International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

An Experimental Investigation on Free Vibrational Analysis of Natural Fiber Hybrid Composite Plates and Fiber Metal Laminate Composite Plate

Dr. MadhuSudhanPrasad Manchala
Assisstant Professor
Department of Mechanical Engineering,
University College of Engineering,
JNTUK, Kakinada,
Andhra Pradesh 533003, India

Perla Ramakanth
M.Tech Scholar
Department of Mechanical Engineering,
University College of Engineering,
JNTUK, Kakinada,
Andhra Pradesh 533003, India

Lakshmi Manasa Birada
Assisstant Professor
Department of Mechanical Engineering,
University College of Engineering,
JNTUK, Kakinada,
Andhra Pradesh 533003, India

Abstract: - This study presents a combined numerical and experimental investigation of the free vibration behavior of flax and areca fiber reinforced hybrid composite plates and a titanium E-glass fiber metal laminate (FML) plate. Three square five-layer plates were fabricated using the hand lay-up technique and evaluated under CFFF and CFCF boundary conditions. The flax–areca hybrid laminates were prepared with F/A/A/A/F and A/F/F/F/A stacking sequences, while the FML plate employed a symmetric Ti/GF-E/GF-E/GF-E/Ti configuration. All laminates were arranged with a [0°/90°/0°/90°/0°] fiber orientation. Numerical free vibration analysis was performed using the Finite Element Method in ANSYS APDL 19.2 to determine natural frequencies and mode shapes. Experimental modal analysis was conducted using an impact hammer technique, with vibration responses processed through SUMURAI and ME'scope software. Excellent agreement was observed between numerical and experimental results. The flax–areca hybrid composites exhibited lower natural frequencies, where as the titanium E-glass FML plate demonstrated higher stiffness and superior vibration resistance, indicating their suitability for lightweight automotive and aerospace structural applications.

Keywords: Titanium, E-glass Fiber, natural fibers, Epoxy Resin, Modal Analysis, Natural Frequencies.

1. INTRODUCTION

Lightweight composite materials are widely used in modern engineering because of their high strength-to-weight ratio, corrosion resistance, and tailor able properties. Natural fiber reinforced polymer composites, such as flax and areca, offer sustainable and cost-effective solutions for lightweight structural applications but are limited by lower stiffness in vibration-critical conditions. Hybridization of flax and areca fibers improves mechanical performance by balancing stiffness and toughness. In this study, all laminates were fabricated as five-layer plates with a [0°/90°/0°/90°/0°] fiber orientation, which significantly influences stiffness and dynamic response. Fiber Metal Laminates (FMLs), particularly titanium, E-glass fiber laminates, combine the stiffness and durability of titanium with the strength and vibration damping of glass fiber epoxy layers. Comparing the free vibration behavior of flax–areca hybrid composites and titanium glass fiber FML plates provides useful guidance for designing lightweight, vibration-sensitive structures for automotive, aerospace, and marine applications. Banana fiber-reinforced composites have been widely investigated for their mechanical and dynamic characteristics, demonstrating their suitability for automotive and marine structures [1]. Flax fiber composites have also gained considerable attention due to their renewability, biodegradability, and moderate mechanical strength, making them appropriate for lightweight structural panels [4]. The dynamic behavior of composite structures, including natural frequencies, mode shapes, and damping characteristics, is a critical design consideration under vibrational and dynamic loading conditions. Analytical and numerical approaches have provided valuable insights into these behaviors. Nayak et al. [2] analyzed the free vibration response of composite sandwich plates using Reddy's higher-order shear deformation theory, while Alexander and Augustine [3] investigated the vibration and damping behavior of

GFRP and BFRP laminated composites under different boundary conditions. Experimental investigations play a vital role in validating numerical and analytical models. Merzuki et al. [5] conducted experimental studies on fibre-metal laminates (FMLs) to evaluate their free vibration response, while Saheb and Deepak [6] employed experimental modal testing to analyze laminated composite plates, focusing on natural frequencies and mode shapes. Further experimental studies on graphene-reinforced laminated composites [7] and viscoelastic sandwich structures [8] demonstrated improvements in stiffness, damping, and vibration absorption. Srividya et al. [9] combined analytical, experimental, and finite element methods to study isotropic and orthotropic laminates, highlighting the importance of model validation. FMLs, which integrate metallic and fiber-reinforced polymer layers, exhibit enhanced dynamic and vibro-acoustic performance. Merzuki et al. [10] performed combined numerical and experimental investigations on FMLs under free vibration. Vaiduriyam and Chinnapandi [11] analyzed the vibro-acoustic behavior of FMLs, emphasizing the influence of hybrid configurations, while Merzuki et al. [12] studied glass fiber–aluminium reinforced polymer laminates, confirming their superior stiffness and damping properties. Advanced hybrid structures have further improved vibration performance. Wang et al. [13] investigated Ti-6Al-4V sandwich beams with corrugated channel cores, and Gnanasekaran et al. [14] examined Kevlar/Jute fiber-reinforced titanium-based laminates, reporting enhanced mechanical and vibrational behavior. Collectively, these studies highlight the importance of understanding free vibration behavior of natural fiber composites and FMLs. Building on this foundation, the present work investigates the dynamic response of flax–areca hybrid composite plates and Ti/GF/Ti FML plates under CFFF and CFCF boundary conditions using combined experimental and numerical approaches.

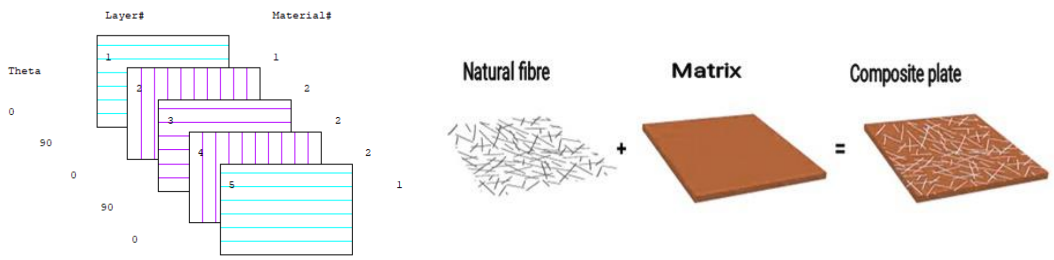


Fig 1. Five layered natural fiber laminated square plate.

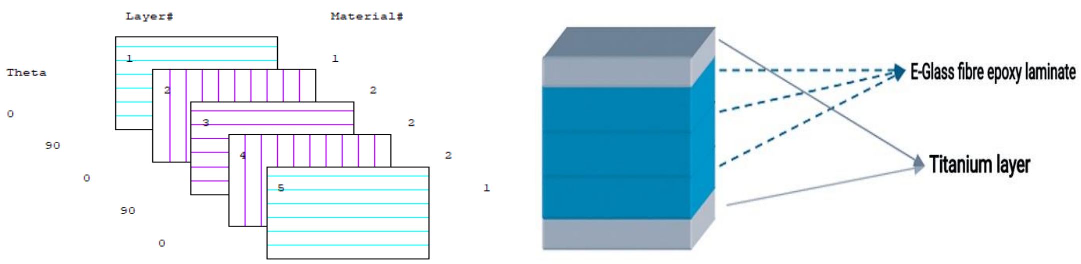


Fig 2. Five layered fiber metal laminated square plate.

2. MATERIAL MODELLING

2.1 Raw Materials And Sample Fabrication

The raw materials used in this study included flax fiber mats, areca fiber mats, E-glass fiber mats, titanium foil sheets, and an epoxy resin system consisting of LY556 epoxy resin and HY951 hardener. Flax and areca fibers were selected as natural reinforcements due to their low density, biodegradability, and adequate mechanical properties. E-glass fiber and titanium foil were used to fabricate fiber metal laminate (FML) plates because of their high stiffness, strength, and superior vibration resistance. All laminates were arranged with a five-layer [0°/90°/0°/90°/0°] fiber orientation to ensure uniform in-plane stiffness and effective load transfer. Three square composite plates were fabricated using the hand lay-up technique, with specimen dimensions selected in accordance with ASTM D7264 standards. All plates had identical dimensions of 250 mm × 250 mm × 3.5 mm. Two plates consisted of flax–areca hybrid composite laminates with five-layer stacking sequences of F/A/A/A/F and A/F/F/F/A, where F and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

A denote flax and areca fiber layers, respectively. The third plate was an FML with a symmetric Ti/GF-E/GF-E/GF-E/Ti configuration, in which titanium foil formed the outer layers and E-glass fiber–epoxy laminates constituted the core. During fabrication, LY556 epoxy resin was mixed with HY951 hardener in the manufacturer recommended ratio and uniformly applied to each layer to ensure complete wetting, strong interfacial bonding, and minimal void formation. The laminates were consolidated under uniform pressure, cured at room temperature, post-cured for enhanced stability, and machined to ASTM-compliant dimensions for numerical and experimental free vibration analysis under CFFF and CFCF boundary conditions.

Table 1. Mechanical Properties of Titanium foil sheet material (Ti).

property	value
Density (ρ) kg/m³	4680
Young's Modulus (E) GPa	112
Poisson's Ratio (ν)	0.29

Table 2. Mechanical properties of orthotropic values

Property	**E-Glass fiber/epoxy**	**Flax Fiber/epoxy**	**Areca Fiber/epoxy**
Longitudinal elastic modulus (E1) Gpa	36	26	17
Transverse elastic modulus (E2) Gpa	7.32	8.21	6.34
Thickness elastic modulus (E3) Gpa	7.32	8.21	6.34
In-plane poisson's ratio (ν12, ν13)	0.27	0.32	0.34
Thickness Poisson's ratio (ν23)	0.34	0.36	0.37
In-plane Shear modulus (G12, G13) Gpa	2.96	4.23	3.31
Thickness Shear modulus (G23) Gpa	3.14	2.91	2.32
Density (ρ) kg/m³	1740	1340	1240

2.2 FE Analysis And Modelling

In the present work, finite element analysis of square composite and fiber metal laminate plates was performed using the ANSYS 19.2 Mechanical Parametric Design Language (APDL) environment. Three five-layered square plates with dimensions of 250 mm × 250 mm × 3.5 mm were modeled, consisting of flax–areca natural fiber hybrid composite laminates and a titanium/E-glass fiber reinforced fiber metal laminate. The numerical model incorporated the material properties such as elastic modulus, Poisson's ratios, shear modulus, and density for each constituent layer. Flax fiber/epoxy, areca fiber/epoxy, E-glass fiber/epoxy, and titanium were considered as the constituent materials, and their mechanical properties were adopted from literature and experimental data. The laminate stacking sequences included F/A/A/A/F and A/F/F/F/A for the hybrid natural fiber composites, and a symmetric Ti/GF-E/GF-E/GF-E/Ti configuration for the fiber metal laminate plate. The plates were discredited using eight-nodes quadrilateral shell elements (SHELL281), which are suitable for layered composite and sandwich structures, as illustrated in Fig. 2. All laminate layers were assumed to be perfectly bonded with uniform thickness, and free vibration analysis was carried out under CFFF and CFCF boundary conditions to extract natural frequencies and corresponding mode shapes.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

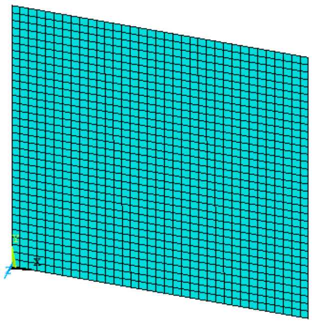


Fig 3. Modeling of laminated three square plates (250 mm × 250 mm × 3.5 mm) utilizing ANSYS 19.2 Mechanical APDL

3. EXPERIMENTATION

In the present work, the vibration characteristics and dynamic behavior of the five-layered fiber metal laminated (FML) and hybrid natural fiber composite square plates were investigated using Experimental Modal Analysis (EMA). The EMA setup allows the determination of natural frequencies, mode shapes, and dynamic response under free vibration conditions. A data acquisition system with eight input channels was employed to record the vibration response. One channel was connected to an excitation hammer, and another to a uniaxial accelerometer. The accelerometer was attached to the plate surface using beeswax to ensure proper contact and vibration transfer. Controlled impact excitation was applied to the plate using the hammer at quarter-point locations to induce free vibration, and the resulting structural response was measured by the accelerometer at multiple points across the plate. The frequency response functions (FRFs) obtained from the experiments were processed using the SAMURAI software to extract dynamic parameters, while ME Scope software was used to visualize and animate the mode shapes. The natural frequencies obtained from the FRFs were assigned to the ME Scope model along with the corresponding FRFs to generate animated representations of the mode shapes. The experimental setup consisted of the following equipment: Excitation hammer, Uniaxial accelerometer, Eight-channel data acquisition system, PC or laptop with modal analysis software, (5) Test specimen, (6) SAMURAI software, and (7) ME Scope software. Figures 3 and 4 illustrate the experimental arrangement and the application of varied boundary conditions (CFFF and CFCF) for the square plates.

(a) **(b)** **(c)** **(d)**

Fig 4. (a) Experimental Setup, (b) PCB accelerometer, (c) data acquisition system, (d) Impact hammer

(a) F/A/A/A/F **(b) A/F/F/F/A**

Fig 5. (a) F/A/A/A/F, (b) A/F/F/F/A five layered square plates under CFFF, CFCF plate boundary scenario

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

CFFF **CFCF**

Fig 6. Five layered FML square plate (Ti/GF-E/GF-E/GF-E/Ti) under CFFF, CFCF plate boundary scenario

4. RESULTS AND DISCUSSIONS

4.1 Modal Analysis Of Three Different Composite Square Plates

In the present work, the free vibration characteristics of three five-layered composite square plates were studied using numerical and experimental methods. The plates consisted of two flax–areca natural fiber hybrid laminates with stacking sequences F/A/A/A/F and A/F/F/F/A, and one titanium/E-glass fiber reinforced fibre metal laminate with a symmetric Ti/GF-E/GF-E/GF-E/Ti configuration. All specimens were fabricated with identical dimensions of 250 mm × 250 mm × 3.5 mm in accordance with ASTM D7264 standards, and bidirectional 0°/90° fiber orientations were used in all fiber layers. Finite element modal analysis was carried out using ANSYS 19.2 Mechanical APDL, where the plates were modeled with eight-noded SHELL281 elements and layer-wise material properties were assigned assuming uniform thickness and perfect bonding. Free vibration analyses were performed under clamped–free–free–free (CFFF) and clamped–free–clamped–free (CFCF) boundary conditions. Experimental Modal Analysis was conducted using an impact hammer and a uniaxial accelerometer, with frequency response functions processed using SAMURAI and ME Scope software. Good agreement between numerical and experimental results was observed.

Table 3. Natural frequencies(Hz) of F/A/A/A/F square plate under CFFF, CFCF plate boundary scenario

Plate Scenarios	CFFF			CFCF		
Mode No	**EMA**	**FEM**	**Error**	**EMA**	**FEM**	**Error**
Mode1	38.9	37.83	2.7	249.5	240.18	3.7
Mode2	74.2	72.38	2.4	271.4	263.76	2.8
Mode3	205.3	202.11	1.5	374.6	368.77	1.5

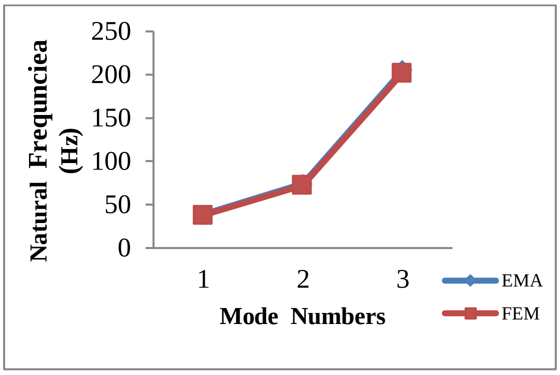
Table 4. Natural frequencies(Hz) of A/F/F/F/A square plate under CFFF, CFCF plate boundary scenario

Plate Scenarios	CFFF			CFCF		
Mode No	**EMA**	**FEM**	**Error**	**EMA**	**FEM**	**Error**
Mode1	32.4	31.49	2.8	204.4	200.19	2.0
Mode2	66.9	64.76	3.1	227.6	224.34	1.4
Mode3	196.3	190.38	3.0	338.2	334.78	1.0

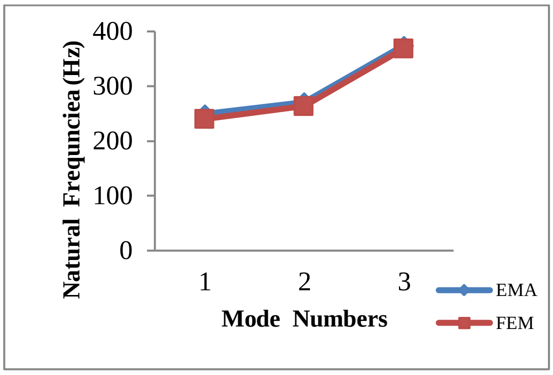
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Table 5. Natural frequencies(Hz) of five layered FML square plate under CFFF, CFCF plate boundary scenario

Plate Scenarios	CFFF			CFCF		
Mode No	**EMA**	**FEM**	**Error**	**EMA**	**FEM**	**Error**
Mode1	42.3	41.09	2.8	266.3	261.16	1.9
Mode2	101.1	98.90	2.1	312.2	308.58	1.1
Mode3	256.7	251.10	2.0	509.6	502.54	1.3

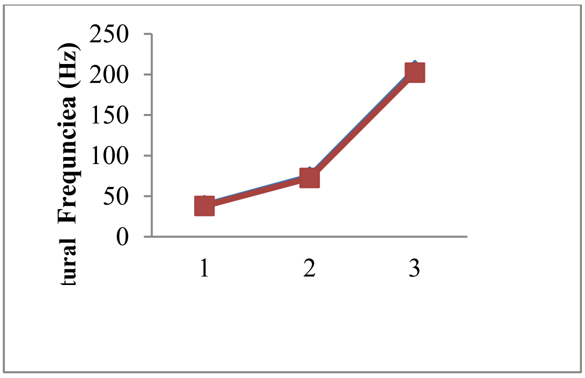


(a) CFFF



(b) CFCF

Fig 7. (a) and (b) Natural Frequencies of F/A/A/A/F square plate with mode numbers



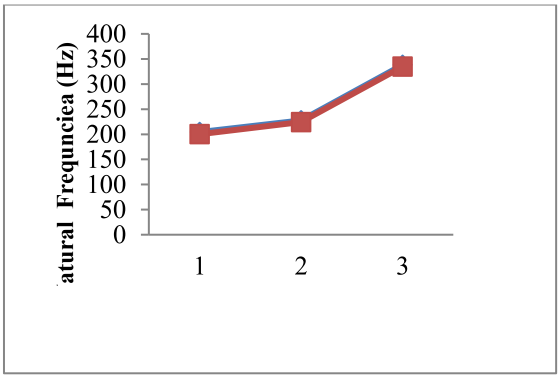
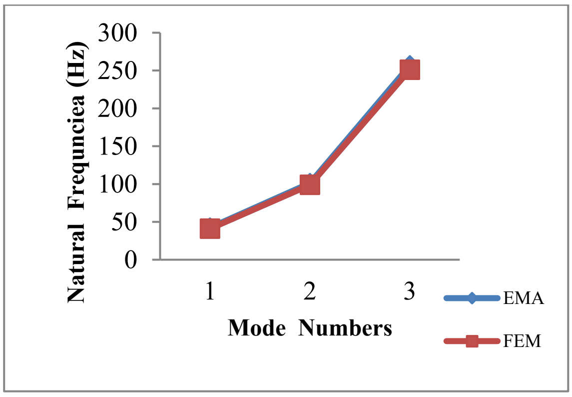
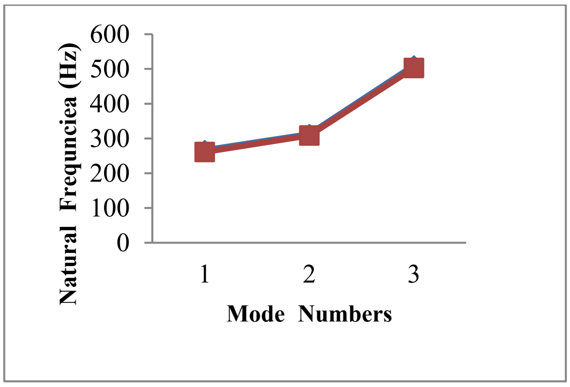


Fig 8. (a) and (b) Natural Frequencies of A/F/F/F/A square plate with mode numbers



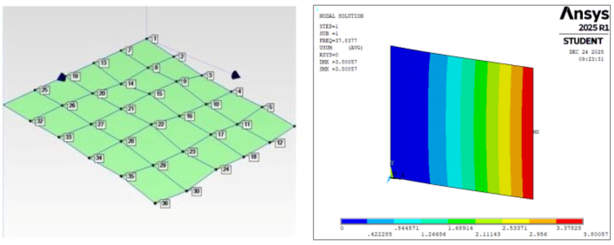
(a) FML-CFFF



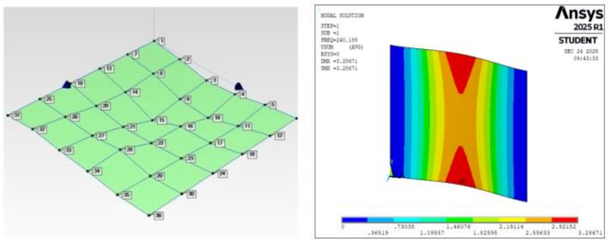
(b) FML-CFCF

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

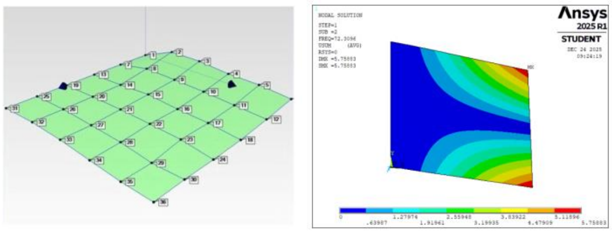
Fig 9. (a) and (b) Natural Frequencies of five layered Ti/Gf-E/Gf-E/Gf-E/Ti square plate with mode numbers



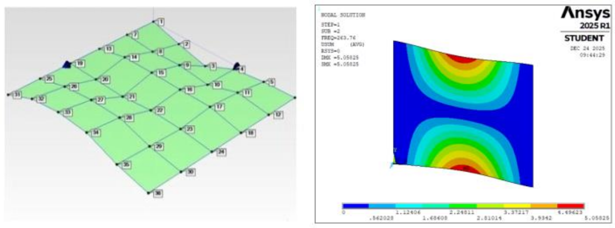
First Mode, EMA = 38.9 Hz and ANSYS = 37.8 Hz



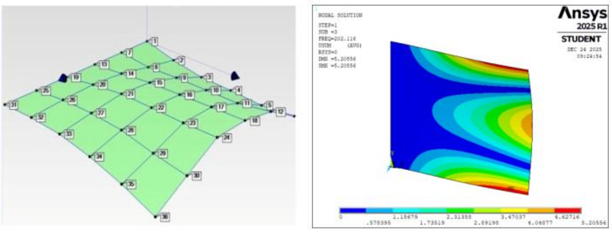
First Mode, EMA = 249.5 Hz and ANSYS = 240.18 Hz



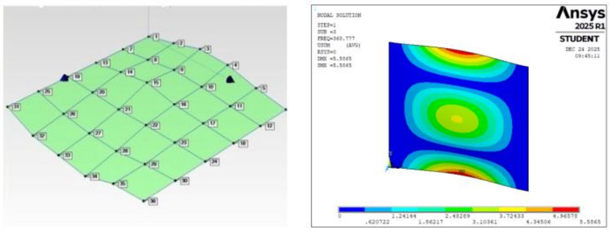
Second Mode, EMA = 74.2 Hz and ANSYS = 72.3 Hz



Second Mode, EMA = 271.4 Hz and ANSYS = 263.7 Hz



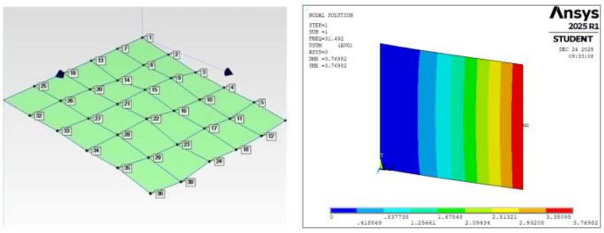
Third Mode, EMA = 205.3 Hz and ANSYS = 202.1 Hz



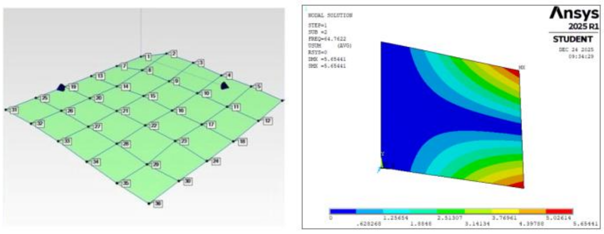
Third Mode, EMA = 374.6 Hz and ANSYS = 368.7 Hz

Fig 10. Model shape of CFFF square plate of F/A/A/A/F with EMA and ANSYS

Fig 11. Model shape of CFCF square plate of F/A/A/A/F with EMA and ANSYS



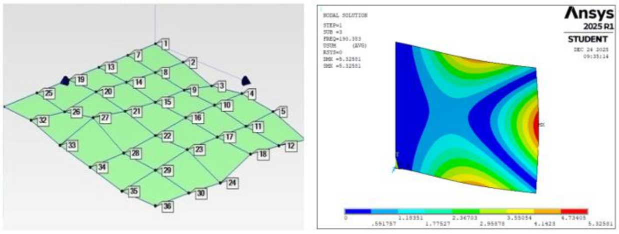
First Mode, EMA = 32.4 Hz and ANSYS = 31.4 Hz



Second Mode, EMA = 66.9 Hz and ANSYS = 64.7 Hz

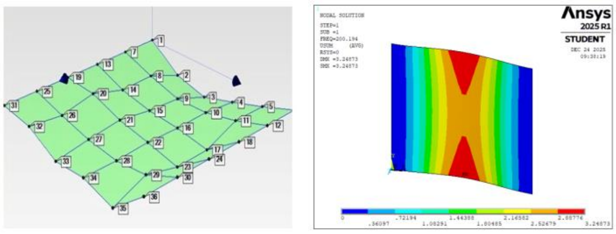
Fig 12. Model shape of CFFF square plate of A/F/F/F/A with EMA and ANSY

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

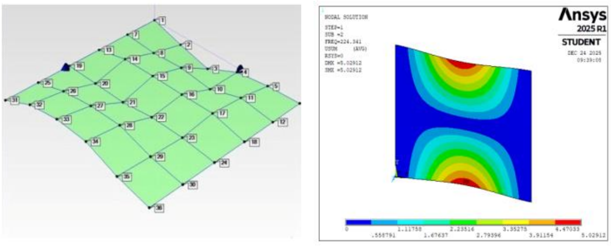


Third Mode, EMA = 196.3 Hz and ANSYS = 190.3 Hz

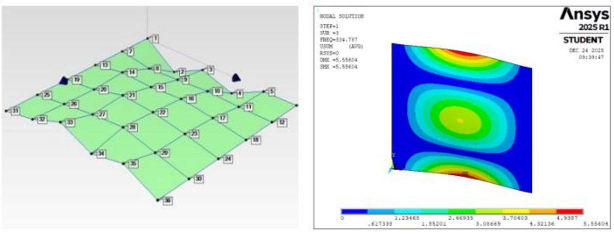
Fig 12. Model shape of CFFF square plate of A/F/F/F/A with EMA and ANSYS



First Mode, EMA = 204.4 Hz and ANSYS = 200.1 Hz

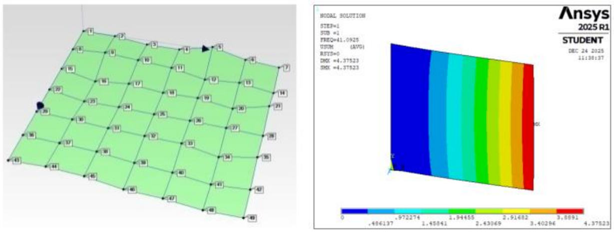


Second Mode, EMA = 227.6 Hz and ANSYS = 224.34 Hz

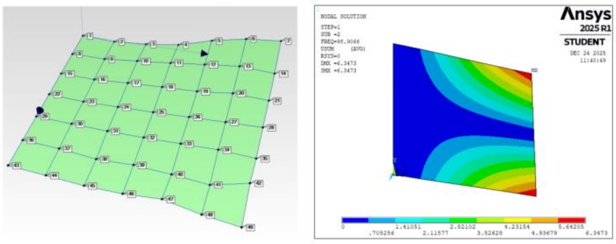


Third Mode, EMA = 338.2 Hz and ANSYS = 334.7 Hz

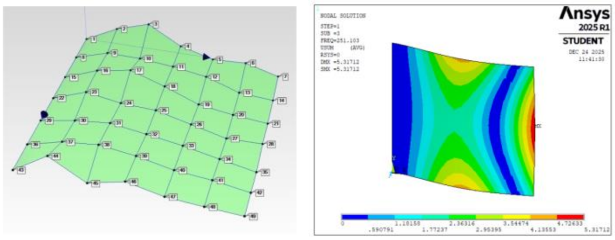
Fig 13. Model shape of CFCF square plate of A/F/F/F/A with EMA and ANSYS



First Mode, EMA = 42.3 Hz and ANSYS = 41 Hz



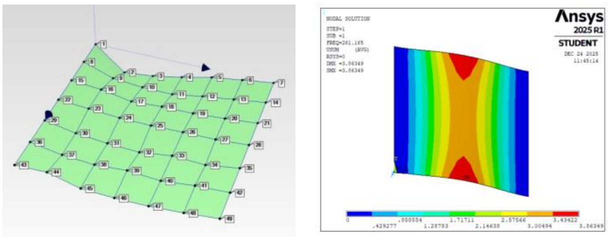
Second Mode, EMA = 101.1 Hz and ANSYS = 98.9 Hz



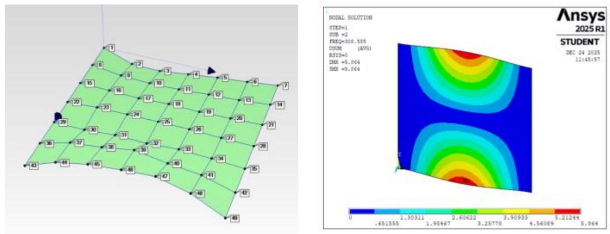
Third Mode, EMA = 256.7 Hz and ANSYS = 251.1 Hz

Fig 14. Model shape of CFFF Fml square plate of Ti/Gf-E/Gf-E/Gf-E/Ti with EMA and ANSYS

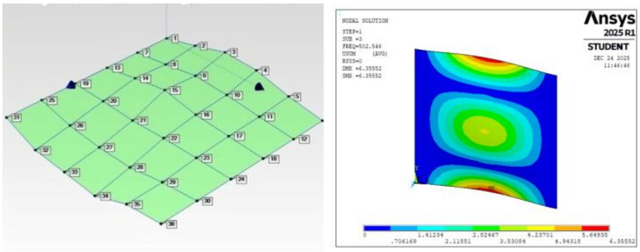
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025



First Mode, EMA = 266.3 Hz and ANSYS = 261.1 Hz



Second Mode, EMA = 312.2 Hz and ANSYS = 308.5 Hz



Third Mode, EMA = 509.6 Hz and ANSYS = 502.5 Hz

Fig 15. Model shape of CFCF Fml square plate of Ti/Gf-E/Gf-E/Gf-E/Ti with EMA and ANSYS

The natural frequencies obtained from Experimental Modal Analysis (EMA) and the Finite Element Method (FEM) are compared for three five-layer laminated plate configurations under CFFF and CFCF boundary conditions. The comparison is carried out for the first three vibration modes, and the percentage error between experimental and numerical results is evaluated. For the F/A/A/A/F laminate, natural frequencies increase with mode number under both boundary conditions. The percentage error under CFFF ranges from 1.5% to 2.7%, while under CFCF it increases slightly, reaching a maximum of 3.7% in the first mode, indicating acceptable agreement. The A/F/F/F/A laminate shows errors between 2.8% and 3.1% for CFFF, with the highest deviation in the second mode. Under CFCF, lower errors of 1.0% to 2.0% are observed due to increased boundary stiffness. The Ti/Gf-E/Gf-E/Gf-E/Ti laminate exhibits the highest natural frequencies. Percentage errors remain below 2.8% for CFFF and under 2.0% for CFCF, confirming strong EMA–FEM correlation.

5. CONCLUSIONS

The experimental and numerical investigation of five-layer laminated composite plates demonstrates a strong correlation between Experimental Modal Analysis (EMA) and Finite Element Method (FEM) results for all configurations and boundary conditions considered. The natural frequencies increase with mode number for all laminates, confirming the consistency of the vibrational response. Among the boundary conditions, the CFCF constraint consistently produces higher natural frequencies and lower percentage errors compared to the CFFF condition, highlighting the significant influence of boundary stiffness on dynamic behavior. The Ti/Gf-E/Gf-E/Gf-E/Ti laminate exhibits the highest natural frequencies due to its superior material stiffness, while the flax–areca hybrid laminates show comparable and reliable performance with acceptable deviations. The maximum percentage error remains within 3.7%, validating the accuracy and reliability of the finite element model. Overall, the results confirm that FEM can effectively predict the vibration characteristics of both natural fiber hybrid composites and fibre metal laminates, supporting their potential use in lightweight structural applications.

REFERENCES

[1] [1] Ismail A.E., Bujang I.Z. and Awang M.K. Regional conference on Engineering Mechanics, Manufacturing and Architecture (EM*ARC) (Vibration and Comfort Research Group) Study on the Dynamic Characteristics of Banana Fiber Reinforced Composites 2007 © 2007 Noise.

[2] [2] K. Nayak, S. S. J. Moy, R. A. Shenoi, 2002, Free vibration analysis of composite sandwich plates based on Reddy's higher-order theory, Journal of composites.

[3] [3] J. Alexander and B. S. M. Augustine, 2015, Free vibration and damping characteristics of GFRP and BFRP laminated composites at various boundary conditions, Indian Journal of Science and Technology.

[4] [4] Libo Yan, Nawawi Chouw, Krishnan Jayaraman, 2014, Flax fibre and its composites – A review, composites, part-B 56, pp. 296-317.

[5] [5] Merzuki, m. N. M., rejab, m. R. M., sani, m. S. M., zhang, b., & quanjin, m. (2019d). Experimental investigation of free vibration analysis on fibre metal composite laminates. Journal of mechanical engineering and sciences, 13(4), 5753–5763. Https://doi.org/10.15282/jmes.13.4.2019.03.0459

[6] [6] Saheb, k. M., & deepak, s. (2022a). Free vibration analysis of a laminated composite plate using experimental modal testing. Materials today proceedings, 72, 1573–1583. Https://doi.org/10.1016/j.matpr.2022.09.390

[7] [7] Free vibration analysis of graphene reinforced laminated composite plates using experimental modal testing. (2023). In mechanics of advanced composite structures (vol. 10, pp. 363–374). Https://doi.org/10.22075/macs.2023.28869.1448

[8] [8] Experimental modal analysis of viscoelastic sandwich structures. (2025). In mechanics of advanced composite structures (vol. 12, issue 1, pp. 181–198) [journal-article]. Semnan university press. Https://doi.org/10.22075/macs.2024.32500.1587

[9] [9] Srividya, k., anusha, p., kavitha, e., sri, m. N. S., & sravani, v. (2022b). Analytical and experimental study on fva of isotropic and orthotropic laminates with fem validations. Incas bulletin, 14(4), 145–156. Https://doi.org/10.13111/2066-8201.2022.14.4.12

[10] [10] Merzuki, m., ma, q., rejab, m., sani, m., & zhang, b. (2021). Experimental and numerical investigation of fibre-metal-laminates (fmls) under free vibration analysis. Materials today proceedings, 48, 854–860. Https://doi.org/10.1016/j.matpr.2021.02.409

[11] [11] Vaiduriyam, a. R., & chinnapandi, l. B. M. (2022). Experimental and numerical investigation of the vibro-acoustic behavior of fiber metal laminate. Journal of the brazilian society of mechanical sciences and engineering, 44(7). Https://doi.org/10.1007/s40430-022-03559-y

[12] [12] Merzuki, m. N. M., rejab, m. R. M., sani, m. S. M., zhang, b., quanjin, m., & rafizi, w. (2019). Investigation of modal analysis on glass fiber laminate aluminium reinforced polymer: an experimental study. Iop conference series materials science and engineering, 469, 012065. Https://doi.org/10.1088/1757-899x/469/1/012065

[13] [13] Wang, x., zhao, z., li, l., zhang, z., zhang, q., han, b., & lu, t. J. (2018). Free vibration behavior of ti-6al-4v sandwich beams with corrugated channel cores: experiments and simulations. Thin-walled structures, 135, 329–340. Https://doi.org/10.1016/j.tws.2018.11.008

[14] [14] Gnanasekaran, k., arunkumar, k., rajesh, m., saraçyakupoğlu, t., loganathan, p., vijayakumar, r., ramprakash, s., & vijayabalan, p. (2025). Experimental investigation on mechanical and vibrational analysis of kevlar/jute fiber stacked titanium sheet-based metal fiber laminates. Journal of polymer research, 32(9). Https://doi.org/10.1007/s10965-025-04577-9