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Effect of layer thickness on natural frequency of E-glass composite

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A B S T R A C T

Fiber Reinforced Polymers (FRPs) are composite materials composed of a polymermatrix reinforced with fibers, offering a unique blend of strength, flexibility, andlightweight properties.FRPscan replace the metals if they are prepared by considering the effects of composition and number of layers on their mechanical properties.The composite plates are tested with FFT for vibration analysis and naturalfrequency is determined for resonance. Finite element analysis is conducted and frequency response results are obtained.Also, a comparison is made among analytical, simulation and experimental results for understanding of factor affecting the percentage error.

Keywords: Fiber Reinforced Polymers (FRPs), FFT, natural frequency, FEA

1. Introduction

The composite materials are material having stronger fibers which are surrounded by weaker material matrix. [1] The composites are of different kind the popular types are polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramic matrix composites (CMCs), as well as particle-reinforced composites. [2] The composite material shows high strength-to-weight ratios, corrosion resistance, tailored properties, and design flexibility, making them suitable for a wide range of applications in industries like aerospace, automotive, marine, construction, and electronics.

When the composite materials are subjected to dynamic loading it produces repeated vibrations which finally lead to fatigue, causing micro cracks and delamination over time.This paper is focused on investigation of effect of number of layers and aspect ratio on characteristics of E-glass woven rovingcomposite material.

Nomenclature

E	Modulus of elasticity or Young's modulus
ρ	Material density
A	Cross section area
l	Length
(β_n l)^2	End condition constant depends on boundary condition
B1	Node number 1
B2	Node number 2
B3	Node number 3

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2. Methodology

Initially three E-glass woven roving composite platesare prepared by varying the layer thickness. By using FFT analyzer vibration analysis of composite plates is done and natural frequency is determined for resonance. The plates are modelled and finite element analysis is conducted using ANSYS software, to obtain the frequency response. Analytical, simulation and experimental results are compared for understanding of factor affecting the percentage error.

3. Fabrication of E-glass woven roving composites

The hand lay-up and spray-up manufacturing techniques is used to fabricate the composite. For preparing sample, 1:1 weight ratio of fiber to matrix was used.Plies of WR are joined in the required order using contact moulding in an open mould by hand lay-up.A robust, flat plywood platform was used. A plastic sheet was placed on the plywood platform. A thin layer of polyvinyl alcohol is applied using spray. Polyvinyl alcohol acts as a releasing agent. n order to provide a smooth outside surface and shield the fibers from direct environmental exposure, laminating begins with the application of a gel coat (epoxy and hardener) that is brushed onto the mould. From a roll of woven roving, ply was cut. After applying layers of reinforcement to the mould over the gel coat, the gel coat was brushed on once again. Steel rollers with serrated edges were used to release any trapped air. Before the gel coat had completely set, the aforementioned procedure was carried out again during the hand lay-up. Once more, a plastic sheet was used to cover the plate's top, and polyvinyl alcohol was applied inside the sheet as a releasing agent. After that, a strong, heavy flat metal platform was placed on top of the plate for compression. The plates were left for at least 48 hours, before precisely shaped for testing. The fabrication materials include, reinforcement (E-glass wovenroving), epoxy resin, diamine hardener, and a releasing agent (polyvinyl alcohol). Table 1 shows the details of the three composite plates prepared for experimentation.

Table 1 - Plate designation and their details

Sr. no.	Plate designation	Fiber orientation	Layers (No.)	Length and breadth (mm)	Thickness (mm)	Density (kg/m^3)
1	C_0/90_8 250*250	[0/90]	8	250*250	3.45	1493.3
2	C_0/90_12 250*250	[0/90]	12	250*250	3.8	1726.3
3	C_0/90_16 250*250	[0/90]	16	250*250	5.8	1688.275

4. Determination of mechanical properties of composite specimen

To determine the constants experimentally, specimens were subjected to tensile testing in compliance with ASTM standards D 638-08 and D 3039/D 3039M-2006.In each case, the specimen with flat strip having constant cross section was maintained.The dimension of specimen is mentioned in Table2.

Table 2 Size of the specimen for tensile test

Length (mm)	Width (mm)	Thickness (mm)
165	13	4

The specimen is loaded monotonically to failure in a universal testing machine with a suggested rate of extension (rate of loading) of 5 mm/minute in order to measure the Young's modulus.The value of Young's modulus found 2.34e10. Using two strain gauges in the longitudinal and transverse directions, the Poisson's ratio obtained from the ratio of transverse to longitudinal strain is equal to 0.171. Fig 1 shows the tensile testing of specimen.

Fig 1 - Tensile test of woven fiber Glass/Epoxy composite specimen on UTM.

5. Determination of natural frequency by theoretical calculations

The natural frequency of plates at free- free boundary condition, with 8,12 and 16 layers is determined by using Euler's Bernoulli theory, The following equations are used to determine the natural frequency of plates. Table 3 shows the natural

Natural Frequency $=(\beta_n l)^2 X\sqrt{\frac{E\times I}{\rho\, A l^4}}$ rad/sec

Natural Frequency $=\frac{1}{2\pi}(\beta_n l)^2 X\sqrt{\frac{E\times I}{\rho\, A l^4}}$ Hz

Where,

E —Modulus of Elasticity N/m2

I — Moment of Inertia m4

l — Length, m

ρ — Material density Kg/m3

A — Cross section area m2

$(\beta_n l)^2$ — End condition constant depends on boundary condition

Table 3 - Natural frequency calculations by Euler's and Bernoulli theorems

Plate No.	Plate designation	n	$(\beta_n l)^2$	E	I	ρ	A	l	ω_n	fn
1	C_0/90_8_250*250	1	22.3	2.30E+10	8.55E-10	1493	8.60E-04	2.50E-01	1.40E+03	222.35
		2	61.7	2.30E+10	8.55E-10	1493	8.60E-04	2.50E-01	3.86E+03	615.20
		3	121	2.30E+10	8.55E-10	1493	8.60E-04	2.50E-01	7.58E+03	1206.46
2	C_0/90_12_250*250	1	22.3	2.30E+10	1.14E-09	1726	9.50E-04	2.50E-01	1.43E+03	227.20
		2	61.7	2.30E+10	1.14E-09	1726	9.50E-04	2.50E-01	3.95E+03	628.61
		3	121	2.30E+10	1.14E-09	1726	9.50E-04	2.50E-01	7.74E+03	1232.76
3	C_0/90_16_250*250	1	22.3	2.30E+10	4.06E-09	1688.3	1.35E-03	2.50E-01	2.28E+03	363.66
		2	61.7	2.30E+10	4.06E-09	1688.3	1.35E-03	2.50E-01	6.32E+03	1006.19
		3	121	2.30E+10	4.06E-09	1688.3	1.35E-03	2.50E-01	1.24E+04	1973.24

6. Experimental determination of natural frequency

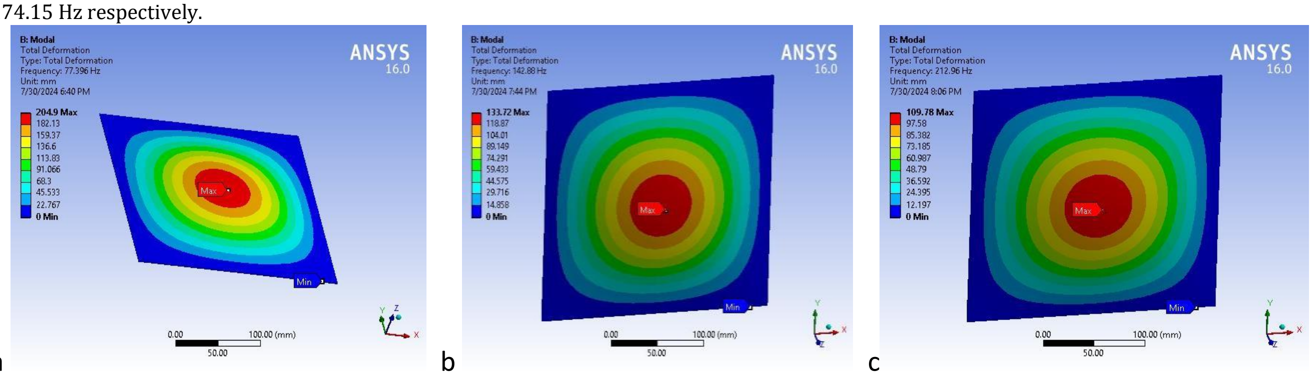
Fig 2 shows the schematic of experimental setup used to determine the natural frequency of the plates. The plate is hanged freely in the air and accelerometer sensor is placed on the composite plate to be tested. The freely hanged plate is excited by a small impact hammer to set it to vibrations. Because the plate is hanged free in the air it produces natural vibrations. The setup consists of data acquisition system with computer software, accelerometer sensor, an instrumentation amplifier used for signal conditioning, a modal hammer and cables along with computer software DEWE Soft 6.

a b c

Fig 2–(a)Schematic of Experimental Setup; (b) Plate setup; (c)Accelerometer mounting

7. Determination of natural frequency by FEA

To simulate the composite plate, Shell 99 element is used in the linear layer. Shell 99 element is utilized for laminated framework, the plate's border condition is free.ANSYS free mesher was used for meshing with 676 nodes and 625 elements. The modal frequency for plates with 8, 12 and 16 layers is shown in figure 3 (a), (b) and (c) respectively.The natural frequency for C_0/90_8_250*250 plate at nodesB1, B2 &B3 are 77.396, 140.94 & 174.15 Hz respectively.



a b c

Fig 3– FEA results of (a)C_0/90_8_250*250, (b) C_0/90_12_250*250 (c) C_0/90_16_250*250

8. Comparison of theoretical, simulation and experimental results

The results of frequency of three nodes B1, B2 and B3, obtained by theoretical, analytical and experiment methods for platesC_0/90_8_250*250, C_0/90_12_250*250 and C_0/90_16_250*250 are shown in Table 4.

Table 4 - Natural frequency by Theoretical, Analytical and Experimental methods

Plate	Node no.	Frequency Theoretical (Hz)	Frequency Analytical (Hz)	Frequency Experimental (Hz)
	B1	77.90	77.396	73
C_0/90_8_250*250	B2	141.28	140.94	134
	B3	175.193	174.51	167
	B1	144.3628	142.88	140
C_0/90_12_250*250	B2	288.7257	284.15	281
	B3	301.6813	299.71	291
	B1	214.3	212.96	208

C_0/90_16_250*250	B2	434.19	432.25	419
	B3	444.48	442.82	431

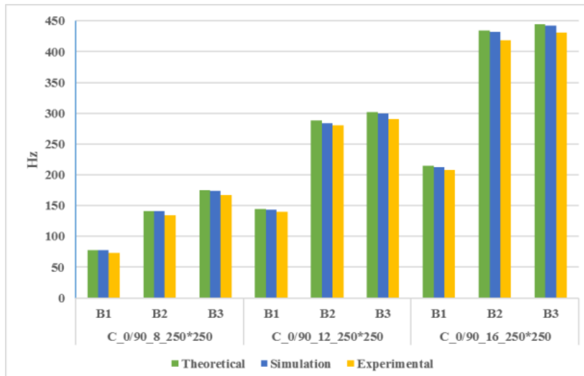


Fig 4– Comparison of Theoretical, Analytical and Experimental natural frequency

Figure 4 shows the Comparison of Theoretical, Analytical and Experimental natural frequency.As seen in the tables, the natural mode of frequency in experimental results can occasionally vary within a range. An approximate agreement with the FEM-based program is demonstrated. The percentage error between the experimental value and the programmed value falls as the mode no rises.

9. Conclusion

Using a data gathering system, the glass/epoxy laminated composite plates are produced and modal testing is carried out for free-free boundary conditions. FFT is used to get frequency response functions.The theoretical and analytical natural frequency are in agreement with the experimental frequency.The error percentage between the ANSYS package and the experimental value is within 15%. The discrepancy is most likely caused by uncertainty in elastic characteristics as well as other factors mentioned. It is discovered that, under the Free-free boundary condition, the natural frequency of the plate rises as the aspect ratio increases. Natural frequency has grown along with the number of layers.

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