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Research Paper

Mechanical and Vibrational Analysis of Chicken Feather Hybrid Composites

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Due to significant advancements in composites across various fields of engineering, the selection of materials (fibers and/or matrix) for manufacturing composites for specific and/or required applications has become increasingly important nowadays. The use of natural fibres, which possess good mechanical properties, is gaining attention as they can mitigate the environmental harm caused by artificial fibers. One notable natural fiber is chicken feather fiber (CFF), a waste by-product that poses a significant disposal problem. In this study, CFFs were employed to fabricate lightweight composites using hand-layup process and were tested according to ASTM standards for tensile, flexural, and vibrational properties. The extracted CFF were combined with glass fibers in varying weight ratios – 0%, 10%, and 20% – to fabricate a hybrid composite material. Frequency response tests conducted using a fast Fourier transform (FFT) analyzer provided the natural frequency and different mode shapes of all composite samples. Furthermore, finite element analysis (FEA) simulations of all hybrid composite (HC) specimens was simulated in ANSYS, and the results were compared with experimental values.

Keywords: hybrid composites; chicken feather fibers (CFFs); tensile test; flexural test; FFT technique; CFF composites.

1. Introduction

Composites are advanced engineering materials widely used across various fields of engineering, replacing pure elements and alloys that are costlier and involve labor intensive manufacturing processes. Metals and alloys exhibit reduced reliability, heavy weight, susceptibility to chemical degradation (rusting, corrosion etc.), and sometimes they do not offer multiple desirable characteristics simultaneously. These drawbacks constrain their applications in industries such as aerospace, automobile, machinery, etc. In contrast, composites are lightweight, cost-effective, exhibit good mechanical and physical properties, and are less affected by chemical agents' damage, making them increasingly popular over the years. Among these, natural composites have garnered significant attention due to their strength, compatibility, lightweight nature, and durability. Natural composites are fabricated using natural fibers such as jute, cotton, coconut, silk, etc., which are extracted and processed to be used as reinforcements in composites. These natural fibers are particularly known for their high specific strength and stiffness, stemming from their structural composition and nutrient content, such as proteins. Composites produced using these natural fibers are eco-friendly, easily disposable and resistant to chemical reactions (rusting or corrosion) caused by external agents.

CFF is a notable example of natural fiber-reinforced materials, where the reinforcement comprises of chicken feathers. Chicken fibers are among the most abundantly produced natural fibers, with around 2–3 billion tons of feathers generated every year. Of this, 70% ends up as waste, while only 30% is used in some composite construction materials (such as fiberboard and particle board), pillow stuffing, etc. Since these feathers are natural fibers that exhibit a greater strength than many manmade fibers, their application in various composites reduces the use of manmade fibers as well as the cost of production. CFF are bio-degradable and recyclable, highlighting their environmentally benefits and making them appropriate for circular economy and sustainable development goals. The amino acids present in the structure of these feathers are cross-linked within their structural composition, resulting in fibers that are tough, solid, and lightweight, and with good thermal and insulating properties. In the present study, these fibers are combined with epoxy resin and glass fibres to form a hybrid composite (HC), using the hand-layup technique. The incorporation of chicken fibers and glass fiber into epoxy resin increases the tensile strength, flexural strength, and natural frequencies of the HC, which are tested according to ASTM standards.

A comprehensive review of the mechanical, physical, and thermal properties of CFF-based composites was conducted by Bansal and Singh [1]. Earlier research on the properties of fiberboard made with different proportions of wood fiber (medium-density fiberboard-MDF) and CFF were evaluated by Winandy *et al.* [2], revealing that the initial strength and rigidity of MDF-CFF composites were lower compared to those made with other wood fibers. The mechanical properties in polyester and phenyl-ester composites reinforced with CFF were investigated by Subramani *et al.* [3], who found that tensile and flexural properties could be strengthened by increasing the CFF weight percentage. A study on chicken feather waste as a material for nonwoven insulators by Soekoco *et al.* [4] conducted experiments by adjusting the orientation of chicken feathers in order to achieve the optimum insulation content, thereby measuring the material's thermal properties. Vibration analysis of sisal fiber-reinforced epoxy-based composites using an FFT analyzer was conducted by Prasad *et al.* [5], while Adediran [6] presented both analytical and experimental vibration analysis of glass fiber-reinforced composite beams, providing significant insights for the current research work. Additionally, the hand lay-up technique and ANSYS-based analysis was detailed by Balaji *et al.* [7] provided valuable insights, while the research on laminate mixtures of natural fibers conducted by Sadashiva and Purushothama [8] was useful in shaping the present study. Furthermore, the investigation on the mechanical properties of epoxy-based CFF composites by Harun Basha *et al.* [9] revealed higher ultimate stress, yield stress, compressive strength, tensile strength, and elongation.

2. Experimentation

2.1. Materials used

In the present study, CFFs and glass fibers are used as reinforcement materials combined with epoxy LY556 resin as the matrix, hardener HY951 (a low-viscosity fluid), and polyvinyl alcohol (PVA) as a barrier between the mould surface and the substrate. The viscosity and density of the epoxy resin are 12 000 mPa and 1.2 gm/cm^3, respectively, at 25°C. The density of the hardener is 0.95 gm/cm^3 with a melting point of 120°C. PVA, a water-soluble releasing agent, has a viscosity of 230 mPa with a pH of around 6.85 to 7.27. The epoxy matrix binds the fiber reinforcements together giving the hybrid composite a definitive shape, while distributing the load evenly throughout the reinforcement. This uniform load distribution contributes significantly to the composite's overall strength.

2.2. Fabrication of the hybrid composite

The bottom slab of the mould (die) is carefully cleaned with thinner, polished with wax, and coated with a releasing agent (PVA solution), as shown in Fig. 1.

Fig. 1. Applying releasing agent.

The same procedure is applied to the upper slab, which is then allowed to dry. An epoxy resin and hardener mixture is prepared in a 10 : 1 ratio as recommended (where 1 g of hardener is sufficient to cure10 g of resin within a specified time). Dried chicken feathers and fiberglass are cut into the required shapes with dimensions according to ASTM standards for subsequent testing. Once the mould is dry, fiberglass and chicken feathers are distributed into the mould cavity with varying weight ratios for different specimens. The resin-hardener mixture is then poured over the fibers and thorough compaction is achieved using hand rollers to eliminate any air bubbles, as shown in Fig. 2. The mould is closed with the upper slab while loads are applied to compress the specimen in order to maintain the thickness of 3 mm. The composite is allowed to cure for 20–24 hours before the specimen is removed from the mould. Various hybrid composite specimens are made with different CFF composition, as shown in the Table 1.

FIG. 2. Preparation of specimen.

Table 1. Weight ratios of the hybrid composite.

Constituent [%]	SI	SII	SIII
Epoxy resin mixture	50	50	50
Fiber glass	50	40	30
Chicken feather fiber	0	10	20

2.3. Characterization

Tensile strength. The tensile test of a composite evaluates key mechanical properties such as tensile strength, yield strength and ductility. The tensile test of CFF hybrid composites was conducted on a Universal Testing Machine (UTM) with various specimens according to ASTM D-3039 standard ($250 \times 25 \times 3$ mm). These testing specimens are mounted using grips on the UTM with a suitable pre-load applied, as depicted in Fig. 3. Similar procedure is carried out for all the specimens with varying CFF weight ratios (i.e., 0%, 10%,

FIG. 3. Experimental setup for tensile test.

and 20%) to obtain a stress-strain curve. Figure 4 presents an SII CFF specimen post- tensile test with an elongation of about 3 to 4 mm before breaking due to increased tensile load.

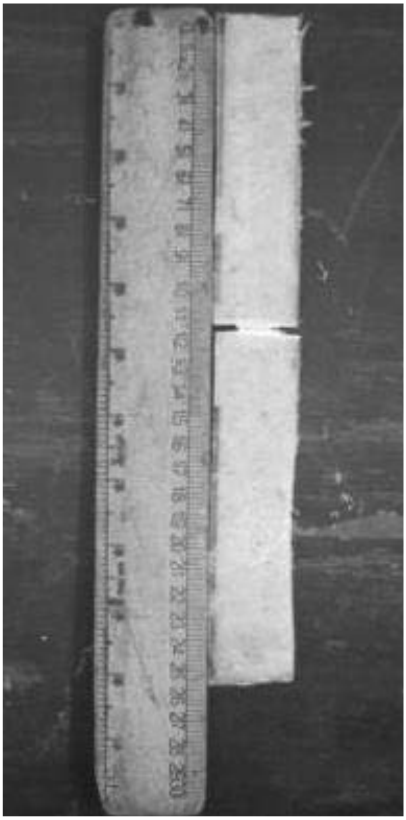

FIG. 4. Specimen after tensile testing.

Flexural strength. The flexural test is commonly performed to measure the composite material's flexural modulus and flexural strength. The two-point bending method was used in testing all the specimens according to the ASTM D-7276 standard ($120 \times 13 \times 3$ mm) on a UTM, as shown in Fig. 5. A central varying load is applied to each specimen, supported as a simply supported beam, until maximum deformation is observed and the HC fractures. This procedure is repeated for all three specimens (SI, SII, and SIII) with varying CFF weight percentages.

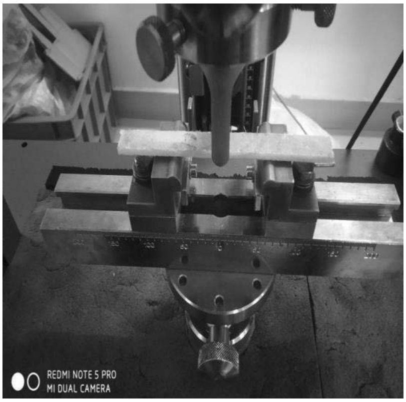

Fig. 5. Experimental setup for flexural test.

Modal analysis. The natural frequencies, mode shapes, damping ratio, and phase angle of any composites are determined using the FFT method. Three HC specimens with dimensions of $300 \times 300 \times 3$ mm are prepared for the vibrational analysis as in compliance with ASTM standards. A grid of 7×6 (42 points) with each grid measuring 50×50 mm was marked on each of the specimen's surface, while five measurements were taken at each grid point in order to analyze the vibrations. The specimen placed on the experimental setup is shown in Fig. 6.

Fig. 6. Experimental setup for modal analysis.

The major components used in the present experimental study include: a vibrating body, a uniaxial accelerometer (10.24 mV/(m/s^2)), an impulsive force hammer (2.172 mV/N, plastic/vinyl), a Data Acquisition System-DAQ (4 channels, ±V, 24-bit software), LabVIEW software (2009 version), and a display monitor. The impact hammer, acting as a force transducer, is used to apply force at each grid point to excite the specimen by allowing it to vibrate. A piezoelectric accelerometer placed at the measurement point detects these vibrations and transmits the data to an amplifier, before it is fed to the analyzer. The DAQ is used to process the vibrations by removing unwanted noise, convert continuous signal into a discrete signal, and transforming discrete signals from the time domain to the frequency domain using a FFT associated with the analyzer. The average of the five measurements are calculated and recorded. Potential measurement errors in the experimental tests include: measurement noise, incorrect accelerometer positioning and the impact of its mass mass, non-uniformity in specimen properties (e.g., voids, variations in thickness, non-uniform surface finishing), fiber misalignment, and resin flow or bleed-out during curing. These factors could lead to slight modulus variations.

3. Results with discussions

3.1. Experimental results

Appropriate tensile loads were applied using a computer-controlled UTM for all three specimens at a constant crosshead speed of 2 mm/min. All tests were carried out under strict supervision at room temperature. The tensile stress versus strain graph for SI, SII, and SIII specimens are shown in Fig. 7. The two-point bending test conducted for various compositions of CFF, resulted in stress-deformation graphs as shown in Fig. 8. The tensile strength of the HC with 0% CFF content is found to be 171 MPa, 138 MPa for 10% CFF content and 127 MPa for 20% CFF content, as shown in Table 2. Also, the flexural strengths obtained from the UTM for 0%, 10%, and 20% CFF are 134 MPa, 69.7 MPa, and 160 MPa, respectively (Table 2). The experimental results from these two tests indicate that tensile strength decreases as the CFF

Table 2. Tensile and flexural properties of CFF composites.

Specimen	Tensile strength [MPa]	Tensile modulus [MPa]	Flexural strength [MPa]	Flexural modulus [MPa]
SI (0% CFF)	171	753	134	4880
SII (10% CFF)	138	641	69.7	3730
SIII (20% CFF)	127	143	160	8840

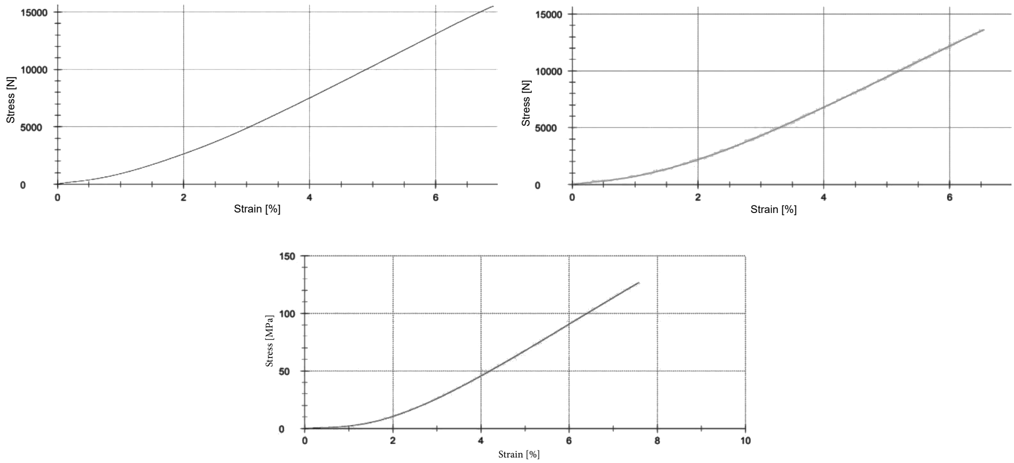

FIG. 7. Tensile stress-strain graphs for SI, SII, and SIII HC specimens.

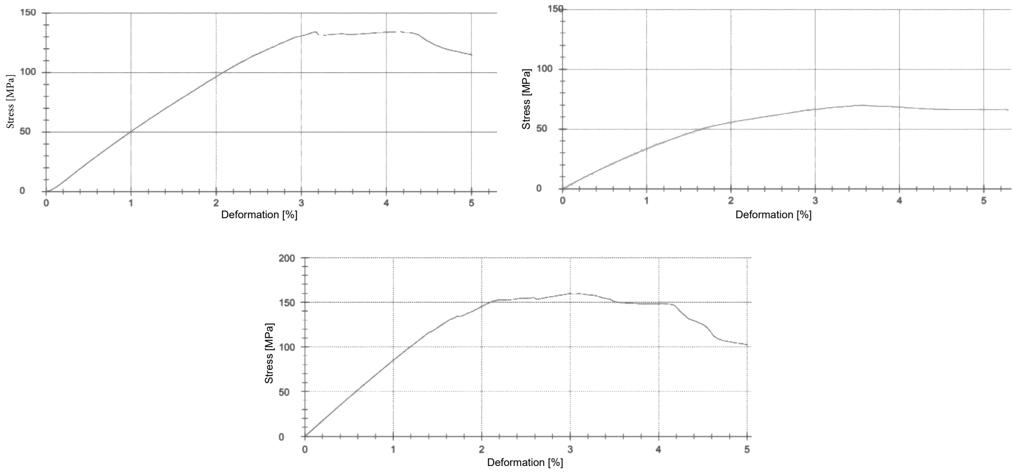

FIG. 8. Flexural stress-deformation graphs for SI, SII, and SIII HC specimens.

weight percentage in the glass fiber-epoxy resin composite increases. However the flexural strength of the composite initialy decreases with a 10% addition of CFF t and the increases drastically with a 20% CFF content. Hence, while adding chicken feather fibers to a glass fiber composite enhances the flexural properties of the HC, it does not significantly improve tensile properties.

High-speed airborne and/or space vehicles resonate during flight, inflicting irreparable damage to these vehicles, leading to economic losses. Resonance can impair the performance of high-speed cars and potentially cause significant damage to high-speed vehicles, both domestically and internationally. As a result, resonance phenomena should be avoided as much as possible in engineering practice. In order to minimize resonance, modal tests can be conducted to determine the inherent frequencies of certain structures. This not only improves the safety of high-speed vehicles but also improves the accuracy of flight control systems and flight characteristics. Modal testing is frequently employed in structural dynamics analysis in the fields of aeronautics, mechanical engineering, and electrical engineering. In this study, the modal characteristics of all the HC specimens were analyzed using the frequency response function (FRF) approach, which was obtained from the FFT analyzer. The data was transferred to a display system for processing and curve fitting. The output data from the analyzer provided the required natural frequency, damping factor, and mode shapes, which were displayed on the screen. The magnitude vs frequency response graph for the 0%, 10%, and 20% CFF hybrid composite are displayed in Figs. 9, 10, and 11, respectively. The white line, in all the graphs, represents the actual curve, while the red line represents the curve fitting. The peaks on the graph indicate the natural frequencies. The first five modes (bending mode, twisting mode, double bending mode, combination of bending and twisting mode, and complex mode) were obtained for all the HCs (refer to the Appendix). The modal properties for the first five modes of all the HC specimens (SI, SII, and SIII) are presented in Tables 3 to 5. From the experimental analysis, it is evident that the polymer matrix composite with 20% CFF exhibits the highest natural frequencies of about 310.45 Hz in mode 5. A higher weight percentage of CFF enhances the natural frequency of the hybrid composite, which proves that it can withstand higher levels of vibration.

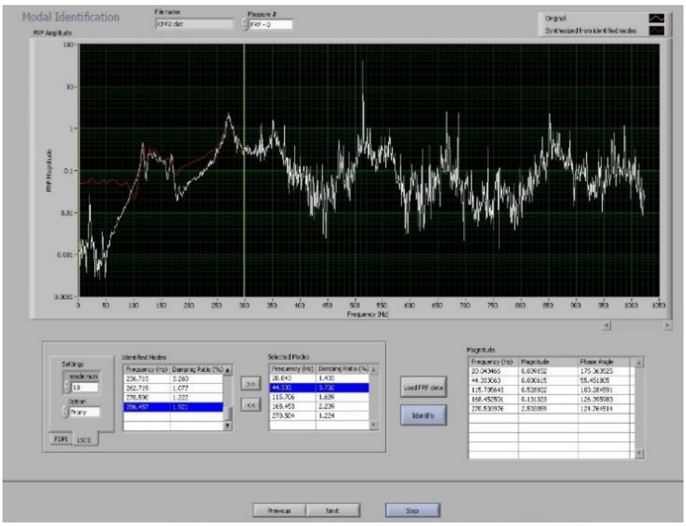

Fig. 9. Magnitude–frequency response-0% CFF content composite.

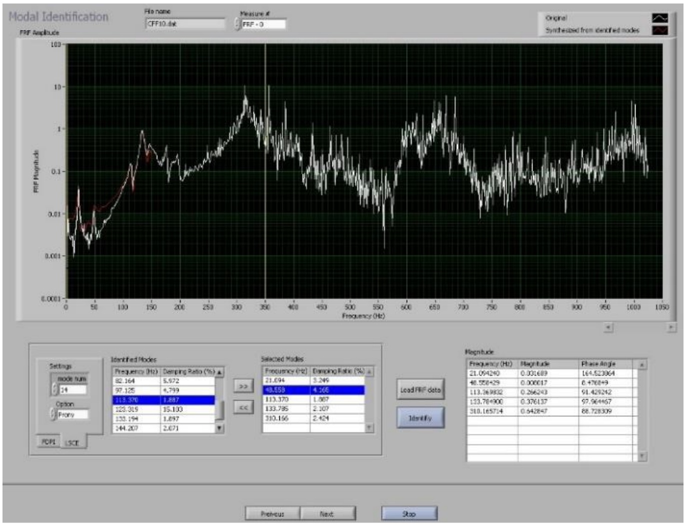

Fig. 10. Magnitude–frequency response-10% CFF content composite.

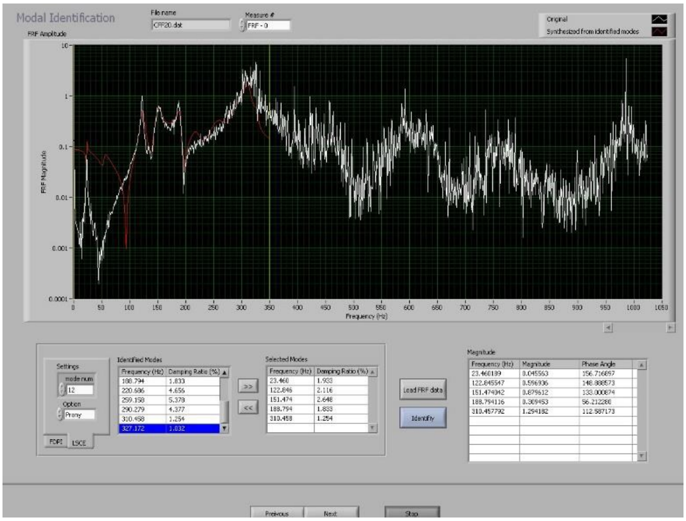

Fig. 11. Magnitude–frequency response-20% CFF content composite.

Table 3. Modal properties of SII composite.

Mode No.	Frequency f [Hz]	Damping factor ξ [%]	Magnitude	Phase angle
1	20.0434	1.433	0.009152	175.3635
2	44.3330	3.732	0.000615	55.4518
3	115.7056	1.689	0.528922	103.2845
4	168.4525	2.209	0.131323	126.3959
5	270.5039	1.224	2.503059	124.7651

Table 4. Modal properties of SII composite.

Mode No.	Frequency f [Hz]	Damping factor ξ [%]	Magnitude	Phase angle
1	21.0942	3.249	0.0316	164.523
2	48.5584	4.165	0.0080	8.4768
3	113.369	1.887	0.2662	91.429
4	133.7849	2.107	0.3761	97.9644
5	310.1657	2.424	0.6428	88.728

Table 5. Modal properties of SIII composite.

Mode No.	Frequency f [Hz]	Damping factor ξ [%]	Magnitude	Phase angle
1	23.460	1.933	0.0455	156.71
2	122.8455	2.116	0.596	148.888
3	151.474	2.648	0.8796	133.000
4	188.794	1.833	0.309	56.212
5	310.457	1.254	1.294	112.587

3.2. Simulation results

Finite element analysis (FEA) is a computer-aided engineering (CAE) technique used to analyze the behavior of materials in real-time world applications. FEA is widely used to analyze testing samples, which in-turn reduces the need for physical prototypes, making the analysis simpler and more cost-efficient. The three main three stages of FEA include the pre-processor, the analyzer/solver, and the post-processor. The pre-processor deals with the design of appropriate models by applying meshing and boundary conditions. The solver takes input from the pre-processor or any design files, inspects the information, solves the problem and generates am output file (if there is no error in the input file). The post-processor collects the data from the analyzer/solver and displays it to the user in graphical and tabular formats, with different colors used for different parts of the model. In the present study, ANSYS APDL package is used for solving the prototype model for tensile, flexural and vibrational analysis.

The FEA performed on the tensile specimens SI, SII, and SIII with exact dimensions provide the von Mises stresses and deformations, as pictured in Figs. 12, 13, and 14, respectively. The tensile stress or von Mises stress, obtained from FEA decreases with an increase in the weight percentage of CFF, which are similar to the results of the UTM test. The flexural strength of the HC, defined as its ability to resist deformation, was determined for the testing model dimensions in ANSYS APDL. The flexural stresses or von Mises stresses, and deformations for all the specimens are presented in Figs. 15, 16, and 17. The FEA analysis results show an increase in flexural strength with the increase in

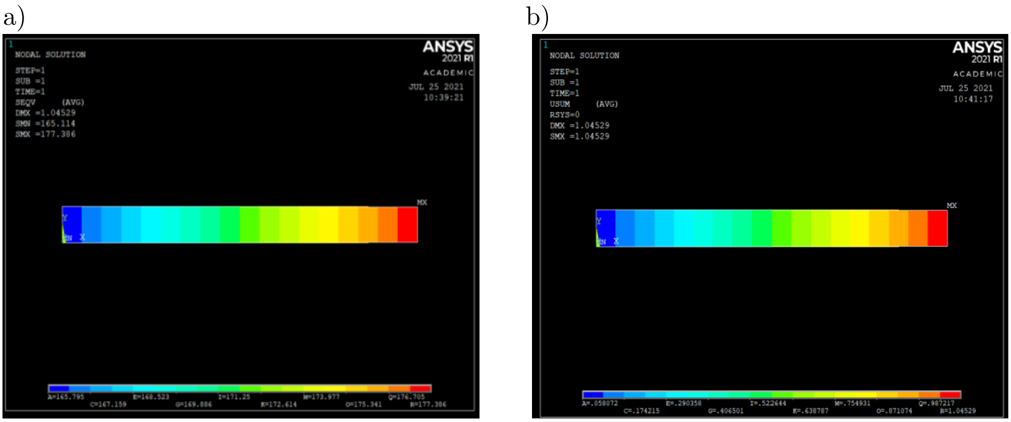

FIG. 12. (a) von Mises stress and (b) displacement plot for SI tensile specimen.

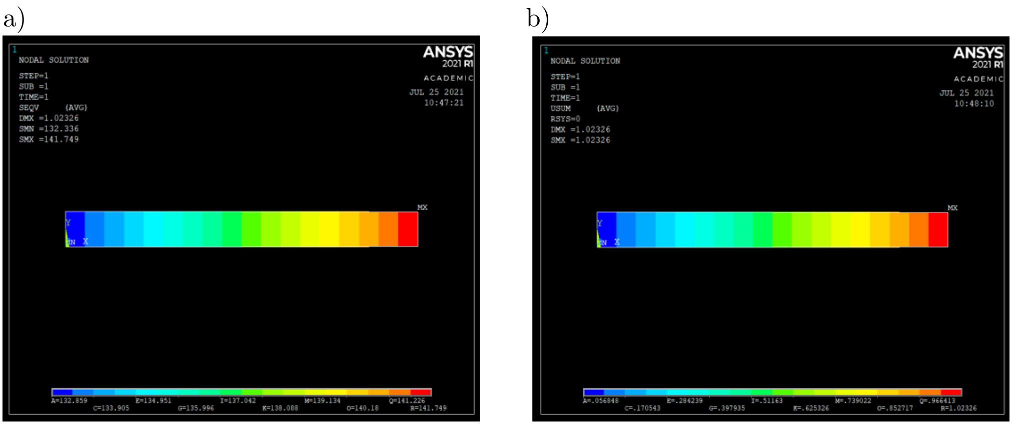

FIG. 13. (a) von Mises stress and (b) displacement plot for SII tensile specimen.

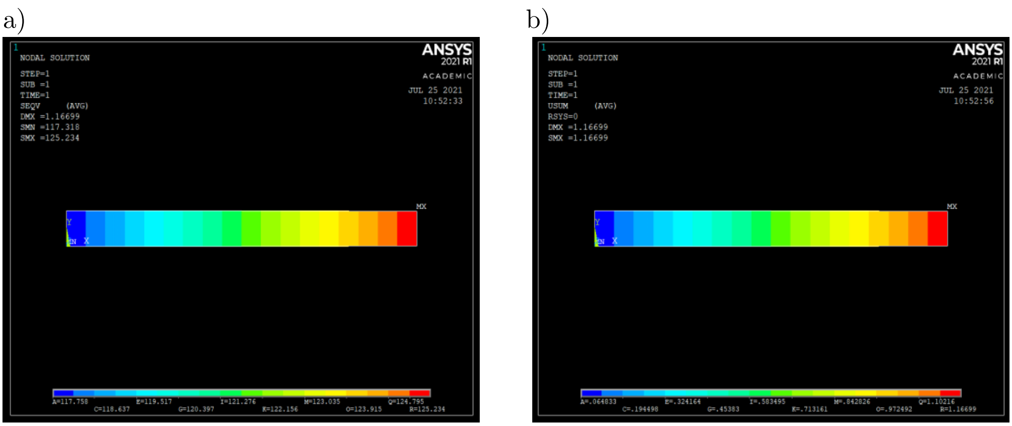

FIG. 14. (a) von Mises stress and (b) displacement plot for SIII tensile specimen.

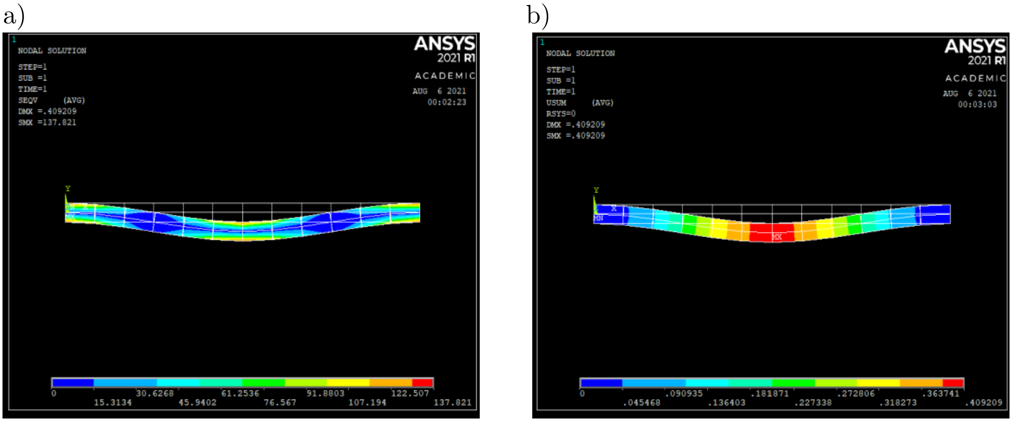

FIG. 15. (a) von Mises stress and (b) displacement plot for SI flexural specimen.

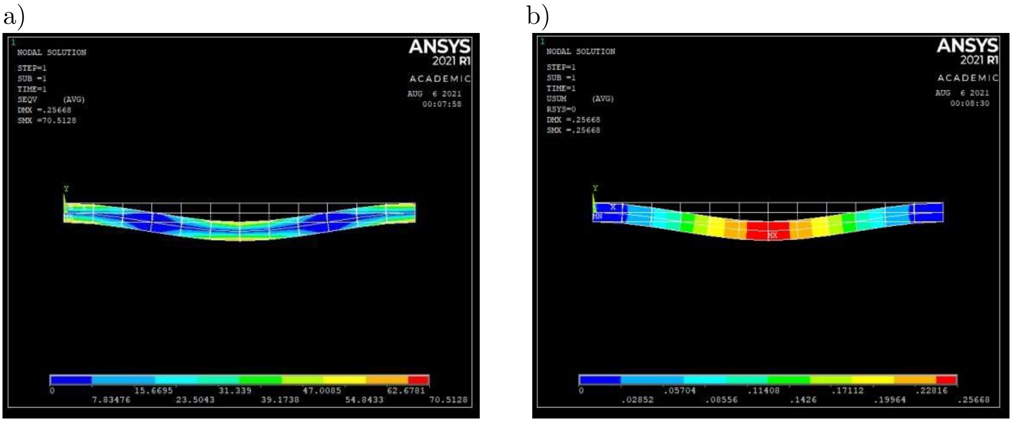

FIG. 16. (a) von Mises stress and (b) displacement plot for SII flexural specimen.

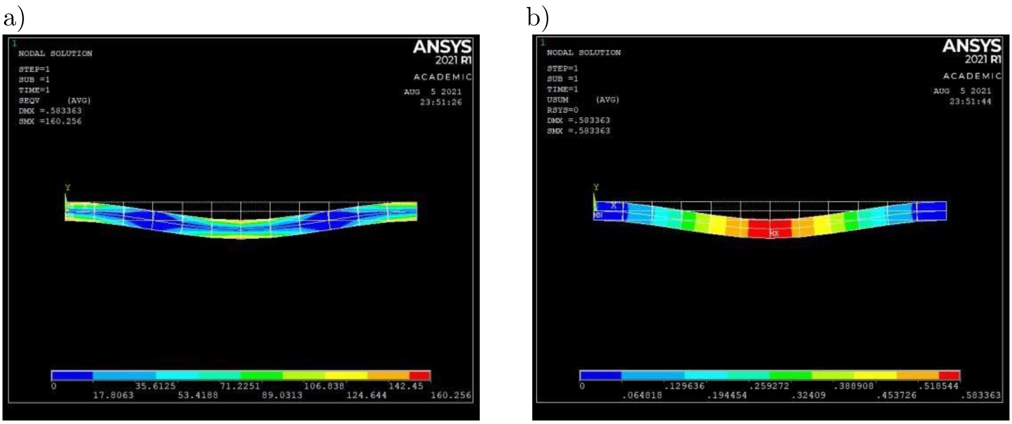

FIG. 17. (a) von Mises stress and (b) displacement plot for SIII flexural specimen.

CFF weight percentage, which similar to the experimental findings, as plotted in Figs. 21a and 21b. The highest flexural strength obtained is 160 MPa for a 20% CFF composite. A comparison of the numerical and experimental results for both tensile and flexural tests indicates that the values are nearly identical.

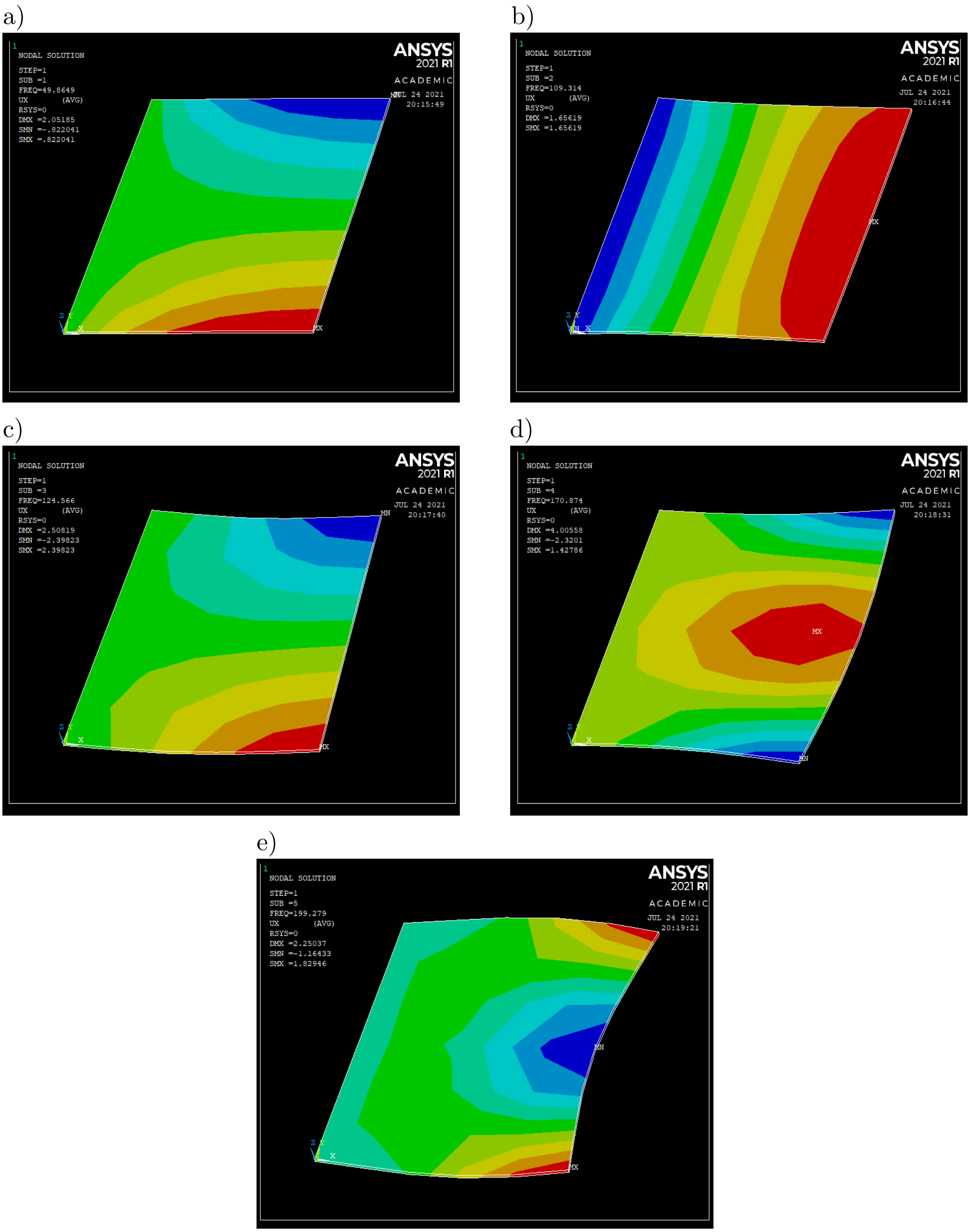

Fig. 18. FEA mode shapes for 0% CFF composite specimen.

Due to the characteristics of the chicken feather fiber and fiberglass composite, along with structural difficulty, the resonance phenomenon occurs more frequently at low frequencies than at high frequencies. As a result, when using

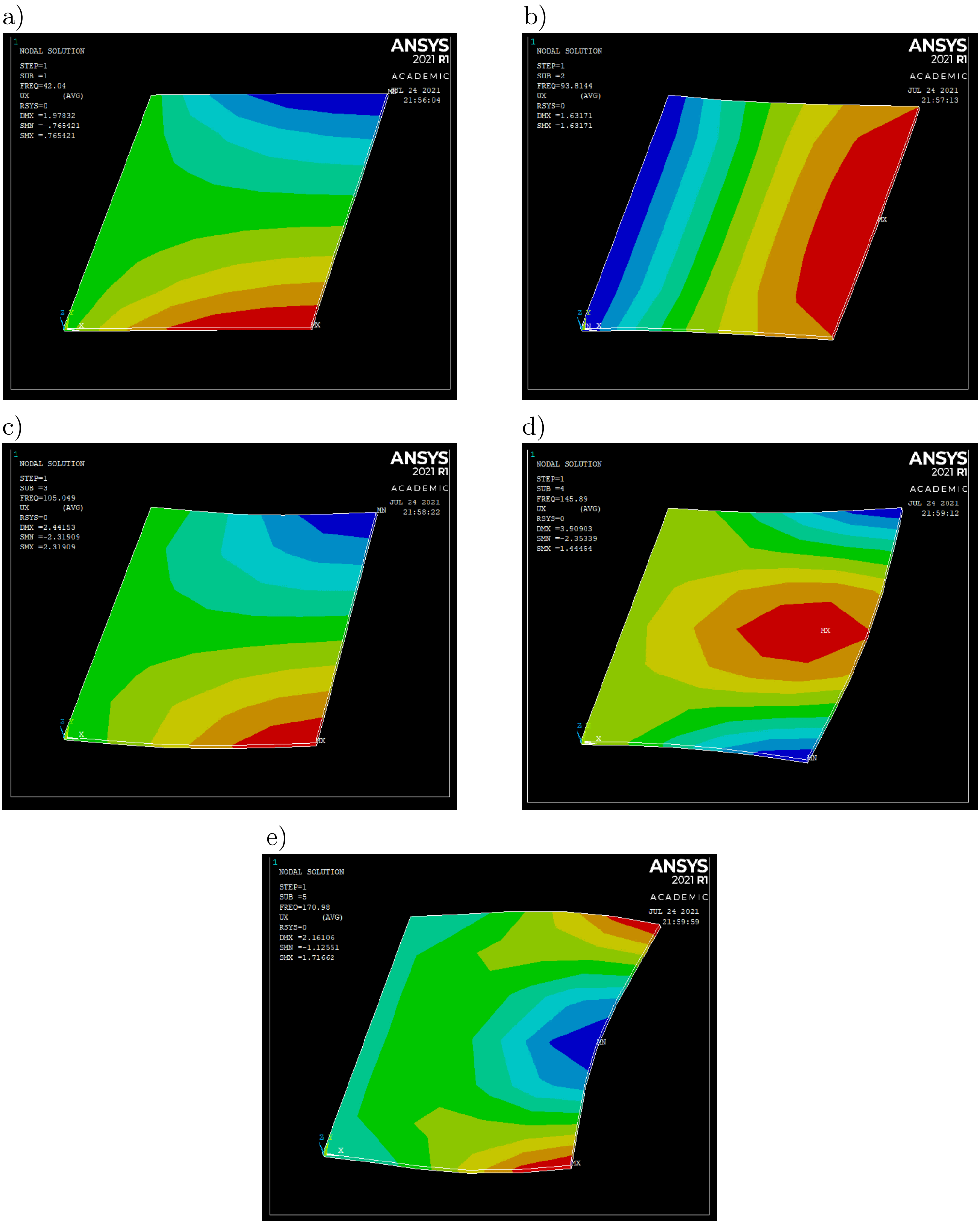

FIG. 19. FEA mode shapes for 10% CFF composite specimen.

FEA to investigate the low frequency level, a total of five modes were set for modal analysis. All five mode shapes and natural frequencies of specimens SI, SII, and SIII are pictured in Figs. 18, 19, and 20, respectively. The FEA results for the five natural frequencies of different CFF weight ratio specimens concluded

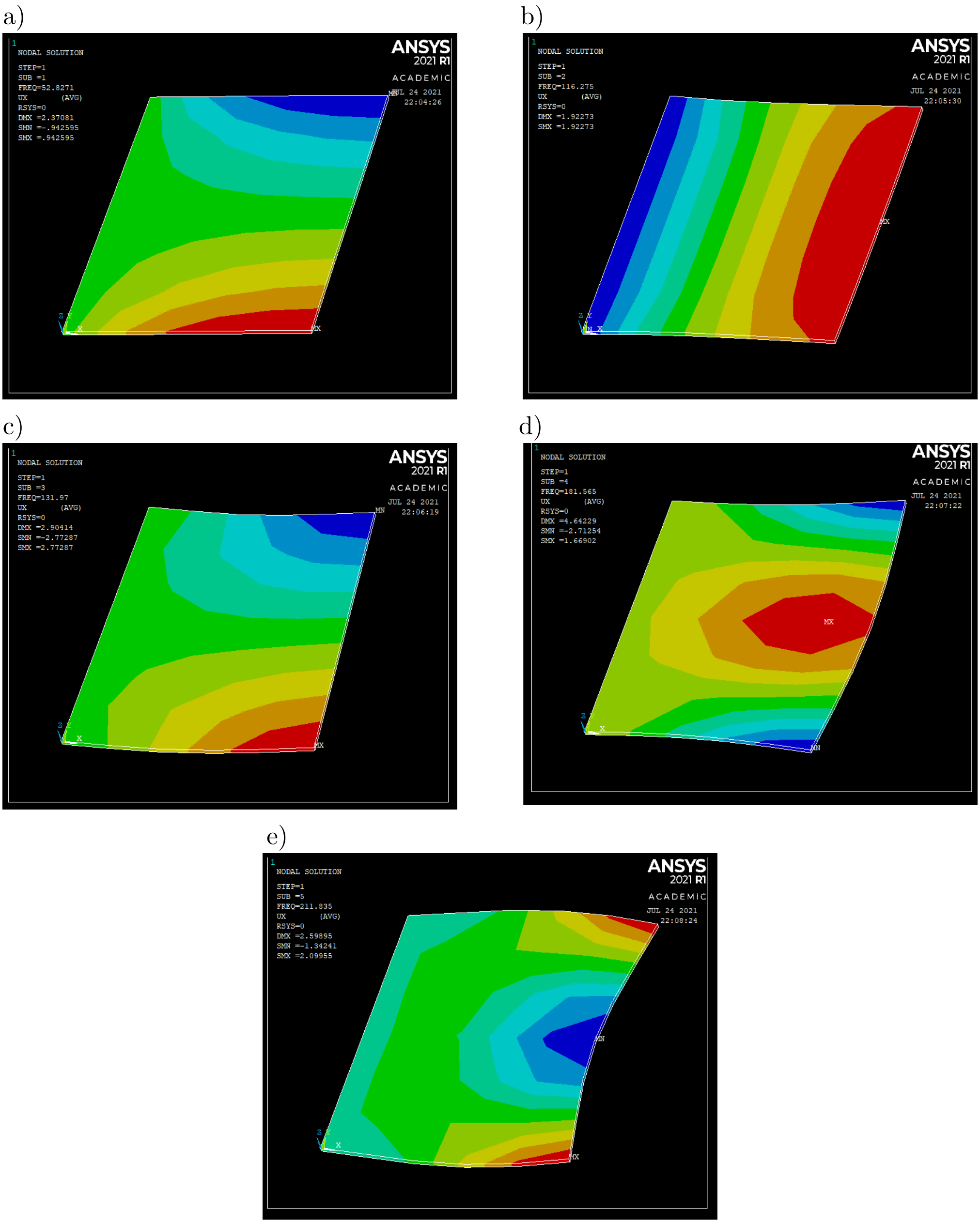

FIG. 20. FEA mode shapes for 20% CFF composite specimen.

that the experimental results are similar to the FEA analytical result in some modes, as plotted in Figs. 22, 23, and 24. Hence, the numerical results are validated against the experimental results. The highest value of natural frequency was obtained for the 20% CFF hybrid composite, which infers that this composite material has high stiffness and rigidity. Therefore, this hybrid composite can be used in air transport components, sporting goods, and rotary machines, as it can withstand the vibrations produced. The high flexural strength signifies

a) b)

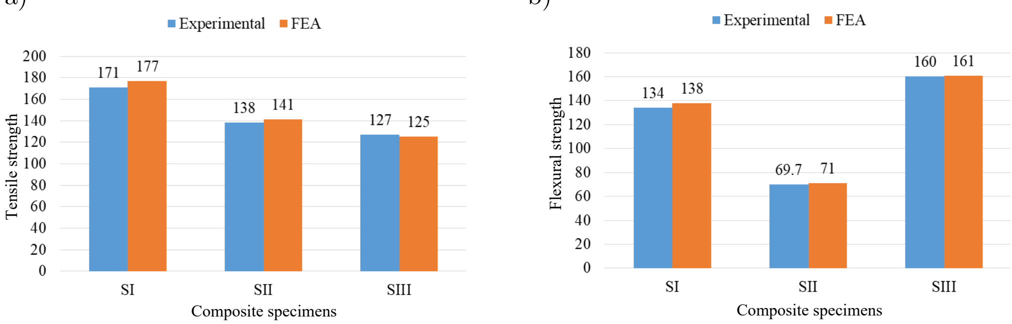

Fig. 21. Comparison of experimental versus FEA results for tensile strength (a) and flexural strength (b).

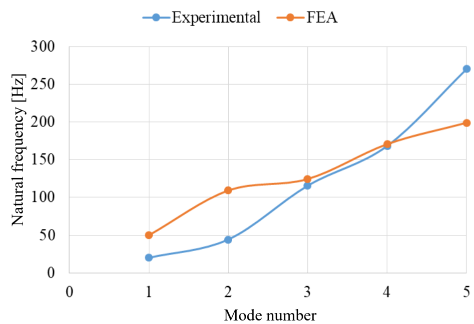

Fig. 22. Comparison of experimental values with FEA for 0% CFF.

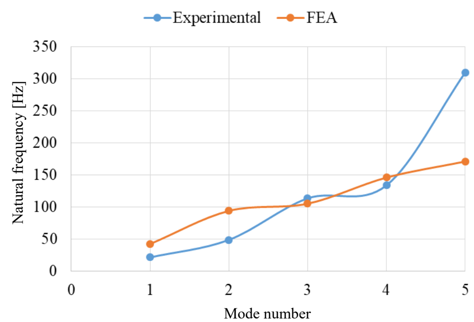

Fig. 23. Comparison of experimental values with FEA for 10% CFF.

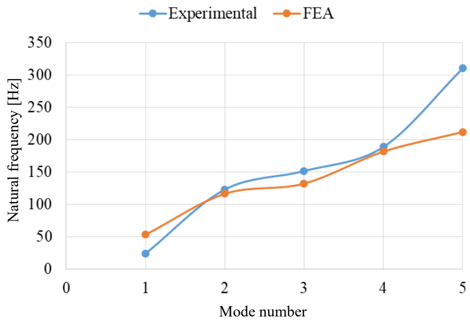

Fig. 24. Comparison of experimental values with FEA for 20% CFF.

excellent restoration property. Since this HC is a low-density material, it can be widely used in aerospace applications as a weight-reducing material.

4. Conclusions

The current research work dealt with the development of a new class of natural HCs with waste CFF and glass particles. Mechanical characterization and vibrational studies were carried out for three different compositions of CFF and glass particles, resulting in the following inferences:

- The tensile strength of the HC with glass particles (SI) was higher while the addition of CFF (SII and SIII) decreased the tensile stress and modulus values.
- The three-point flexural test for 0%, 10%, and 20% CFF content HC achieved higher flexural stress of about 160 MPa for 20% CFF, which is higher than that of 0% and 10% CFF weight compositions.
- Five natural frequencies and mode shapes of the HC specimens using a FFT analyzer were obtained experimentally. These results indicate that the addition of CFF led to an increase in the frequency response of the proposed HCS.
- Higher natural frequencies are always preferred for greater dynamic stability and efficiency in order to avoid resonance; therefore, they can be used in aeronautical applications.
- The SIII composite material (with 20% CFF content) had an average natural frequency of 159.4Hz, which is higher than that of SII (with 10% CFF content) and SI (with 0% CFF content). As a result, the proposed SIII HC has good dynamic stability and stiffness.
- The FEA results for tensile, flexural, and modal analysis were determined for all the specimens using ANSYS APDL, and the results were in agreement with the experimental study.

The present study concluded that the natural chicken feather fibre reinforced polymer matrix material is best suited for structural and non-structural applications, based on both experimental and FEA methodologies.

Appendix

The five mode shapes obtained from an FRF approach are shown below in Fig. 25 for an SI (0% CFF) HC specimen. Almost identical mode shapes were obtained for SII and SIII specimens, and hence their figures Are not shown here.

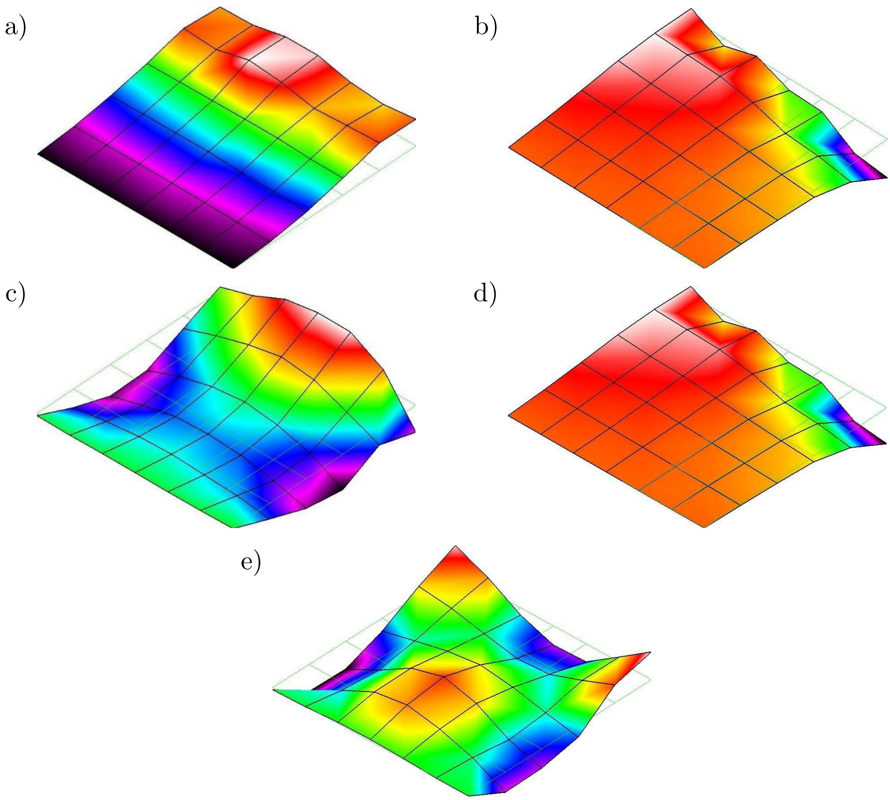

Fig. 25. (a) Bending mode, (b) twisting mode, (c) double bending mode, (d) combination of bending & twisting mode, and (e) complex mode for an SI composite specimen.

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