Study on Behavior of Composite Laminated Plates under Free Vibration Analysis

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Abstract— With the advancement of the materials and manufacturing technologies in recent years, the laminated composites have enhanced their applications in modern advanced engineering structures. The finite element method has developed as a very powerful tool for engineering problems, whereas a discretized geometry is obtained through the meshing process. The laminated composites are finding wide spread applications in aerospace, automotive, nuclear reactor vessels, ship building industry etc due to their high specific strength, stiffness, light weight and extended fatigue life. In this study, the behavior of square composite laminated plate under free vibration analysis is investigated. FEAST^{SMT} 2020 is used for the finite element analysis. Effect of various parameters such as stacking sequence, number of layers and boundary conditions on the natural frequency of composite laminated plates are studied. From the analysis, cross-ply laminate showed better results for clamped boundary condition and angle-ply laminate for simply supported boundary condition. And increase in number of layers showed a steady increase in natural frequency.

Keywords: Free Vibration, Composite Laminated Plate, Natural Frequency, FEAST^{SMT}, Stacking Sequence, Boundary Condition

I. INTRODUCTION

Fibers embedded in a matrix form composites, which are man-made materials. The matrix supports the fiber and transmits the external load to the fiber through shear stresses at the fiber tips at the fiber-matrix interface, with the fiber serving as the primary load carrier. Structural element which is made of unidirectional plies, or sheets stacked together in the right orientation to meet design requirements, is an example of a laminated plate. When two or more laminae stacked together to form a single structural component, the result is a laminate. Principal material directions of laminae are oriented in such a fashion so as to produce a structural element with desired properties in all directions. The laminae may be made of same or different material and have individual thicknesses.

A standard composite laminate coordinate system aligns the X-axis with the fiber direction and the Y-axis orthogonal to the fiber direction. The 3-axis is normal to the plane of the composite laminate. The laminae which is oriented alternatively at 0° and 90^0 is termed as a cross-ply laminate. The fiber oriented alternatively at θ and –θ is termed as angle-ply laminate. Composite laminates have been developed and utilized because of its outstanding bending rigidity, light weight, high strength, non-magnetic, high durability, low specific weight, superior isolating qualities, excellent vibration characteristics and good fatigue properties. The uses of composite laminated structures include aircraft, missiles, spacecraft, ships, trains, automobiles, ceilings, walls, bridges etc.

The main objectives of this study are given as follows:

1) To analyze the free vibration behavior of composite laminated plates using FEAST^{SMT} software.
2) To compare the natural frequency of composite laminated plates by changing different parameters such as stacking sequence, number of layers and boundary conditions.
3) To find out the optimum stacking sequence, boundary condition and effect of number of layers which gives maximum natural frequency.

II. LITERATURE REVIEW

Behnam Daraei et al. (2021) investigated the free vibration analysis of cross and angle-ply composite laminated plates. The results showed that the dimensionless frequency of composite laminated square plate having stacking sequence [90/0/90] with two cases of boundary conditions such as opposite edges simply supported and free (SFSF) and opposite edges simply supported and clamped (SCSC) decreases with increase in thickness-to-length ratio. The dimensionless natural frequencies of the SCSC composite laminated square plate was higher for angle-ply laminates having 30^0 fiber orientation and least for 60^0 fiber orientation.

Mohamed Amine Bennaceur and Yuang ming Xu (2019) studied the free vibration analysis of simply supported composite laminated plate. The results showed that the natural frequencies was highest for simply supported composite laminated plate with stacking sequence [0/45/0] and lowest for plate having stacking sequence [0/90/0].

Peng Shi et al. (2018) conducted free vibration analysis of laminated composite plate. The results showed that the normalized first six natural frequencies of simply supported square laminated plate [0/90/90/0] increases with increase in length-to-thickness ratio. The natural frequency of plate having clamped boundary condition was more than that of simply supported plate for same material and geometric properties.

Amirhadi Alesadi et al. (2017) studied layer wise (LW) and Equivalent Single Layer (ESL) for the free vibration analysis of composite laminated plates. The square composite plate having stacking sequence [0/90/90/0] with all edges simply supported showed more frequency than the same plate with [0/90] stacking sequence. Two layered clamped square composite plate with stacking sequence [-30/45] showed lower frequency than [0/45]. LW approach provides more accurate results in comparison with ESL approach.

Mahmoud Yassin Osman et al. (2017) addressed free vibration of rectangular composite laminated plates by varying parameters such as stacking sequence, aspect ratio,

material properties, length/thickness ratio, boundary conditions and length/width ratio on the natural frequency. The greatest effect was caused by the length/width ratio and the least effect was due to modular ratio and properties of the composite material. As a plate becomes thinner (a/h becomes larger), the non-dimensional frequency increases. As width of the plate decreases, non-dimensional frequency increases, while actual frequency decreases rapidly. As the modular ratio (E_1/E_2) increases, non-dimensional frequency decreases for the same composite laminated plate with same boundary conditions. The built-in plate had higher frequency values when compared with that of free plate.

III. FREE VIBRATION ANALYSIS

When there is no external force producing the motion, free vibration occurs, and the vibration of the system is generated by the system's initial displacement from the equilibrium position. The natural frequencies of the laminated composite plate of various stacking sequence, number of layers and support conditions are considered for the study.

A. Geometric and Material Properties of Composite Laminated Plate

The composite material taken is graphite and epoxy. The length (a) and breadth (b) of composite laminated plate is 500mm x 500mm respectively and thickness of laminate (h) is 5mm. The length-to-breadth (a/b) ratio is 1 and length-to-thickness (a/h) ratio is100. The geometric and material properties of composite laminated plate considered for this study is shown in table 1 and 2 respectively. The laminated plate is made up of many laminae that are assumed to have the same thickness, density, and orthotropic material qualities.

Material	Graphite/epoxy
Length	500mm
Breadth	500mm
Thickness	5mm

Table 1: Geometric Properties of Composite Laminated Plate

Modulus of elasticity (GPa)	Poisson's ratio	Shear modulus (GPa)	Density (kg/m^3)
E_1= 181	μ_{12}= 0.28	G_{12} = 7.17	1578
E_2 = 10.3	μ_{13}= 0.28	G_{13}= 7.17	
E_3 = 10.3	μ_{23}= 0.33	G_{23} = 2.87	

Table 2: Material Properties of Composite Laminated Plate

The subscripts 1, 2 and 3 denote the directions longitudinal, transverse and normal to the plate.

B. Varying Parameters

The different parameters taken into consideration for free vibration analysis of composite laminated plates are stacking sequence, number of laminae and boundary conditions, see table 3. Symmetric cross-ply laminate [0/90/90/0], balanced angle-ply laminate [30/-30/-30/30], [45/-45/-45/45], [60/-60/-60/60], symmetric laminate [0/45/45/0] and asymmetric laminate [0/45/60/0] are the different stacking sequence considered for this study. Fiber direction in a lamina which may be oriented at an angle to the plate axes. The ply angle of each layer is measured from the global x-axis to the fiber direction.

Stacking sequence	No. of layers	Boundary condition
[0/90/90/0]	4	All edges simply supported (SSSS)
[30/-30/-30/30]	8	
[45/-45/-45/45]	12	
[60/-60/-60/60]	16	All edges clamped (CCCC)
[0/45/45/0]	20	
[0/45/60/0]	24	
	28	

Table 3: Varying Parameters

In order to find the optimum stacking sequence, free vibration analysis is carried out by changing the stacking sequence and keeping the number of layers constant i.e., 4. The optimum stacking sequence for both simply supported and clamped boundary conditions is to be done. Then, by keeping the optimum stacking sequence constant, free vibration analysis is to be done by changing number of layers. The whole analysis is been carried out under two boundary conditions such as all edges simply supported and all edges clamped. Thus 24 analyses is done to find effect of these three parameters.

C. Modeling

The composite laminated plate is modeled with the geometric and material properties shown in table 1 and table 2. The modeled plate having simply supported boundary condition and stacking sequence [45/-45/-45/45] with mesh size 60 x 60 is shown in figure 1. The modeled composite laminated plate having stacking sequence [0/90/90/0] with all edges clamped having mesh size 40 x 40is shown in figure 2.

Fig. 1: Modeled composite laminated plate with all edges simply supported

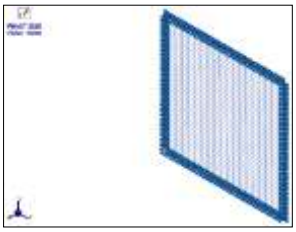

Fig. 2: Modeled composite laminated plate with all edges clamped

IV. RESULTS AND DISCUSSION

A. Effect of Stacking Sequence

The effect of stacking sequence is studied under free vibration analysis by keeping the number of layers as 4. Two set of boundary conditions such as all edges simply supported (SSSS) and all edges clamped (CCCC) are considered for this study. The variation of first five natural frequencies with fiber

orientation of four layered square composite laminated plate with all the edges simply supported and all edges clamped are shown in table 4 and 5 respectively. A graph is plotted with natural frequency against stacking sequence for simply supported and clamped composite laminated plate, see figure 3 and 4.

Stacking sequence	Natural frequency (Hz)				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
[0/90/90/0]	10.84	20.44	33.19	39.63	42.96
[30/-30/-30/30]	12.15	22.72	34.25	37.85	49.08
[45/-45/-45/45]	12.62	25.52	35.31	42.50	54.49
[60/-60/-60/60]	12.15	22.72	34.25	37.85	49.08
[0/45/45/0]	11.22	18.47	31.80	38.61	44.64
[0/45/60/0]	11.12	18.69	32.88	38.25	44.30

Table 4: Natural Frequencies of 4 Layered Simply Supported Plate

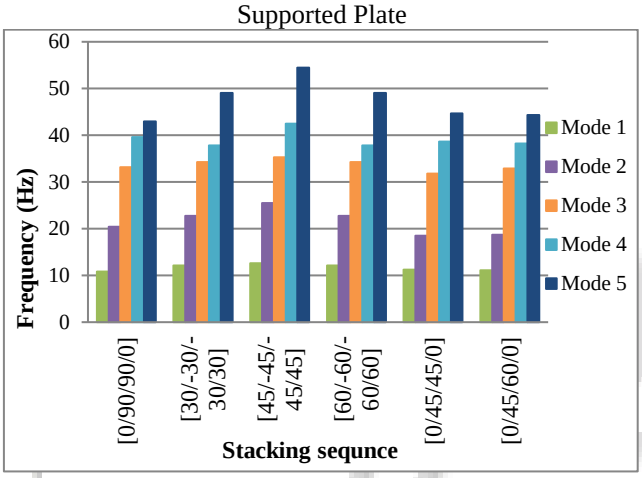

Fig. 3: Frequency vs stacking sequence of 4 layered simply supported plate

From the results obtained, the simply supported composite laminated plate with stacking sequence [45/-45/-45/45] showed the highest first natural frequency i.e., 12.62Hz when compared to other fiber orientations such as [0/90/90/0], [30/-30/-30/30], [60/-60/-60/60], [0/45/45/0] and [0/45/60/0]. The lowest first natural frequency is 10.84Hz for cross-ply laminated plate [0/90/90/0].

Stacking sequence	Natural frequency (Hz)				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
[0/90/90/0]	22.98	37.19	45.38	58.94	70.74
[30/-30/-30/30]	21.31	33.14	50.68	50.89	64.38
[45/-45/-45/45]	20.81	33.97	45.63	56.73	63.59
[60/-60/-60/60]	21.31	33.14	50.68	50.89	64.38
[0/45/45/0]	22.87	30.40	44.71	58.40	64.43
[0/45/60/0]	22.82	30.92	46.36	57.97	64.19

Table 5: Natural Frequencies of 4 Layered Clamped Plate

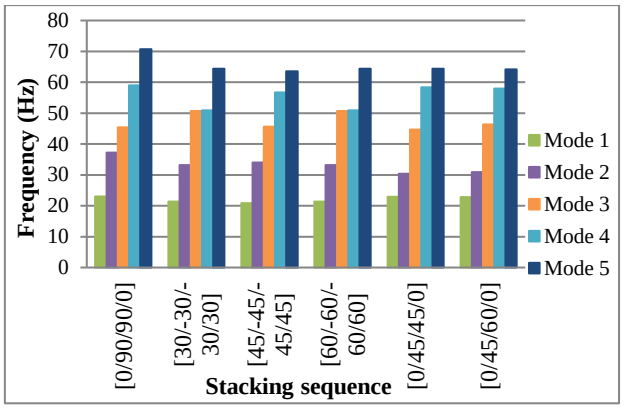

Fig. 4: Frequency vs stacking sequence of 4 layered clamped plate

The results showed that the clamped composite laminated plate having stacking sequence [0/90/90/0] showed the highest first natural frequency i.e., 22.98Hz when compared to other stacking sequences such as [30/-30/-30/30], [45/-45/-45/45], [60/-60/-60/60], [0/45/45/0] and [0/45/60/0]. First five mode shapes of the composite laminated plate with stacking sequence [0/90/90/0] having clamped boundary condition is shown in figure 5. The lowest first natural frequency is 20.81Hz for laminated plate having stacking sequence [45/-45/-45/45].

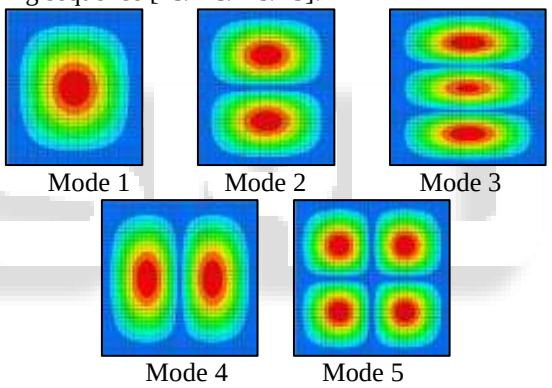

Fig. 5: First six mode shapes of [0/90/90/0] oriented clamped composite laminated plate

B. Effect of number of layers

The effect of number of layers is analyzed by keeping the optimum stacking sequence [45/-45/-45/45] for simply supported plate and [0/90/90/0] for clamped plate constant for the whole analysis. First five natural frequencies with different number of layers such as 4, 8, 12, 16, 20, 24 and 28 of simply supported and clamped composite laminated plate is shown in table 6 and 7 respectively. A graph is plotted with natural frequency against number of layers for simply supported and clamped composite laminated plate, see figure 6 and 7.

No. of layers	Frequency (Hz)				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
4	12.62	25.52	35.31	42.50	54.49
8	13.76	29.90	35.85	51.56	58.72
12	13.96	30.89	36.31	53.60	59.39
16	14.02	31.32	36.73	54.44	59.62
20	14.05	31.56	37.01	54.87	59.72
24	14.06	31.71	37.52	55.12	59.78

28	14.07	31.82	37.85	55.28	59.81

Table 6: Natural Frequencies of [45/-45/-45/45] Simply Supported Plate

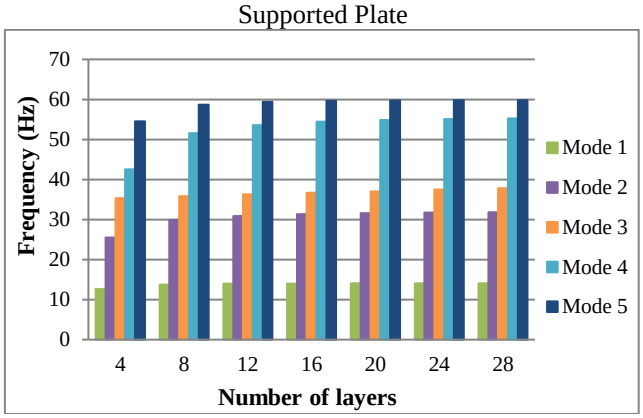

Fig. 6: Frequency vs number of layers of simply supported plate

By analyzing the graph, it is clear that the natural frequency of all modes of simply supported goes on increasing slightly by increasing the number of layers.

No. of layers	Frequency (Hz)				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
4	22.976	37.190	45.38	58.940	70.74
8	23.046	41.261	45.702	63.981	73.113
12	23.058	43.374	46.564	64.053	77.977
16	23.063	44.385	46.917	64.077	80.272
20	23.065	44.977	47.399	64.089	81.609
24	23.065	45.366	47.850	64.094	82.483
28	23.066	45.643	48.299	64.099	83.102

Table 7: Natural Frequencies of [0/90/90/0] Clamped Plate

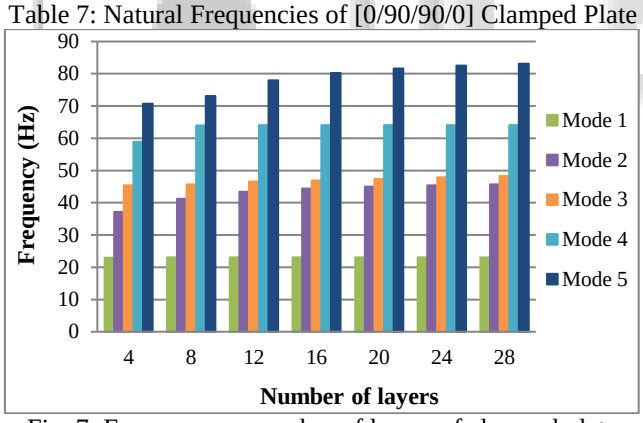

Fig. 7: Frequency vs number of layers of clamped plate

The results showed that the effect of natural frequency of all modes of clamped plate is similar to that of simply supported plate. For both cases the natural frequency increases slightly by increasing the number of layers from 4 to 28.

C. Effect of Boundary Condition

Two boundary conditions such as all the edge simply supported (SSSS) and all the edges clamped (CCCC) are taken into consideration. The variation of natural frequencies with stacking sequence for SSSS and CCCC boundary condition is shown in figure 8. The graph plotted with natural frequency against number of layers for SSSS and CCCC boundary condition is shown in figure 9.

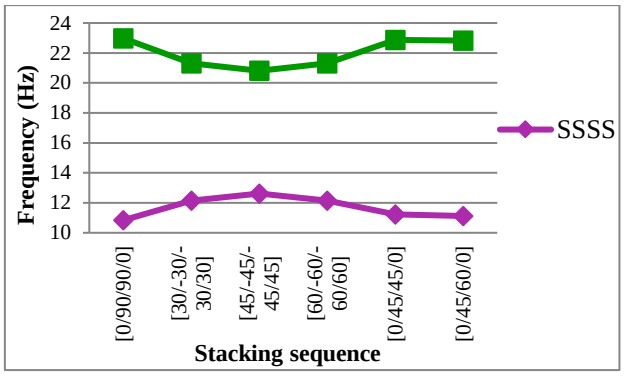

Fig. 8: First natural frequency vs stacking sequence of simply supported and clamped plate

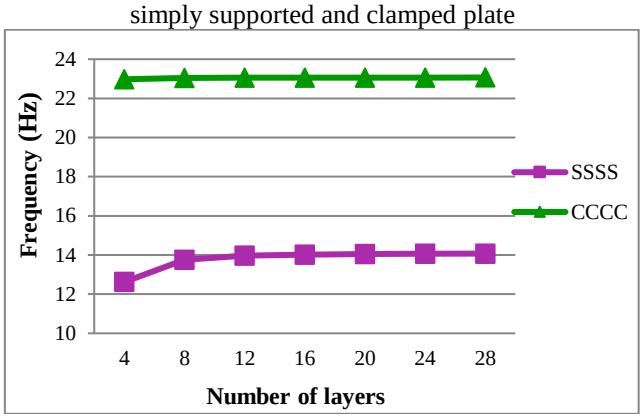

Fig. 9: First natural frequency vs number of layers of simply supported and clamped plate

The results clearly showed that there is a huge difference in natural frequencies between simply supported and clamped plate. The composite laminated plate having clamped boundary condition showed higher natural frequencies for all modes than simply supported plate.

V. CONCLUSIONS

Based on the discussion of results, the conclusions are as follows:

- Composite laminated plates having [45/-45/-45/-45] stacking sequence showed higher natural frequency than cross-ply, asymmetric laminates for simply supported boundary condition.
- The lowest natural frequency was showed by [0/90/90/0] stacking sequence for simply supported plate.
- For clamped boundary condition, plates with symmetric cross-ply condition [0/90/90/0] showed higher natural frequency than angle-ply and asymmetric laminates.
- And the lowest natural frequency was showed by composite laminated plates having stacking sequence [45/-45/-45/45] for clamped boundary condition.
- As the number of laminae increases the natural frequency also increases for both simply supported and clamped composite laminated plates.
- The natural frequency is highest for laminated plates having clamped boundary condition than simply supported one.

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