Experimental and Finite Element Studies on Free Vibration of Areca Leaf Sheath Reinforced Polymer Composites

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ABSTRACT

The present work deals with the experimental and finite element free vibration studies on areca leaf sheath reinforced polymer composites. In this study fundamental frequencies are obtained for five boundary conditions numerically (such as CFFF, CFCF, SSSS, CSCS and CCCC) and only for 2 boundary conditions (CFFF and CFCF) experimentally. The natural frequencies were determined using the CQUAD8 finite element of MSC/NASTRAN and a comparison made between the experimental values and the finite element solution. The effects of age of areca palm, number of layers, type of surface modification, and boundary conditions on the natural frequencies of composites were studied. The experimental values of the first, second, and third natural frequencies agree with those of the finite element solution in the case of areca leaf sheath reinforced composites under CFFF and CFCF boundary conditions. The natural frequency values increased with an increase in the number of layers, age of areca palm, and alkali percentage from 5 to 15%. Among the different boundary conditions considered, composites with the CCCC boundary condition have exhibited higher values of natural frequencies than other boundary conditions under finite element solutions.

1. Introduction

Due to the wide usage of composites in many mechanical applications, several tests are important to identify the capacity of the composites prepared. Among several tests, the determination of mechanical and vibration responses plays a key role in the different structures and applications. Some of the studies on vibration analysis of natural fibers are presented below.

The classical laminate theory was used [1] to study the laminated carbon/epoxy composite beams for vibration studies. A study on the impact of fiber length and weight percentage on free vibration aspects was analyzed on short sisal fiber (SFPC) and short banana fiber (BFPC) polyester composites. The laminated composites' fundamental frequencies and relevant modular damping values were gathered by conducting experimental modal analysis [2]. Sisal and banana fiber-reinforced (random) polymer composites exhibited maximum natural frequency as measured with other compositions such as different weight percentages on banana, sisal, and hybrid composite because wt % will improve the stiffness of the material [3].

A study on the impact of fiber length and weight percentage on free vibration aspects was analyzed on short sisal fiber (SFPC) and short banana fiber (BFPC) polyester composites. The laminated composites' fundamental frequencies and relevant modular damping values were gathered by conducting experimental modal analysis [4]. Also, it was briefed about using sisal and the glass fiber combination with the polyester resin in fabricating composites and making use of it in vibration applications [5]. Effect of layer orientation, BC's, and the number of layers were evaluated experimentally and numerically for sisal fiber composites, jute fibers, and hybrid materials [6].

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Biodegradable sisal/jute epoxy composites were evaluated analytically and numerically in vibration studies [7]. Using shell 281 elements in Ansys software, Thomas and Sreehari (2019) [8] evaluated natural frequency values for composite beams fabricated with flax, sisal, and aloe-vera fibers.

With the new vibration-damping method, thermoplastic composites based on polypropylene/natural fibers (like kenaf, hemp, flax) and glass fiber composites had been studied to describe nature at higher frequencies [9]. And adaptability of natural fiber composites made of flax and Cordenka epoxy for high-performance structural applications was tested. Woven flax and reconstructed cellulose (Cordenka) textiles were soaked in commercially available resin to form laminated composites, and through them, dynamic responses were analyzed [10].

Analytical and experimental investigations were made on the vibration of composite beams by considering interfacial delaminations concerning beam thickness [11]. A similar kind of investigation was attempted under 2D plane stress conditions [12]. A FE model was prepared to study the free vibration analysis of laminated beams and identified fundamental frequencies closely related to experimental results. Experimental investigation on natural frequencies for the composites made of woven fiber glass-epoxy with denominations under different BC's and obtained results are presented for 1st, 2nd, and 3rd modes, which are found to be the least for CFFF (cantilever) condition and the highest for CCCC (four sides clamped) condition [13]. Analytical and numerical models were analyzed through parametric studies for natural frequencies of delaminated bi-layer beams [14].

Similarly, using ANSYS 16.0, static-modal analysis of glass/epoxy composite beam was done (analytically and numerically) [15]. Natural frequencies found in this examination were 16.00 and 100.21 Hz for the first two modes, respectively. In the same fashion, ANSYS 17.1 modal analysis of glass/epoxy composite cantilever beam was done (analytically and numerically) [16].

Analytical and numerical analysis on composite shafts fabricated with different stacking sequences and a different number of layers (such as 10, 58, and 68 layers) was made using ABAQUS finite element software and MATLAB code for numerical studies [17]. The least frequency values were recorded for the least amount of weight % of fibers (5% white) in the composites. Among all BC's categories, a specimen with CCCC and CFFF conditions has exhibited the highest and least values of frequencies experimentally and numerically (ANSYS 14.0) [18]. Vibration analysis was carried by varying the aspect ratio and stacking order of the glass/ epoxy composite plates under fixed–free BC and using experimental and numerical techniques [19].

Experimental and numerical investigations on the effect of delamination on free vibration studies (ANSYS 16.0) of E- glass epoxy Composites were carried [20]. ANSYS 16.0 workbench and some experimental models were studied for vibration responses of laminated composites with different radii of curvatures [21]. Experimental and numerical investigation on damping properties of natural fiber-reinforced composites and their hybrids were studied by Sawant and Mache (2018) for different combinations such as jute/epoxy, hemp/epoxy, glass/epoxy, glass/jute/epoxy, jute/ glass/epoxy, aluminum/jute/epoxy, and aluminum/glass/epoxy [22].

Effect of stacking sequence, NL, and BC's were evaluated for Aloe-vera fiber-reinforced composite beams [23]. The jute fiber reinforced polymer composite plates were examined using an impulse excitation technique to assess the numerical studies and tests material characteristics [24].

Unsymmetrical sandwich beams were evaluated for free vibration studies using the finite element method (Solid works and ABAQUS). The findings of this paper reveal that free vibration frequencies will vary depending upon the position of the neutral axis [25].

Pingulkar and Suresha (2016) [26] concluded that natural frequencies of laminated composite plates were found sensitive compared to varying volume fractions to the hybridization and the orientation of the ulterior layers. Moreover, by using commercially available finite element analysis software (ANSYS), it was recorded that $[0^{0c}/45^{0g}/-45^{0g}/90^{0c}]_S$ hybrid plates have higher natural frequencies compared to $[0^{0g}/45^{0c}/-45^{0c}/90^{0g}]_S$ hybrid plates. The influence of fiber orientations on the natural frequencies of unidirectional, bidirectional, and hybrid laminated composite beams was estimated through experiments and using ANSYS 15 software [27]. Nonlinear and free vibration analysis carbon/epoxy laminated curved panels were evaluated [28]. In this study commercial finite element package (ANSYS) was used to assess some of the parameters like thickness ratio, curvature ratio, and constraint conditions. Orthotropic hyper composite plates were analyzed theoretically and numerically (Ansys 14.0) to investigate the vibration responses of hyper composites [29]. Increased fiber (date palm) volume fraction resulted in the increased natural frequency of the composites under varying boundary conditions were reported by Deli (2016) [30]. And also, it was identified that

the natural frequency increases with an increase in the strength of reinforcement fiber. The use of the Ansys 14.0 version also showed the same trend with a close agreement with the experimental values.

Cracked composite cantilever beams were evaluated experimentally and numerically (using hypermesh as pre and post-processor and Optistruct as the solver) for vibration analysis of GFRP [31]. Similarly, using a series of experiments and the Ansys 15.0 tool, the influence of crack position and crack length on the dynamic characteristics of cantilever beams was studied during the vibration analysis by Kumar et al. (2017) [32]. An increase in the number of layers from 3 to 5 of jute is woven roving's in epoxy composites has resulted in the rise in the natural frequency from the analysis made through experimental technique and Ansys workbench [33]. Using Ansys 14.4 software, natural frequencies of laminated composite beams were evaluated through FEM and shear deformation theory [34].

Laminated antisymmetric cross-ply plates with different central cut-outs (circle, square) have slightly reduced the natural frequencies compared to plates without cut-outs. This gradual variation is due to the variation in the stiffness of the plate due to the introduction of cut-outs [35]. In this study, Hypermesh and Nastran software were used to extract the natural frequency values. Using different elements such as CQUAD4 and CQUAD8 in hypermesh software, skew angle effect, the number of layers, aspect ratio, stacking sequence, and BC's on fundamental frequencies of antisymmetric composites were studied [36]. Similarly, cylindrical skew panels [37] and skew plates [38] were analyzed experimentally and numerically for free vibration studies. Using FEM, free end analysis of cantilever beam was done [39]. Using MATLAB software first three fundamental natural frequencies obtained are presented.

Hirwani et al. (2016) [48] have attempted to study the free vibration behavior of the curved laminated composite panels for different geometries (cylindrical, spherical, elliptical, hyperboloid, and flat) experimentally and using FE package (ANSYS APDL). Further, Luffa cylindrica fiber-reinforced epoxy composites were analyzed experimentally, and MATLAB code was developed based on the higher-order finite element (FE) model. Also, Bisen et al. has attempted to study the effect of fiber volume fractions on the elastic properties of Luffa cylindrica fiber-reinforced composites for four different weight percentages of treated Luffa fiber (0%, 3.2%, 6.4%, and 9.6%) [49].

Numerical Analysis of Transient Responses of Delaminated Layered Structures was analyzed using mid-plane theories, and experimental validation was made to understand that not only the size of the delamination but also the modular ratio, the thickness ratios, and the aspect ratios have a remarkable influence on the dynamic responses of the delaminated structure [50].

Acoustic radiation responses of doubly curved laminated composite shell panels subjected to harmonic excitation are investigated numerically in the higher-order shear deformation theory [51] to study the effect of support conditions and the lamination scheme, which found greatly influence the acoustic radiation from the panels.

The influences of the different structure-dependent design parameters on the nonlinear dynamic responses are investigated using smart composite curved structure using collocation and non-collocation configuration [52], developed a numerical model of skew sandwich shell panel [53], which also reveals that the results obtained from the selected (MATLAB) aid give more accurate results when compared with experimental values.

Two higher-order shear deformation theories were modeled mathematically for a laminated, composite, shear deformable plate in conjunction with finite element steps. For these plates, free vibration, bending, and transient responses were investigated with delamination [54]. The modal responses of multi-walled carbon nanotube-reinforced composite sandwich structural plate are evaluated for the elevated temperature environment using a higher-order polynomial kinematic model and the iso-parametric finite element steps [55]. Similarly, the FE approach was carried for studying Stress, Deflection, and Frequency Analysis of CNT Reinforced Graded Sandwich Plate under Uniform and Linear Thermal Environment [56], and vibration characteristic of carbon nanotube reinforced polymer composite structures was carried by Mehar et al. [57] using MATLAB and commercially available ANSYS software for theoretical and experimental analysis.

Influences of the dimensional variables such as aspect ratio, side to thickness ratio, and support condition on the acoustic radiation behavior of the fruit fiber-reinforced polymeric composite are predicted theoretically for vibroacoustic responses, and the obtained results are verified experimentally [58]. Similarly, a coupled FE approach was used to analyze modal responses of laminated composites with cut-outs [59].

Numerical prediction and experimental validation of free vibration responses of hybrid composites made with Glass/Carbon/Kevlar curved panel structures were made with ANSYS. Modal responses are obtained via a simulation model considering the individual layer effects of

each fiber through the static-structural module [60]. Similarly, numerical eigenfrequency analysis with experimental validation for variable cut-out (square/rectangular) forborne layered glass/epoxy flat/curved panel structures was carried with different parametric variations [61] also, studies on eigenfrequency responses of Luffa cylindrica sponge fiber polymer composites were made by Satankar et al. (2020) [62].

Vibro-Acoustic Responses of Un-Baffled Multi-Layered Composite Structure were made using numerical study under different End Conditions, and obtained results were validated through Experimental results [63]. An experimental approach was proposed for Static, Free Vibration, and Transient Response of Laminated Composite Curved Panels [64]. However, a numerical method is also implemented in this work to analyze the obtained experimental results.

Chethan et al. (2018) [65] have attempted to identify Areca Sheath fiber-reinforced biocomposites' mechanical and vibrational characteristics by Fast Fourier Analysis. Also, a Finite Element Analysis (Ansys 14.5) for all specimens was carried out, and the results were compared with the experimental values.

From the above studies, it is evident that very few studies highlight the use of areca fiber-reinforced composites in dynamic analysis. And the detailed experimental approach is also hard to find from the studies made on natural fiber composites. And hence, in the present paper, an attempt is made on vibration studies of areca leaf sheath reinforced composites by adopting the suitable experimental method to aid to fill the gap in the literature and using the finite element results for the validation of areca leaf sheath reinforced composites for various parameters.

2. Experimental and Finite element procedure

Physical, morphological, and mechanical characterization of ALSRCs by considering the factors such as aging of the fibers, orientation, chemical modification of the fibers, etc., were studied in detail by the author [46, 47]. And the same samples were considered in the present study for further dynamic analysis.

2.1 Experimental procedure

The effect of surface modification, the number of layers, and different boundary conditions on free vibration characteristics are studied using the vibration tester. The rectangular specimen is clamped at rigid support up to a length of 30 mm. In the present study, a piezoelectric accelerometer was directly attached to the test sample with adhesives. The accelerometer is connected to a signal conditioning unit (Fast Fourier Transform Analyzer), where the signal goes through the charge amplifier and an Analog-to-Digital Converter (ADC). With the help of the impact hammer, the test sample is excited at a selected point for different boundary conditions. Five repeated trials were made, and the average of the Frequency Response Function (FRF) was sent to the computer through a USB port. The pulse lab software accompanying the equipment recorded the signals directly in the computer's memory. The signal was then read and processed to extract different features, including frequencies. The frequencies were measured by moving the cursor to the peaks of the FRF. Five separate experimental determinations were done in each specimen's natural frequency, and then the average value was adopted.

In the present work, the FFT analyzer used for the experiment is OROS-24 (±10 V Inputs, 24 bits), Phaser Analyzer (FFT Analyzer) was used as a data acquisition system and has 7 input channels. Following Figures 1 and 2 show the analyzer and impact hammer used in the present work.

Figure 3 shows a schematic diagram of the vibration tester used to find out the modal analysis of ALSRC's using an impact hammer. At the end of the rectangular specimen, the accelerometer was attached. High frequencies can be obtained by using a modally tuned impact hammer. The output signal from the accelerometer is captured in a personal computer by using a data acquisition system.

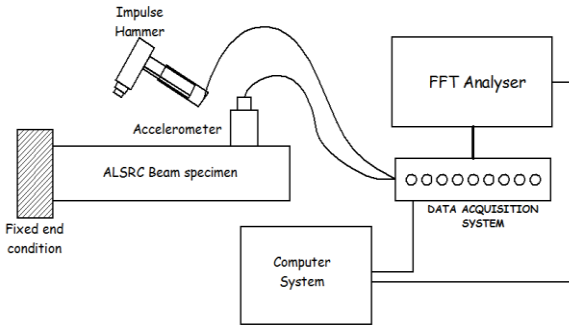**Fig. 1:** Phaser (FFT) Analyzer

Fig. 2: Impact Hammer

Fig. 3: Schematic Experimental Setup for Vibration Studies

2.2 Finite Element Analysis (FEA)

The finite element analysis was performed using CQUAD4 and CQUAD8 elements of MSC/NASTRAN. The CQUAD4 element is a four-node plate element having six degrees of freedom/node (translational (u, v, w) and rotational (θ_x, θ_y, θ_z)). The CQUAD8 element is an eight-node isoparametric shell element having six degrees of freedom/node (translational (u, v, w) and rotational (θ_x, θ_y, θ_z)). Both the elements take into account the shear deformations. Figure 4 depicts the arrangements of ALS's in ALSRC's and its geometry in the present work.

Usually, in the normal modal analysis, there will not be any load application on the sample specimen, and the damping properties of the structure will not be considered. Henceforth, the motion equation considered is of the form:

$$[K]\{\delta\} - [M]\{\delta\} = 0 \tag{1}$$

where [K] is the stiffness matrix representing the elastic property and [M] is the mass matrix representing the inertial property of the considered structure. These matrices were obtained automatically by the software used (MSC/NASTRAN) as per the geometrical and other properties of the FE model considered. When the harmonic solution is assumed, Eq. (1) reduces to an eigenvalue problem. The governing differential equation is then given for linear free vibration analysis is,

$$\big[[K] - \lambda_i [M]\big]\{\phi_1\} = 0 \tag{2}$$

where $\{\phi\}$ corresponds to the eigenvector of the eigenvalues (the nature or characteristic frequency). Each eigenvalue is proportional to a fundamental frequency; there is a corresponding eigenvector or mode shape. The relation between the eigenvalues and fundamental frequencies is as given below:

$$f_i = \sqrt{\frac{\lambda_i}{2\pi}} \tag{3}$$

Evaluation of the eigenvalues and associated mode shapes were done through eigenanalysis. The Lanczos method was used in the study. It combines the best characteristics of the other techniques and calculates exact values of Eigenvalues and vectors (MSC/Nastran Software, User Reference Manual, 2013). The geometry and coordinate systems of CQUAD4 and CQUAD8 elements are shown in Figures 5 and 6.
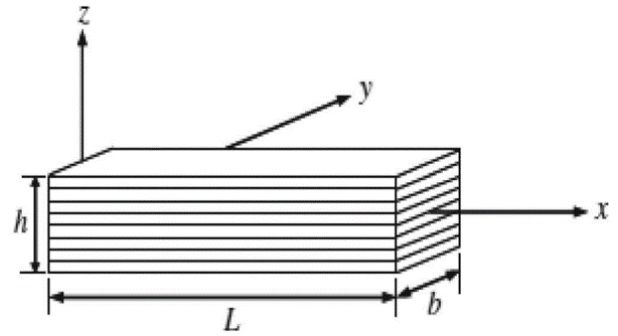

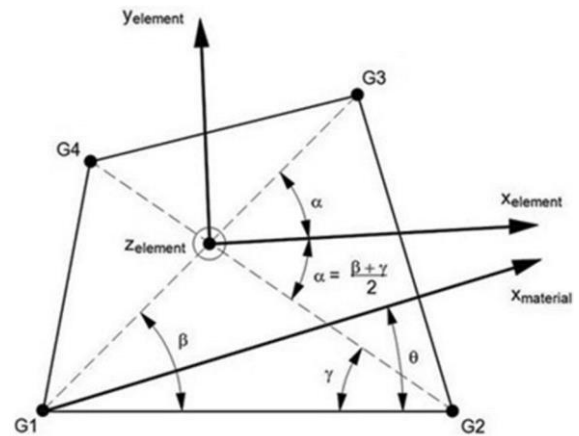**Fig. 4:** Geometric Layout of Composite Laminate.

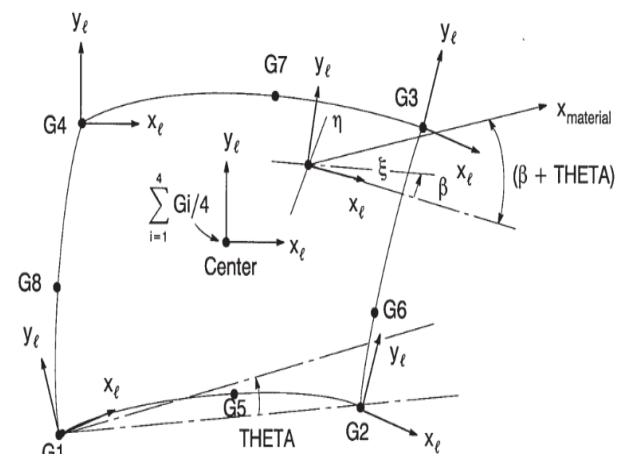**Fig. 5:** Geometry and Coordinate System CQUAD4 Element

Fig. 6: Geometry and Coordinate System CQUAD8 Element

Table 1. Convergence study details for natural frequency of Areca leaf sheath reinforced composite beam under CFFF boundary condition (L=200mm, b=20mm, E_1= 38070 N/mm^2, v_{12} = 0.22, G_{12} = 3050 N/mm^2, ρ= 2.20×10^{-9} N/mm^3)

Element Size	Element Type	Fundamental Frequencies (Hz)					
		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
10 × 1	CQUAD4	13.14	32.04	51.21	101.92	103.43	149.89
(l × b)	**CQUAD8**	**13.17**	**45.25**	**51.67**	**105.73**	**142.3**	**153.67**
20 × 2	CQUAD4	13.16	45.27	51.64	105.47	144.41	153.69
	CQUAD8	**13.17**	**51.76**	**52.02**	**106.04**	**153.71**	**157.36**
30 × 3	CQUAD4	13.17	50.01	51.72	105.84	153.74	156.76
	CQUAD8	**13.17**	**51.77**	**53.67**	**106.09**	**153.73**	**157.51**
40 × 4	CQUAD4	13.17	51.75	52.07	105.97	153.76	157.14
	CQUAD8	**13.17**	**51.77**	**54.29**	**106.12**	**153.74**	**157.56**

(Bold values indicate that the element used (CQUAD8) yields better result when compared to CQUAD4)

A convergence study was undertaken to establish the number of elements required for ensuring adequate accuracy. This study was performed using a two-dimensional finite element plate model with dimensions 200 mm × 20 mm (length × width), as shown in Figure 7. The boundary conditions used in the present work are shown in Figure 8.

2.3 Convergence studies

The convergence study has been performed on CFFF boundary condition [40] on areca leaf sheath reinforced composites using CQUAD4 (four-node plate element) and CQUAD8 (eight-node isoparametric curved shell element) elements of MSC / NASTRAN. Usually, CQUAD4 elements are quadrilateral 4 - noded plate elements with six DOF, namely three translational (u, v, w) and three rotational (θ_x, θ_y, θ_z). Similarly, CQUAD8 elements are 8 -noded iso-parametric shell elements, which have six DOF.

Fig. 7: Finite Element Model

Fig. 8: Boundary Conditions [66]

The PSHELL factor is appropriate for the study of small to moderately thick structures and has eight nodes in total, and every node has six degrees of freedom (DOF) in this element. The six DOF's include three translations and rotations along the x, y, and z directions, respectively. The theory of first-order shear deformation governs the precision of the modeling of these composite shell structures. The modal analysis was performed, and the shapes of the mode and the natural frequencies were obtained. In the present work, the Nastran solver is used to extract the Eigenvalues from which natural frequency and modal values could be extracted. For not very high order vibration modes, the influence of rotary inertia can be ignored for low beam width to height ratio. Even for a larger width-to-height ratio, the influence is not significant [41]. In general, the influence of shear deformation is more significant than that of rotary inertia. It can be ignored only for low width to height ratio in the case of lower-order vibration modes. Table 1 shows the convergence study made for the Areca leaf sheath reinforced composite beam material for different element mesh sizes. Convergence details are furnished with table 1 for the Areca leaf sheath reinforced composite beam (L=200mm, b=20mm, E_1= 38070 N/mm^2, v_{12} = 0.22, G_{12}= 3050 N/mm^2, ρ= 2.20×10^{-9} N/mm^3). Compared to the CQUAD4 (four-node shell element) element, it was noticed that the CQUAD8 (eight-node shell element) element yielded better performance. For further study of ALSRC samples, the CQUAD8 element was preferred in the present study.

2.4 Validation

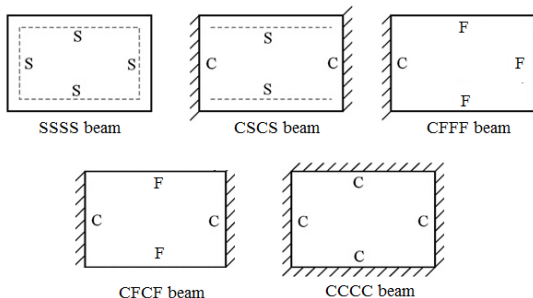The validation for the finite elements CQUAD4 and CQUAD8 was performed by comparing the values for natural frequencies obtained in the present work with those available in the literature. The same is presented in Table 2 for different boundary conditions. It can be seen

from Table 2 that the results obtained with the CQUAD8 element are closer to the literature values than the results obtained with the CQUAD4 element. It can be seen from Table 2 that the results obtained using the present elements (CQUAD8) are in good agreement with the literature values.

3. Results and discussion

Concerning the different boundary conditions mentioned, the results are presented in the following sections for CFFF, CFCF, and SSSS/CSCS/CCCC.

3.1 CFFF boundary condition

The natural frequency mainly depends on the rigidity of the specimen; rigidity will depend on the beam's cross-section to be tested and boundary conditions. The cross section's rigidity depends on substantial stability, stiffness, and bending stiffness conditions [42].

Under the CFFF boundary condition, experimental and finite element studies have been made for several areca leaf sheath reinforced composites (ALSRC's) with different surface modifications, number of layers, and age of the areca palm from which ALSs selected. The results obtained are tabulated in table 3 through table 5 for untreated (UT), 5% Alkali treated, and 10% Alkali treated composites, respectively. The first three mode shapes obtained through FEA for the 4Y-5L-UT specimen under the CFFF boundary condition are shown in Figure 9.

Under the CFFF boundary condition, untreated – 5 layer – 7 years aged areca palm leaf sheath reinforced composite exhibited superior values of natural frequencies (Mode 1 – 59.01 Hz), and least value were recorded for 10% Alkali treated - 1 layered – 3 years aged areca palm leaf sheath reinforced composites (Mode 1 – 0.09 Hz).

Table 2. Validation checks for previous results with present work for a composite beam with CQUAD8 elements under different boundary conditions

Boundary Condition	Ref. 's	Natural Frequency in Hz					
		Reference Values			Present Work Values		
		Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
CFFF	[11]	81.86	---	---	85.08	523.57	561.52
	[14]	79.83	---	---	83.50	225.46	514.15
	[18]	18.82	---	---	20.75	64.64	69.01
	[20]	12.13	75.97	99.93	12.43	77.71	103.07
	[32]	7.39	46.30	58.67	7.36	46.14	28.62
	[43]	41.35	60.66	221.52	51.39	59.63	102.43
	[44]	261.23	361.49	754.62	270.31	335.52	684.21
	[45]	28.80	180.05	503.91	25.91	161.93	296.59
CCCC	[18]	194.37	---	---	179.56	185.37	194.68
	[25]	217.16	597.59	1057.1	218.52	601.52	1056.56
	[21]	2456.35	3849.81	3938.79	2235	3550	4479
	[43]	346.59	651.51	781.06	336.40	388.32	508.29
CS	[25]	149.68	171.17	484.4	150.61	487.58	1015.83
SSSS	[21]	2141.62	3726.88	3830.13	2236	3518	4480
	[43]	164.37	404.38	492.29	154.50	207.71	330.11

Table 3. Natural frequency values for untreated ALSRCs under CFFF boundary condition

Specimen	Untreated ALSRCs					
	Natural Frequency (Hz)					
	Numerical Values			Experimental Values		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	0.12	0.719	1.25	0.11 (1.45)	0.69 (1.56)	1.20 (1.75)
3Y-2L	0.35	2.16	3.95	0.34 (1.35)	2.07 (1.77)	3.79 (1.66)
3Y-3L	2.50	12.49	14.99	2.42 (1.56)	11.97 (1.67)	14.37 (1.56)
3Y-4L	10.73	39.49	62.28	10.40 (1.67)	37.85 (2.12)	59.69 (1.45)
3Y-5L	50.58	124.89	270.89	49.02 (1.54)	119.69 (2.34)	259.60 (2.04)
4Y-1L	0.07	0.42	1.04	0.06 (1.77)	0.40 (1.57)	1.00 (1.88)
4Y-2L	0.55	3.34	3.77	0.53 (1.78)	3.20 (1.89)	3.61 (1.99)
4Y-3L	2.09	9.78	12.48	2.03 (1.34)	9.37 (1.56)	11.96 (1.65)
4Y-4L	7.37	31.79	43.60	7.14 (1.22)	30.45 (1.79)	41.78 (1.79)
4Y-5L	27.74	91.34	158.17	26.88 (1.22)	87.54 (1.79)	151.58 (1.80)
5Y-1L	0.12	0.96	1.25	0.12 (1.34)	0.92 (1.11)	1.20 (0.98)
5Y-2L	0.13	2.43	3.91	0.12 (1.45)	2.33 (1.45)	3.74 (1.34)
5Y-3L	2.95	9.32	12.68	2.86 (1.54)	8.93 (1.89)	12.15 (1.45)
5Y-4L	6.35	34.89	43.90	6.15 (1.34)	33.44 (1.55)	42.07 (1.34)
5Y-5L	32.72	94.94	172.59	31.70 (1.43)	90.98 (1.21)	165.40 (1.01)
6Y-1L	0.13	0.82	1.16	0.13 (1.43)	0.79 (1.21)	1.11 (1.01)
6Y-2L	0.65	3.24	3.89	0.63 (1.67)	3.11 (1.00)	3.73 (1.31)
6Y-3L	2.12	10.05	12.66	2.05 (2.45)	9.64 (2.00)	12.13 (1.95)
6Y-4L	6.44	26.13	37.87	6.25 (2.11)	25.04 (2.30)	36.30 (1.34)
6Y-5L	37.57	90.63	199.93	36.41 (1.89)	86.85 (1.89)	191.60 (2.00)
7Y-1L	0.29	0.77	1.23	0.28 (1.33)	1.70 (1.66)	3.77 (1.21)
7Y-2L	1.67	3.23	3.43	1.61 (1.45)	3.09 (1.65)	3.29 (1.23)
7Y-3L	2.66	9.32	12.87	2.58 (1.34)	8.93 (1.55)	12.33 (2.12)
7Y-4L	6.19	24.34	47.82	6.00 (1.65)	23.33 (1.11)	45.83 (0.88)
7Y-5L	59.01	93.19	151.92	57.18 (1.45)	89.31 (1.30)	145.59 (1.25)

Table 4. Natural frequency values for 5% Alkali treated ALSRCs under CFFF boundary condition

Specimen	Numerical Values			Experimental Values		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	0.09	0.57	1.08	0.09 (1.66)	0.54 (1.77)	1.02 (1.56)
3Y-2L	1.06	2.57	3.45	1.02 (1.25)	2.46 (1.37)	3.27 (1.27)
3Y-3L	3.12	10.99	17.98	2.99 (1.32)	10.54 (1.85)	17.03 (1.87)
3Y-4L	5.45	26.42	32.64	5.23 (1.90)	25.32 (1.67)	30.92 (1.35)
3Y-5L	27.94	88.90	158.34	26.77 (1.23)	85.20 (1.98)	150.00 (1.65)
4Y-1L	0.10	0.62	1.19	0.10 (2.45)	0.60 (1.89)	1.13 (2.40)
4Y-2L	0.532	2.99	3.22	0.51 (1.67)	2.87 (1.85)	3.05 (1.45)
4Y-3L	2.69	10.12	15.63	2.58 (1.76)	9.70 (1.98)	14.81 (1.33)
4Y-4L	13.28	34.80	72.20	12.72 (1.98)	33.35 (1.78)	68.40 (1.37)
4Y-5L	41.19	98.39	218.58	39.47 (2.05)	94.29 (1.93)	207.08 (1.87)
5Y-1L	0.14	0.88	1.05	0.14 (1.43)	0.84 (1.32)	0.99 (1.87)
5Y-2L	1.13	3.12	3.21	1.08 (1.54)	2.99 (1.87)	3.04 (2.00)
5Y-3L	2.66	9.71	15.41	2.55 (1.76)	9.31 (2.10)	14.61 (2.13)
5Y-4L	15.09	33.70	78.50	14.46 (1.64)	32.29 (2.11)	74.37 (2.43)
5Y-5L	49.26	91.65	216.39	47.20 (2.43)	87.83 (2.76)	205.00 (3.01)
6Y-1L	0.09	0.54	1.04	0.08 (1.43)	0.52 (1.98)	0.98 (1.89)
6Y-2L	0.65	3.15	3.88	0.62 (1.54)	3.02 (1.65)	3.68 (1.87)
6Y-3L	3.12	10.25	17.77	2.99 (1.76)	9.83 (1.87)	16.83 (1.89)
6Y-4L	11.56	31.35	63.42	11.08 (1.43)	30.04 (1.98)	61.89 (1.72)
6Y-5L	40.50	95.78	214.31	38.81 (1.43)	91.79 (1.98)	203.03 (2.30)
7Y-1L	0.09	0.56	1.08	0.09 (1.25)	0.54 (1.43)	1.02 (1.55)
7Y-2L	0.67	3.04	3.96	0.64 (1.35)	2.91 (1.48)	3.75 (1.68)
7Y-3L	3.64	10.52	20.23	3.49 (1.40)	10.08 (1.55)	19.17 (1.54)
7Y-4L	12.41	31.89	67.15	11.89 (1.05)	30.56 (1.76)	63.62 (1.88)
7Y-5L	58.13	103.79	279.36	55.71 (1.88)	99.46 (1.96)	264.66 (2.10)

Table 5. Natural frequency values for 10% Alkali treated ALSRCs under CFFF boundary condition

| Specimen	10% Alkali Treated ALSRCs					
	Natural Frequency (Hz)					
	Numerical Values			Experimental Values		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	0.09	0.56	1.01	0.09 (1.00)	0.55 (0.91)	0.98 (1.33)
3Y-2L	0.52	3.153	3.24	0.51 (1.25)	3.09 (1.32)	3.14 (1.54)
3Y-3L	2.52	10.65	15.60	2.50 (1.65)	10.43 (1.53)	15.12 (1.88)
3Y-4L	5.17	24.07	30.81	5.11 (2.11)	23.58 (1.78)	29.86 (1.45)
3Y-5L	21.91	82.62	127.56	21.69 (2.24)	80.94 (2.32)	123.61 (2.01)
4Y-1L	0.15	0.90	1.15	0.14 (1.57)	0.88 (1.24)	1.12 (1.65)
4Y-2L	0.82	3.73	4.88	0.81 (1.58)	3.66 (1.74)	4.73 (1.85)
4Y-3L	2.48	10.35	14.63	2.46 (2.24)	10.14 (2.57)	14.18 (2.03)
4Y-4L	13.48	34.07	72.64	13.35 (1.25)	33.37 (1.58)	70.40 (1.84)
4Y-5L	36.97	92.75	198.81	36.59 (1.35)	90.86 (1.48)	192.67 (1.57)
5Y-1L	0.15	0.90	1.09	0.15 (1.89)	0.88 (1.58)	1.06 (2.05)
5Y-2L	0.42	2.60	3.00	0.42 (1.25)	2.54 (1.58)	2.91 (1.45)
5Y-3L	2.76	9.80	15.95	2.74 (1.38)	9.60 (1.88)	15.46 (1.98)
5Y-4L	12.48	28.42	65.33	12.36 (0.96)	27.84 (1.30)	63.31 (1.64)
5Y-5L	43.37	105.09	231.09	42.93 (1.48)	102.94 (1.69)	223.94 (1.63)
6Y-1L	0.09	0.57	0.99	0.09 (0.98)	0.56 (1.45)	0.96 (1.73)
6Y-2L	0.53	2.98	3.23	0.53 (0.58)	2.92 (0.95)	3.13 (1.13)
6Y-3L	2.88	9.97	16.58	2.86 (1.35)	9.77 (1.48)	16.07 (1.29)
6Y-4L	6.97	26.09	40.54	6.90 (1.12)	25.56 (1.36)	39.28 (1.48)
6Y-5L	41.02	89.24	211.69	40.61 (1.29)	87.42 (1.49)	205.15 (1.78)
7Y-1L	0.13	0.8	1.07	0.13 (1.03)	0.79 (1.25)	1.04 (1.67)
7Y-2L	0.68	3.36	4.10	0.68 (0.99)	3.29 (1.18)	3.97 (1.25)
7Y-3L	2.89	9.18	16.39	2.86 (1.13)	8.99 (1.38)	15.88 (1.21)
7Y-4L	15.08	33.20	78.10	14.93 (1.55)	32.52 (1.25)	75.68 (1.56)
7Y-5L	33.32	92.68	183.77	32.99 (1.99)	90.79 (2.05)	178.09 (2.18)

Mode 1

Mode 2

Mode 3
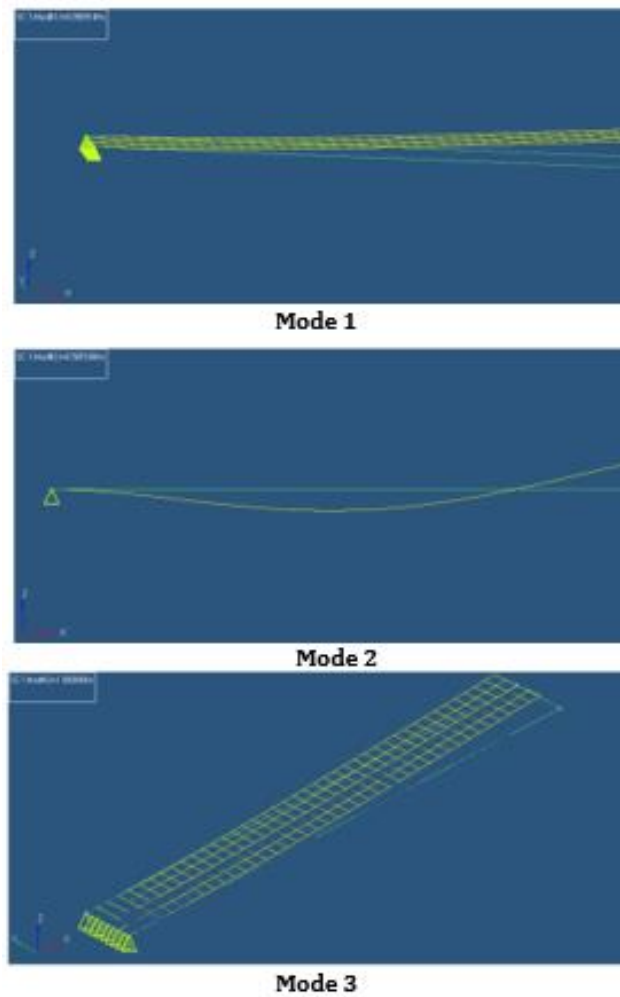
Fig. 9. The first three mode shapes of the ALSRC (4Y-5L-UT) for CFFF boundary condition

3.2 CFCF boundary condition

Under the CFCF boundary condition, experimental and finite element studies have been made for several areca leaf sheath reinforced composites (ALSRC's) with different surface modifications, number of layers, and age of the areca palm from ALS selected. The results obtained are tabulated in table 6 through Table 8 for untreated (UT), 5% Alkali treated, and 10% Alkali treated composites, respectively. The first three mode shapes obtained through FEA for the 4Y-5L-UT specimen under the CFCF boundary condition are shown in Figure 10. 5% Alkali treated – 5 layer – 7 years aged areca palm leaf sheath reinforced composites have shown the highest natural frequencies (Mode 1 – 252.28 Hz) under the CFCF boundary condition. And 10% Alkali treated – 1 layer – 3 years aged areca palm

leaf sheath reinforced composites have shown the least value for natural frequencies (Mode 1 – 0.57 Hz). 5% Alkali treated – 5 layer – 7 years aged areca palm leaf sheath reinforced composites have shown the highest natural frequencies (Mode 1 – 252.28 Hz) under the CFCF boundary condition. And 10% Alkali treated – 1 layer – 3 years aged areca palm leaf sheath reinforced composites have shown the least value for natural frequencies (Mode 1 – 0.57 Hz).

3.3 SSSS/CSCS/ CCCC boundary conditions

Tables 9-11 numerically extracted natural frequency values for untreated (UT), 5% Alkali treated, and 10% Alkali treated ALSRCs under SSSS, CSCS, and CCCC boundary conditions. And Figures 11-13 depict the first three mode shapes obtained through FEA for the 4Y-5L-UT specimen under SSSS, CSCS, and CCCC boundary conditions.

Table 6. Natural frequency values for untreated ALSRCs under CFCF boundary condition

	Untreated ALSRCs					
	Natural Frequency (Hz)					
Specimen	Numerical Values			Experimental Values		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	0.73	1.97	3.76	0.70 (1.00)	1.88 (0.91)	3.59 (1.10)
3Y-2L	2.18	5.90	11.31	2.11 (1.05)	5.65 (1.30)	10.84 (1.33)
3Y-3L	14.86	37.88	68.17	14.40 (1.12)	36.30 (1.11)	65.33 (1.20)
3Y-4L	60.65	147.69	249.10	58.78 (1.12)	141.54 (1.25)	238.72 (0.88)
3Y-5L	154.57	374.49	587.71	149.79 (1.15)	358.89 (1.30)	563.23 (1.35)
4Y-1L	0.42	1.15	2.24	0.41 (1.35)	1.10 (1.40)	2.14 (1.45)
4Y-2L	3.35	8.83	16.41	3.24 (1.37)	8.46 (1.50)	15.72 (1.55)
4Y-3L	12.33	31.15	55.62	11.95 (1.40)	29.86 (1.50)	53.31 (1.55)
4Y-4L	42.88	107.14	189.46	41.55 (1.05)	102.68 (1.25)	181.57 (1.35)
4Y-5L	152.75	364.62	576.11	148.03 (1.45)	349.43 (1.56)	552.11 (1.75)
5Y-1L	0.98	2.38	5.35	1.92 (1.35)	5.14 (1.77)	9.90 (1.66)
5Y-2L	3.87	9.40	17.14	3.75 (1.55)	9.01 (1.68)	16.43 (1.56)
5Y-3L	12.22	31.24	56.1	11.84 (1.67)	29.94 (2.12)	53.76 (1.45)
5Y-4L	47.98	78.66	187.72	46.50 (1.77)	75.38 (1.57)	179.90 (1.88)
5Y-5L	160.95	364.67	590.91	155.97 (1.78)	349.48 (1.89)	566.30 (1.99)
6Y-1L	0.83	2.21	4.18	0.80 (1.34)	2.12 (1.56)	4.00 (1.64)
6Y-2L	3.85	9.82	17.68	3.73 (1.22)	9.41 (1.79)	16.94 (1.78)
6Y-3L	12.82	31.70	56.69	12.42 (1.34)	30.38 (1.11)	54.33 (0.98)
6Y-4L	37.12	91.85	161.15	35.97 (1.45)	88.02 (1.34)	154.44 (1.45)
6Y-5L	187.23	419.89	571.25	181.26 (1.54)	402.32 (1.89)	546.65 (1.45)
7Y-1L	0.57	1.55	2.99	0.55 (1.34)	1.48 (1.55)	2.86 (1.45)
7Y-2L	10.27	27.22	50.93	9.95 (1.43)	26.09 (1.55)	48.81 (1.34)
7Y-3L	13.26	46.79	47.99	12.85 (1.43)	44.84 (1.21)	45.99 (1.01)
7Y-4L	31.37	84.42	184.25	30.40 (1.67)	80.90 (1.00)	176.57 (1.31)
7Y-5L	190.73	407.54	579.90	184.83 (2.14)	390.56 (1.89)	555.74 (1.21)

Table 7. Natural frequency values for 5% Alkali treated ALSRCs under CFCF boundary condition

Specimen	Numerical Values			Experimental Values		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	0.57	1.55	2.98	0.55 (1.77)	1.48 (1.56)	2.85 (1.43)
3Y-2L	6.62	17.74	24.60	6.42 (1.45)	17.00 (1.30)	23.58 (1.25)
3Y-3L	17.45	42.18	69.33	16.91 (1.65)	40.42 (1.11)	66.44 (0.88)
3Y-4L	32.30	82.02	147.06	31.30 (1.33)	78.60 (1.66)	140.93 (1.21)
3Y-5L	152.48	361.66	560.75	147.76 (1.66)	346.59 (1.77)	537.39 (2.13)
4Y-1L	0.63	1.70	3.27	0.61 (1.45)	1.63 (1.55)	3.13 (1.67)
4Y-2L	3.21	8.29	15.12	3.11 (1.43)	7.94 (1.32)	14.49 (1.87)
4Y-3L	15.25	37.28	32.85	14.78 (2.45)	35.73 (1.89)	31.48 (2.38)
4Y-4L	68.28	155.94	219.51	66.17 (1.92)	149.44 (1.35)	210.36 (1.42)
4Y-5L	204.67	458.87	620.54	198.34 (1.77)	439.75 (1.78)	594.68 (1.76)
5Y-1L	0.88	2.34	4.37	0.85 (1.56)	2.24 (2.18)	4.18 (1.33)
5Y-2L	5.90	13.62	19.66	5.72 (1.23)	13.05 (1.98)	18.84 (1.65)
5Y-3L	15.00	36.48	61.27	14.54 (1.43)	34.96 (1.87)	58.72 (1.65)
5Y-4L	72.94	161.39	212.52	70.68 (1.54)	154.66 (1.87)	203.67 (2.00)
5Y-5L	369.15	882.04	1398.04	357.73 (1.76)	845.29 (2.10)	1339.79 (2.00)
6Y-1L	0.55	1.48	2.84	0.53 (1.64)	1.42 (2.10)	2.72 (2.13)
6Y-2L	3.84	9.76	17.51	3.72 (1.70)	9.35 (1.76)	16.78 (2.64)
6Y-3L	17.16	40.95	64.68	16.63 (1.70)	39.24 (1.736)	61.99 (1.99)
6Y-4L	60.18	138.33	197.69	58.32 (1.87)	132.57 (1.34)	189.45 (1.32)
6Y-5L	200.44	448.51	604.05	194.24 (2.45)	429.82 (2.54)	578.88 (2.98)
7Y-1L	0.57	1.53	2.94	0.55 (1.24)	1.46 (1.35)	2.81 (1.56)
7Y-2L	3.91	9.84	17.52	3.79 (1.36)	9.43 (1.45)	16.79 (1.75)
7Y-3L	19.32	44.99	66.35	18.72 (1.54)	43.12 (1.65)	63.59 (1.75)
7Y-4L	63.38	144.16	201.12	61.42 (1.54)	138.15 (1.54)	192.74 (1.68)
7Y-5L	252.28	535.94	654.63	244.48 (1.23)	513.61 (1.98)	627.35 (1.65)

Table 8. Natural frequency values for 10% Alkali treated ALSRCs under CFCF boundary condition

| Specimen	10 % Alkali Treated ALSRCs					
	Natural Frequency (Hz)					
	Numerical Values			Experimental Values		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	0.57	1.54	2.95	0.55 (1.54)	1.47 (1.87)	2.82 (2.00)
3Y-2L	3.15	8.23	15.17	3.05 (1.76)	7.89 (2.10)	14.54 (2.13)
3Y-3L	18.78	55.17	93.68	18.20 (1.67)	52.87 (1.00)	89.78 (1.31)
3Y-4L	30.43	76.87	137.20	29.49 (2.11)	73.67 (2.30)	131.48 (1.34)
3Y-5L	124.43	304.27	521.04	120.58 (1.89)	291.59 (1.89)	499.33 (2.00)
4Y-1L	0.90	2.41	4.52	0.87 (1.33)	2.31 (1.66)	4.32 (1.21)
4Y-2L	4.81	12.12	21.58	4.66 (1.45)	11.62 (1.65)	20.68 (1.23)
4Y-3L	14.36	35.69	62.85	13.92 (1.65)	34.20 (1.11)	60.23 (0.88)
4Y-4L	68.44	155.15	214.85	66.32 (1.45)	148.69 (1.30)	205.90 (1.25)
4Y-5L	187.17	423.72	585.03	181.38 (1.77)	406.07 (1.56)	560.65 (1.43)
5Y-1L	0.90	2.29	4.46	0.87 (1.66)	2.19 (1.77)	4.27 (2.13)
5Y-2L	2.60	6.87	12.80	2.52 (1.45)	6.58 (1.55)	12.27 (1.67)
5Y-3L	15.49	37.48	61.83	15.01 (1.43)	35.92 (1.2)	59.25 (1.87)
5Y-4L	60.84	135.11	179.23	58.96 (1.90)	129.48 (1.35)	171.76 (1.45)
5Y-5L	216.73	487.25	662.80	210.03 (1.67)	466.95 (1.35)	635.18 (1.98)
6Y-1L	0.58	1.56	2.99	0.56 (1.76)	1.49 (2.00)	2.86 (1.45)
6Y-2L	3.21	8.30	15.12	3.11 (1.56)	7.95 (2.18)	14.49 (1.33)
6Y-3L	16.07	38.70	62.87	15.57 (1.33)	37.09 (1.98)	60.25 (1.65)
6Y-4L	39.52	96.53	164.69	38.30 (1.54)	92.51 (1.87)	157.83 (2.00)
6Y-5L	196.08	431.66	562.85	190.01 (1.76)	413.67 (2.10)	539.40 (2.13)
7Y-1L	0.82	2.17	4.09	0.79 (1.64)	2.08 (1.54)	3.91 (1.76)
7Y-2L	4.06	10.32	18.54	3.93 (1.32)	9.89 (1.54)	17.77 (1.70)
7Y-3L	15.78	37.40	57.90	15.29 (1.76)	35.84 (1.87)	55.49 (1.89)
7Y-4L	72.45	159.85	209.39	70.21 (1.54)	153.19 (1.87)	200.66 (2.00)
7Y-5L	174.83	403.97	584.50	169.42 (1.90)	387.14 (1.89)	560.14 (2.10)
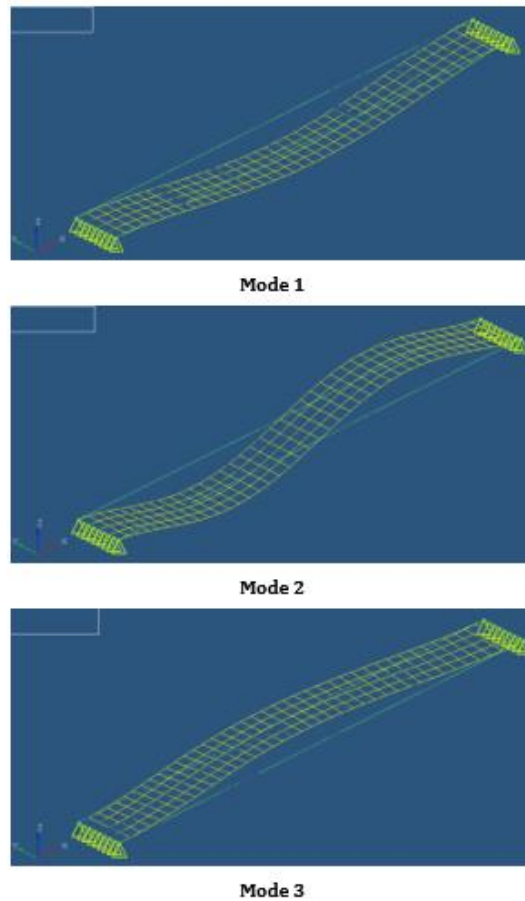
Fig. 10. The first three mode shapes of the ALSRC (4Y-5L-UT) for the CFCF boundary condition.

Table 9. Natural frequency values for untreated ALSRCs under SSSS, CSCS, and CCCC boundary conditions

Specimen	Untreated ALSRCs								
	Natural Frequency (Hz)								
	SSSS			CSCS			CCCC		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	35.15	35.35	35.73	35.16	35.40	35.83	38.46	38.94	39.72
3Y-2L	117.17	117.67	117.60	117.20	117.79	118.87	123.0	124.38	126.66
3Y-3L	389.14	391.03	395.46	389.37	391.86	397.05	393.16	398.56	407.40
3Y-4L	1233.96	1241.42	1259.41	1234.97	1244.70	1264.63	1244.09	1261.69	1290.50
3Y-5L	2333.88	2465.05	2667.69	2349.12	2469.88	2707.55	2395.91	2574.47	2866.46
4Y-1L	26.75	26.94	27.28	26.76	26.98	27.35	31.32	31.66	32.21
4Y-2L	115.77	116.28	117.37	115.82	115.46	117.77	118.29	119.85	122.39
4Y-3L	304.73	306.28	309.95	304.92	306.97	311.22	307.79	312.05	319.03
4Y-4L	992.34	997.64	1010.36	993.02	1000.04	1014.58	1001.28	1015.26	1038.14
4Y-5L	2859.05	2877.71	2922.72	2861.72	2885.69	2934.39	2878.44	2919.41	2986.44
5Y-1L	28.47	29.12	30.30	28.50	29.25	30.58	32.92	32.32	34.63
5Y-2L	85.27	87.03	90.99	85.45	87.74	92.45	110.96	116.23	120.86
5Y-3L	237.44	254.49	282.41	323.30	329.37	343.57	324.01	332.01	348.59
5Y-4L	904.30	928.61	987.23	907.68	939.20	1003.57	934.63	990.45	1081.77
5Y-5L	2374.79	2462.07	2670.62	2387.66	2497.48	2718.30	2448.00	2626.24	2917.47
6Y-1L	34.00	34.18	34.52	34.01	34.22	34.63	36.01	36.47	37.23
6Y-2L	100.47	100.99	102.17	100.53	101.20	102.58	101.96	103.37	105.68
6Y-3L	313.00	314.59	318.35	313.19	315.30	319.65	316.47	320.85	328.02
6Y-4L	815.54	820.13	831.16	816.14	822.18	834.64	822.87	834.42	853.34
6Y-5L	2842.76	2866.60	2920.99	2846.34	2874.55	2929.89	2857.10	2898.30	2965.66
7Y-1L	33.48	33.69	34.06	33.49	33.73	34.15	37.88	38.31	39.96
7Y-2L	81.75	83.36	86.75	81.89	83.91	87.96	105.18	115.19	125.12
7Y-3L	238.88	256.39	285.03	330.02	337.33	355.07	331.04	340.61	360.30
7Y-4L	886.46	911.30	971.03	889.92	921.95	987.12	917.14	972.83	1063.93
7Y-5L	2916.66	2948.94	3023.00	2921.50	2959.97	3035.60	2937.15	2993.88	3086.62

Table 10. Natural frequency values for 5% Alkali treated ALSRCs under SSSS, CSCS and CCCC boundary conditions

Specimen	SSSS			CSCS			CCCC		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	30.97	31.13	31.41	30.98	31.16	31.49	33.41	33.79	34.42
3Y-2L	84.39	85.67	88.20	84.48	86.03	89.00	96.03	99.71	105.75
3Y-3L	343.53	345.68	350.86	343.83	346.61	352.30	346.29	351.21	359.25
3Y-4L	821.84	825.99	835.72	822.33	827.80	839.12	831.49	842.98	861.79
3Y-5L	2783.29	2801.98	2846.90	2786.00	2809.83	2858.06	2801.78	2841.74	2907.11
4Y-1L	34.37	34.53	34.84	34.38	34.57	34.92	36.82	37.23	37.92
4Y-2L	92.29	92.74	94.75	92.33	92.92	94.10	93.95	95.23	97.32
4Y-3L	315.88	317.77	322.32	316.13	318.60	323.66	318.79	323.29	330.67
4Y-4L	1090.62	1099.23	1119.22	1092.00	1102.33	1122.96	1096.96	1112.75	1138.55
4Y-5L	3087.04	3113.06	3172.35	3090.97	3121.68	3181.91	3101.97	3146.69	3219.84
5Y-1L	31.94	32.09	32.39	31.96	32.14	32.50	32.88	33.31	34.01
5Y-2L	97.72	98.45	100.18	97.83	98.73	100.53	98.26	99.67	101.97
5Y-3L	303.99	305.80	310.21	304.24	306.62	311.50	306.10	310.43	317.51
5Y-4L	1056.89	1066.37	1087.44	1058.30	1069.21	1090.40	1062.24	1077.59	1102.69
5Y-5L	3023.21	3069.34	3179.40	3029.62	3088.52	3107.50	3081.74	3087.32	3194.21
6Y-1L	30.23	30.37	30.63	30.24	30.40	30.70	32.22	32.58	33.17
6Y-2L	98.22	98.71	99.85	98.28	98.92	100.26	99.24	100.61	102.84
6Y-3L	319.87	322.05	327.20	320.17	322.93	328.49	322.59	327.51	335.06
6Y-4L	983.14	990.58	1008.12	984.26	993.41	1011.64	988.17	1002.35	1025.55
6Y-5L	3007.17	3032.49	3090.32	3011.04	3040.92	3099.58	3020.07	3063.59	3134.78
7Y-1L	29.43	29.57	29.82	29.44	29.60	29.89	31.09	31.45	32.03
7Y-2L	94.64	95.13	96.29	94.70	95.35	96.70	95.61	96.93	99.11
7Y-3L	329.27	331.68	337.38	329.62	332.32	338.32	331.50	336.26	344.03
7Y-4L	998.99	1007.34	1025.61	1000.17	1009.86	1028.95	1005.01	1019.48	1043.15
7Y-5L	3258.78	3293.22	3364.09	3263.64	3300.38	3370.22	3272.44	3319.97	3397.66

Table 11. Natural frequency values for 10% Alkali treated ALSRCs under SSSS, CSCS, and CCCC boundary conditions

Specimen	SSSS			CSCS			CCCC		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
3Y-1L	28.82	29.01	29.27	28.86	29.00	29.37	31.26	31.63	32.24
3Y-2L	100.05	100.69	101.68	100.29	100.87	102.04	101.90	103.26	105.48
3Y-3L	371.05	376.09	387.48	371.58	378.14	391.60	287.84	290.59	294.75
3Y-4L	750.30	754.12	763.20	750.77	755.83	766.34	757.91	768.41	785.61
3Y-5L	2581.55	2596.82	2633.69	2583.62	2603.61	2644.66	2602.69	2639.44	2699.58
4Y-1L	34.42	34.59	34.94	34.43	34.64	35.05	35.99	36.46	37.23
4Y-2L	116.55	117.14	118.57	116.62	117.51	119.06	117.59	119.22	121.89
4Y-3L	322.30	324.11	328.42	322.53	323.91	329.80	325.73	330.03	337.79
4Y-4L	1067.64	1076.35	1096.33	1068.93	1079.35	1099.84	1073.74	1089.21	1114.50
4Y-5L	2907.00	2930.82	2985.49	2910.53	2939.00	2994.97	2923.65	2965.78	3034.67
5Y-1L	32.61	32.78	33.12	32.63	32.83	33.23	34.01	34.46	35.19
5Y-2L	92.42	92.81	93.65	92.45	92.95	93.95	94.21	95.43	97.44
5Y-3L	306.59	308.48	313.05	306.85	309.31	314.34	308.86	313.24	320.40
5Y-4L	891.03	898.93	916.56	892.20	901.34	919.12	895.77	908.71	929.88
5Y-5L	3295.23	3322.88	3385.90	3299.35	3332.08	3396.24	3312.72	3360.49	3438.61
6Y-1L	28.34	28.49	28.77	28.35	28.32	28.85	30.59	30.96	31.57
6Y-2L	91.80	92.26	93.28	91.85	92.44	93.64	93.59	94.87	96.97
6Y-3L	311.61	313.59	318.34	311.89	314.44	319.65	314.04	318.51	325.81
6Y-4L	814.87	819.75	831.51	815.53	821.90	834.96	821.89	833.52	852.53
6Y-5L	2801.69	2827.07	2883.35	2805.52	2834.55	2890.97	2813.92	2854.59	2921.09
7Y-1L	31.65	32.10	32.42	31.96	32.15	32.52	33.41	33.85	34.56
7Y-2L	104.24	104.77	106.00	104.30	105.00	106.43	105.56	107.02	109.41
7Y-3L	286.64	288.63	293.34	286.91	289.43	294.47	289.10	293.24	300.00
7Y-4L	1040.62	1050.15	1071.12	1042.01	1052.89	1073.95	1046.40	1061.55	1086.31
7Y-5L	2906.89	2928.38	2979.35	2910.13	2936.76	2990.01	2921.69	2963.58	3032.08

Mode 1

Mode 2

Mode 3
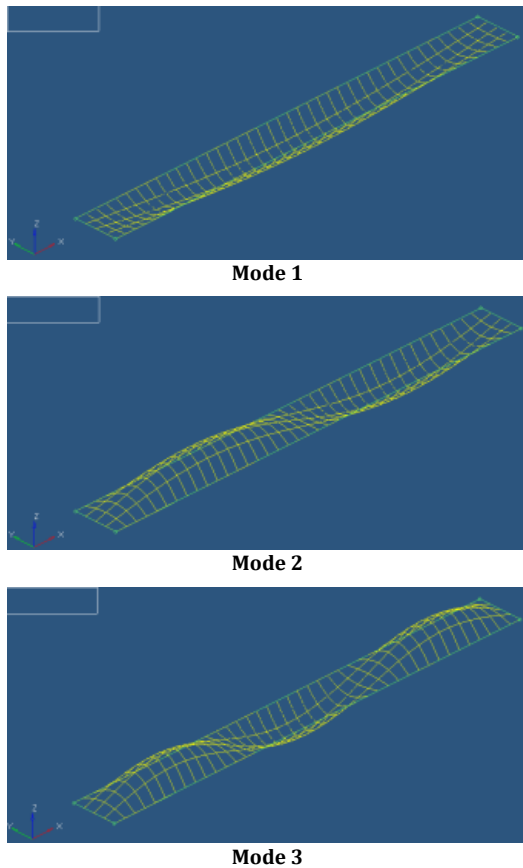
Fig. 11. The first three mode shapes of the ALSRC (4Y-5L-UT) for SSSS boundary condition.

Mode 1

Mode 2

Mode 3
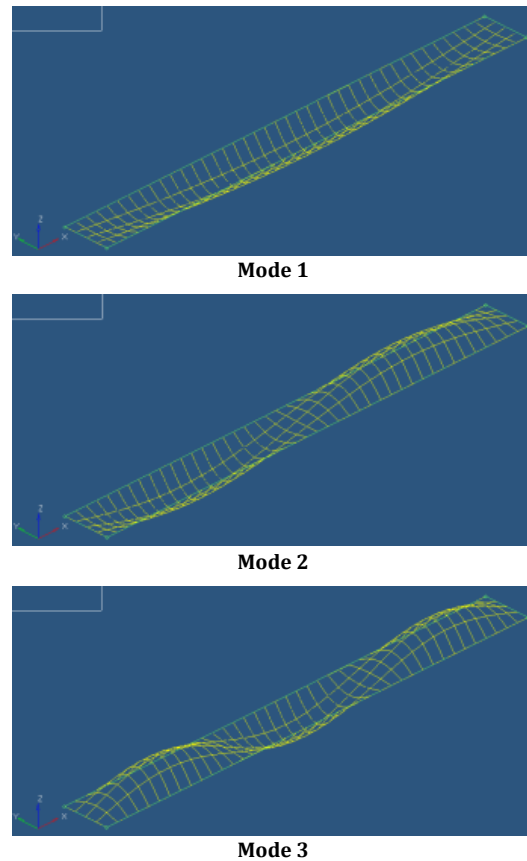
Fig. 13. The first three mode shapes of the ALSRC (4Y-5L-UT) for CCCC boundary condition.
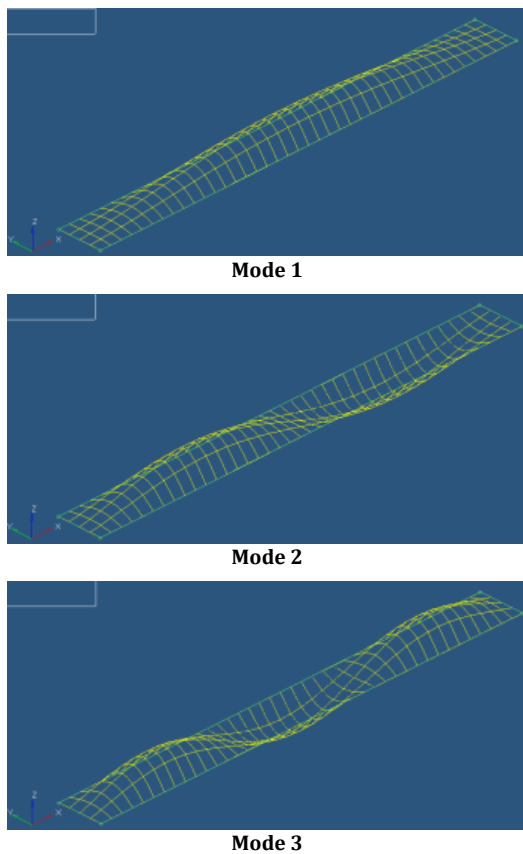

Mode 1

Mode 2

Mode 3

Fig. 12. The first three mode shapes of the ALSRC (4Y-5L-UT) for CSCS boundary condition.

Untreated - 5 layer – 7 years aged areca palm leaf sheath reinforced composites exhibited higher values for natural frequencies under SSSS (Mode 1 – 2916.66 Hz), CSCS (Mode 1 – 2921.50 Hz), and CCCC (Mode 1 – 2937.15 Hz) boundary conditions.

Similarly, 5% Alkali treated - 5 layer – 7 years aged areca palm leaf sheath reinforced composites have shown higher values for natural frequencies under SSSS (Mode 1 – 3258.78 Hz), CSCS (Mode 1 – 3263.64 Hz), and CCCC (Mode 1 – 3272.44 Hz) boundary conditions.

But for 10% Alkali treatment, 5 layer – 5 years aged areca palm leaf sheath reinforced composites have shown higher values for natural frequencies under SSSS (Mode 1 – 3295.23 Hz), CSCS (Mode 1 – 3299.35 Hz), and CCCC (Mode 1 – 3312.72 Hz) boundary conditions.

The following general conclusions have been made from the above tables for CFFF, CFCF, CCCC, SSSS, and CSCS boundary conditions adopted for ALSRC's. Experimental work is carried out per the facilities available (CFFF and CFCF), and numerical analysis is carried out for all the present work's boundary conditions.

Among all the different boundary conditions, samples tested with CCCC boundary conditions have exhibited higher values of natural frequencies than other conditions. And, natural frequency values increased with the number of

layers and the percentage of alkali treatment during the surface modification in all cases. Also, the least value of natural frequencies was recorded for single-layered samples in all the boundary condition categories.

Among all the conditions considered in the present work on determining natural frequencies of ALSRCs, the highest natural frequency value was recorded for 5Y-5L-10% Alkali treated samples (Mode 1 - 3312.72 Hz) under all edges clamped condition (CCCC).

4. Conclusions

Several major conclusions were drawn from the vibration studies. The modal analysis was carried out to determine the natural frequencies and mode shapes. The fundamental frequencies were numerically determined for five boundary conditions and only for 2 boundary conditions (CFFF and CFCF) experimentally in the present study. Based on these studies following remarks have been made,

a) Effect of layers number, age of areca palm, and type of surface modification:
- In the case of ALSRC beams, natural frequency values were found to increase concerning increase in the number of layers, age of the areca palm, and the type of surface modification
- The least values were recorded for single-layered ALSRC, and higher values were recorded for ALSRC with 5 layers in all the cases considered.
- Moderate values were observed in 5% Alkali treated ALSRC's due to the improper elimination of impurities from the ALS, which affects the interactions between reinforcement and matrix materials.
- Comparatively lesser values in the natural frequency were observed in 10% Alkali treated ALSRC due to the complete removal of impurities from the ALS. This will provide the proper bonding between the fiber and resin to make a sound structure that absorbs the vibrations to keep the structure safe.
- Among different combinations of ASL reinforced composites, ALS with 10% Alkali treatment had exhibited reduced natural frequency values compared to 5% treated and untreated ALSRC's.
- Finally, the experimental results of all the ALSRC's considered in the present work are in good agreement with the numerically extracted results.

b) Effect of boundary conditions
- Among the different boundary conditions used, the CCCC condition resulted in the maximum values in the natural frequencies of all the categories.
- Natural frequencies for CFFF and CFCF boundary conditions are found to be the least value.
- In all the cases, the natural frequency was found to increase concerning the number of layers of the composite fabricated.
- Experimental results of all the ALSRC's considered in the present work agree with the numerically extracted results.

Upon considering the above points, ALSRCs were considered in the structural applications as in automobile industries, aerospace applications, interior designing applications as structural panels, etc.

Nomenclature

Following are the variables used in the manuscript.
l	Length of the composite sample
b	The breadth of the composite sample
C	Clamped boundary condition
F	Free boundary condition
S	Simple support boundary condition
1L	1 layered composite
2L	2 layered composite
3L	3 layered composite
4L	4 layered composite
5L	5 layered composite

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