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DEVELOPMENT AND VIBRATION ANALYSIS OF GREEN COMPOSITE

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Abstract: Natural fibers are being focused on for use in composite research instead of synthetic fibers, due to properties such as being lightweight, cost-effective, biodegradable, environmentally friendly, and easy to manufacture. In order to effectively use these composites in real-world applications, the vibrational behavior of the composites needs to be studied in addition to their mechanical strength and chemical properties. Various loading conditions and vibration configurations are present in real-world applications. The manufacturing of natural fiber composite beams with bidirectional orientation was undertaken in the current study to measure their transverse vibration with different end configurations and to determine their tensile strength. Tensile tests were carried out on the beam in accordance with ASTM standards to obtain the necessary mechanical properties. The fiber component used was bi-directional cotton yarn, while Cashew Nut Shell Liquid (CNSL) resin was used as the matrix material and hexamethylenetetramine was used as a hardener. The vibration test was conducted using Arduino DE software, which provided time-based data and measured acceleration. Fast Fourier Transformation (FFT) was performed in MATLAB R2016a to convert time domain data into frequency domain and determine the natural frequencies of the composite beams.

***Keywords*- Natural fiber, Cashew Nut Shell liquid (CNSL) Resin, Bio-composite Material, Green Composite, Tensile Test**

I. INTRODUCTION

Composite materials are widely used in various industries due to their superior properties, such as high strength, durability, and lightweight. One promising approach to producing composites is by using eco-friendly and renewable resources, such as natural fibers and bio-based resins. Cashew Nut Shell Liquid (CNSL) is an eco-friendly and versatile raw material used to create bio-based resin for composites. CNSL-based composites have a high strength-to-weight ratio, stiffness, impact resistance, and dielectric properties suitable for various applications, including structural, automotive, electronic packaging, and medical. CNSL-based composites are biocompatible, non-toxic, and sustainable, making them a substitute for traditional petroleum-based materials [1]. Another eco-friendly resource that can be used as a reinforcing fiber in composites is cotton fiber. Cotton fiber is widely available, biodegradable, and has excellent mechanical properties. Therefore, combining CNSL resin with cotton fiber as a reinforcing agent can result in composites that have both excellent mechanical properties and are eco-friendly. In this context, the production of CNSL resin-based composites with cotton fiber as a reinforcement material is an emerging area of research that has the potential to offer a sustainable solution for various applications.

II. LITERATURE REVIEW

A composite material was manufactured by stacking glass fiber and jute ply with resin, compressing and molding them for 30 minutes at 170°C and 70kg/cm2. The resulting composite material had good mechanical properties and is suitable for applications where high strength and stiffness are not necessary [2].

The addition of CNSL up to 16 vol% improves the mechanical properties of epoxy composites, specifically elongation at break and tensile strength. CNSL contains phenolic compounds that can crosslink with the epoxy matrix, resulting in a durable composite with enhanced thermal stability suitable for high-temperature applications [3].

The study compares the mechanical properties of CNSL resin composites to polyester resin composites, with and without fiber reinforcement, to investigate the potential of CNSL resin as a natural alternative to polyester resin in composite development.

The results show that CNSL resin composites are comparable to those made with polyester resin, indicating the potential of natural resins as a viable substitute for synthetic resins in fiber-reinforced plastic composite development. The study encourages further research in the development of natural materials for composite applications [4].

The literature review examines the manufacturing and mechanical characteristics of a hybrid natural fiber composite made by incorporating natural fibers and secondary fillers into the matrix through compression moulding. The mechanical properties of the composite laminates are evaluated, and the study finds that cashew nut shell dust fillers enhance the composite's mechanical properties,

with the best improvement observed at 6 wt% fillers. However, the improvement in properties saturates after this point. The resulting eco-friendly composite can be used as a viable alternative to plastics. The review concludes that the improvement in properties is due to a good fiber-matrix adhesion at the interface, as confirmed by morphological analysis [5].

The literature review examines the mechanical properties and free vibration characteristics of two types of pure green composite laminates made from natural flax fiber with alkaline treatment. Both laminates were fabricated using the hand layup method and tested for mechanical properties and free vibration characteristics according to ASTM standards. The review discusses the results of the tensile, flexural properties, and modal frequency values of the two types of laminates [6].

This literature review investigates the improvement of mechanical properties in Cashew Nut Shell Resin (CNSR) composites reinforced with chemically modified coconut fibers. Hand lay-up techniques were used to fabricate the composites, which were then tested for mechanical properties. The results showed a significant improvement in tensile strength and young modulus by over 200% and 305%, respectively, with compressive properties also showing improvement. SEM images indicated good adhesion between the matrix and fibers. The study concludes that CNSR composites can be used in panel or ceiling production, with chemical treatment of fibers affecting mechanical properties and adhesion between matrix and fibers [7].

This study investigated the effect of alkali treatment and fiber content on the properties of cashew nut shell liquid (CNSL) composites. Sisal and banana fibers were incorporated into CNSL resin using hand lay-up technique, and treated with 5% sodium hydroxide solution. Results showed improved bonding strength and high tensile/flexural strength at 30% fiber content. Water resistance was also tested, with lower water absorption in sea water at 10% fiber content, indicating good water resistance. The study concludes that high strength properties can be achieved at 30% fiber content in these hybrid natural composites [8].

In this study, the authors explored the benefits of adding spent tea leaf particles to jute/cotton bio composites. They found that the addition of tea leaf particles significantly improved the mechanical properties and thermal stability of the composites, due to the unique chemical composition of the tea leaf particles [9].

The study investigates the addition of cashew nut shell dust to sisal fiber/epoxy composites and observes significant improvements in mechanical properties, attributing them to the chemical composition of the dust that enhances interfacial bonding between fibers and the matrix. The study suggests potential use of the dust as a reinforcing filler in eco-friendly composites [10].

The study explores the use of natural fiber composites in the automobile industry, comparing their material indices for beam and panel structures. Advantages of natural fiber composites include lower weight and cost, increased fuel efficiency, and ease of production. However, there are also issues with compatibility and stability. The study suggests hemp/PP and flax/PP composites for stiff and cheap or strong and cheap beam and panel structures, while carbon steel is recommended for bending loaded beam and panel structures [11].

The article studies the mechanical and dynamic properties of hybrid composites made from coconut sheath and sisal fibers and the impact of stacking sequence. The study shows improved tensile and impact strength compared to individual fibers, with stacking sequence having a significant impact. It highlights the potential of natural fibers in composites and the importance of considering stacking sequence for specific applications, suggesting that these composites have potential for high-strength applications requiring impact resistance and vibration damping properties [12].

The article investigates the free vibration behaviour of natural fiber reinforced composites using both finite element analysis and experimental techniques. The study finds that natural frequency and stiffness of the composite increase with increasing fiber content and are affected by fiber orientation and stacking sequence. The study highlights the potential of natural fiber reinforced composites for structural applications and emphasizes the importance of considering fiber orientation and stacking sequence in composite design and optimization [13].

The paper investigates the free vibration behaviour of a hybrid composite beam made of CFRP and GFRP and studies the effect of L/h ratio on the natural frequency of the beam using the finite element method. The study finds that longer and thinner beams have lower natural frequencies, and as the natural frequency increases, the amplitude of vibration decreases. These findings have implications for the design of composite structures, emphasizing the importance of considering L/h ratio and natural frequency [14].

The paper investigates the influence of design parameters on the natural frequencies and mode shapes of glass/epoxy laminated composite plates. The authors conduct vibration tests on rectangular composite plates with different aspect ratios and compare the experimental results with finite element analysis predictions. The study concludes that aspect ratio and stacking sequence significantly affect the natural frequencies and mode shapes of composite plates, with FEA accurately predicting the natural frequencies and mode shapes. The paper emphasizes the importance of considering design parameters when designing composite structures with desired vibration characteristics [15].

This paper explores how the layering pattern affects the vibrational behaviour of hybrid composite materials made of coconut sheath and banana fiber. The authors find that natural frequencies and mode shapes are influenced by the pattern's symmetry and number of layers. The authors validate the experimental results and investigate the effect of design parameters on vibrational behaviour using the finite element method. The study provides insights into the vibrational behaviour of hybrid composite materials and emphasizes the importance of considering the layering pattern in designing composite structures with desired vibrational characteristics [16].

This study analyses the vibrational characteristics and mechanical properties of natural fiber composite beams using analytical modelling and ANSYS simulation. Results show that hemp FRPC has higher strength and modulus of elasticity, while hemp-sisal FRPC has slightly lower impact strength but higher tensile and flexural strength. These composites are suitable for various applications, such as household, aerospace, high-speed turbine machinery, and automobile applications. Average error between analytical and simulation results is 1-2%, and between analytical and experimental results is 5-8% due to defects and physical factors [17].

The paper investigates the vibration behavior of natural fiber composite beams with different end conditions. It examines how the boundary conditions affect the beams' natural frequencies and mode shapes. The study focuses on natural fiber composites, which are eco-friendly materials made from plant-based fibers embedded in a polymer matrix. Vibration analysis techniques, both experimental and numerical, are used to analyze the beams' behavior. The results demonstrate the variations in natural frequencies and mode shapes caused by different end conditions. The findings have practical implications for designing and optimizing composite structures, especially those using natural fiber composites, enhancing their performance and durability. The paper provides valuable insights for engineers and researchers in the field of composite materials and structural dynamics [18]

This study investigates the vibrational properties of natural fiber composite beams with different end conditions using experimental and theoretical analyses. Natural fiber composites are environmentally friendly and cost-effective materials, and understanding their vibrational behavior is crucial for their optimal design and application. The experimental setup involves fabricating composite beams using various natural fibers and matrix materials and subjecting them to different end conditions. Vibration testing equipment is used to measure the natural frequencies and mode shapes of the beams. Theoretical models, such as the Euler-Bernoulli beam theory or Timoshenko beam theory, are employed to predict the vibrational properties, incorporating material properties and using techniques like finite element analysis. The experimental and theoretical results are compared and analyzed to assess the accuracy of the theoretical models. The study also focuses on the effects of different end conditions on the vibrational properties, providing insights into stiffness, damping, and energy dissipation characteristics. The findings have practical implications for the design of natural fiber composite structures, aiding in material selection, structural design, and vibration control strategies. Further research can explore additional factors to enhance the understanding of the vibrational behavior of these composites. Overall, this study contributes to the development of efficient and sustainable structures using natural fiber composites [19].

III. EXPERIMENTAL DETAILS

3.1 Materials

The natural fiber used in this case is cotton, which has been processed into a bidirectional yarn type, meaning that the fibers have been aligned in two directions to provide strength and stiffness in multiple directions. The bio resin used is Cashew Nut Shell Liquid (CNSL), which is derived from the shells of cashew nuts and is a renewable and eco-friendly alternative to synthetic resins. To harden or cure the CNSL, hexamethylenetetramine is used as a crosslinking agent. This is a common method of curing thermosetting resins like CNSL, where the crosslinking agent reacts with the resin to form a network of chemical bonds, creating a strong and durable material.

Table 3.1: *Technical Data Sheet of CNSL*

Test	Unit	Specifications	Test Procedure
Specific Gravity at 30˚C	gm/cc	0.96-1.02	SMC TP 15
Iodine Value	-	300 Max	WIJ'S METHOD
ASH Content	wt %	2.0 Max	SMC TP 08
Loss in weight on heating	wt %	3.0 Max	SMC TP 30
Moisture content	wt %	2.0 Max	SMC TP 22
Acid value	Mg/koh	94-107	SMC TP 09

3.2 Fabrication of Composite Material

To prepare a sample piece from CNSL resin and cotton fabric as a fiber with hexa hardener as a cross-link agent, the following steps can be followed:

- Cutting of the cotton fabric: The cotton fabric should be cut to the desired size and shape for the sample piece.
- Preparation of the mould: Select a mould of the desired size and shape for the sample piece. Clean the mould thoroughly and apply a mould release agent to prevent the sample from sticking to the mould.
- Mixing of the CNSL resin and hexa hardener: The CNSL resin and hexa hardener should be mixed in the recommended ratio, following the manufacturer's instructions. Stir the mixture thoroughly to ensure even distribution of the hardener.
- Impregnation of the fabric: Dip the cotton fabric into the mixed resin and hardener, making sure it is completely saturated. Use a brush to ensure that the fabric is evenly coated with the resin mixture.
- Placement of the fabric in the mould: Place the impregnated fabric into the prepared mould, ensuring that it is flat and free of wrinkles.
- Curing: Allow the resin to cure for the recommended amount of time, which can vary depending on the specific resin and hardener used.
- Demoulding: Once the resin has cured, remove the sample piece from the mould by gently tapping the mould or using a demoulding agent.
- Post-curing: The sample piece may require post-curing after demoulding to achieve its full strength and durability. Follow the manufacturer's instructions for post-curing.

3.3 Mechanical Testing and Vibration

Mechanical testing and vibration analysis are crucial for understanding the behavior and properties of green composites, which are eco-friendly materials made from natural fibers and bio-based resins. By subjecting these materials to various mechanical tests and analyzing their vibration characteristics, researchers can evaluate their strength, stiffness, and durability. This information is important for designing and optimizing green composites for various applications in industries such as automotive, construction, and aerospace.

3.4 Tensile Test

The Tensile Test is conducted on a Universal Testing Machine (UTM) using the ASTM D638 standard. The specimen that will be used for the test will be in the shape of a dumbbell and will be prepared using the same code. The specimen will be clamped between two jaws as depicted in a figure and will then be subjected to tensile loading at a constant velocity of 5mm/min until it yields.

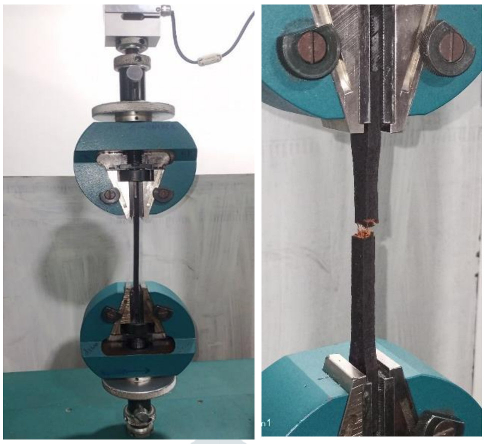


Figure 3.1: Test set up for tensile test

Figure 3.2: Test specimen before and after Tensile Test

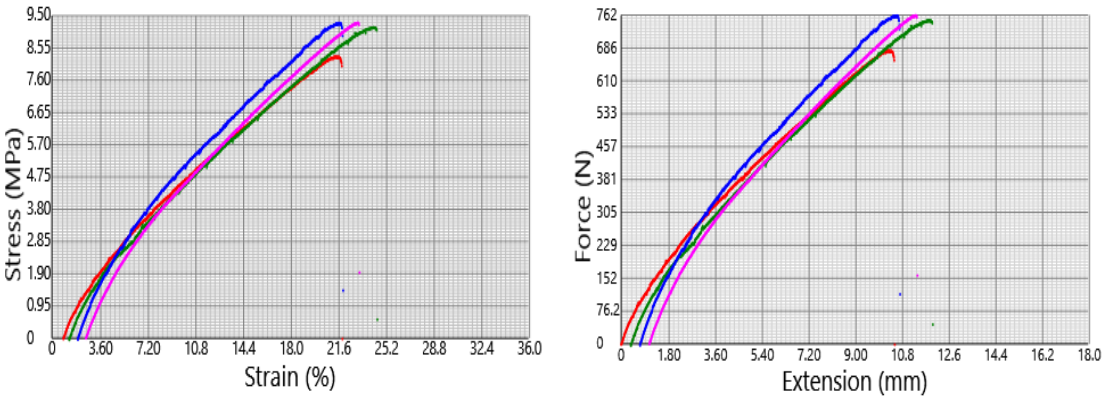


Figure 3.3: Tensile Test Graph

Table 3.2: Tensile Test Result

Specimen No.	Max. Load (N)	Max. Extension (mm)	Elongation (%)	Tensile Strength (MPa)	Modulus of Elasticity (MPa)
1	680	10.3	21.5	8.30	51.9
2	750	11.5	23.6	9.18	59.1
3	761	9.91	20.3	9.29	71.4
4	762	10.3	21.0	9.30	71.0

3.5 Vibration Test

In this study, a vibration test was conducted using the standard ASTM E756 on a beam measuring 200×35×5.7mm. The beam was affixed with an accelerometer and subjected to force using a small tack hammer. The CSV file containing the accelerometer readings was logged using an Arduino UNO, and the natural frequency was determined by using Fast Fourier Transform (FFT) in MATLAB R2016a. Different beams end conditions were used by changing the clamp, and two types of clamps were used, a fixed clamp and a hinged clamp.

The collected data was output by the software in the time domain, with a MATLAB code written to read the time and acceleration data from the Excel file and perform FFT on the acceleration data. The data was stored in separate files, each containing four columns of time and acceleration in the X, Y, and Z axes. The Z-axis was identified as the useful axis, and FFT was performed using MATLAB on the time and Z-axis acceleration data from each file.

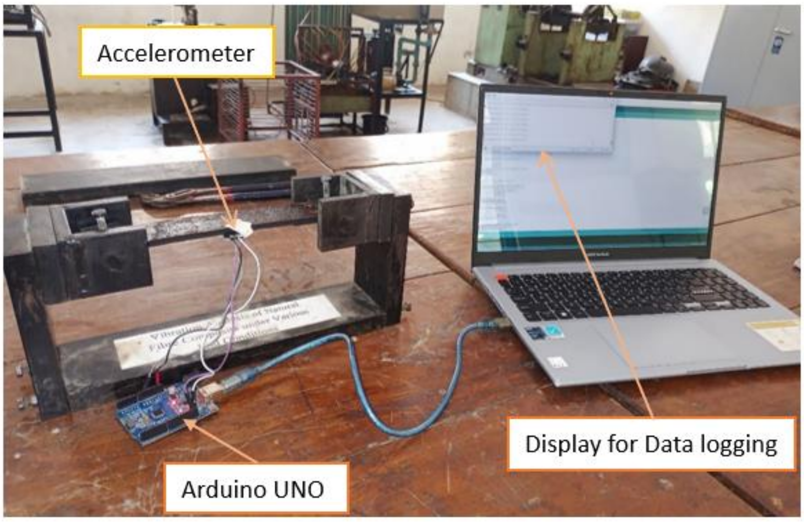


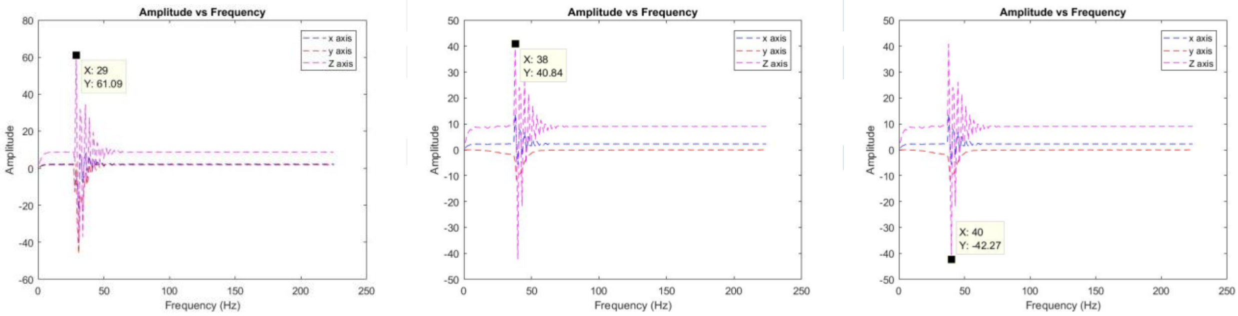
Figure 3.4: Experimental Set Up

3.6 Frequency Response Graph

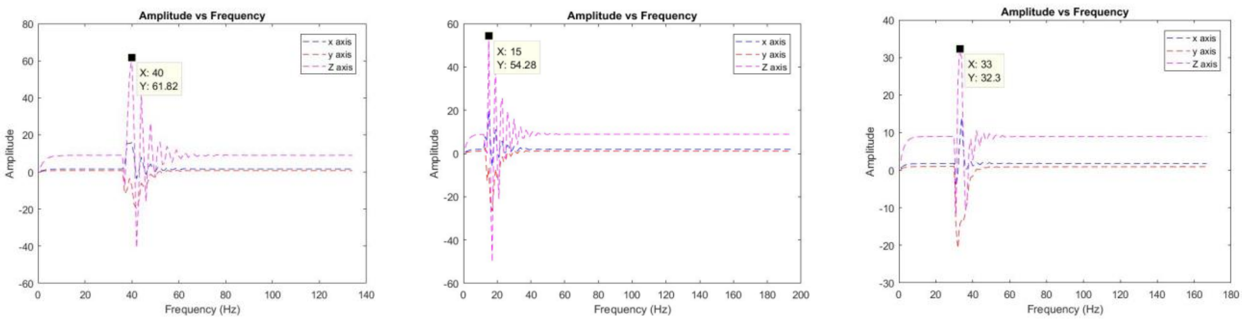
The frequency response graph was generated for different end conditions including cantilever, clamped-clamped, and supported-supported vibration tests. Three readings were taken for each of the three specimens, and the average value of the natural frequency was calculated. In the cantilever, clamped-clamped, and supported-supported vibration tests, the frequency response graph was generated. For each of the three specimens, three readings were taken, and the natural frequency was calculated by taking the average value of these readings.

Frequency response for Cantilever beam

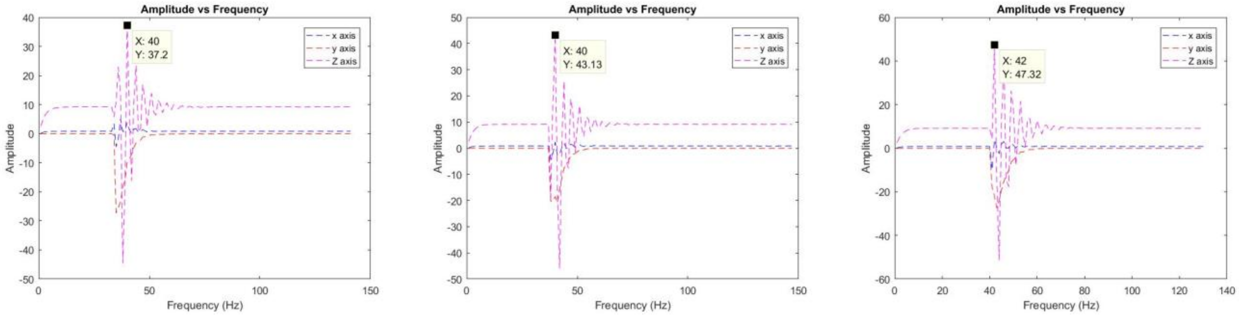
Following figures shows the graph of frequency vs amplitude for cantilever beam end configuration.



Frequency response for cantilever beam of Specimen 1



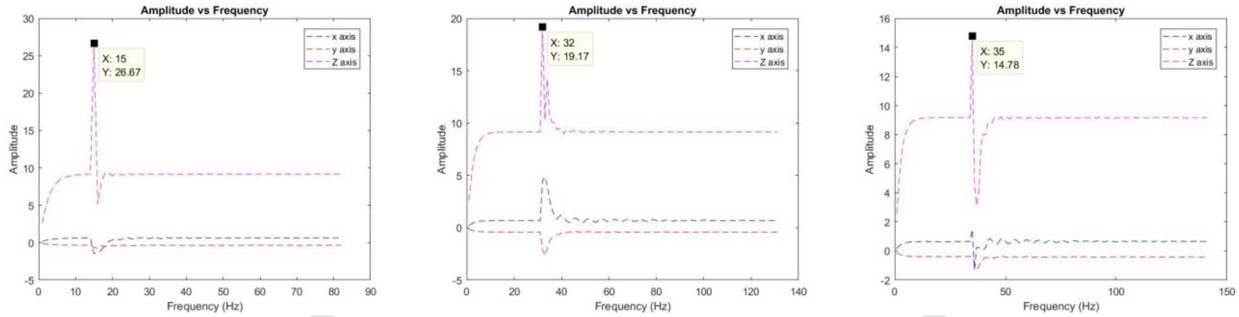
Frequency response for cantilever beam of Specimen 2



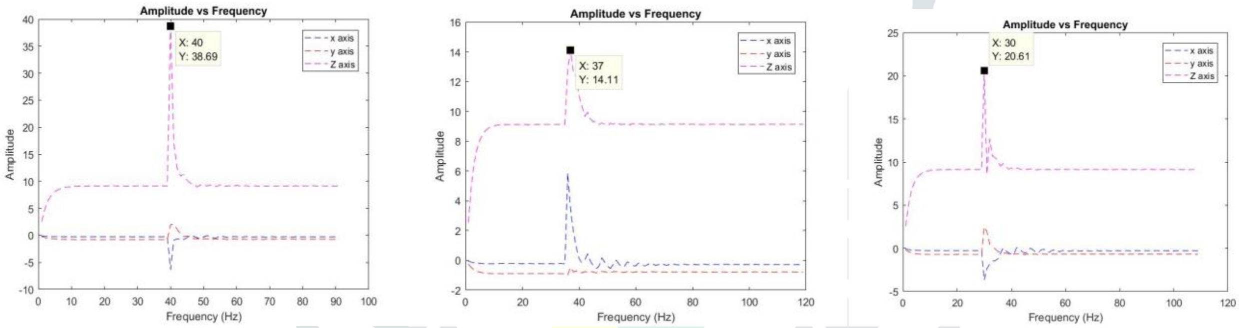
Frequency response for cantilever beam of Specimen 3

Frequency response for clamped-clamped beam

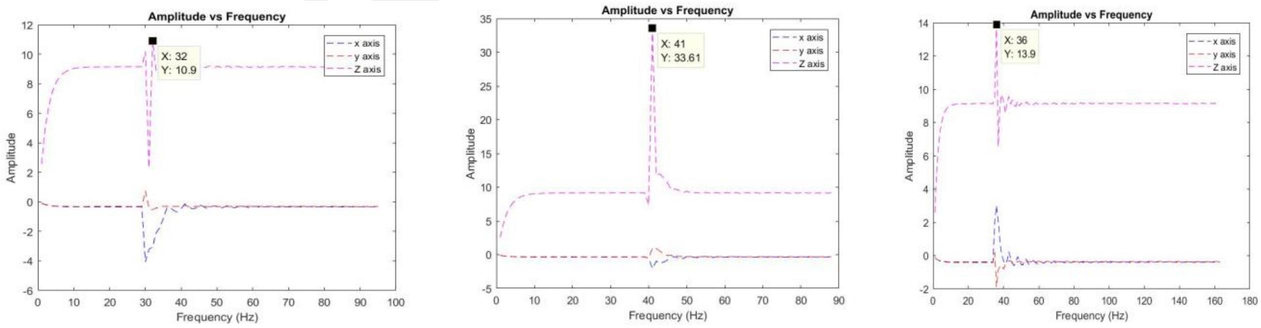
Following figures shows the graph of frequency vs amplitude for clamped-clamped beam end configuration.



Frequency response for clamped-clamped beam of Specimen 1



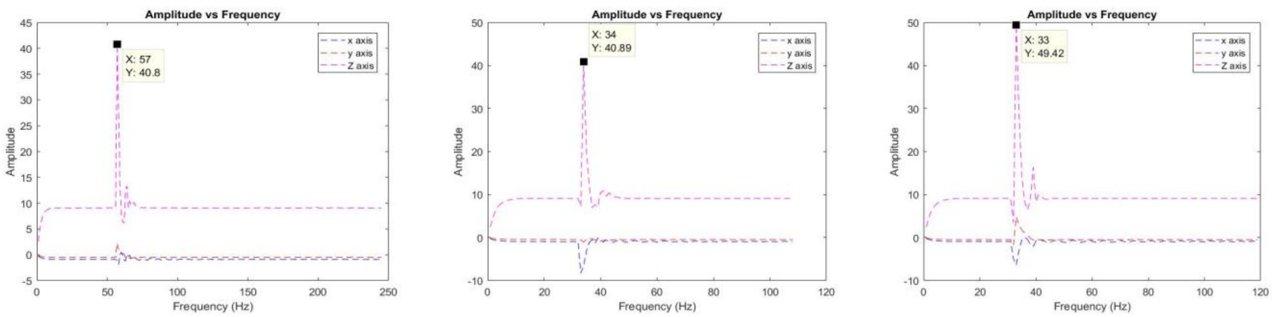
Frequency response for clamped-clamped beam of Specimen 2



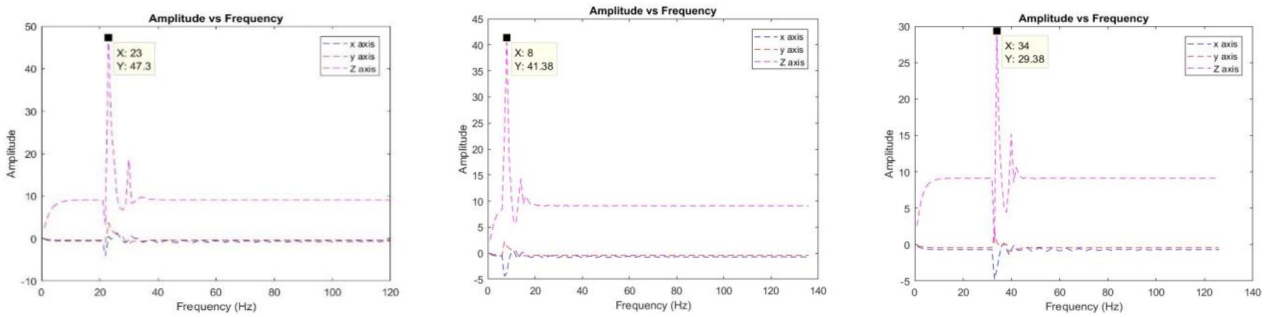
Frequency response for clamped-clamped beam of Specimen 3

Frequency response for supported-supported beam

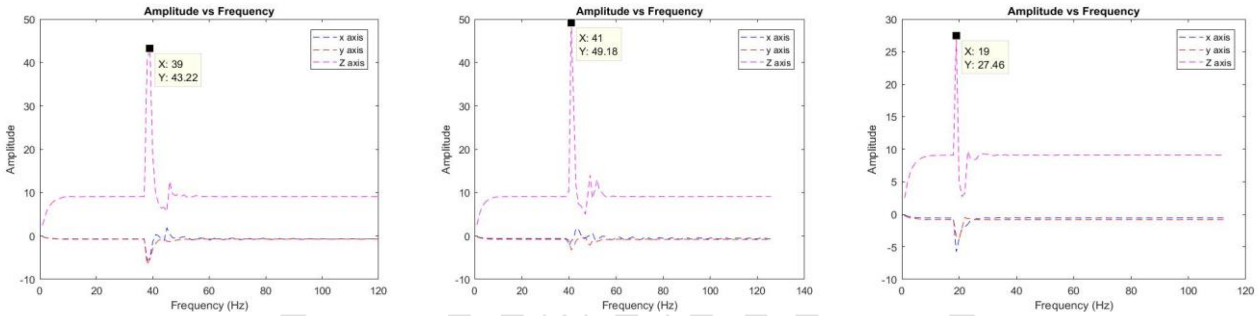
Following figures shows the graph of frequency vs amplitude for supported-supported beam end configuration.



Frequency response for supported-supported beam of Specimen 1



Frequency response for supported-supported beam of Specimen 2



Frequency response for supported-supported beam of Specimen 3

Table 2.3: *Experimental result of Natural Frequency for various end conditions*

Beam	Natural Frequency (Hz)		
	End Condition		
	Cantilever	Clamped-Clamped	Supported-Supported
Specimen 1	35.66	27.33	41.33
Specimen 2	29.33	35.66	21.66
Specimen 3	40.66	36.33	33

IV. CONCLUSION

A major area of research in composites is the use of natural fibers due to their comparative properties such as low cost, light weight, good mechanical properties, safety in manufacturing, low environmental impact, less energy requirement, and biodegradability. Therefore, the vibrational characteristics of composite beams need to be studied along with their mechanical properties. For this purpose, an experiment was conducted using an Arduino UNO and accelerometer MPU-6050 system, which provided data based on time and acceleration measurements. The time domain data was then converted into the frequency domain using Fast Fourier Transformation (FFT) in MATLAB, and the natural frequencies were determined. In addition, it was revealed by the Vibration Analysis that the supported-supported beam had a higher natural frequency than other configurations. The natural frequency indicates the maximum frequency that the material can withstand under different end conditions. Overall, valuable insights into the vibrational characteristics of natural fiber composites were provided by this study, which may be useful in various applications such as automotive and aerospace engineering.

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