Vibration Analysis of Natural Fiber Composite Beam under Various End Conditions

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***Abstract*— The today's research trend in composite is for the development of composite with natural fibre instead of synthetic fibre. It is because of Properties like light weight, low cost, bio-degradability, low environmental impact and ease to manufacture. It becomes necessary to study the vibrational behavior of composite in addition to mechanical strength and chemical properties for effective utilization in real world applications as they subjected to many types of loading condition and different types of vibration with different configurations. In present work a natural fibre composite beam is manufactured with unidirectional orientation for measurement of transverse vibration with different end configurations results obtained from analytical method and modal analysis in ANSYS are compared. The mechanical properties are considered by performing tensile, flexural and impact test on the beam according to ASTM standards. Hemp and sisal fiber are taken as fiber component and ARSONOL IP 1005 P, unsaturated polyester resin is as matrix material. The vibration test is performed using LabVIEW software, which gives data based on time and measures the acceleration. To convert time domain data into frequency domain, Fast Fourier Transformation (FFT) is done in MATLAB and natural frequencies are found out. Those results are also compared with analytical results, with the results obtained by modal analysis in ANSYS and with the results obtained by Neural Network Tool of MATLAB.**

Keywords*— Free Vibration, Natural Fiber, Composite Material, Properties Of Composite, FEA, Neural Network.

I. INTRODUCTION

Natural fiber composites are attracting the researcher because of advantages that these fibers make available over conventional reinforcing synthetic fiber. Natural fibers possess properties like light weight, low environmental impact, biodegradability and non-abrasive characteristics. In fact, certain drawbacks like poor moisture resistance, lower stability, hydrophilic nature, lower life cycle and poor fire resistance properties create the resistance in use of natural fiber composite. However nowadays new surface treatments are developed which increases mechanical properties of natural fibers makes them available for certain industrial applications. In the light of mechanical and economical properties, there are different type of natural available from different species and different origin. Mechanical properties of various fibers are compared with synthetic fibers. Since glass fiber has occupied more than 90% of market for reinforcement in composite industry, lower mechanical properties and improper (poor) bonding characteristics of fiber with matrix material limited the use of natural fiber. With the development of improved technology mechanical properties of this natural fiber are started improving. Despite that natural fibers are currently facing the problem of poor fire resistance, lack of dimensional stability and hydrophilic nature, which tends to affect the mechanical properties.

The researchers also studied effect of volume fraction of fiber on mechanical properties, which shows increasing trend in mechanical properties of composite as volume fraction of fiber increased up to 50%. After that the mechanical properties of composite shows decreasing trend due to poor adhesion of fiber with matrix material [1].Despite of having lower life cycle compared to synthetic fiber, natural fiber composites are looking like to be superior to glass fiber as they required larger fraction of fiber which tends to reduce the overall weight and also they have less environmental impact compared to glass fiber composites. [2]. The reduction in overall weight improves the fuel efficiency which in turns results in fuel saving [3] and also reduction of cost.

Effect of layering pattern is carried out by different researchers [4, 5]. Various combinations has been studied and compared with glass fiber composite to replace synthetic fibers in as many as possible ways and to promote use of natural fiber composites. Effect of addition of Nano clay is also studied with different layering pattern of glass and coconut sheath to reduce the fraction of glass fiber [6] The research is also on going to study the vibrational behavior of natural fiber composite beam in addition to other mechanical properties [7]. Different researcher studied or examined free vibration characteristics of natural fiber composite beam with different fiber length [8] , with different weightage fraction [9] and analysis of mechanical properties are carried out for various composites [10] to find effect of such parameters. The short length fiber shows better results as they have less surface damage as compared to long fibers and 50% weight shows the higher mechanical properties while better damping properties are achieved with 35% w/w ratio of fiber to matrix. There is some functional relationship between damping and temperature, but there is inverse relationship between first natural frequency and temperature as increased in temperature reduce the natural frequency as increase in temperature will decrease the young modulus and there is a relation between natural frequency and young's modulus [11]. As composite is anisotropic material increase in weightage fraction of fiber initially increase in the transverse, compressive and shear strength but then it start decreasing [12]. The effect of cut off on the centre of the composite plate has been studied as cut out is commonly used as an access port to connect other appliances [13].

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Effect of orientation of fiber in composite also studied and it shows that composite with (0^0) fiber orientation shows maximum mechanical properties and it start decreasing as fiber orientation increases towards (90^0) [14]. Effect of various end conditions are also studied which shows maximum natural frequency for clamped-clamped condition while cantilever condition shows minimum value of natural frequency [15].

However, for varied shaped structures or system may be analyzed with soft computing techniques more effectively. Soft Computing techniques constitute artificial neural networks (ANN), fuzzy logic, machine learning and genetic algorithm [16]. Soft computing methods are different from classical computing method , unlike classical computing method it is tolerant of imprecision, an uncertainty, a partial truth to achieve tractability, an approximation, robustness, decreases solution cost and a better relation with reality [17].On over all, ANN has a benefits of parallelism, high speed evaluation, less time consumption, optimization to problem, well suited to constrained problem, easy to design, understandable. So, ANN is one of the beneficial method for soft computing technique and also an optional method used to obtain solutions of mathematical form of dynamic systems, represented with the help of ordinary differential equations. [18, 19].

II. EXPERIMENTAL WORK

For testing of mechanical properties, the standard specimens of Hemp fiber, Sisal fiber and Hemp-Sisal fiber with 10 w/w ratio of fiber to matrix weight have prepared. To investigate mechanical properties tensile, impact and flexural test are performed.

A. *Tensile test*

Tensile test is performed using ASTM standard on UTM machine. The beam is prepared according to ASTM D368. The Figure 1 shows the standard specimen and the dimensions are given in Table 1.The specimen before and after tensile test shown in Figure 2.

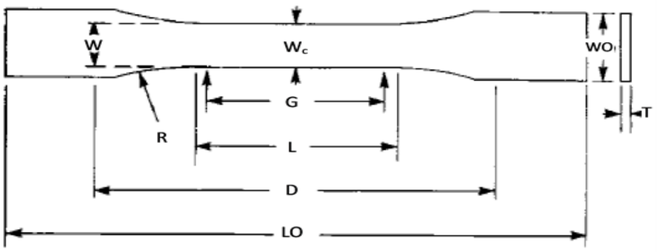

Fig. 1. Dimensions of dumbbell shape

TABLE I. DIMENSIONS OF DUMBBELL SHAPE

Notation	Meaning	Thickness up to 7 mm (mm)
W	Width of narrow section	13
L	Length of narrow section	57
WO	Width overall	19
LO	Length overall	165
G	Gauge length	50
D	Distance between grips	115
R	Radius of fillet	76

(a) Before (b) After

Fig. 2. Test specimen before and after tensile test

In Table 2, the results of tensile test are shown. The hemp-sisal FRPC shows the grater tensile strength compared to Hemp and Sisal FRPC.

B. *Flexural test*

The flexural test is also performed on UTM machine. The specimens are prepared with standard ASTM D790. The beam prepared with the dimensions of $12.7\times127\times5$ mm^3. The Figure 3 shows test specimen before test and after test while Table 3 shows the results of test

TABLE II. TABLE 1: RESULT OF TENSILE TEST

Beam	Max. Load (N)	Max. Extension (mm)	Elongation (%)	Tensile strength (MPa)	Modulus of Elasticity (MPa)
Hemp FRPC	1660	1.28	2.44	25.6	1140
Sisal FRPC	1420	1.76	3.56	21.9	797
Hemp-sisal FRPC	1810	2.04	4.15	27.8	682

Fig. 3. Test specimen before test and after flexural test

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TABLE III. FLEXURAL TEST RESULTS

Specimen	Width (mm)	Thickness (mm)	Max. force (N)	Flexural strength (MPa)	Flexural strain (%)	Modulus (MPa)
Hemp FRPC	12.7	5	167	63.3	1.58	4530
Sisal FRPC	12.7	5	134	50.7	1.91	2910
Hemp-sisal FRPC	12.7	5	146	55.1	2.18	2820

C. *Impact test*

Charpy test is used to measure the impact strength of the composite beam are shown in Figure 4 shows the test specimen before test and after impact test while Table 4 shows the result of test.

Fig. 4. Test Specimen before test and after impact test

TABLE IV. IMPACT TEST RESULTS

Beam	Impact strength (J)
Hemp FRPC	2.50
Sisal FRPC	2.15
Hemp-sisal FRPC	2.34

D. *Vibration test*

Vibration analysis is performed with different end conditions and LabVIEW is used for measuring the acceleration. This software gives data of time and acceleration. To find out natural frequency Fast Fourier Transformation (FFT) is performed in MATLAB and natural frequencies are plotted and measured. Figure 5 shows test set up for doing experimental work while Table 5 shows the results of vibration analysis and Figure 6 shows frequency response curve.

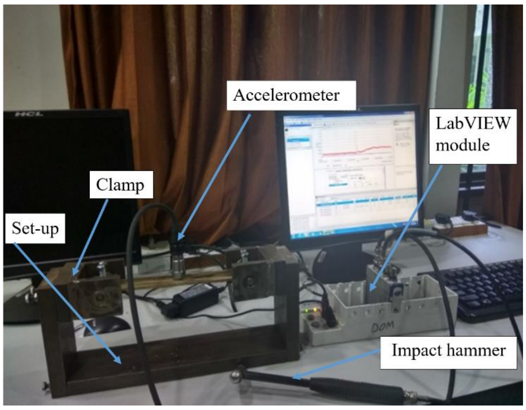

Fig. 5. Set up for vibration measurement

TABLE V. EXPERIMENTAL RESULT OF NATURAL FREQUENCY FOR DIFFERENT FRPC FOR VARIOUS END CONDITIONS

Beam	Mode no	Natural frequency (Hz)			
		End configuration			
		Cantilever	*Clamped-Clamped*	*Clamped-Supported*	*Supported-Supported*
Hemp-FRPC	1	16.8	109.8	76.17	48.44
	2	106.2	302.7	241.8	193.8
	3	297.3	590.6	503.9	427.7
Sisal-FRPC	1	14.06	91.8	62.5	40.23
	2	87.5	248.4	203.9	161.3
	3	245.7	498	418	353.5
Hemp-Sisal FRPC	1	13.67	89.06	61.33	39.84
	2	87.11	246.5	198.8	156.3
	3	241.4	493	409	344.9

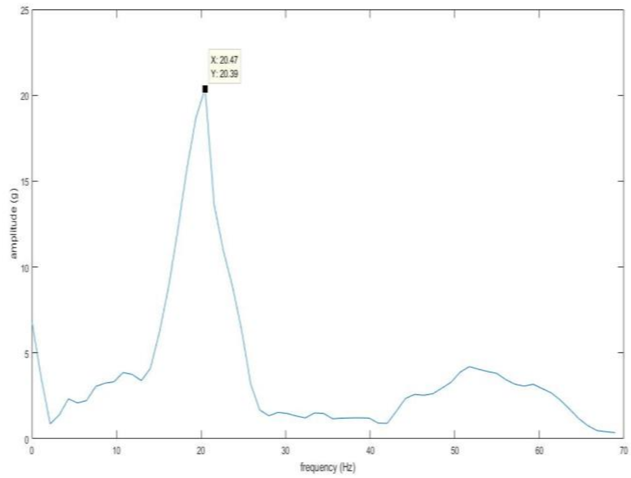

Fig. 6. Frequency response curve

III. THEORETICAL ANALYSIS

For theoretical analysis, considering the beam as continuous and free undamped system. Since the beam is made of composite material, so data regarding the physical properties of matrix material and resin like density, young's modulus and poison's ratio of individual material and by weightage or volume fraction of matrix material used for making the composite are to be theoretically calculated and subsequently the natural frequency for respective END condition by theoretical analysis. For analyzing natural frequency, requires properties like young's modulus, density and poisons ratio of beam can be calculated by equations (1), (2) and (3). By results of equations (1), (2) and (3), frequency is theoretically obtained by equation (4).

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1) *Young's modulus (E_c)*

a) *In case of axial loading,*

$$E_c = (E_m \times V_m) + (E_f \times V_f) \tag{1}$$

b) *For transverse loading,*

$$\frac{1}{E_c} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \tag{2}$$

2) *Poison's ratio (μ_c)*

$$\mu_c = \frac{\varepsilon_t}{\varepsilon_l} = \mu_f V_f + \mu_m V_m \tag{3}$$

3) *Density (ρ_c)*

$$\frac{1}{\rho_c} = \frac{W_f}{\rho_f} + \frac{W_m}{\rho_m} \tag{4}$$

$$\rho_c = \rho_f V_f + \rho_m V_m \tag{5}$$

4) *Natural frequency (f)*

$$w = \beta^2 \sqrt{\frac{EI}{\rho A}} = (\beta l)^2 \sqrt{\frac{EI}{\rho A l^4}} \tag{6}$$

$$w = 2\pi f \tag{7}$$

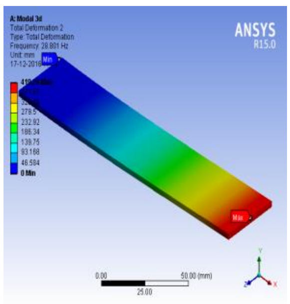
Where, W *and* V are weightage fraction and volume fraction respectively. There is many possible type of beam configuration. Following Table 6 shows the governing equation for some of different beam configuration. Satisfying equation 3.4 of Natural Frequency we get different values of β for known length of beam and from these values of β natural frequency at different mode can be found out.

TABLE VI. GOVERNING EQUATION FOR DIFFERENT BEAM CONFIGURATION

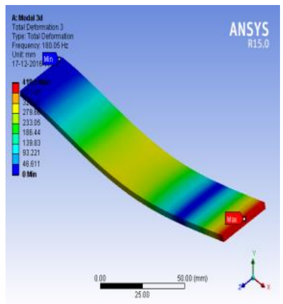
Beam configuration	Frequency equation	Value of βl for		
		1st *natural frequency*	2nd *natural frequency*	3rd *natural frequency*
Clamped-free	$\cosh(\beta l)\cos(\beta l)+1=0$	1.875104	4.694091	7.854757
Clamped-clamped	$\cosh(\beta l)\cos(\beta l)-1=0$	4.730041	7.853205	10.995608
Clamped -supported	$\tan(\beta l)-\tanh(\beta l)=0$	3.926602	7.068583	10.210176
Supported-supported	$\sin(\beta l)=0$	π	2π	3π

IV. FINITE ELEMENT MODELING

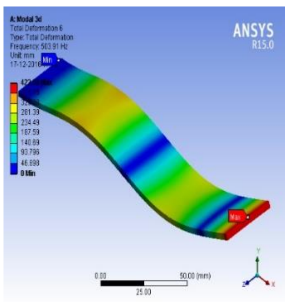
ANSYS 15.0 is used for analysis purpose. Model analysis module is used for the model analysis. Beam is modelled in ANSYS and various end conditions are configured and analysis done to find out natural frequencies of different beam with different end conditions. Figure 7 shows visual interpretation of different mode of vibration and Table 7 shows the results of ANSYS analysis.



(a) mode 1



(b) mode 2



(c) mode 3

Fig. 7. Vibrating pattern of beam at different mode for Cantilever beam

V. NEURAL NETWORK ANALYSIS

Neural Network Tool of MATLAB R2017a for analysis purpose. Neural Network is prepared consisting of Hidden Layer Size of 10 with 3 input variables and 1 output. Training, Validation and Testing of Network is done and analysis results are obtained. Figure 8 shows Neural Network while Figure 9 shows regression pattern of network at different mode for Cantilever beam and Table 8 shows the results of ANN analysis.

TABLE VII. ANSYS RESULTS OF NATURAL FREQUENCY AT VARIOUS MODES

beam	Mode no	Natural frequency (Hz)			
		End configuration			
		Cantilever	*Clamped-Clamped*	*Clamped-Supported*	*Supported-supported*
Hemp-FRPC	1	18.622	119.76	81.832	51.94
	2	116.31	328.48	264.49	207.78
	3	324.6	640.59	550.06	466.33
Sisal-FRPC	1	15.339	98.649	67.407	42.785
	2	95.81	270.58	217.87	171.15
	3	267.38	527.67	453.1	384.13
Hemp-Sisal FRPC	1	14.777	95.029	64.934	41.215
	2	92.294	260.65	209.87	164.87
	3	257.57	508.42	436.47	370.04

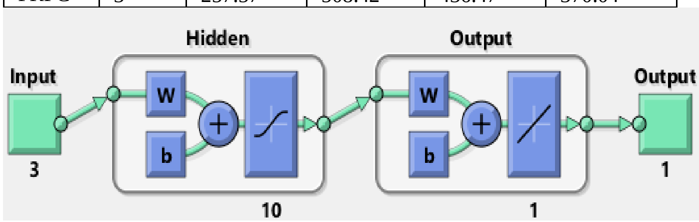
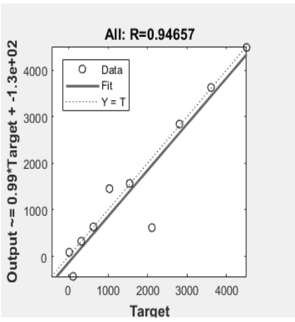
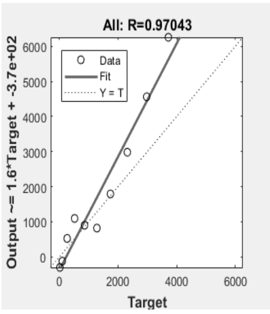


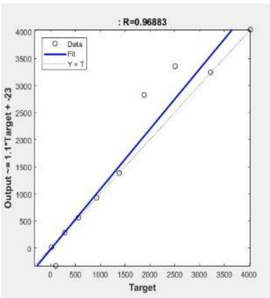
Fig. 8. Neural Network (Inputs: βl , E and ρ and Output: Frequency)



(a) Hemp



(b) Sisal



(c) Sisal-Hemp

Fig. 9. Regression pattern of network at different mode for Cantilever beam

VI. RESULT AND DISCUSSION

Table 9 shows the comparison of natural frequency obtained by different method namely experiment, analytical and ANSYS.

From Table 9, it is clear that cantilever beam configuration have minimum natural frequency for same mode compared to other end configuration, while natural frequencies are maximum for clamped-clamped condition followed by clamped-supported and supported-supported configuration. Among all hemp FRPC have maximum natural frequency for same mode followed by sisal FRPC and hemp-sisal FRPC.

TABLE VIII. ANN RESULTS OF NATURAL FREQUENCY AT VARIOUS MODES

beam	Mode no	Natural frequency (Hz)			
		End configuration			
		cantilever	Clamped-clamped	Clamped-supported	Supported-supported
Hemp-FRPC	1	18.22	119.18	81.26	51.28
	2	115.21	335.36	262.78	204.33
	3	321.87	637.14	544.86	424.02
Sisal-FRPC	1	15.026	98.17	67.06	42.18
	2	94.87	252.06	214.16	169.34
	3	262.19	524.07	447.91	378.64
Hemp-Sisal FRPC	1	14.61	95.04	62.07	40.89
	2	92.08	265.28	204.56	168.52
	3	253.34	496.36	407.19	363.92

Hemp-sisal FRPC possess maximum tensile strength of 27.8 MPa with maximum elongation of 4.15% (2.04 mm), followed by hemp FRPC with tensile strength of 25.6 MPa and maximum elongation of 2.44% (1.28 mm) and sisal FRPC with maximum tensile strength of 21.9 MPa and maximum elongation of 3.56% (1.76 mm).

VII. CONCLUSION

Due to comparative properties like light weight, low cost, good mechanical properties, low environmental impact, less energy requirement, safety in manufacturing and bio-degradability natural fibres are now become the major area for research in composites to replace the synthetic fiber. So now it is necessary to study the vibrational characteristics of composite beam with the study of mechanical properties. Here analytical modelling is presented considering the transverse isotropy, which gives an idea about nature frequency of composite beam. Mathematical modelling is also done in ANSYS 15.0 to verify the validity of mathematical modelling. Natural frequency obtained by mathematical modelling is supported by ANSYS result and Neural Network Analysis result. It also gives an idea about natural frequency of beam.

Results shows that hemp FRPC possess higher tensile strength, modulus of elasticity higher impact strength and comparative flexural strength which enable it to available for various applications

Despite of having slightly less impact strength, hemp-sisal FRPC can be used for various application due to its higher tensile strength and comparative flexural strength. In the hemp-sisal FRPC hemp fiber provides strength to composite while addition of sisal fiber improves the flexibility of composite.

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These composites are preferably used in household applications aerospace structure application, high speed turbine machinery and in automobile applications such as bumper of car, side panel back panel of door, roof and dash board in place of glass fiber composite.

		END Configuration	Cantilever			Clamped-Clamped			Clamped-Supported			Supported-Supported		
		Mode	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Natural frequency (Hz)	*Hemp-Sisal FRPC*	*ANSYS*	14.777	92.294	257.57	95.029	260.65	508.42	64.934	209.87	436.47	41.215	164.87	370.04
		Analytical	14.21	91.68	254.89	94.87	256.78	502.88	64.34	206.22	429.65	40.89	161.37	363.96
		Experiment	13.67	87.11	241.4	89.06	246.5	493	61.33	198.8	409	39.84	156.3	344.9
		Neural Network	14.61	92.08	253.34	95.04	265.28	496.36	62.07	204.56	407.19	40.89	168.52	363.92
	Sisal FRPC	*ANSYS*	15.339	95.81	267.38	98.649	270.58	527.67	67.407	217.87	453.1	42.785	171.15	384.13
		Analytical	15.04	94.67	262.19	98.17	267.88	524.07	67.06	214.16	447.91	42.18	167.34	378.64
		Experiment	14.06	87.5	245.7	91.8	248.4	498	62.5	203.9	418	40.23	161.3	353.5
		Neural Network	15.026	94.87	262.19	98.17	252.06	524.07	67.06	214.16	447.91	42.18	169.34	378.64
	Hemp FRPC	*ANSYS*	18.622	116.31	324.6	119.76	328.48	640.59	81.832	264.49	550.06	51.94	207.78	466.33
		Analytical	18.22	115.21	321.87	119.18	326.62	637.14	81.26	262.78	544.86	51.29	204.27	459.39
		Experiment	16.8	106.2	297.3	109.8	302.7	590.6	76.17	241.8	503.9	48.44	193.8	427.7
		Neural Network	18.22	115.2	321.8	119.1	335.36	637.1	81.26	262.78	544.86	51.28	204.33	424.02

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