

Comparative Study of Carbon Fiber Composite rod with Steel by using Modal Analysis and FEA

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ABSTRACT: The composite materials are well known by their excellent combination of high structural stiffness and low weight. Their inherent anisotropy allows the designer to tailor the material in order to achieve the desired performance requirements. Thus, the main objective of this work is to contribute for a 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, experimental and numerical analysis using the Finite Element Method have been carried out. It is very important to design the composite material by arranging volume fraction which gives optimum results at low cost and low weight. The objective of this dissertation is to analyze experimentally and by finite element method the mechanical behavior of cantilever rod made of carbon fiber composite material.

KEYWORDS: Comparative study, Steel, Carbon fiber composite, Experimental Modal analysis (EMA), Finite Element analysis (FEA).

I. INTRODUCTION

The advanced composite materials such as graphite, carbon, Kevlar and Glass with Suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composites, where as in alloys, constituent materials are soluble in each other and form a new material which has different properties from their constituents.

1.1 Classification of Composite Materials

Composite materials can be classified as -

- i. Polymer matrix composites
- ii. Metal matrix composites
- iii. Ceramic Matrix

Technologically, the most important composites are those in which the dispersed phase is in the form of a fiber. The Design of fiber-reinforced composites is based on the high strength is the ratio between strength and density. Specific modulus is the ratio between strength and density. Specific modulus is the ratio between modulus and density. Fiber length has a great influence on the mechanical characteristics of a material. Long continuous fibers are easy to orient and process, while short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include impact resistant, low shrinkage, improved surface finish and dimensional stability. Fiber orientation in each layer can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.

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1.2 Properties of Composite Materials

The physical properties of composite materials are generally not isotropic (independent of direction of applied force or load) in nature, but rather are typically orthotropic (depends on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. In contrast, isotropic materials (for example, aluminium or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments. Hybrid materials are those formed by combining both the conventional (steel, aluminium etc.) and non-conventional (composites) materials. It gives the combined properties of the both and forms new one.

The objective of this dissertation is to analyze experimentally and by finite element method the mechanical behaviour of cantilever rod made of steel and carbon fiber composite material.

II. PROBLEM STATEMENT

Steel components have high density, so they are heavy in applications. Steel has corrosion problem. To get rid of these problems a new material is investigated now days which has low density and high strength. This material can be a substitute for steel in future. This is carbon fiber epoxy composite material. Modal analysis is the study of the dynamic properties of structures under vibrational excitation. The goal of modal analysis in structural mechanics is to determine the natural frequencies and mode shapes of an object during free vibration. It is suitable to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and results of the calculations are acceptable.

III. OBJECTIVES

1. To study and analyse the effect of variables in composite cantilever work piece which changes the vibration levels in terms of natural frequencies. So that outcome data will be helpful to modify or redesign.
2. To compare the experimental results of natural frequencies with FEM results. We can find the difference which will be later applicable to all similar ANSYS works for cantilever rod so as to save the time of experimentation for every new cantilever application, design or modification.
3. Comparison of FEA results of steel with carbon fiber composite rod FEA results.
4. Model analysis of steel experimentally.
5. Compare experimental results for steel and carbon composite rod.

IV. WORKING METHODOLOGY

The analysis work is carried out by using following methodologies-

A] Experimental Modal Analysis

Experimental Modal analysis is one of the techniques to find out Natural frequency. The experimental analysis is done using FFT. The procedure includes-

- a) Preparation of Model
- b) Modal analysis.

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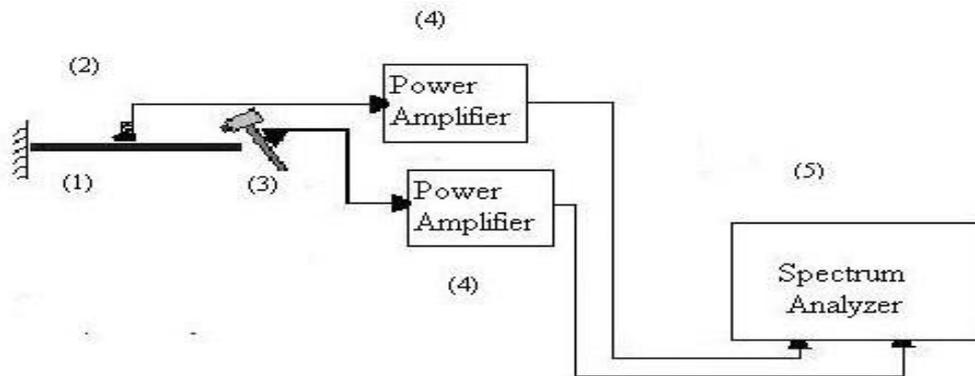
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Fig.1. Actual Experimental Set-up



1- Cantilever beam, 2- Accelerometer, 3- Impact hammer with (piezoelectric cells),
4- Power amplifier, 5- Spectrum Analyzer.

Fig.2. Experimental Modal Analysis

B] Finite Element Analysis

The Finite Element Analysis is the effective as well as convenient method to evaluate natural frequency. In this dissertation, the FE analysis is done with the help of ANSYS software. The procedure includes-

1. Modeling using suitable software.
2. Selection of proper element for meshing.
3. Specifying required material properties like modulus of elasticity, poisson's ratio, etc.
4. Applying boundary conditions and constraints.
5. Carrying out the Post Process in ANSYS to solve the problem.
6. Plotting the results.

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V. EXPERIMENTAL RESULTS

Experimental Results of Steel And Carbon Fiber Composite in terms of Frequency as below-

Mode Shape	Steel (Hz)	Carbon Fiber Composite (Hz)
1	3.52	92.4
2	20.08	402.6
3	21.12	603.0
4	24.55	845.7
5	61.70	1150
6	75.59	1426.2
7	120.61	2358
8	124.84	2665.8
9	127.96	2995.7
10	169.07	3499

Table No.1 Experimental results of Steel and Carbon Fiber Composite

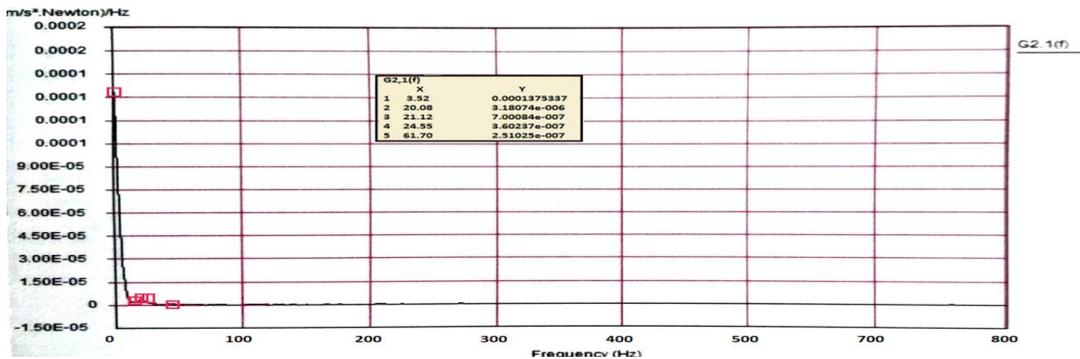


Fig. 3. FFT Readings for Steel

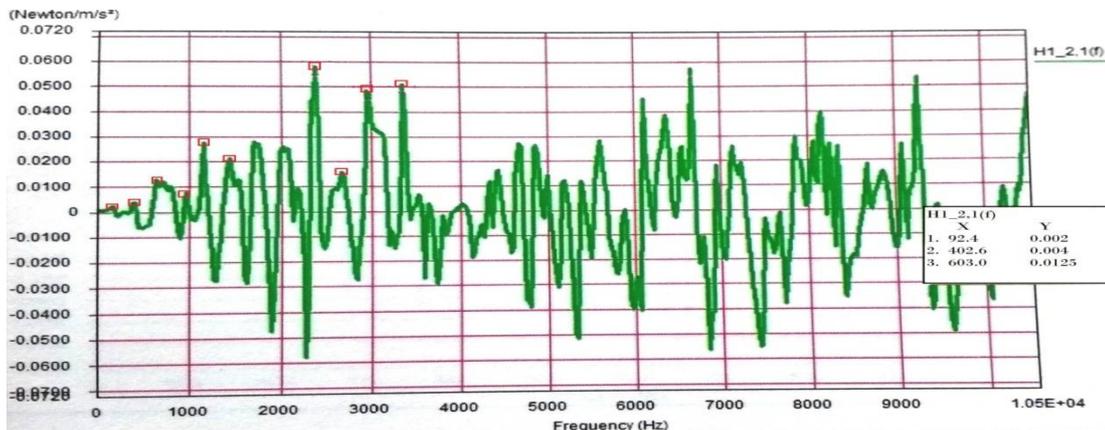


Fig. 4. FFT Readings for Carbon fiber composite

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VI. FINITE ELEMENT ANALYSIS

A] For Steel

The dimensions and the material constant for a uniform fixed free beam (cantilever beam) are:

- Material of beam = Steel,
- Total length (L) = 0.250 m, width (B) = 0.050 m, height (H) = 0.005m,
- Mass density (ρ) = 7856 kg/ m³.
- Poisson Ratio (μ) = 0.3
- Young's Modulus (E) = 210 x 10⁹ N/m² or Pa

Mode Shape	Numerical frequency from ANSYS (Hz)	Von Mises Stress
1	3.35071	2.8371
2	20.5941	2.8131
3	20.9932	2.80286
4	21.1684	3.67307
5	58.9072	2.78762
6	66.2618	3.97567
7	111.588	2.75948
8	115.888	2.79561
9	119.141	4.34463
10	164.152	2.02542

Table No. 2. Numerical results for Steel

B] For Carbon Fiber Composite

The dimensions and the material constant for a uniform fixed free beam (cantilever beam) are:

- Material of beam = Carbon Fiber Composite
- Total length (L) = 0.250 m, width (B) = 0.050 m, height (H) = 0.005m,
- Mass density (ρ) = 1600 kg/ m³,
- Poisson Ratio (μ) = 0.33
- Young's Modulus (E_x) = 120 x 10⁹ N/m² or Pa
- Young's Modulus (E_y) = 7.9 x 10⁹ Pa
- Young's Modulus (E_z) = 7.9 x 10⁹ Pa
- Shear Modulus (G_x) = 5.5 x 10⁹ Pa
- Shear Modulus (G_y) = 5.5 x 10⁹ Pa
- Shear Modulus (G_z) = 5.5 x 10⁹ Pa

Mode Shape	Numerical frequency from ANSYS (Hz)	Von Mises Stress
1	81.402	6.3631
2	400.52	8.3264
3	506.59	6.3390
4	743.76	6.0941
5	1277.0	9.3195
6	1402.9	6.3018
7	2359.6	10.245
8	2706.7	6.2524
9	3236.6	5.6028
10	3730.8	10.615

Table No. 3. Numerical results for Carbon Fiber Composite

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VII. RESULTS AND DISCUSSION

I] Comparison of Finite Element Analysis (FEA) and Experimental Modal Analysis (EMA) results of Steel.

Mode Shape	Numerical frequency from ANSYS (Hz)	Experimental frequency from EMA (Hz)
1	3.35071	3.52
2	20.5941	20.08
3	20.9932	21.12
4	21.1684	24.55
5	58.9072	61.70
6	66.2618	75.59
7	111.588	120.61
8	115.888	124.84
9	119.141	127.96
10	164.152	169.07

Table No. 4. Comparison of FEA and EMA results of Steel

From above table we observed that, the results of Finite element analysis and experimental analysis are compared and they are in good agreement for Steel.

II] Comparison of Finite Element Analysis (FEA) and Experimental Modal Analysis (EMA) results Carbon Fiber Composite.

Mode Shape	Numerical frequency from ANSYS (Hz)	Experimental frequency from EMA (Hz)
1	81.402	92.4
2	400.52	402.6
3	506.59	603.0
4	743.76	845.7
5	1277.0	1150
6	1402.9	1426.2
7	2359.6	2358
8	2706.7	2665.8
9	3236.6	2995.7
10	3730.8	3499

Table No. 5. Comparison of FEA and EMA results of Carbon Fiber Composite

From above table we observed that, the results of Finite element analysis and experimental analysis are compared and they are in good agreement for Carbon Fiber composite.

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III] Comparison of Finite Element Analysis (FEA) results of Steel with Carbon Fiber Composite.

Mode Shape	Steel	Carbon Fiber Composite
	Numerical frequency from ANSYS (Hz)	Numerical frequency from ANSYS (Hz)
1	3.35071	81.402
2	20.5941	400.52
3	20.9932	506.59
4	21.1684	743.76
5	58.9072	1277.0
6	66.2618	1402.9
7	111.588	2359.6
8	115.888	2706.7
9	119.141	3236.6
10	164.152	3730.8

Table No. 6. Comparison of FEA results of Steel with Carbon Fiber Composite

From above table we observed that, the results of Steel and Carbon fiber composite by Finite element analysis are compared and it is observed that natural frequencies for laminated carbon composite are much higher than steel.

IV] Comparison of Experimental Modal Analysis (EMA) results of Steel and Carbon Fiber Composite.

Mode Shape	Steel	Carbon Fiber Composite
	Experimental frequency from EMA (Hz)	Experimental frequency from EMA (Hz)
1	3.52	92.4
2	20.08	402.6
3	21.12	603.0
4	24.55	845.7
5	61.70	1150
6	75.59	1426.2
7	120.61	2358
8	124.84	2665.8
9	127.96	2995.7
10	169.07	3499

Table No. 7. Comparison of Experimental results of Steel and Carbon Fiber Composite

From above table we observed that, the results of Steel and Carbon fiber composite by Experimental Modal analysis are compared and it is observed that natural frequencies for laminated carbon composite are much higher than steel.

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VIII. CONCLUSION

There is great interest in use of carbon fiber composites for light weight automotive applications. Low cost carbon fibers and intermediate products as well as low cost, high throughput processing technologies are rapidly evolving.

To avoid structural damages caused by undesirable vibrations, it is important to determine:

- 1 - The natural frequencies of the structure to avoid resonance.
- 2 - The mode shapes to reinforce the most flexible points or to determine the right positions to reduce weight or to increase damping.

By using the modal analysis, we can obtain the different natural frequencies of any structure or machine component which serves the following purposes, Such as:

- a) Optimization of structure's dynamic characteristics (mass, stiffness, damping).
- b) Risk assessment of having the resonance phenomenon.
- c) Prediction of dynamic behaviour.
- d) Long term structural health monitoring.

Natural frequencies of both steel and composite material are calculated using FFT analysis and these results are validated by modal analysis in ANSYS 16 software.

From both the results it is observed that, natural frequencies for laminated carbon composite are much higher than steel.

From above result it is suggested that, use of laminated carbon composite in various applications is useful instead steel to sustain high frequencies.

The proposed method can be extended for crack identification and fault diagnosis in various Beams and Shafts and rotating machine element.

REFERENCES

- [1] R. Jones, "An Advanced Book on Mechanics of Composite Material", second edition.
- [2] Akira kuraiishi, Stephen W. Tsai, and Julie wang, "Material Characterization of Glass, Carbon and Hybrid - Fiber SCRIMP Panels", Contractor 4 Report for Sandia national Laboratories, PP 1-16.
- [3] J. M. Corum, R. L. Battiste, W. Ren and M. B. Ruggles, "Durability - Based Design Criteria for a Chopped - Glass - Fiber Automotive Structural Composite": ORNL / TM, PP 182-190.
- [4] W. J. Padgett, "A Multiplicative Damage Model for strength of Fibrous composite Materials", IEFE transactions on reliability, VOL. 47, 1998 March, PP 45-53.
- [5] Daniel David Samborsky, PHD Thesis, Montana state university, Bozeman. Montana. On, "Fatigue of E-glass fiber reinforced composite materials and substructures", April 2012, PP 23-26.
- [6] Kin-tak Lau, Li-min Zhou, Xiao-ming Tao, "Control of natural frequencies of a clamped-clamped composite beam with embedded shape memory alloy wires", Composite Structures 58, Elsevier, (2002), PP 39-47.
- [7] Hubertus F. von Bremen, Vladimir S. Sokolinsky, J. André Lavoie and Steven R. Nutt, "Experimental and analytical study of natural vibration modes of soft core sandwich beam", Center for Composite Materials, University of Southern California, Los Angeles, CA 90089-0241, USA.
- [8] V. Tita, J. de Carvalho and J. Lirani, "Dynamic Analysis of Fiber Reinforced Composite Beams", 15th Brazilian Congress of Mechanical Engineering November, Vol. XXV, No. 3, July-September 2003, PP 306-309.
- [9] C. Balias, V. Markakis, S. Anagnou, E.P. Koumoulos, C.A. Charitidis, "Carbon fiber production: a step-by-step design and market analysis", National Technical University of Athens, School of Technical Engineering Research Unit of Advanced, Composite, Nano Materials & Nanotechnology, R-NanoLab 9 Heroon, Polytechniou St., Zografos.
- [10] C. Azoury, A. Kallassy, B. Combes, I. Moukarzel, R. Boudet, "Experimental and Analytical Modal Analysis of a Crankshaft", IOSR Journal of Engineering Apr. 2012, Vol. 2(4) pp: 674-684.
- [11] Parshuram D, Sunil Mangsetty, "Design and Analysis of Composite/Hybrid Drive Shaft for Automotives", The International Journal of Engineering And Science (IJES) ||Volume|| 2 ||Issue|| 01 ||Pages|| 160-171 ||2013|| ISSN: 2319 - 1813 ISBN: 2319 - 1805.
- [12] Chetan D. Patil, Nilesh R. Farande, Prof. R. D. Patil, "Vibration Analysis of Glass Epoxy Composite Plate With Variable No. of Layers", International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE) ISSN: 2349-7947, Volume: 1 Issue: 3, 005- 007.
- [13] Xiaosong Huang, "Fabrication and Properties of Carbon Fibers", *Materials* 2009, 2, 2369-2403, ISSN 1996-1944.
- [14] NishaA.S., Saraswathy B, "Dynamic Analysis of Delaminated Sandwich Composites", ISSN: 2249-6645, Vol.3, Issue.1, Jan-Feb. 2013 pp-172-177.
- [15] G.M Sayeed Ahmed, SirajuddinElyasKhany, Syed HamzaShareef, "Design, Fabrication and Analysis of a Connecting Rod with Aluminum Alloys and Carbon Fiber", ISSN: 2319-8753, Vol. 3, Issue 10, October 2014, PP 16674-16687.
- [16] RathodJairam C, Gaur Abhay Singh V, "Vibration Analysis of Composite Material Mono Leaf Spring", Vol. 2, Issue 2, PP 129-133.