Determination of Vibrational Characteristics of Coir, Banana and Aloe Vera Fibres Reinforced Hybrid Polymer Matrix Composites

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In the last few years, green composites are becoming more suitable for applications over synthetic composite. There has been a growing interest in recent years in the utilisation of natural fibres in making low-cost building material. However, these natural fibre-based composites are not fully environmentally friendly because the matrix resins are non-biodegradable. In this paper, an attempt is made to fabricate green composites with coir, banana, and aloe vera fibres as reinforcement and hybrid polymer as matrix. The hybrid polymer is prepared from natural and synthetic resins. This work intends to find the vibrational characteristics of these composites. The influence of three parameters, i.e. CNSL in hybrid polymer, fibre volume, and fibre discontinuities on vibrational characteristics are considered. This work is carried out using FEA and the FEA results are validated by experimental results.

NOMENCLATURE

GP	General purpose resin
CNSL	Cashew nut shell liquid resin

1. INTRODUCTION

Natural fibres from renewable natural resources have the potential to act as biodegradable reinforcing materials and hence they are good alternatives to synthetic fibres. Natural fibres have good biodegradability, low density, low cost, better thermal, and insulating properties. The use of natural fibres is increasing day by day in the automobile industry, military, and space applications. Recently it is reported that 27 components of 'Mercedes S class' are manufactured based on the composite made from natural fibre. Recently many types of natural fibres such as palm, flax, hemp, jute, straw, wood, rice husk, wheat, barley, oats, bam-boo, sugarcane, grass reeds, sisal, coir, banana, aloe vera fibre, and etc. are used instead of synthetic fibre. The reinforcement of these fibres provides good strength to composite. Wang and Huang took two thousand fibres between 8 and 337 mm randomly from a coir fibre stack.[1] Composite boards were fabricated by using a hot press machine with the coir fibre as the reinforcement and the rubber as matrix and tensile strength of the composites was investigated. The average tensile strength was 560.1 N. Njoku et al. studied the effect of alkali treatment and fibre content variation on the tensile properties of coir fibre reinforced cashew nut shell liquid (CNSL) composite.[2] The results showed that tensile strength and modulus of the CNSL/Coir composite increased as the weight fraction of coir fibres was increased up to a fibre content of 30%. The composites exhibited reduction in elongation at break as fibre content was increased. Arrakhiz et al. selected three chemical treatments denoted silane, sodium hydroxide (NaOH), and dodecane bromide (C12) to improve the interface adhesion between fibres and polyethylene matrix.[3] It was found that composites obtained with treated fibres possess better mechanical properties than those of composites made with untreated fibres, the Young's modulus in the composites was higher for the alkaline treated fibres than the raw fibres. The C12 composite shows a significant tensile modulus when compared to raw fibres reinforced polymer. Reis studied coconut, sugar cane bagasse, and banana fibres.[4] Without any additional input cost, banana fibres can be used for industrial and general purposes. Banana fibre is detected to be a good reinforcement in polyester resin. Kulkarni et al. studied the mechanical behaviour of banana fibre.[5] They found that banana fibre fails during tension test due to pull out microfibrils by tearing of the cell walls. Ku et al. studied the tensile properties of natural fibre reinforced polymer composites.[6] The tensile strengths of the natural fibre reinforced polymer composites increased with fibre content, up to a maximum or optimum value and then drops. Gassan and Bledzki studied that using NaOH alkali treatment of fibres improved the tensile strength of jute/epoxy composite.[7] This alkali treatment also improved the interfacial bonding, mechanical interlocking, and more resin fibre interpenetration at the interface. Mujahid et al. studied the experimental modal analysis on composite having coconut coir as filler and the natural latex resin as a matrix material.[8] There are 4% by volume of the coir fibre that used to fabricate the composites with 40% wet, 50% wet, 60% wet, and 70% wet of coir fibre. The results were found that the dynamic characteristics are greatly dependent on the volume percentage of fibres. The increase of coir fibres will make the composite tend to have low stiffness and ductility. Petrone et al. investigated the vibrational characteristics, such as the mode shapes, the natural frequencies, and the damping ratio of recyclable foam sandwich panels, and compared the results of experimental and finite element analysis.[9] The structural loss

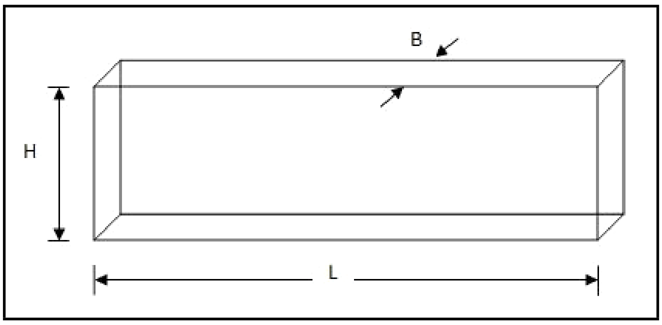

Figure 1. Geometry of standard specimen.

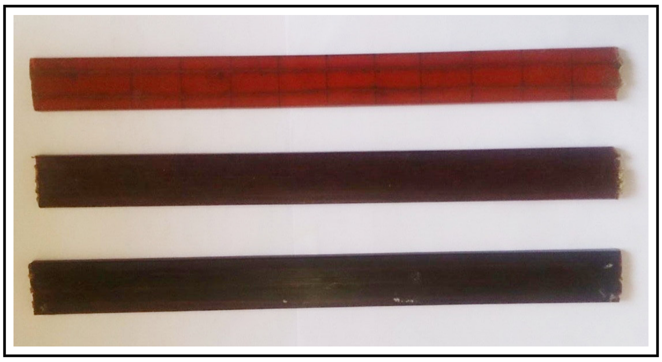

Figure 2. Composite samples for vibration with no fibre discontinuity.

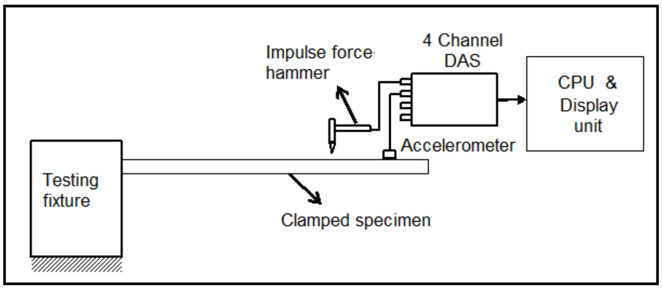

Figure 3. Schematic experimental set up.

factor was also measured using the reverberation time method. Prasad et al. investigated the tensile characteristics of jute and banana fibre reinforced hybrid polymer matrix composites and compared the results of experimental and finite element analysis.[11] Palani Kumar and Jeya Sekaran discussed the extraction process and the processing methods of natural fibres like banana, aloe vera, kenaf, and sisal fibres.[12] Faruk et al. studied the characteristics of different types of natural fibres and matrices such as synthetic polymers, bio polymer, and polymer blends.[13] They elaborated clearly about the interface adhesion between fibre and matrix, physical and chemical treatments on fibres, fabrication methods, and the performance of composites. Maffezzolia et al. investigated the mechanical characteristics of composite made using synthesized cardanol based matrix and chemical treated short ramie, flax, hemp, and jute fibres.[14]

The purpose of this paper is to study the vibrational characteristics of coir, banana, and aloe vera fibre reinforced hybrid polymer composites. The three different parameters, CNSL percentage, fibre volume, and fibre discontinuity are considered and totally nine combinations for each fibre are arrived through the Taguchi method, which is then applied for composite preparation. Finite element analyses for these composites are done and the FEA results are validated with experimental results.

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1. Material Preparation and Geometry

The reinforcements and matrix, used in this work to prepare composites, are natural fibres (coir fibre, banana fibre, aloe vera fibre) and hybrid polymer respectively. The hybrid polymer is a blended mixture of general-purpose polyester resin (GP resin) and cashew nut shell liquid (CNSL) in different proportions. Methyl ethyl ketone peroxide and cobalt naphthenate are used as catalyst and hardener respectively. GP resin and CNSL were procured from S.M. Composites, Chennai, India, and Golden Cashew nuts, Pondicherry, India respectively. The coir, banana, and aloe vera fibres used for this work were obtained from local farmers, Tamil Nadu, India.

The hand layup method is used to prepare samples. The samples are prepared in different combination of varying parameters such as CNSL percentage in hybrid polymer, fibre volume in percentage, and number of fibre discontinuity. GP resin and CNSL are mixed in different ratios to get the hybrid polymer and used as a matrix material. The CNSL percentage: GP percentage ratios used in this work are 5:95, 15:85 and 25:75. The fibre volume in percentage is calculated by adopting unit cell concept. Three different fibre volume percentages such as 5.2%, 7.8%, and 10.4% considered in this work are attained by increasing the number of fibres in parallel and column wise. The fibre volume in composite is increased by increasing the fibre content while keeping the volume of the composite as constant. Fibre discontinuity means dividing the total length of a fibre into two equal parts (i.e. one discontinuity) and three equal parts (i.e. two discontinuities).

The fibres used in this work are raw and not subjected to any type of chemical treatment. Fibres are arranged parallel to each other column-wise and horizontal to the plastic mould. The ends of each fibre are fixed into the plastic mould and ensured that the fibres are straight. Then the prepared hybrid polymer, after adding proper ratio of catalyst and hardener, is poured into the mould. Curing is carried out at room temperature and kept undisturbed for 72 hours without any pressure application.

The length, breadth, and thickness of the beam are taken as 300 mm, 30 mm, and 4 mm respectively, according to the (L/H) ratio i.e. (for thin beam, $L/H < 100$), which is shown in Fig. 1. Only three samples are prepared in each fibre to validate with finite element results. Samples are kept undisturbed for 72 hours for curing at room temperature. Figure 2 shows the prepared samples with no fibre discontinuity for vibration testing.

The modal parameters such as the mode shapes and the natural frequencies are determined experimentally through modal tests using DEWESOFT 7.11 software to find the natural frequency and mode shape of the specimens. Clamped free condition is used for performing experiments, specified starting from the left end of the composite beam along counter clockwise direction. Figure 3 shows the schematic experimental setup.

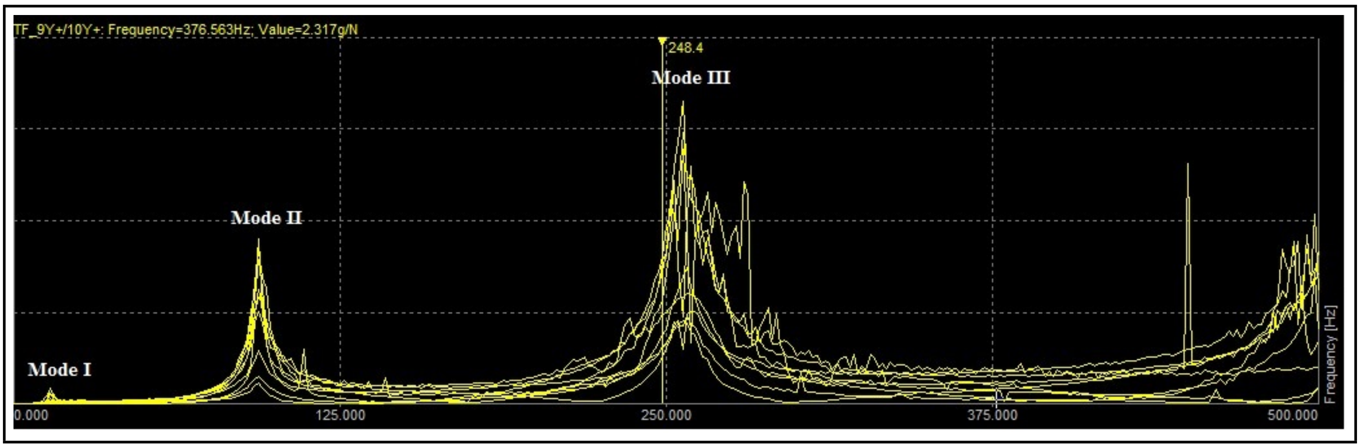

Figure 4. Experimental result obtained for sample 1.

Table 1. Manufacturing parameters.

Parameters		
CNSL % (A)	A1	5
	A2	15
	A3	25
Fibre volume in percentage (B)	B1	5.2
	B2	7.8
	B3	10.4
Fibre discontinuity in numbers (C)	C1	0
	C2	1
	C3	2

Table 2. Taguchi L9 Array.

Sample No.	CNSL %	Fibre volume	Fibre discontinuity
1	A1	B1	C1
2	A1	B2	C2
3	A1	B3	C3
4	A2	B1	C2
5	A2	B2	C3
6	A2	B3	C1
7	A3	B1	C3
8	A3	B2	C1
9	A3	B3	C2

The four-channel data acquisition system (Model No. ATA-DAQ042451) was interfaced with DEWESOFT. The specimens are excited using the roving hammer (Impulse Force Hammer-086C03) method. A uniaxial accelerometer, oriented along the z-axis, is fixed on the top of the clamped beam to measure the acceleration due to excitation. This acceleration signals are converted into the frequency-response function using four channel data acquisition system. The natural frequencies of the beam are extracted from the peaks in the frequency-response function and the corresponding mode shapes are also obtained. Figure 4 shows the experimental result obtained for sample 1.

The optimization study is carried out to find the optimum combination of parameters which gives the best result, by considering three factors such as fibre volume fraction, CNSL percentage, and fibre discontinuity. In each parameter study, three levels are considered. The design and analysis of experiments (DOE) using the Taguchi method is followed. An L9 orthogonal array is taken, which is shown in Tables 1 and 2. Minitab software is used, performing ANOVA analysis.

2.2. Modelling and Finite Element Analysis

Modelling is carried out using Solid Works (2010) and imported to ANSYS 14.5 workbench for simulation. The finite element modal analysis is carried out for all nine combinations given in Table 2 using coir fibre as reinforcement. The same is also carried out using banana fibre and aloe vera fibre as reinforcements respectively. The properties of fibre were taken from the books by Lewin and Mohanty et al.[15,16] The properties of hybrid polymer are taken from Prasad et al.[11] Table 3 shows the properties like Young's modulus, Poisson's ratio, and density for the hybrid polymer.

The simulation is carried out using ANSYS workbench, where the contact of fibre and matrix is established and element type solid 186 is chosen with fine mesh. Figure 5 shows the modelling of the specimens using Solid Works 2010 and Fig. 6 presents meshed model in ANSYS 14.5.

3. RESULTS AND DISCUSSION

The modal parameters, such as the natural frequencies and mode shapes, obtained experimentally, are compared with their respective numerical ones, obtained through a finite element analysis. Finite element modal analysis is carried out with CFFF boundary condition for all specimens. Experimental modal tests are carried out for few samples with a CFFF boundary condition for all fibres. Figures 7(a) to 7(c) represent different mode shapes for the coir fibres.

The natural frequencies of the three modes obtained from the finite element analysis (FEA) of the nine specimens for all fibres are shown in Table 4. The comparison of the experimental results and FEA results for samples 1 and 6 for all three fibres are presented in Tables 5, 6, and 7.

3.1. Regression Equations

Regression analysis is a statistical process for estimating the relationships among variables. Regression analysis helps to

Table 3. Properties of hybrid matrix.

Material property	Hybrid polymer		
	5% CNSL	15% CNSL	25% CNSL
Density (ρ), kg/m^3	9132.8	9106.5	9080.5
Young's Modulus (E), MPa	151.06	55.9	24.195
Poisson's Ratio (ν)	0.35	0.35	0.35

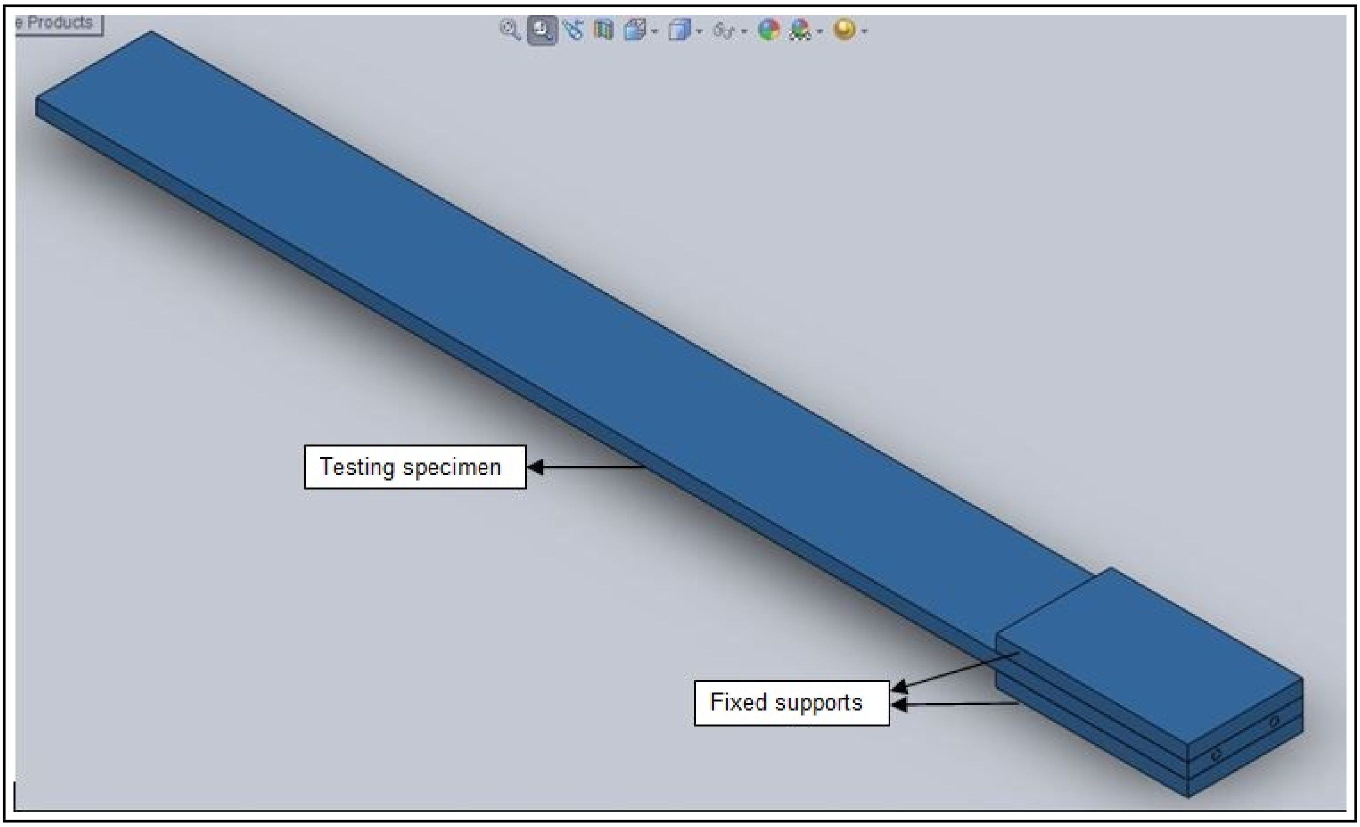

Figure 5. Modelling image of specimen with fixed supports.

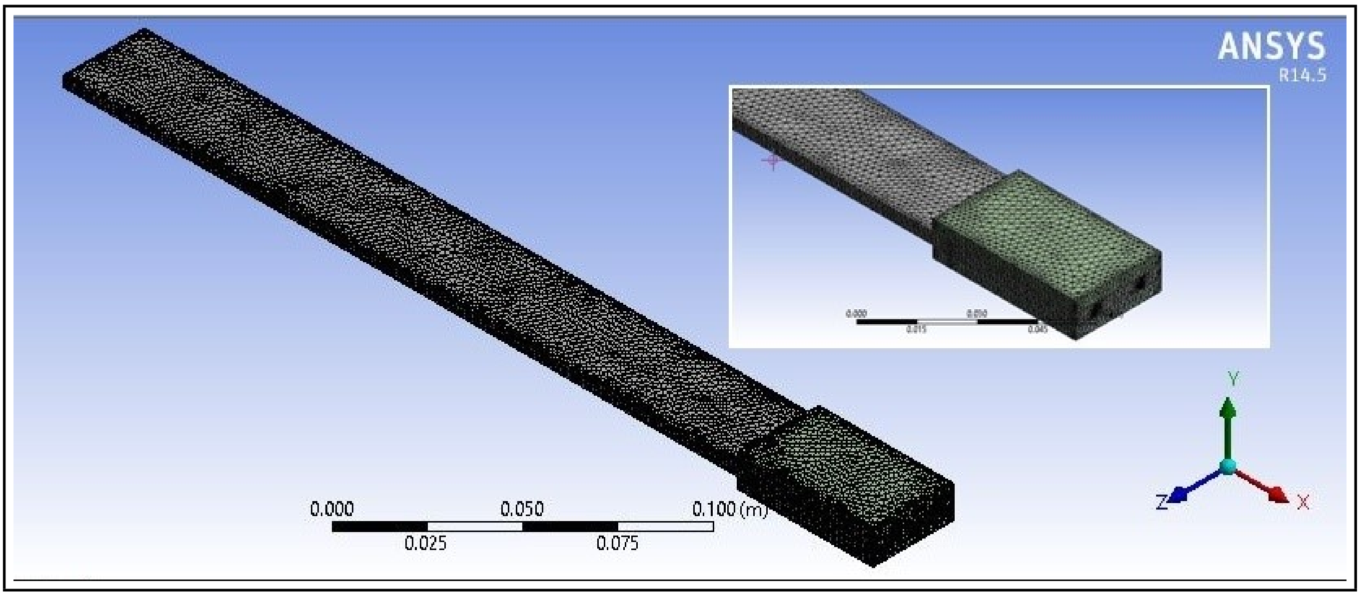

Figure 6. Meshing of specimen.

Table 4. FEA results for all fibres.

Sample number	Coir fibre			Banana fibre			Aloe vera fibre		
	Mode I	Mode II	Mode III	Mode I	Mode II	Mode III	Mode I	Mode II	Mode III
1	19.65	110.67	303.86	13.77	86.21	241.19	15.439	96.629	275.21
2	16.27	100.92	285.48	7.63	47.75	133.49	18.279	112.641	321.283
3	20.69	128.62	354.33	10.85	67.93	189.95	20.668	128.497	353.976
4	10.93	67.25	192.48	6.48	40.17	113.77	15.793	98.294	277.163
5	12.10	75.10	205.96	9.86	61.24	172.97	14.469	89.367	242.148
6	17.67	110.75	309.61	15.54	96.82	272.56	19.105	121.32	357.78
7	8.830	54.55	147.53	8.93	55.80	155.63	9.650	59.311	158.652
8	10.60	66.33	185.29	14.68	91.79	256.19	13.442	84.132	235.072
9	15.90	89.28	289.48	8.64	53.67	147.52	15.883	89.196	289.98

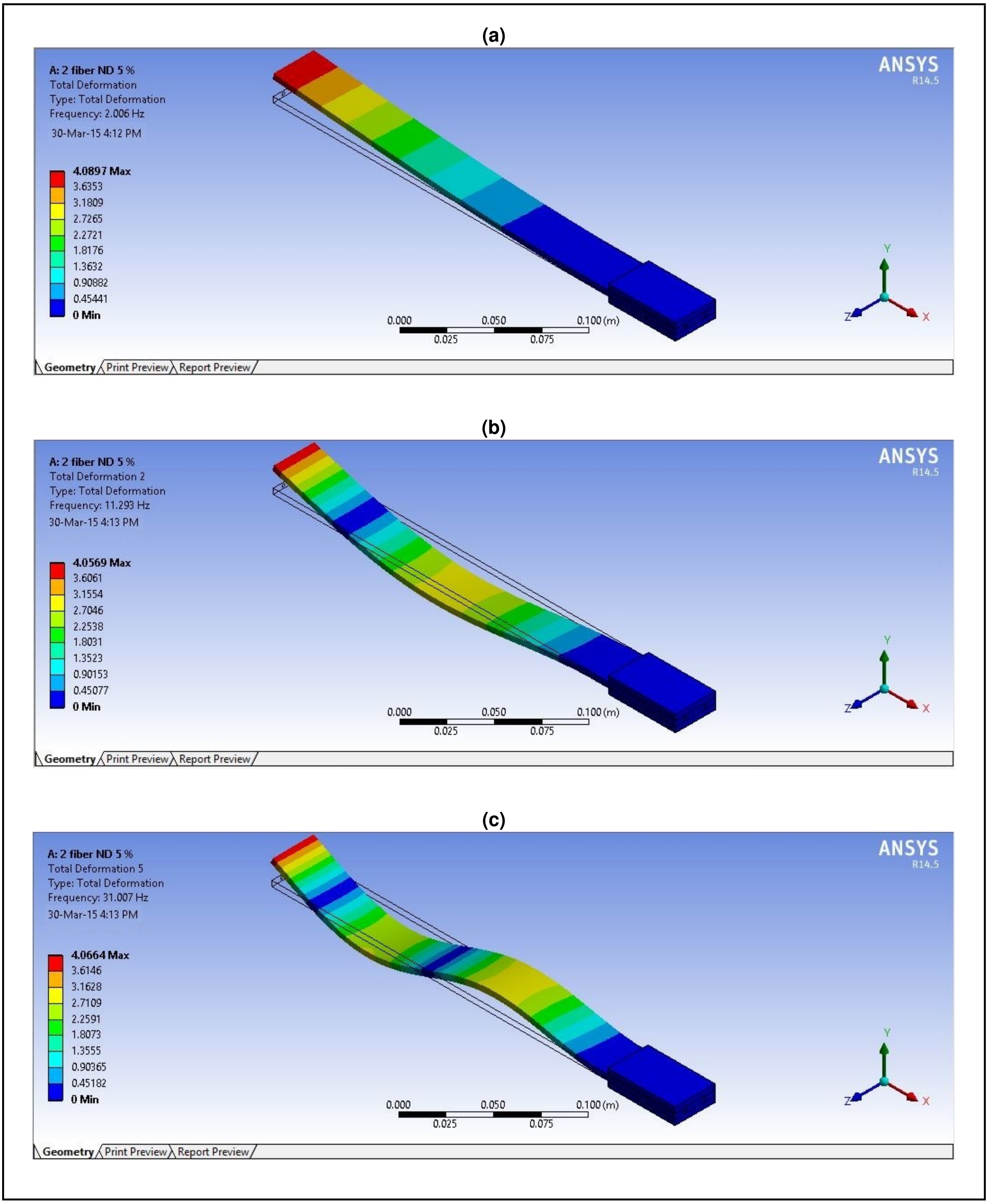

Figure 7. Mode shapes and deformation for different frequencies.

Table 5. Comparison of experimental and numerical results for coir fibre.

Mode no.	Frequency (Hz)		Error (%)
	Experimental	Numerical	
Case I — sample 1			
Mode I	17.559	19.65880	10.68
Mode II	103.55	110.6714	6.430
Mode III	272.94	303.8686	10.17
Case II — sample 6			
Mode I	13.347	13.53184	1.360
Mode II	78.175	84.68474	7.680
Mode III	219.97	236.6798	7.060

Table 6. Comparison of experimental and numerical results for banana fibre.

Mode no.	Frequency (Hz)		Error (%)
	Experimental	Numerical	
Case I — sample 1			
Mode I	14.10	13.77	2.40
Mode II	92.92	86.21	7.78
Mode III	250.82	241.19	3.99
Case II — sample 6			
Mode I	11.57	10.85	6.64
Mode II	75.15	67.95	10.59
Mode III	210.35	189.95	10.74

understand the relation between the value of dependent variable and the value of independent variable. The regression equations for coir fibre reinforced matrix are:

$$\text{Mode I frequency} = 18.9 - 0.366\ \text{CNSL}\ \% + 0.033\ \text{Fibre volume}\ \% - 0.504\ \text{No. of discontinuity}; \quad (1)$$

$$\text{Mode II frequency} = 104 - 2.15\ \text{CNSL}\ \% + 1.84\ \text{Fibre volume}\ \% - 4.10\ \text{No. of discontinuity}; \quad (2)$$

$$\text{Mode III frequency} = 277 - 5.73\ \text{CNSL}\ \% + 6.50\ \text{Fibre volume}\ \% - 12.4\ \text{No. of discontinuity}. \quad (3)$$

The regression equations for banana fibre reinforced matrix are:

$$\text{Mode I frequency} = 14.1 - 0.354\ \text{CNSL}\ \% + 0.163\ \text{Fibre volume}\ \% - 0.001\ \text{No. of discontinuity}; \quad (4)$$

$$\text{Mode II frequency} = 88.2 - 2.22\ \text{CNSL}\ \% + 1.01\ \text{Fibre volume}\ \% - 0.11\ \text{No. of discontinuity}; \quad (5)$$

$$\text{Mode III frequency} = 249 - 6.25\ \text{CNSL}\ \% + 2.67\ \text{Fibre volume}\ \% - 0.88\ \text{No. of discontinuity}. \quad (6)$$

The regression equations for aloe vera fibre reinforced matrix are:

$$\text{Mode I} = 15.4 - 0.257\ \text{CNSL}\ \% + 1.11\ \text{Fibre volume}\ \% - 0.293\ \text{No. of discontinuity}; \quad (7)$$

$$\text{Mode II} = 100 - 1.75\ \text{CNSL}\ \% + 6.20\ \text{Fibre volume}\ \% - 2.37\ \text{No. of discontinuity}; \quad (8)$$

$$\text{Mode III} = 267 - 4.38\ \text{CNSL}\ \% + 20.5\ \text{Fibre volume}\ \% - 10.0\ \text{No. of discontinuity}. \quad (9)$$

Figures 8(a) to 8(c) present the main effect plots for natural frequency, which is selected by recommending nominal the best results. From the results of the ANOVA analysis, the following points are inferred:

Table 7. Comparison of experimental and numerical results for aloe vera fibre.

Mode no.	Frequency (Hz)		Error (%)
	Experimental	Numerical	
Case I — sample 1			
Mode I	14.633	15.439	5.22
Mode II	92.342	96.629	4.43
Mode III	270.28	275.21	1.85
Case II — sample 6			
Mode I	17.676	19.105	7.47
Mode II	110.642	121.32	8.80
Mode III	309.297	357.78	13.55

(1) It reveals that the increment of the fibre volume content in the matrix for all CNSL percentage has a dominant effect on the flexural stiffness, as well as the natural frequency of the composite.

(2) As the number of discontinuity increases, the natural frequencies for all modes decrease. At the same time, when the fibre volume increases, the natural frequency increases and it almost compensates the loss that happened due to the increase in the number of discontinuities.

(3) Even though the natural frequency decreases, the level of flexibility increases when the CNSL content increases in matrix proportion. This property infers that this material is going to be an alternative one for elastomeric materials in the future.

(4) It is found that the coir or aloe vera reinforced hybrid matrix composite possesses better dynamic characteristics than the banana reinforced hybrid matrix composite. This reveals that coir and aloe vera fibres have better adhesion with the hybrid matrix than banana fibre.

(5) The primary source of polymerization happening is due to cardanol, which is a major constituent of CNSL. CNSL can be used with other synthetic polymers to have a control on mechanical properties as well as to increase bio content. A small quantity of CNSL will induce toughness and increase the flexibility of the structure. Too much CNSL content leads to decrease in other mechanical characteristics such as strength, stiffness, etc. But it provides better wear resistance and corrosion resistance, essentially, the biodegradability of the material increases.

(6) As the coir, banana, and aloe vera fibres are not in fabric form, the fibre content in the composite is small. This leads to poor interface adhesion between the fibre and the matrix. Conversion of these fibres into a yarn type is under research. Once these natural fibres are in fabric form, and treated with a proper alkali treatment, they will experience enhanced interface adhesion.

4. CONCLUSIONS

In the present work, a comparative study on the dynamic characteristics of three natural fibres reinforced hybrid polymer composite for three different parameters are conducted. In particular, the influences of these three fibres in the aspect of vibrational characteristics with this hybrid matrix are evaluated. This work clearly states that the increase in fibre volume

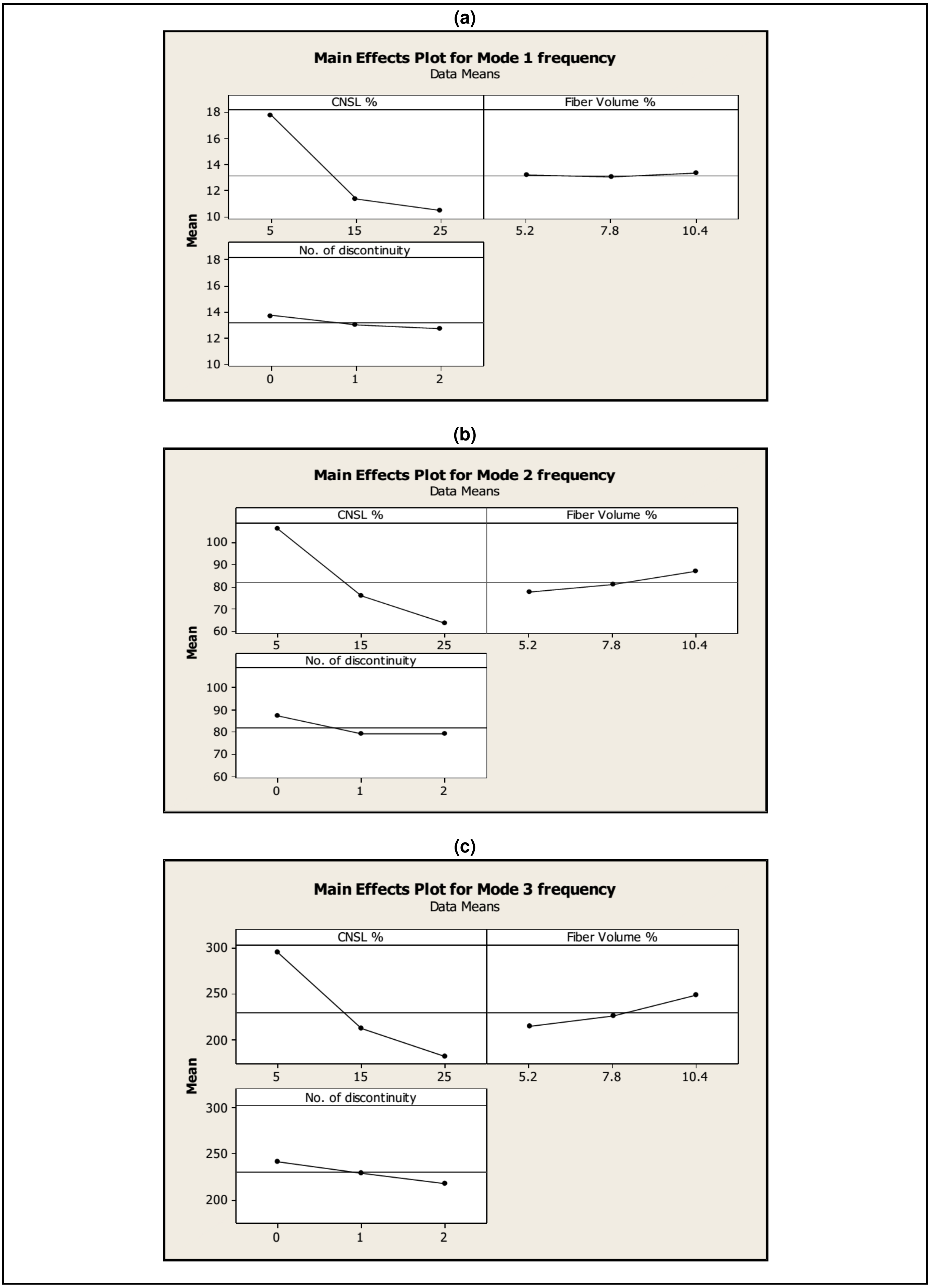

Figure 8. Main effect plot for coir fibre reinforced hybrid polymer matrix composites.

has a great influence on the natural frequency for all the fibres, even though loss happened in the natural frequency due to the increase in the number of discontinuity and the CNSL content in the matrix proportion. From the developed regression equations using ANOVA analysis, the best possible combination among three different parameters is obtained to get better results for all fibres. It is also found that the coir and aloe vera fibres provide better results with this matrix than banana fibre.

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