A Comparative Study of Finite Element Analysis on Cantilever Beam with Different Materials Subjected toUniformly Distributed Load

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Abstract

The beam structure finds itsapplications in various fields such as the aviation sector, wind industries, mechanical and civil fields. In these fields, a cantilever beam is one of the most common structuralelement. For a successful mechanical design structure, proper material selection is one of the most vital factor. In this study, a numerical approach has been carried out to investigate the free vibration and static structural analysis of rectangular shape cantilever beam with different materials such as structural steel, carbon fiber/epoxy, glass fiber/epoxy. A comparative study of finite element analysis such as natural frequency, Von-mises stress, and deformation has been accomplished for structural steel, carbon fiber/epoxy, and glass fiber/epoxy. Also, a magnificent weight reduction is demonstrated for composite material. Here, carbon fiber and glass fiber have been considered as fiber and resin epoxy is considered as matrix. At Ansys ACP, for the composite material, twelve layers of lamina has been considered for carbon fiber/epoxy and glass fiber/epoxy. Unidirectional laminas are used in laminated composite layups. The stacking sequence is considered $[0^0]_{12}$ and the lamina thickness is 0.5mm for both composite materials. The result of this study can be applied to select the best material for cantilever type beam structure under static and dynamic loading conditions.

Keywords: Composite material, Ansys ACP, FEA, Cantilever beam, Weight reduction, Natural frequencies, Modal analysis, Static structural analysis

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1. INTRODUCTION

In the last several years, due to their desirable properties such as high strength-and stiffness-to-weight ratio and anisotropic properties of a material, composite beams structure, columns, and rods are widely employed in the civil, mechanical, aeronautical, and aviation sectors. In many fields, fiber-reinforced composite materials have overtaken traditional materials such as mild steel, structural steel, and stainless steel in popularity. Composite beams, often known as spars, are used in lightweight components like aircraft wings and wind turbine blades to give main stiffness against bending deformation. They are also commonly utilized in the aviation sector owing to their capacity to resist large temperature and pressure variations. Also, they are commonly used in the manufacture of plane fuselage and wings, rudders, elevators, wing flaps, spoilers, floor beams and panels, helicopter main and tail propeller blades, space vehicles, missiles, rockets, and so on because of their excellent mechanical properties. It is necessary to do a vibration study on a structure in order to ensure that it is safe. Natural frequency and static structural analysis are the two most important characteristics that determine a structure's safety in this way. When a cyclic load is applied, the urge to vibrate is very common. Dynamics is regarded as one of the most essential and significant aspects of designed-based mechanical engineering research. The modal is concerned with the dynamics of mechanical structures when they are subjected to dynamical excitation. Resonance occurs when the amplitude of a beam's natural frequency and the periodic load applied to the beam are equal. The current comparative study is concerned with free vibration and static structural analysis of a

cantilever beam with different materials. Cantilever-like structures are used extensively in the aerospace, civil, mechanical, and wind sectors[1–6].

An ample number of studies of vibration and structural analysis of cantilever beams had been conducted, both numerically and experimentally. Prombut[1]concentrated on classical beam theory, finite element analysis, and first-order shear deformation theory to investigate the deflection of Glass/Epoxy composite cantilever beam. Talekara and Kotambkar[2] focused on the composite cantilever beam with symmetric stacking sequence and 45^0 fiber orientation to investigate the vibration modes of transverse, torsional, and bending by finite element analysis on the Ansys workbench. Four different stacking sequence and five different lengths to thickness ratio has been implemented. They concluded that stacking sequence and fiber orientation can play a vital role in modal analysis. Sahoo and Jena [7] developed an artificial neural network to investigate the modal analysis of a crack cantilever beam, which was made of glass fiber reinforced polymer. Also, a MATLAB code had been generated to analyze the natural frequency. However, there was no discussion of lamina thickness and fiber orientation of composite material. A mild steel cantilever beam with different crack locations and different crack dept had been developed by Ahiwale et al. [8] to investigate the natural frequency. Noolviand Nagarajahar[9]developed a smart hybrid composite cantilever beam. They had analyzed the natural frequency of the smart hybrid composite beam. But there was no mention of the number of lamina and lamina thickness. Gariya et al. [10] focused on a comparative study of soft polymer composite cantilever beams. Critical allowable stress had been investigated by applying the load condition of UDL and point load. Charan et al. [11] focused on vibration analysis of T-section cantilever beam by using Ansys and Matlab. Material, they had considered was mild steel, aluminum, and structural steel. Arunkumar et al. [12] focused on a finite element analysis of cantilever beams with different aluminum alloys. Different type of aluminum alloy were considered to investigate the modal analysis of cantilever beam. They concluded that natural frequency and deformation are related to the modulus of elasticity and density of the material. Also, they had reached a conclusion that increasing the silicon percentage in the aluminum alloy will increase the natural frequency. Tehand[13]revealed that the coupling effect and mode shape can vary by the change of fiber orientation. Also, they concluded that a small increase in fiber orientation can change the mode shape suddenly.

2. THE GEOMETRY OF THE CANTILEVER BEAM

Depending upon the design of the cross-section, various types of cantilever beams are available. A rectangular type cross-section cantilever beam has been investigated in this study. For Finite element analysis, the dimension of the cantilever beam is considered 600mm in length, 30mm in width, and 6mm in thickness.

3. PROPERTIES OF MATERIAL

Mechanical properties of carbon fiber, glass fiber, resin epoxy, and structural steel are shown in Table 3.1, 3.2, 3.3 and 3.4 respectively.

Table 3.1.Mechanical property of carbon fiber[14]

Young Modulus (GPa)	Poisson Ratio	Bulk Modulus (GPa)	Shear Modulus (GPa)	Density(kg/m^3)
230	0.2	-	9	1800

Table 3.2.Mechanical property of glass fiber[15]

Young Modulus (GPa)	Poisson Ratio	Bulk Modulus (GPa)	Shear Modulus (GPa)	Density(kg/m^3)
90	0.22	53.571	36.885	2500

Table 3.3.Mechanical property of resin epoxy[16]

Young Modulus (GPa)	Poisson Ratio	Bulk Modulus (GPa)	Shear Modulus (GPa)	Density(kg/m^3)
3.78	0.316	4.2	1.4	1160

Table 3.4.Mechanical property of structural steel[15]

Young Modulus (GPa)	Poisson Ratio	Bulk Modulus (GPa)	Shear Modulus (GPa)	Density(kg/m^3)
200	0.3	166.67	76.923	7850

4. SIMULATION ON ANSYS

Finite element analysis on Ansys, modal analysis is a technique for predicting the vibration properties of structures, such as natural frequencies, mode shapes, and viscous damping coefficients. In engineering design and analysis, these properties are significant. In this study, the modal analysis has been investigated to predict the vibration characteristic of the cantilever beam at different mode shapes. Also, Static structural analysis has been studied to understand the maximum stress and deformation induce location on the beam.

At Ansys ACP, composite materials have been designed. Carbon fiber and glass fiber are used as fiber and resin epoxy is used as matrix. Twelve layers of lamina are considered for carbon fiber reinforced polymer. Also, twelve layers of lamina are considered for glass fiber reinforced polymer. In a laminated composite layup, a unidirectional lamina is considered. The stacking sequence of carbon fiber and glass fiber is considered $[0^0]_{12}$ and lamina thickness is 0.5mm.

The visual representation of the mode shape for the cantilever beam using Ansys is presented in the form of the figure. Figure 4.1-4.3 represent the vibration characteristic of structural steel, glass fiber/epoxy, and carbon fiber/epoxy respectively at mode 6.

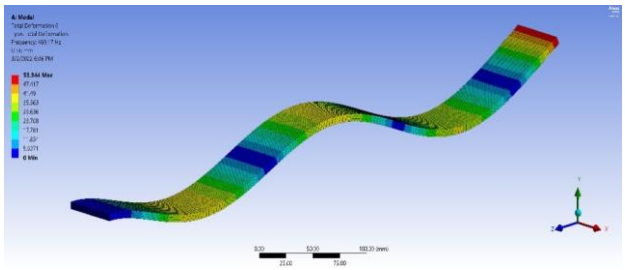


Figure 4.1. Natural Frequency of structural steel at Mode 6

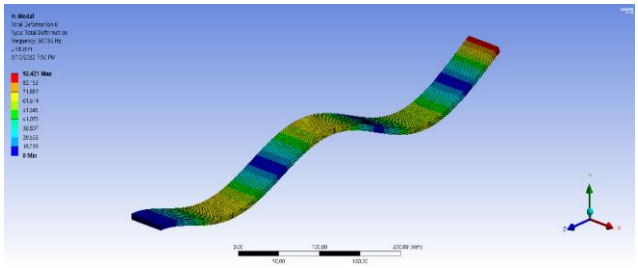


Figure 4.2.Natural Frequency of glass fiber/epoxy at Mode 6

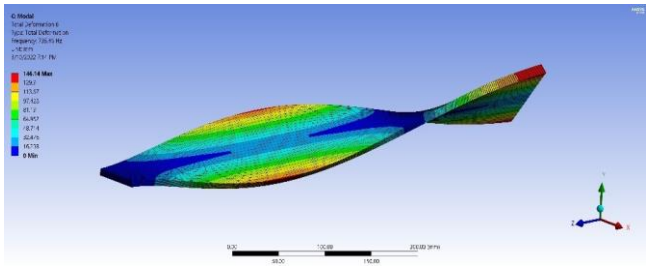


Figure 4.3.Natural Frequency of carbon fiber/epoxy at Mode 6

5. RESULT AND DISCUSSION

5.1. Calculating The Natural Frequency for Different Materials

When a mechanical component undergoes dynamic loading, free vibration analysis will be the most important design parameter. Modal analysis is a technique for determining a mechanical structure's natural frequency and mode shape when it is subjected to free vibration[6].

Table 5. shows that the change of natural frequency for different materials is not the same for all modes of vibration. Every material contains a particular frequency depending on their mechanical property. Due to the high modulus of elasticity and lower mass density the natural frequency of the composite beam is more compared to the structural steel beam. Noolvi et. al. [9]used equation 5.1 to find out the natural frequency of the cantilever beam analytically. For example, at mode 6, the natural frequency of carbon fiber/epoxy is higher than glass fiber/epoxy and structural steel. In figure5.1, the graphical representation of natural frequency has been illustrated.

$$f = \frac{(\beta l)^2}{2\pi}\sqrt{\frac{EI}{\rho A l^4}} \quad (5.1)$$

$$\delta = \frac{Wl^3}{3EI} \quad (5.2)$$

Table 5.1.The natural frequency of cantilever beam for different materials at different mode shape

Material	Natural Frequency (Hz)					
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Structural Steel	13.659	85.545	112.79	239.46	304.91	469.17
Glass fiber/Epoxy	17.173	107.49	131.65	300.5	382.96	587.56
Carbon fiber/Epoxy	31.978	199.32	237.31	238.39	553.32	735.46

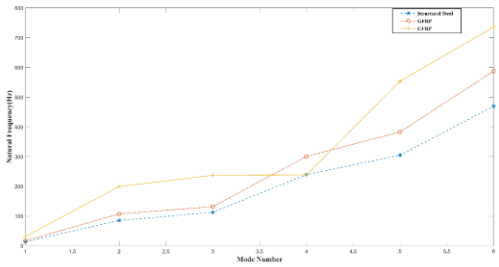


Figure 5.1.Natural Frequency of Each Material

5.2. Static Structural Analysis

For design engineers, it is regarded as a safe value. It's a simple approach to check static structure on Ansys. The material fails when the yield stress value is smaller than the equivalent Von Mises stress value created in it. According to most engineer's experience, normal stress theory somehow doesn't work in many applications[17].

A uniformly distributed load has been applied on the top surface of the beam when one end is fixed. in this case, the applied load is 5N. Figure5.2. is showing the visual representation of static structural analysis of the cantilever beam.

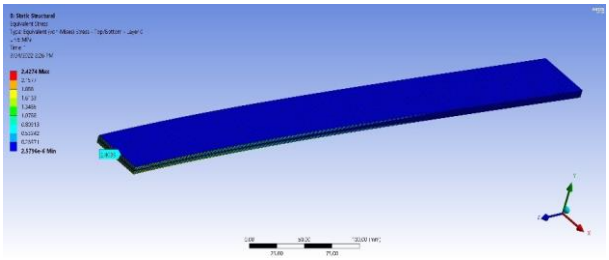
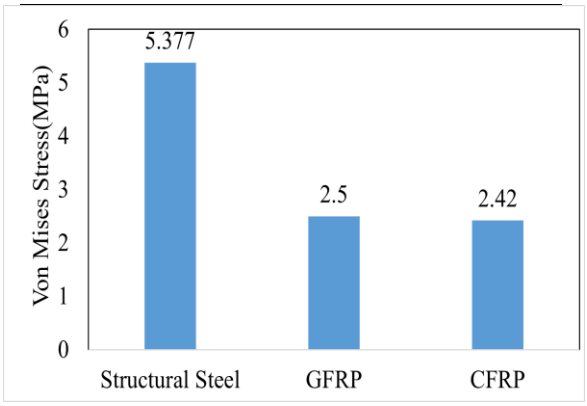


Figure 5.2.Von Mises Stress of Carbon fiber/epoxy

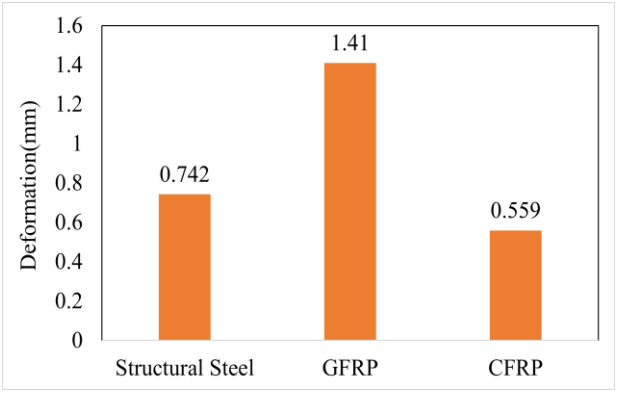
The comparative study of static structural analysis is shown in Table5.2. Where the von-mises stress induces less in composite material compared to structural steel. Due to the lower modulus of elasticity, deformation is more in glass fiber/epoxy. Basavaraj Noolvi et.al.[9]has used equation 5.2 to investigate the deformation of cantilever beam analytically. The graphical representation of static structural analysis has been shown in figure 6.

Table 5.2.Static structural analysis of cantilever beam

Material	Von Mises Stress (MPa)	Deformation (mm)
Structural steel	5.377	0.742
Glass fiber/epoxy	2.5	1.41
Carbon fiber/epoxy	2.42	0.559



(a)



(b)

Figure 5.3.(a)Deformation of Each Material, (b) Von Mises Stress of Each Material

5.3. Weight Reduction

To get greater mechanical efficiency weight reduction is the most important[18-22] part of the design parameter. The graphical representation of weight reduction for the cantilever beam has been demonstrated in figure5.4It indicates that using carbon/epoxy and glass fiber/epoxy, weight reduction of 78.34% and 68.41% respectively has been achieved as compared to structural steel.

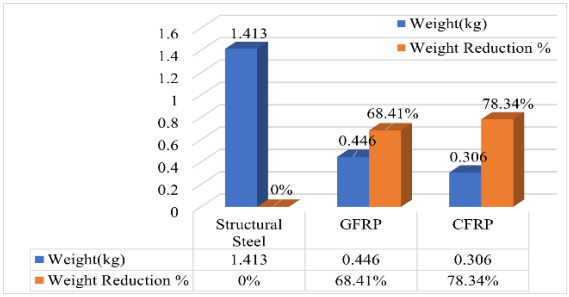


Figure 5.4.Weight Reduction of Each Material

6. CONCLUSION

Composite materials are used in this study are carbon/epoxy, glass/epoxy, and conventional material is structural steel. Natural frequency, von-mises stress, deformation, and weight reduction have been compared in this study.

- Due to its higher stiffness and low mass qualities of composite material, carbon/epoxy and glass/epoxy have high natural frequency compared to conventional material of structural steel. The natural frequency of carbon/epoxy, glass/epoxy, and structural steel are 735.46 Hz, 587.56Hz, and 469.17Hz respectively at mode 6. Is being observed that, composite materials have a high natural frequency compared to structural steel. As a result, composite materials can withstand more resonance due to their high natural frequency.
- When comparing carbon/epoxy, glass/epoxy to structural steel, deformation is greater in glass/epoxy. The reason for this is that glass/epoxy has a lower modulus of elasticity. But, due to the high modulus of elasticity of carbon fiber, deformation is less compared to other materials.
- Through the static analysis tool, when a uniformly distributed load is applied on the top surface of the cantilever beam, the von-misses stress induces less in the composite material beam compared to the structural steel beam. As a result, composite beams can be bear a higher amount of load and will produce less stress compared to the structural steel beam. It has been found that the maximum equivalent Von Mises stress is developed at the fixed end of the cantilever beam. This issue must be kept in mind

while designing and fabricating the cantilever beam.

- Weight reduction has been achieved in the composite beam due to the lower density of composite material compared to the higher density of structural steel.

This study has led to the conclusion that composite material could be the most promising material for beam structure. Due to their magnificent weight reduction and high natural frequency, in the future, the composite material will play an important role in the aviation section, wind turbine industries, civil and mechanical, etc. Further studies can be carried out toanalyze about the hybrid composite structural beam.

7. FIGURE AND TABLES CAPTION LIST

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