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# Free Vibration Characteristics of Carbon and Glass Fiber Hybrid Polymer Composite with Titanium Di-Oxide ($TiO_2$) Powder as Filler

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## Abstract

*Composites play a significant role in the modern designing materials due to their few kind properties like formability, temperature process, and cost-effective nature. Composite materials are generally used in different areas such as automotive and aircraft industry, space vehicles, and machine elements due to its high strength to weight ratio, high resistance to failure in dynamic conditions. This paper deals with the fabrication of carbon, glass-epoxy hybrid composites having a composition of 60-40% with Titanium Di-Oxide ($TiO_2$) nano-powder as a filler material, varying with the percentage of 0.5%, 1%, 2% by weight. The fabrication of the hybrid composite plates according with the ASTM standards. Tensile test and flexural tests are performed to determine the mechanical properties of the composites having various percentage fillers. Modal analysis for vibration analysis using Fast Fourier Transform (FFT) is done and compared to the numerical results, which is obtained from Ansys software.*

***Keywords:*** *Hybrid Composite, Titanium Di-Oxide ($TiO_2$), Tensile, Flexural, FFT*

## 1.0 Introduction

Composites are humankind's recent greatest advanced and adaptable engineering materials. These amazing and fascinating materials are the result of evolution in the field of material research. Composites are anisotropic in nature and are made up of more than two materials joined together with reinforcing fibers or fillers and a matrix which can be ceramic, metallic or polymeric. Composite materials are commonly employed in a various applications, including the automotive and aerospace industries, space spacecraft, and machine components. Composite materials are increasingly being used in the aerospace industry, where its primary application of composite materials were in secondary construction of aircraft such as fairings, tiny doors, and control surfaces and also for major structures like wings and fuselages. Composites play a key role in the new world of material design because they are non-corrosive, have a high strength-to-weight ratio, have such a high resistance to failure in varying conditions, and have flexible qualities such as ductility, temperature process, and are cost-effective. Metal Matrix Composites (MMCs), Ceramic Matrix Composites (CMCs), and Polymer Matrix Composites (PMCs) are the three types of composites which are categorized according to the matrix material which forms a continuous phase. PMCs have a lower processing temperature, hence they are easier to fabricate when compared to metal matrix composites and ceramic matrix composites. PMCs are made up of synthetic fibres such as nylon, carbon, glass, or rayon that are encased in a polymer matrix. Hybridization of fibre is a comprising two or more types in a common matrix for developing new composites which can result in enhanced and improved qualities. Although composite materials have advantages

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over traditional metals, they also have some drawbacks; composites are anisotropic in nature, which means that their properties, such as stiffness and strength, differ in different directions. While using composites in structures with more than one directional force, this causes a significant challenge to the engineers. Filler materials are used in composites to constantly upgrade their material properties. They also can be used to cut down on the cost of matrix resin required. Fillers are divided into two types: conductive fillers and extender fillers. Electrical and thermal conductivity are elevated by using conductive fillers. Extender fillers are used to save money on materials. Ch. Siva Ramakrishna, et.al, (2021) suggested the vibration nature of the carbon/basalt hybrid composites using graphite powder as filler and concluded by mixing 1 %, 2%, 3% of filler will provide a good effect on the vibration behaviour[1]. G. Rout, et.al, (2019). worked on hybrid composites using Euler-Bernoulli beam theory for free vibration analysis using various parameters which had a good results on the natural frequencies of the specimens[2]. G. Rajeshkumar, and V. Hariharan (2012) studied on carbon glass epoxy hybrid composites to understand consequence of angles of inter-ply and aspect ratios for different boundary conditions which has showed increase in frequencies for small aspect ratios and decreases for larger ones[3]. Badatala Ooha and Kondeti Sravanth (2019) worked by altering the fiber orientation of epoxy polymer matrix of kelvar and basalt for fixed boundary condition, (0p/-45p/+45p/-45p/+45/0p) oriented fiber showed good performance and higher natural frequency[4]. S. Madhu and M. Kumara Swamy (2017) investigated natural frequency and damping factor for different natural fiber orientations i.e for uni and bi-directions, apart from the damping property, the unidirectional natural fiber composites has better performances than the bidirectional composites[5]. Ashwini P, et.al, (2021) examined the damping properties for different compositions of angles that is for 0, 30, 45 degrees (JG0, JG1, and JG2) damping factor varied by increasing or decreasing composition material different angle compositions[6]. Iva Surana, et.al, (2019) the effect of the saw dust particles for tensile and vibration properties on basalt composites for various weight contents, which showed a considerable increase in natural frequency for the content of 4%, addition above 4% resulted in a decreased of interfacial strength between matrix and fiber inter phase[7]. K. R. Sumesh and K. Kanthavel (2020) carried out mechanical vibration tests on natural fibers using chemically prepared $TiO_2$ nano powder, it is observed 3% increament in the tensile, flexural and impact strength for different combinations of natural hybrid combinations[8]. N.V. Rachchh and D.N. Trivedi (2018) explored the tensile strength and flexural strength of the composite which has various bagasse fibre content, for 9% bagasse fibre, 17% E-glass fibre, and 74% resin combination showed improvement in mechanical properties as well as enhancement in natural frequencies[9]. Yellamelli Vikas, et.al, (2017) compared specimens of the carbon and E-glass uni-direction hybrid composites for varied stacking sequences, rise up in the mechanical properties is seen when there is increment in the weight fraction of the carbon and E-glass fibers superior performs is observed[10]. Prashanth M D and Basava T (2018) studied dynamic nature of the cross breed blended composite materials for sisal and banana fibers, ductility along with natural frequencies is increased with percentage increase in banana fiber[11]. N.Annlin Bezy and A Lesly Fathima (2015) analyzed the mechanical properties of resin and epoxy using $TiO_2$ as nano particle as filler, and observed as the addition of $TiO_2$ nanoparticles increases has influence on the mechanical properties[12]. Rajesh Mishra et.al, (2012) investigated on basalt/polysiloxane composites using $TiO_2$ filler material, concluded that addition in lower percentage of filler can improve the tensile properties[13]. Iskender Ozsoy et. al, (2015) Investigated the consequence of $Al_2O_3$, $TiO_2$ and fly ash nano and micro filler content to understand the mechanical properties of epoxy resin tensile and flexural modulus increases as micro and nano filler content increases[14].

In this paper mechanical and vibrational analysis of the carbon/glass epoxy hybrid composite using the different percentage of $TiO_2$ nano filler is studied.$TiO_2$ filler has good anti-microbial and good photo catalytic properties having high oxidation efficiency also, non toxic and eco-friendly in nature. Tensile test and flexural test is performed to know the mechanical behaviour of various composites of different percentages and vibration analysis is carried out both numerically and experimentally in which Ansys software for numerical analysis and experimental analysis is carried using LABVIEW software is used for FFT analysis for understanding vibration behaviour of the hybrid composites having different percentage of nano filler.

## 2.0 Fabrication Methodology

Carbon fiber, glass fiber, epoxy are mentioned in the Table 1. Fabrication of composites is done using a hand layup method. Four composites were fabricated of dimensions 220mm × 200mm × 3mm having orientation C-G-C-G-C-G-C-G-C-G-C-G-C for 13 layers in order to get thickness of 3mm as per ASTM standards. For percentage varying 0%, 0.5%, 1%, 2%. Plywood mould is prepared on which a sheet of plastic is placed and a thin film of wax is applied on it. Initially, a carbon fiber of the required dimensions is kept on the sheet and epoxy is applied on the both sides of the fibers. 10% hardener (K-6) is mixed with the epoxy (L-12) and aslo required amount of filler material ($TiO_2$) is added for fabricating of composites with different percentages of filler which shown in the Table 2. The procedure is carried out for the layers until all the layers are satisfied for acquiring

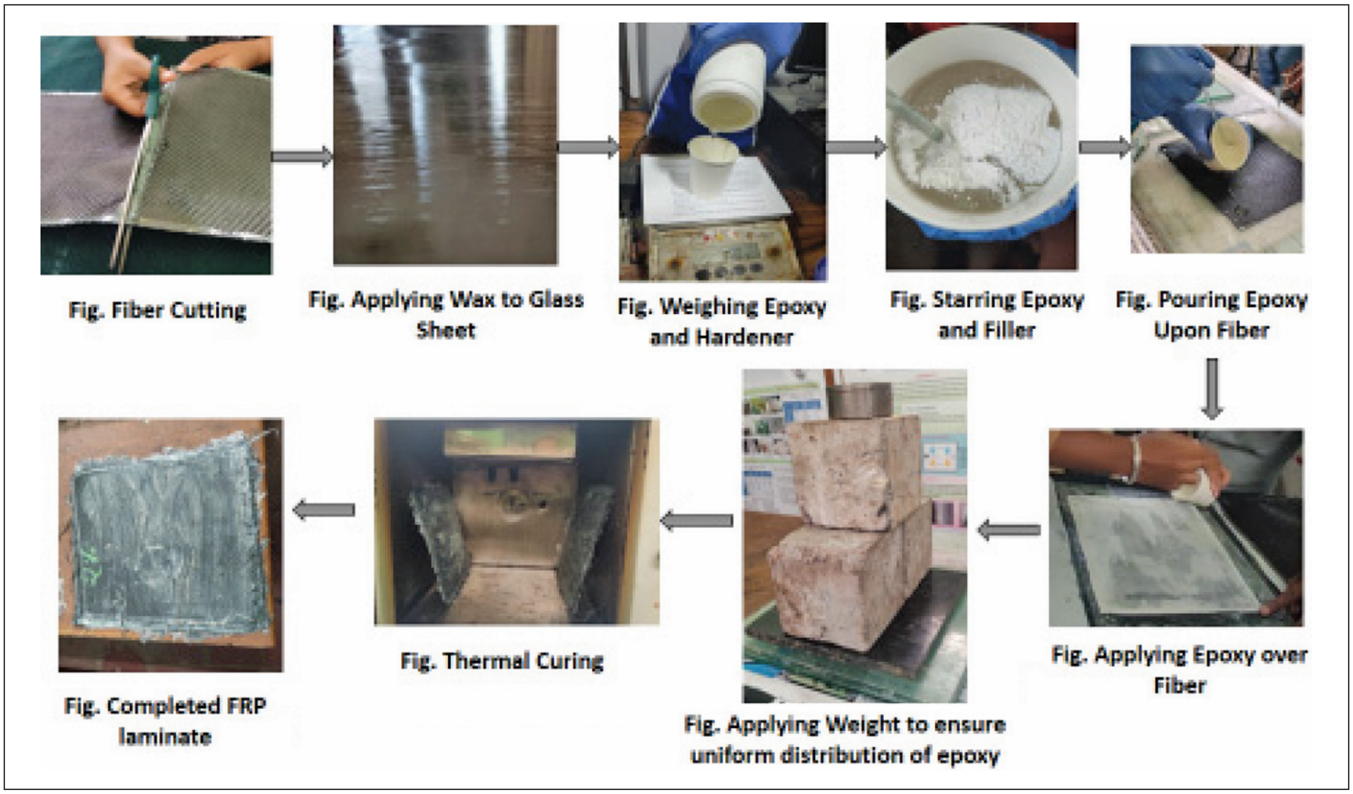



Figure 1 : Fabrication procedure

**Table 1: Materials and mechanical properties**

| Material | Youngs modulus (GPa) | Density ($g/cm^3$) | Tensile strength ($N/mm^2$) |
|---|---|---|---|
| Carbon fiber | 230 | 1.45 | 4000 |
| Epoxy(l-12) | 3.2 | 1.36 | 65 |
| Glass fiber | 76 | 2.54 | 3450 |

**Table 2: Details of fabrication composite**

| Sample | Filler %wt. | Total weight of composite (grams) | Epoxy weight (grams) | Filler weight (grams) |
|---|---|---|---|---|
| 60-40 | 0 | 286.66 | 115 | 0 |
| 60-40 | 0.5 | 286.66 | 113.57 | 1.43 |
| 60-40 | 1 | 286.83 | 111.54 | 2.86 |
| 60-40 | 2 | 286.42 | 109.32 | 5.58 |

required thickness and in order not to have any more epoxy and air bubbles roller is used to clear the air bubbles and epoxy. Then a plastic sheet with a layer of wax is again placed over the last layer and loads are applied on it for better compression, the Figure 1 represents the fabrication procedure. It is kept for 24 hours for curing and for 1 hour in thermal chamber for drying. Composites are cut into the required dimensions for testing.

# 3.0 Results and Discussion

## 3.1 Mechanical Properties

Tensile test and flexural test is been studied which is tested by using universal testing machine (UTM), tensile mode calculation is according to the ASTM-D638 standards and flexural mode is performed according to ASTM-D790 standards the specimen dimensions of both tensile and flexural tests are shown in the Figures 2 and 4 respectively.

## 3.2 Tensile Test

Material resistance is measured by the tensile test by applying a load gradually, the specimen is kept in a universal testing machine and the load is applied at the rate of 5 m/min, tensile test helps in knowing design information on the material strength, ductility, yield strength, and youngs modulus, these tests are of low costs and of standardized conditions. The obtained tensile test values are shown in the

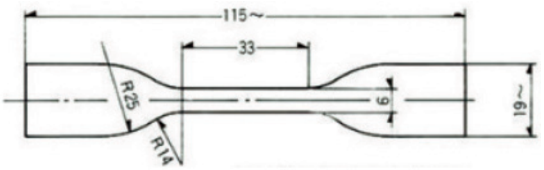



Figure 2 : Tensile test specimen as per ASTM standard

Table 3. The load vs displacement for the different percentage fillers in the tensile test is shown in the Figs. 3a, 3b and 3c.

The tensile stress v/s filler percentage samples graph is shown in the Figure 5, epoxy with 0.5wt% $TiO_2$ has a maximum tensile strength of 942.52 MPa that can withstand the load up to 2751.45N, further increase in percentage of the filler content on the carbon glass hybrid composite showed the decrease in the properties when compared to the 0.5% of the filler content, because as the filler content increases the particles interactions more rather than particle polymer interactions.

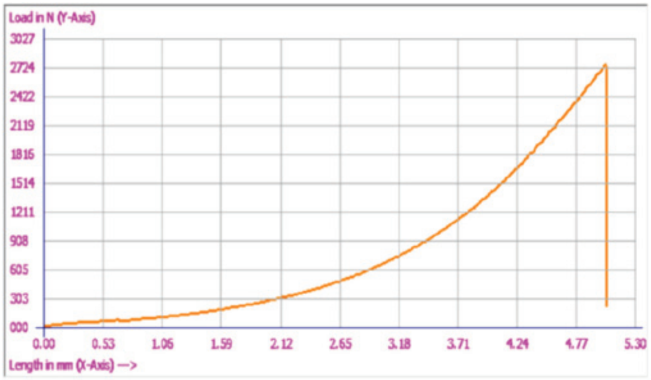



Figure 3a: Load vs displacement graph for 0.5% filler

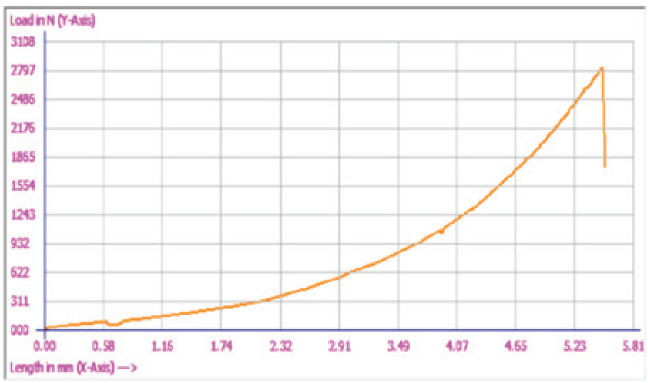



Figure 3b: Load vs displacement graph for 1% filler

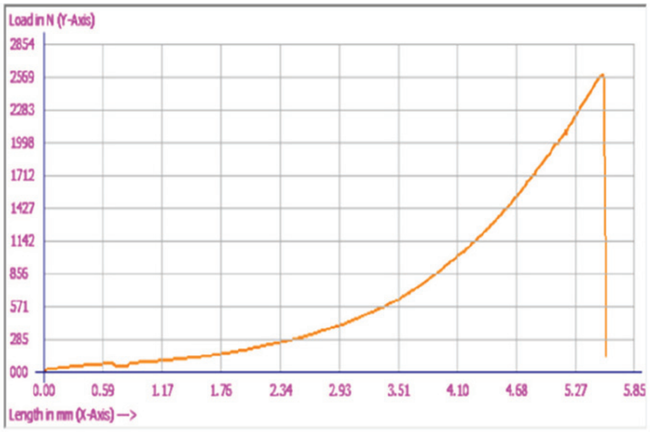



Figure 3c: Load vs displacement graph for 2% filler

## 3.3 Flexural Test

Flexural test is a 3 point loading test in which measures the load required for bending a specimen, flexural test gives the measure of flexural modulus, flexural strength. The results obtained from 3 point bending test is detailed in Table 4. The flexural strength v/s filler percentage samples graph is shown in the Figure 6, The load vs displacement for the different percentage fillers in the flexural test is shown in the Fig.5a, 5b and 5c.

Flexural strength obtained is maximum for the composite with composition of 0.5% $TiO_2$, when compared to others with

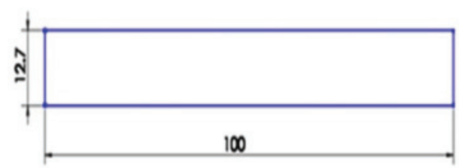



Figure 4: Flexural test specimen as per ASTM standards

**Table 3: Tensile test values for different samples**

| Sample | Peak load (N) | Elongation % | ΔL (mm) | Ultimate Tensile strength ($N/mm^2$) | Tensile modulus (MPa) |
|---|---|---|---|---|---|
| Epoxy | 2732.66 | 15.04 | 5 | 136.76 | 902.61 |
| Epoxy+0.5%$TiO_2$ | 2751.45 | 15.38 | 5.05 | 145 | 947.52 |
| Epoxy+1%$TiO_2$ | 2825.32 | 16.78 | 5.54 | 141.40 | 842.66 |
| Epoxy+2% $TiO_2$ | 2594.92 | 16.92 | 5.58 | 128.78 | 762.11 |

various percentages of filler as the composition percentage increases flexural strength begins to decreases because the constrain between the polymer chain increases thus decreasing a length of the chain reducing the flexural strength which is dependent on the length of the chain.

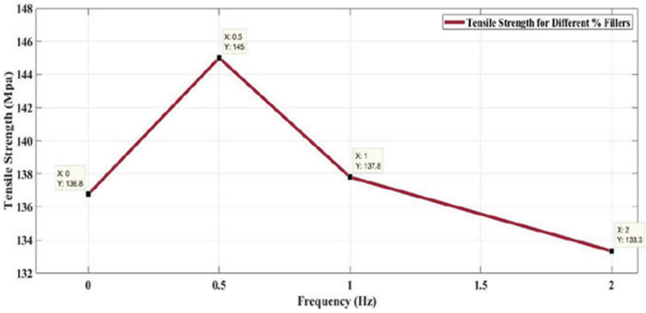



Figure 5: Tensile strength v/s filler percentage variation graph

**Table 4: flexural strength for different samples**

| Sample | Flexural ttrength (MPa) |
|---|---|
| Epoxy | 393.376 |
| Epoxy+0.5% $TiO_2$ | 651.224 |
| Epoxy+1% $TiO_2$ | 544.74 |
| Epoxy+2% $TiO_2$ | 574.07 |

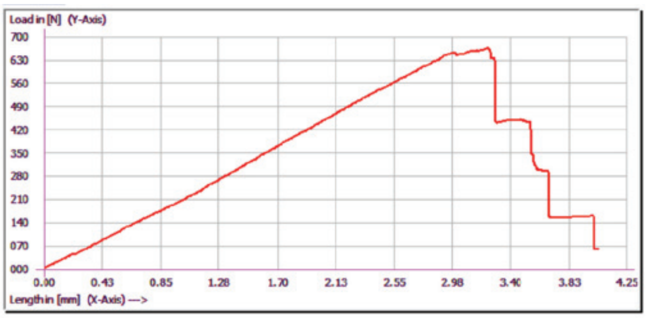



Figure 5a: Load vs displacement graph for 0.5% filler

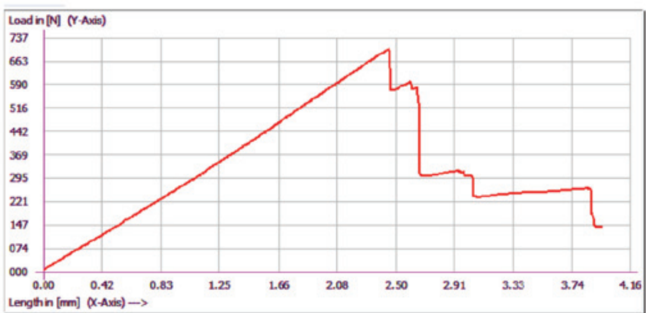



Figure 5b: Load vs displacement graph for 1% filler

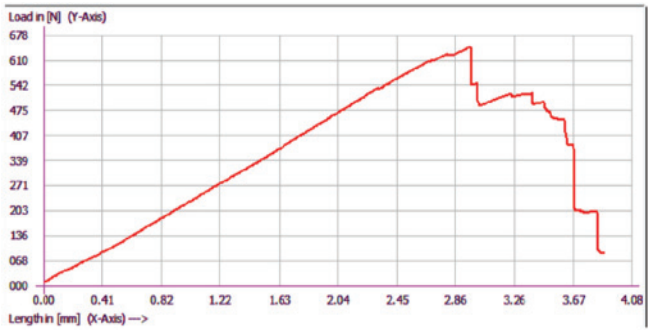



Figure 5c: Load vs displacement graph for 2% filler

## 3.4 Vibration Analysis

The schematic experimental structure were designed to examine the free vibration behaviour of hybrid composite plates using $TiO_2$ as filler, varying for different percentages of 0%, 0.5%, 1%, 2%. The gadget used to measure acceleration forces is known as an accelerometer. Using an impact hammer (08603, PCB Piezotronics, Inc., Depew, NY) to deliver initial excitation, natural frequency of the systems are determined using a FRF test. The National Instruments data acquisition system (NIDAQ) including compact DAQ chasis (NicDaq 9178) with LabVIEW software is utilized to record the vibration response of the plate specimens. To analyze the vibration, a tri-axial accelerometer (356A15, PCB Piezotronics,

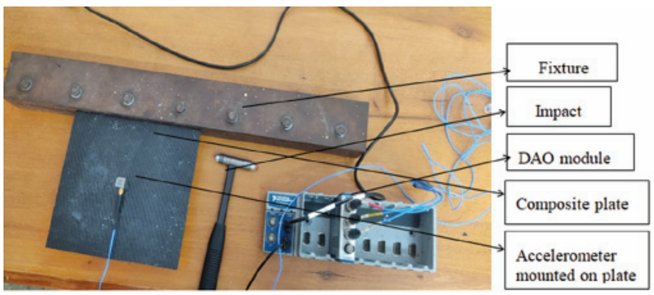



Figure 6: Experimental setup

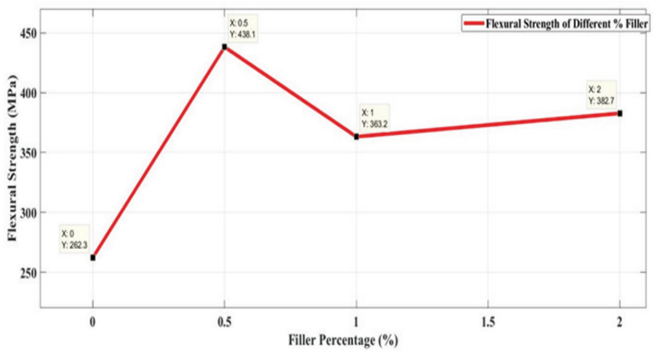



Figure 7: The flexural strength v/s filler percentage variation graph

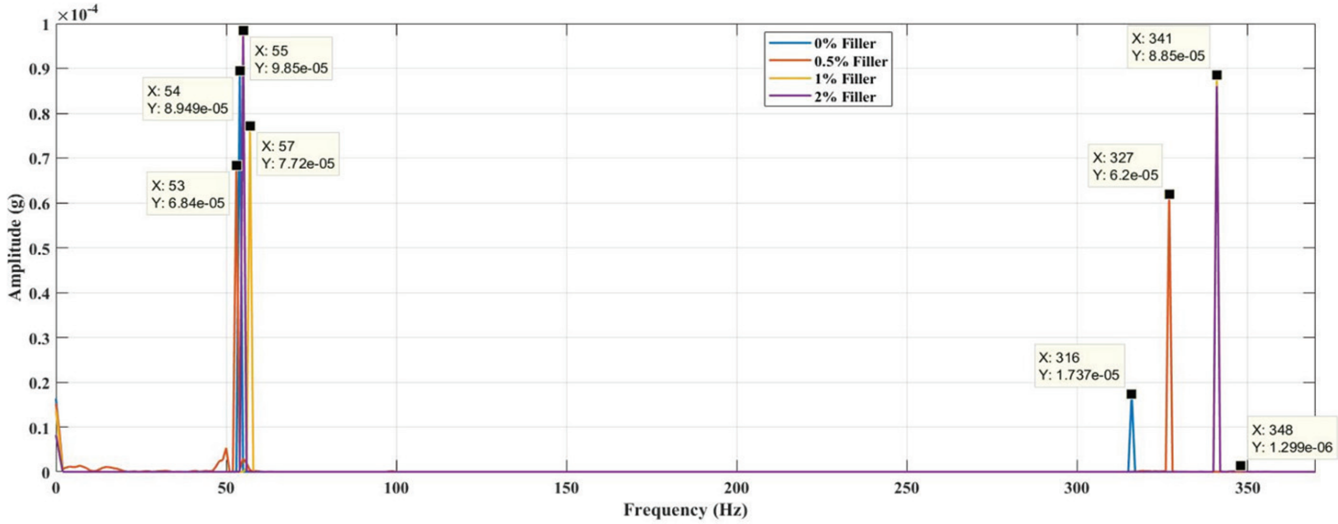



Figure 8: Frequency of first two modes for different percentage filler composite

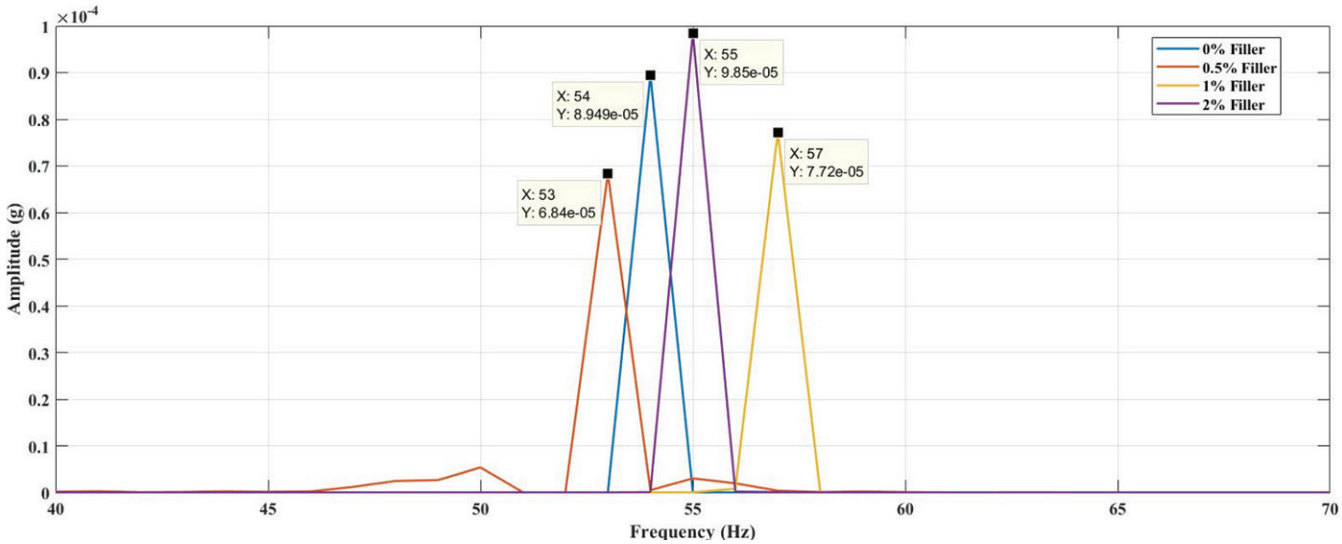



Figure 9: Zoomed view of first mode for different percentage filler composites

Inc., Depew, NY) is attached on the specimen. To take the vibration data and transform it into frequency response functions, a LabVIEW software generates time domain and frequency domain data graph and the information is saved using write to measurement file command. As required, time and frequency domain graphs can be plotted in MATLAB (Mathworks, Natick, MA). The plate dimensions of composite vibration specimen is 210 mm × 200 mm considered. The plate is fixed in a cantilever position (fixed-free), and the entire experimental set up is imaged as illustrated in Figure 7.

The vibration results obtained are combined for all the different compositions and frequency v/s amplitude graph is shown in Figure 8 and indicates the two modes graph of all the composition, Figure 9 indicates zoomed view for the first mode of the vibration. It is observed that the amplitude decreased during the vibration for the 0.5wt% composition of filler composite.

### *3.4.1 Numerical Analysis*

The Ansys software is used for the numerical analysis, in which composite for different percentage of fillers are designed using material modular command, the modal analysis is carried out in order to find out the natural frequencies and mode shapes of the composites. The first mode of the different composites is shown in the Table 5. Natural Frequencies of first two modes is described in the Table 6.

The results are compared with the numerical analysis performed in the Ansys software for the first two modes of vibration by modal analysis, Table 6 indicates comparison of frequency both experimental and numerical analysis results.

**Table 5: First mode shape for different percentage composites**

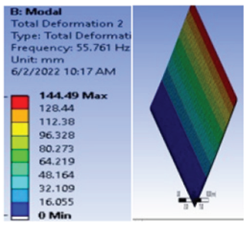
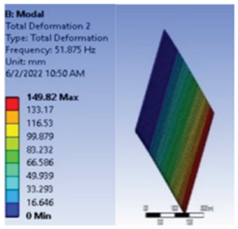
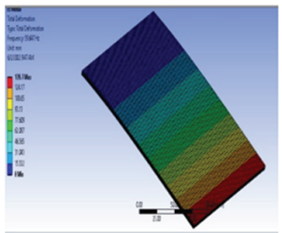
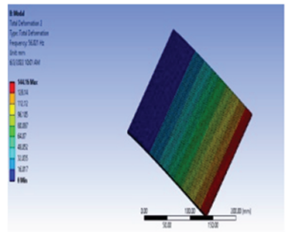
| | Laminate 1 (0%) | Laminate 2 (0.5%) | Laminate 3 (1%) | Laminate 4 (2%) |
|---|---|---|---|---|
| Laminated Composite Plates |  |  |  |  |
| From Ansys Software |  |  |  |  |

**Table 6: comparison of frequency values for different composites**

| Composition of carbon/glass/epoxy composite | Frequency (Hz) | | | |
|---|---|---|---|---|
| | Mode 1 | | Mode 2 | |
| | Experimental | Numerical | Experimental | Numerical |
| 60-40% with 0% $Ti0_2$ | 55 | 56.02 | 327 | 325.87 |
| 60-40% with 0.5% $Ti0_2$ | 57 | 59.64 | 348 | 349.62 |
| 60-40% with 1% $Ti0_2$ | 54 | 55.76 | 316 | 317.14 |
| 60-40% with 2% $Ti0_2$ | 53 | 51.87 | 341 | 342.64 |

## 4.0 Conclusion

In this paper the carbon/glass epoxy hybrid composite for different percentage of $TiO_2$ filler is fabricated using hand layup method.

Tensile and bending/flexural tests were conducted to know the mechanical properties which showed that tensile strength and flexural strength is maximum for 60-40% with 0.5% $TiO_2$ composite compared to other composites for different filler percentages. From modal vibration analysis it is observed that the composite 60-40% with 0.5% $TiO_2$ has maximum vibration frequency, vibration frequency is less for the composite of 60-40% with 2% $TiO_2$. From the mechanical and vibration study it is seen that addition of filler $TiO_2$ has some influence on the mechanical property and frequencies of vibration. For the various percentages filler used 0.5% filler addition to the carbon/glass fiber addition has a good improvement in the properties and also reduced in the vibration frequency.

## References


[1] Ramakrishna, C.S., et al., (2021): Vibration behaviour of graphite powder in carbon/basalt reinforced epoxy composites. Materials Today: Proceedings.

[2] Rout, G., et al., (2019): Experimental and Numerical Analysis of Hybrid Laminated Composite Beam. *International Journal of Applied Engineering Research*, 14(13), 93-99.

[3] Rajeshkumar, G., and Hariharan, V. (2012, March): Free vibration analysis of hybrid-composite beams. In IEEE-International conference on advances in engineering, science and management (ICAESM-2012) (pp.165-170). IEEE.

[4] Ooha, B., et al., (2019): Experimental Investigation and Vibrational Behaviour of Laminated Hybrid Composites.

[5] Madhu, S., and Swamy, M. K. (2017): Free Vibration Characteristics of Natural Fiber Reinforced Hybrid

Polymer Composite Beam. *International Journal of Scientific Engineering and Research*, 5 (10), 81-87.

[6] Kumar, M. D., et al., (2021): Study on static and dynamic behaviour of jute/sisal fiber reinforced epoxy composites. Materials Today: Proceedings, 46, 9425-9428.

[7] Surana, I., et al., (2019): Influence of filler material on mechanical and vibration properties of basalt/epoxy composites. *Materials Research Express,* 6(8), 085342.

[8] Sumesh, K. R., and Kanthavel, K. (2020): Effect of $TiO_2$ nano-filler in mechanical and free vibration damping behaviour of hybrid natural fiber composites. *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* 42(4), 1-12. https://doi.org/10.1007/s40430-020-02308-3

[9] Rachchh, N. V., and Trivedi, D. N. (2018): Mechanical characterization and vibration analysis of hybrid E-glass/bagasse fiber polyester composites. Materials Today: Proceedings, 5(2), 7692-7700.

[10] Yellamelli Vikas et al., (2017): Analysis of Free Vibration Characteristic of Hybrid Polymer Composite Material, *International Journal of Engineering Research & Technology* (IJERT), ISSN: 2278-0181.

[11] Prashanth, M. D., and Basava, T. (2018, June): Vibration analysis of natural hybrid composites by experimental approach. In IOP Conference Series: *Materials Science and Engineering* (Vol.376, No.1, p.012050). IOP Publishing.

[12] Bezy N. A and Fathima, A. L. (2015): Effect of $TiO_2$ nanoparticles on mechanical properties of epoxy-resin system. *International Journal of Engineering Research and General Science*, 3(5), 143-151.

[13] Mishra, R, (2012): Effect of $TiO_2$ nanoparticles on basalt/polysiloxane composites: mechanical and thermal characterization. *Journal of the Textile Institute*, 103(12), 1361-1368.

[14] Ozsoy, I., et al., (2015), The influence of micro and nano-filler content on the mechanical properties of epoxy composites, *Journal of mechanical engineering*, 61(10), 601-609.