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Free Vibration Characteristics of Natural Fiber Reinforced Hybrid Polymer Composite Beam

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Abstract: ***Natural fibers are potential replacement for synthetic fibers in automotive and aerospace engineering in low load applications due to the low carbon footprint associated with them. Reducing the resonant amplitude of the vibration is an important issue in a machine component design process. Generally, damping associated with fiber reinforced composite structure is higher than conventional metal structures due to the visco-elastic behavior. Flax, Hemp and sisal natural fibers are used to fabricate polymer fiber reinforced Composites with different orientation of fibers using Hand Layup method. Vibration analysis of Hybrid Natural composite is carried out by using modal analysis with various Boundary conditions and compared. Natural frequencies and damping ratios are determined for all Hybrid FRP Composite samples using Ansys 15.0.***

Keywords: Hybrid Composite beams, Vibration analysis, Natural frequencies, Damping Ratio, ANSYS 15

1. Introduction

A composite is a material consisting of two or more materials that are synthetically made with dissimilar materials. A composite material also must include chemically different constituent phases which are separated by a clear interface. Numerous composite materials are comprised of just two phases, one is known as the matrix which continuously surrounds the other constituent, which is called the dispersed phase. The properties of the reinforcement phase (i.e., volume fraction, shape and size of particles, distribution and orientation) define the properties of the composite. The roles of matrix in composite materials are to give shape to the composite part, protect the reinforcements to the environment, transfer loads to reinforcements and toughness of material, together with reinforcements. The role of reinforcements in composites is to get strength, stiffness and other mechanical properties.

1.1 Natural FRP Composite

Natural fibers are introduced as a replacement to synthetic fibers in order to reduce the environmental impact of non-biodegradable materials. Natural fiber has advantages over synthetic fibers as they are;

1. Renewable
2. Eco-friendly
3. Low in density
4. Biodegradable
5. High specific strength and stiffness
6. Low cost.

Flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, etc., more often applied as the reinforcement of composites.

1.2 Hybrid composite

Hybrid composites are more advanced composites as compared to conventional FRP composites. Hybrids can have more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases. They have better flexibility as compared to other fiber reinforced composites. Normally it contains a high modulus fiber with low modulus fiber. The high-modulus fiber provides the stiffness and load bearing qualities, whereas the low-modulus fiber makes the composite more damage tolerant and keeps the material cost low. The mechanical properties of a hybrid composite can be varied by changing volume ratio and stacking sequence of different plies. Hybrid configuration is interlayer or layer-by-layer is used.

1.3 Natural frequency

If a system, after an initial disturbance, is left to vibrate on its own, the frequency with which it oscillates without external forces is known as its natural frequency. As will be seen later, a vibratory system having n degrees of freedom will have, in general, n distinct natural frequencies of vibration.

1.4 Damping Factor

Damping is an important factor which postpones the resonance. Composite materials are having very good damping factor. Damping is the energy dissipation of a material or system under cyclic stress. Damping ratio can be obtained from frequency response curve using Half-power bandwidth method.

Damping Ratio= $(\omega_2-\omega_1)/2\omega_n$

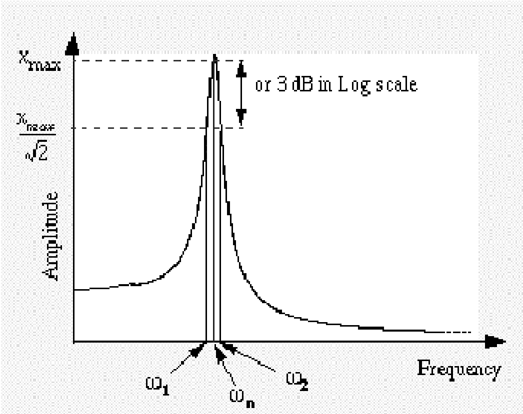

Figure 1: Determination of Damping

M Rajesh [1] In this study influence of surface pre-treatment with sodium hydroxide and hybridization effect of natural fiber improves the mechanical and free vibration properties of polymer composites. K.Senthil Kumar [2] This work addresses the results of experimental investigation carried out on fiber length and weight percentage on mechanical properties and free vibration characteristics are analyzed. 4mm fiber length and 50 wt% fiber content was the best combination. J. Alexander **[3]** This work focuses to compare vibration characteristics such as natural frequency and damping coefficient of BFRP composites with GFRP composites at various fiber orientations and end conditions. BFRP and GFRP composites with unidirectional cloth and Owen fabric are fabricated by compression molding machine and their mechanical properties were determined by using UTM as per ASTM standards. Vibration analysis of these materials was carried out by using modal analysis set up for various end conditions. Natural frequencies and damping coefficients were determined for all materials and end conditions. These results were compared with numerical results which are carried by using ABACUS software. Due to high damping coefficient of Basalt/epoxy composites and better vibration characteristics. J.Alexander[4] Three types of Basalt fabrics are selected (Plain weave, twill weave and qudraxial) BFRP composites with two different thickness are fabricated using hand lay-up process. Modal analysis have been carried out to determine the natural frequency and damping coefficient for BFRP composites with three different weave patterns and two different thickness.

2. Experimentation and Analysis

2.1 Fabrication of Natural FRP Composite

2.1.1 Materials Selected

Table 1: Hemp, Sisal, Flax fibers are taken as reinforcement since they have good properties than remaining Natural fibers.

Properties	Hemp	Sisal	Flax
Density (g/cm3)	1.48	1.33	1.4
Tensile strength (MPa)	550-900	600-700	800-1500
E-Modulus (GPa)	16.8	22	19.8

Table 2: Epoxy (LY556) is used for Matrix phase since it has Better moisture resistance, good adhesion with reinforcement.

Density (g/cc)	Strength Mpa	E-Modulus Gpa	Poisson's ratio
1.32	373	3.4	0.3

2.1.2 Sodium hydroxide treatment

To allow for direct contact between cellulose and matrix Surface of fiber is pre-treated with sodium hydroxide to remove hemicellulose and lignin. Due to this Fiber could not make direct links with matrix material. 5% sodium hydroxide treatment has high mechanical property since there is an increase the adhesion between fiber and matrix.

2.1.3 Hand Lay-Up method

Then the fibers were weighed and accordingly and the resin and hardeners were weighed to get fiber matrix ratio 1:2. Epoxy and hardener are taken in the ration 10:1 and they were mixed by using glass rod in a bowl. Care was taken to avoid formation of bubbles. Because the air bubbles which were trapped in matrix may result failure in the material. The subsequent fabrication process consisted of first putting a releasing film on the mould surface. Next a polymer coating was applied on the sheets. Then fiber ply of one kind was put and proper rolling was done until all the fibers are wetted by the epoxy. Then resin was again applied, next to it fiber ply of another kind was put and rolled. Rolling was done using cylindrical mild steel rod. This procedure was repeated until two alternating fibers have been laid. On the top of the last ply a polymer coating is done which serves to ensure a god surface finish. Finally a releasing sheet was put on the top and a light rolling was carried out. Then a 20 kgf weight was applied on the composite. It was left for 48 hrs to allow sufficient time for curing and subsequent hardening.

2.2 Preparation of test specimens

A jig saw machine was used to cut each laminate into smaller pieces, for Tensile, Flexural and Brinell hardness testing specimens. All the mechanical testing methods that were carried out were based on American Standard Testing Methods (ASTM) to perform mechanical tests namely Tensile Test (ASTM D3038), Flexural Test (ASTM D790) respectively.

Table 3: Astm Standards For Different Tests

S.No	Test Name	Astm Standard	Dimensions (mm^3)
1	Tensile test	D3039	200X25X7
2	Flexural test	D790	127X25X7

2.3 Tensile Test

In a broad sense, tensile test is a measurement of the ability of a material to with stand forces that tend to pull it apart and to what extent the material stretches before breaking. The stiffness of a material which represented by tensile modulus can be determined from stress-strain diagram. The specimens were positioned horizontally in the grips of the testing machine. Modulus of Elasticity

(Gpa) Evaluated by Instron 8801 servo hydraulic testing Machine UTM for Tensile Testing. We get UTS and Young's Modulus values directly from the machine.

Figure 2: Sample loaded on Instron 8801

Figure 3: Tensile test Specimens

2.4 Flexural test Three-point bending (flexural) test

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. Sometime it is referred as cross breaking strength where maximum stress developed when a bar shaped test piece acting as a simple beam is subjected to a bending force perpendicular to the bar. This stress decreased due to the flexural load is a combination of compressive and tensile stresses.

There are two methods that cover the determination of flexural properties of material they are three point loading system and four point loading system. As described in ASTM D790, three-point loading system applied on a supported beam was utilized. Flexural test is important for designer as well as manufacturer in the form of a beam. The material properties Flexural Modulus and Flexural strength were determined using INSTRON 8801 UTM servo hydraulic testing Machine.

Figure 4: Sample loaded in Instron 8801

Figure 5: Test Specimens after flexural test on Instron 8801

2.5 Finite element analysis

Finite element algorithms have become a powerful tool in order to analyze and solve a wide range of engineering problems. The finite element analysis of laminated composite plates in this work is carried out using the software ANSYS 15 APDL. Finite Elements Model and Solution Procedure The 3D model of the cantilever unidirectional and Bidirectional fiber reinforced polymer composite plate having dimensions 200 mm (length) × 30 b mm (width) was constructed.

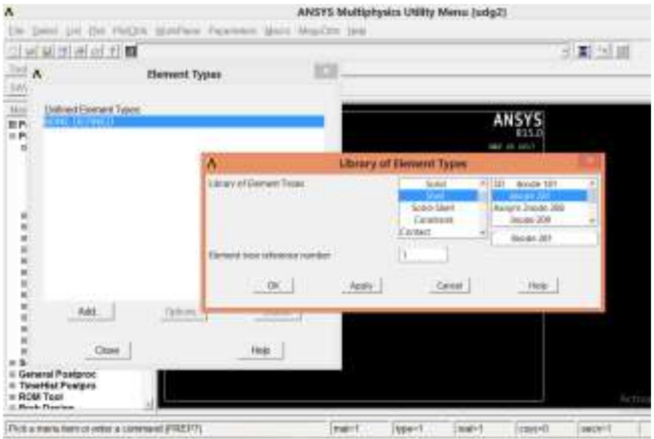

Figure 6: determining the element type of the composite layup

The plate thickness "t" was taken to be dependent on the fiber/matrix combination used in the laminas that made the plate. The ply thickness for composite plates was taken as 3.5 mm respectively. The plate was modeled as a plane area in ANSYS 15 and then meshed using eight noded quadrilateral shell elements (SHELL281). The SHELL281 element is suitable for analyzing thin to moderately-thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. The accuracy in modeling composite shells using these elements is governed by the first order shear deformation theory (FSDT) in which the transverse shear strain is assumed to be constant through the thickness of the shell. The plate was fixed on the edge having dimension of 30 mm. In order to carry out the modal analysis so as to obtain the first four mode shapes and natural frequency. The block Lanczos mode extraction method was used. An APDL code was written to carry out the above steps in FEA and to carry out further parametric study.

Evaluation of the nine elastic moduli to determine the composite material is orthotropic material. By solving the below equations we get the values of elastic constants of composite. Since we know the elastic constants of fiber and matrix materials are used to calculate the values for required composite material is as follows;

Longitudinal Young's modulus, E1
Transverse Young's modulus, E2, E3
Major and Minor Poisson's ratio, v12 v23 v13
In-plane shear modulus, G12 G23 G13
By using strength of materials approach
Longitudinal young's modulus
E11=Ef*V+Em*(1-V)
Transverse young's modulus
E22=Em*(Ef+Em+(Ef-Em)*V)/(Ef+Em-(Ef-Em)*V)
Major poisson's ratio
v12=vf*V+vm*(1-V)
Minor poisson's ratio
v23=vf*V+vm*(1-V)*(1+vm-v12*Em/E11)/(1-vm^2+vm*v12*Em/E11)
Inplane Shear Modulus
G12=Gm*(Gf+Gm+(Gf-Gm)*V)/(Gf+Gm-(Gf-Gm)*V)
G23=E22/(2*(1+v23))
Density of composite
Den=Df*V+Dm*(1-V)

We assume the material is Transversely isotropic material

E33=E22=Transverse young's modulus
v13=v12=Axial poissons ratio for loading in x direction
G13=G12=Axial shear modulus i.e shear stress parallel to the fibers

Table 4: By Calculating We Get 9 Elastic Constants

Elastic Constants	Hemp/Epoxy	Sisal/Epoxy	Flax/Epoxy
E11(Pa)	7.42e09	9.53e09	8.81e09
E22(Pa)	4.47e09	4.71e09	4.68e09
E33(Pa)	4.47e09	4.71e09	4.68e09
V12	0.27	0.30	0.27
V23	0.32	0.35	0.32
V13	0.27	0.30	0.27
G12(Pa)	1.72e09	1.81e09	1.81e09
G23(Pa)	1.68e09	1.73e09	1.76e09
G13(Pa)	1.72e09	1.81e09	1.81e09
Density	1410	1405	1386

Then the shell layup is done and the modeling of composite layup is done using rectangle dimensions 200mmX30mm. Next we go for meshing of the model. Meshing is done by selecting fine mesh globally and meshing is done throughout the composite. After Meshing boundary conditions are applied i.e. cantilever condition is applied. So that it is fixed at one end. Model analysis is done to get the Natural frequency and Mode shapes of the model. Similarly same work is carried out for Fixed at both ends and simply supported end conditions.

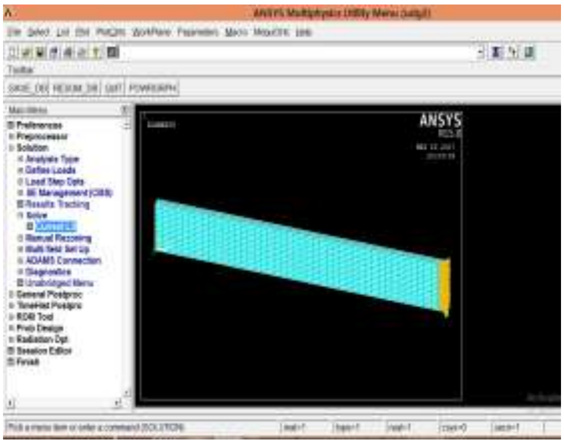

Figure 7: Meshing and Boundary Conditions applied final model

Damping ratio can be obtained from frequency response curve using Half-power bandwidth method. To get this graph we have to do Harmonic analysis. In this we have to apply the pressure required on the area and we have to give range of frequency then we have to solve current ls. Then we go to TimeHist Postpro we have to draw graph between Frequency and Amplitude. From this graph we can determine the Damping Ratio by Half-power bandwidth method.

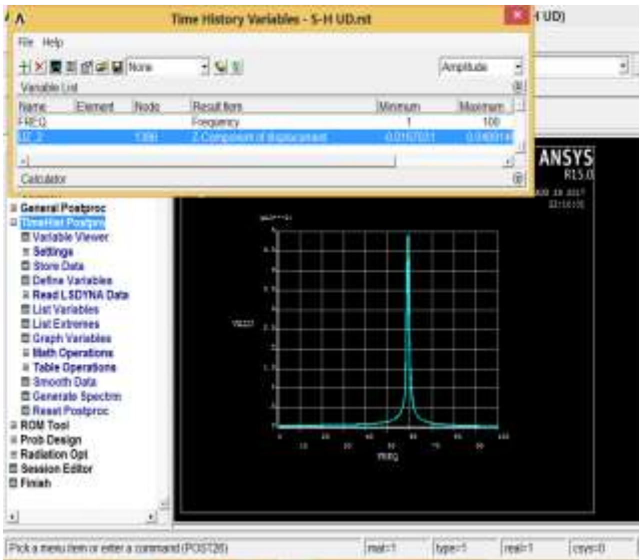

Figure 8: Graph for Frequency Vs Amplitude

3. Results and Discussions

3.1 Tensile test results

Table 5: The Tensile Properties Of Composite Specimens

Specimen	UTS (MPa)	Modulus (E-modulus) (GPa)
SISAL+HEMP/Epoxy (Bidirectional)	34.53	3.12
SISAL+HEMP/Epoxy (Unidirectional)	46.19	3.55
FLAX+HEMP/Epoxy (Unidirectional)	54.51	4.17
FLAX+HEMP/Epoxy (Bidirectional)	17.79	3.08
SISAL+FLAX/Epoxy (Unidirectional)	33.69	2.89
SISAL+FLAX/Epoxy (Bidirectional)	36.22	4.42

Tensile test was carried out on Instron 8801 servo hydraulic testing Machine UTM for Tensile Testing. All the specimens were of Tensile Test (ASTM D3038) standard. The results are tabulated in the table below. By comparing the values of the different samples obtained from tensile test and that are represented in the graph. From graph we can say FLAX+HEMP/Epoxy (Unidirectional) Natural FRP composites have High UTS compared to other Natural FRP composites.

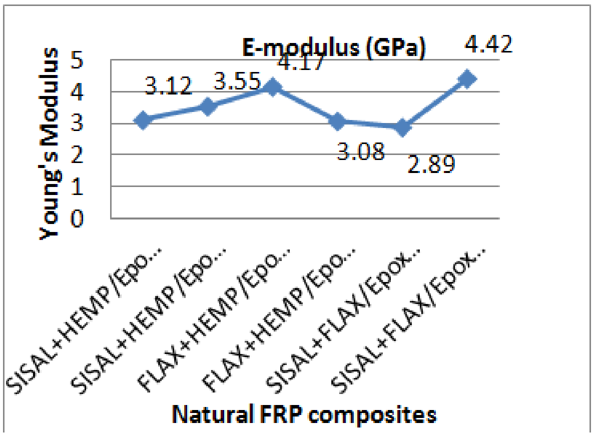

Figure 9: Graph represents Young's Modulus of Different Composite samples

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3.2 Flexural test Three-point bending (flexural) test result

Flexural test is conducted on different composite samples as per ASTM D790 standards All six samples are taken and experiment is conducted on Instron 8801 servo hydraulic testing Machine UTM for Flexural Testing. By comparing the values of the different samples obtained from tensile test and that are represented in the graph. From graph we can say SISAL+HEMP/Epoxy (Unidirectional) Natural FRP composites have High Flexural Modulus compared to other Natural FRP composites.

Table 6: Flexural Modulus values of composite samples

Specimen	Flexural Modulus (Mpa)
SISAL+HEMP/Epoxy (Bidirectional)	3773.10
SISAL+HEMP/Epoxy (Unidirectional)	4236.77
FLAX+HEMP/Epoxy (Unidirectional)	3529.62
FLAX+HEMP/Epoxy (Bidirectional)	2073.38
SISAL+FLAX/Epoxy (Unidirectional)	3303.34
SISAL+FLAX/Epoxy (Bidirectional)	3842.76

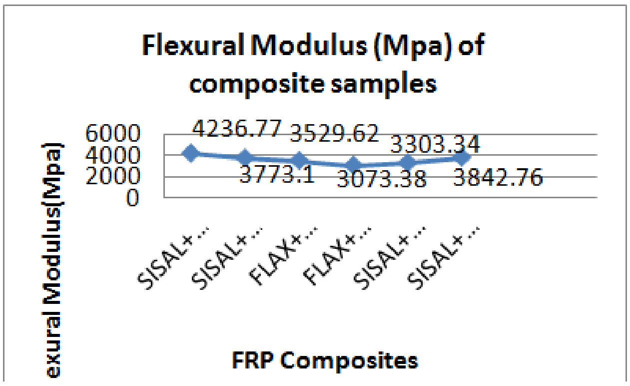

Figure 10: Graph represents Flexural Modulus for different Composite samples

3.3 Natural Frequency and Damping Ratios using ANSYS 15

Model analysis has been done to get Natural frequency and Mode shapes of different orientation of fibers in composite samples in Ansys 15 APDL software. Hybrid E-glass and carbon fiber composites are modeled and analysis is carried out as procedure explained in previous session.

Table 7: Natural Frequency and a Dmping Ratios of different Natural FRP composites samples with 3 Different Boundary Condition

Specimen	Cantilever	Both ends fixed	Simply supported
SISAL+HEMP/Epoxy (Unidirectional)	59.25	374.4	376.16
SISAL+HEMP/Epoxy (Bidirectional)	49.47	313.31	317.24
FLAX+HEMP/Epoxy (Unidirectional)	58.34	368.73	369.7
FLAX+HEMP/Epoxy (Bidirectional)	50.76	313.77	317.88
SISAL+FLAX/Epoxy (Unidirectional)	72.53	392.79	393.52
SISAL+FLAX/Epoxy (Bidirectional)	51.57	326.49	341.89

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Table 8: Damping Ratios of different Natural FRP composites samples

Specimen	Damping ratio
SISAL+HEMP/Epoxy (Unidirectional)	0.018
SISAL+HEMP/Epoxy (Bidirectional)	0.02
FLAX+HEMP/Epoxy (Unidirectional)	0.016
FLAX+HEMP/Epoxy (Bidirectional)	0.0168
SISAL+FLAX/Epoxy (Unidirectional)	0.015
SISAL+FLAX/Epoxy (Bidirectional)	0.021

From the above table the values of Natural Frequency are obtained from ANSYS15 by using model analysis. We can say that Hybrid SISAL+FLAX/Epoxy (Unidirectional) sample has high Natural frequency than any other samples in all three boundary conditions. Damping ratio is good for Bidirectional orientation for SISAL+FLAX/Epoxy.

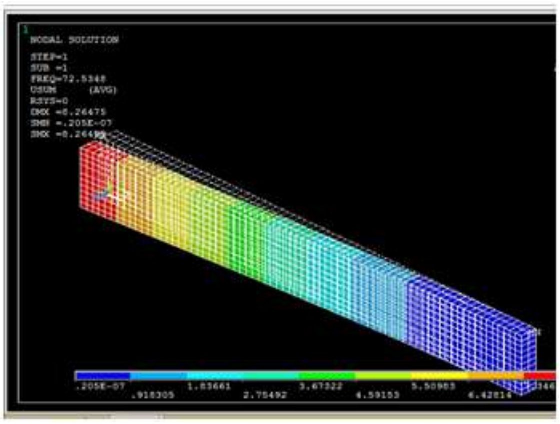

Figure 11: Representing the Mode Shape, Displacement and Natural Frequency of Hybrid SISAL+FLAX/Epoxy with Cantilever boundary condition

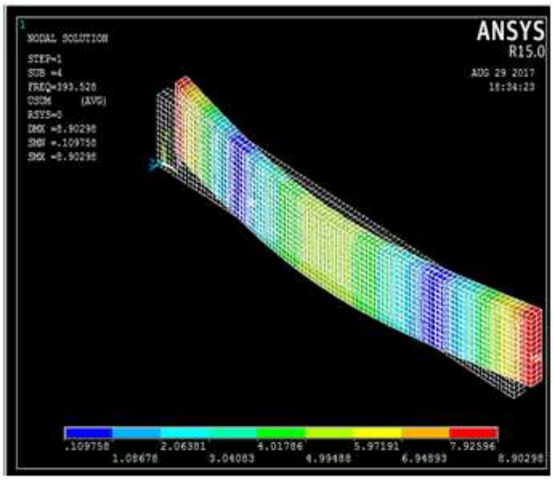

Figure 12: Representing the Mode Shape, Displacement and Natural Frequency of Hybrid SISAL+FLAX/Epoxy with simply supported boundary condition

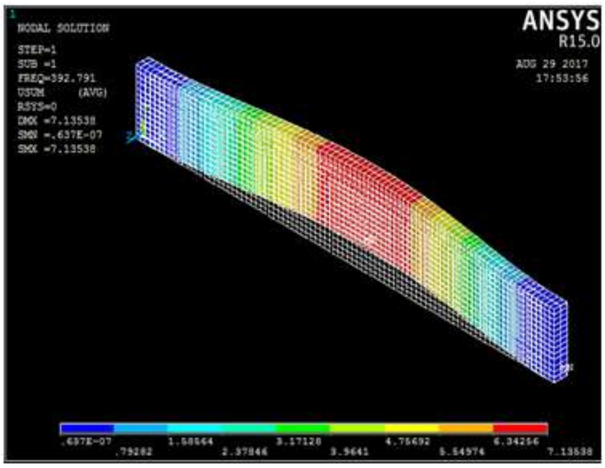

Figure 13: Representing the Mode Shape, Displacement and Natural Frequency of Hybrid SISAL+FLAX/Epoxy with Fixed at both ends boundary condition

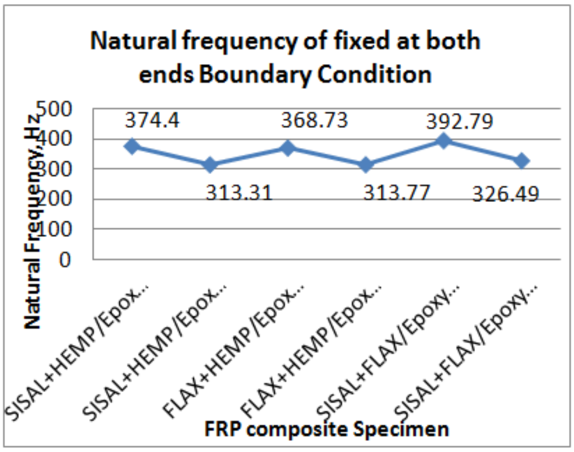

Figure 14: Graph represents Natural frequency for different **FRP Composite Specimen** samples under Fixed at both ends Boundary condition.

4. Conclusion

Hemp, Flax and Sisal continuous fiber Hybrid reinforced polymer composite specimens have been investigated for natural frequency and damping factor for Unidirectional and Bidirectional fiber orientations. The conclusions are summarized as follows.

- Unidirectional oriented Hybrid Natural FRP composite have good results compared to Bidirectional oriented Hybrid Natural FRP composite except damping Property.
- The chemical treatment increases the modulus of the material and increases the stiffness of the composite.
- Maximum Stress value is for FLAX+HEMP/Epoxy Unidirectional Hybrid Natural FRP Composite Specimen is having high value in both Ansys and Experimental results. i.e. 60.93 Mpa and 54.51Mpa respectively.
- The Percentage error is 10.5 between Ansys and Experimental Values of UTS from this the values of Stress are valid.
- SISAL+HEMP/Epoxy (Unidirectional) has the high BHN value i.e 26.31 and unidirectional specimens have

more hardness when compared to bidirectional fiber orientation.

- SISAL+HEMP/Epoxy (Unidirectional) hybrid FRP composite has maximum flexural modules 4236.77Mpa compared to remaining FRP natural fiber Reinforced composites and having high stiffness.
- Natural Frequencies are changing with respect to boundary conditions. Laminate with fixed fixed boundary condition is having very high natural frequency.
- SISAL+FLAX/Epoxy (Unidirectional) Hybrid composites Natural Frequency is more compared to remaining FRP composite in Cantilever, Fixed at both ends and Simply Supported boundary conditions because it has high stiffness.
- Material Damping is high for Bidirectional Natural FRP composite compared to Unidirectional Natural FRP Composite.
- Damping Ratios of SISAL+FLAX/Epoxy (Bidirectional) is more and it has high damping capacity compared to remaining hybrid Natural FRP composite. SISAL+HEMP/Epoxy and SISAL+FLAX/Epoxy Bidirectional specimen has high damping ratio 0.021.

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