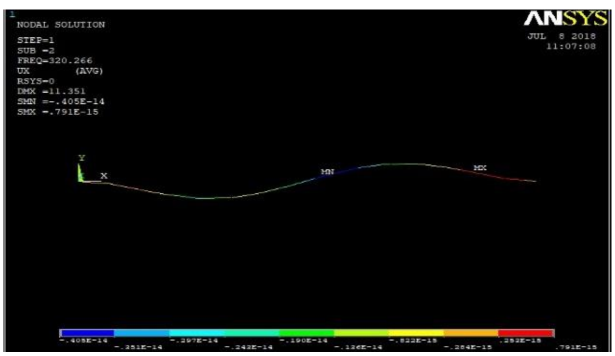

Figure.XII– 2 Mode

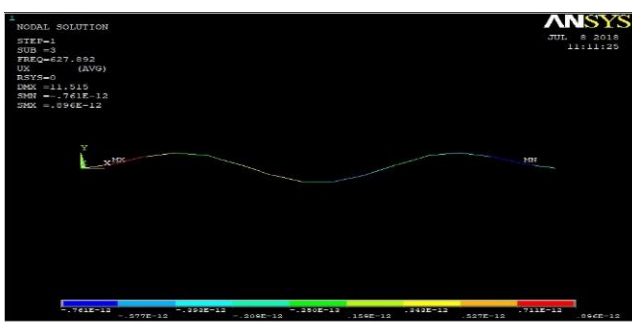

Figure.XII – 3 Mode

From Fig XI to XII shows the first three mode shapes and its corresponding natural frequencies for a Carbon-Epoxy composite beam in Fixed-fixed condition and same procedure has to follow to obtained mode shape and natural frequency for other two composite materials

Table.III. Comparison of MATLAB results with ANSYS results

Composite materials	Boundary conditions	Natural frequencies (Hz)					
		MATLAB results			ANSYS results		
		Mode			Mode		
		1	2	3	1	2	3
Glass-Epoxy	Fixed-free	18.256	114.373	320.335	18.559	114.42	320.38
	Fixed-Fixed	116.134	320.254	627.789	116.18	320.27	627.89
Carbon-Epoxy	Fixed-free	39.577	247.938	694.422	39.581	248.04	694.51
	Fixed-Fixed	251.756	694.246	1360.92	251.86	694.27	1361.1
Graphite fibre reinforced polyimide	Fixed-free	35.392	221.722	620.997	35.396	221.82	621.08
	Fixed-Fixed	225.136	620.839	1217.022	225.23	620.86	1217.2

Table III shows that MATLAB results are almost on par with the results obtained from ANSYS.

VII. DISCUSSION:

From the analysis, it has been observed that some of the parameters are directly affecting the natural frequencies. These parameters are

- Boundary conditions
- Density of material
- Stiffness

Boundary conditions: Modal analysis is carried out for different boundary conditions such as fixed-free, fixed-fixed, and pin-pin. It has been observed that the beam with fixed-fixed boundary condition has a higher natural frequency than other two boundary conditions with the same volume. This is because of the stiffness of beam, which is high in fixed-fixed condition.

Density: In the modal analysis, three different composites materials are taken i.e. Glass-Epoxy, Carbon-Epoxy and Graphite fibre reinforced polyimide. These materials are having different densities.From the results, it has been observed that higher the density the natural frequency decreases. Hence Carbon-epoxy composite beam shows the highest natural frequency as compared to other two composite beams.

Stiffness: Flexural rigidity means resistance offered by beam undergoing bending. From results higher the flexural rigidity (EI), the natural frequency is high. Among all three composite beams, it has been observed that Carbon-epoxy has higher flexural rigidity. This difference is because of higher Young's modulus for carbon-epoxy.

VIII. CONCLUSIONS:

- From the modal analysis of composites with different boundary conditions, it was found that the results of natural frequencies have shown a minimum error in comparison. Hence the results are consistent.

• The natural frequency is maximum at the fixed-fixed condition when compared with all other boundary conditions.

• Higher natural frequencies were found in Carbon-Epoxy composites due to higher Flexural rigidity (EI) when compared with other composite materials.

• Graphite – fibre reinforced polyimide composites have shown higher natural frequencies when compared with Glass-Epoxy composites

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