The Effect of Stacking Sequence and Layer Number on the Natural Frequency of Composite Laminated Plate

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Abstract: By depending on 1st order shear deformation theory, a Graphite Epoxy composite plate has been analyzed dynamically in the present work by using a quadratic element (8-node diso parametric). Every node in this element has 6-degree of freedom (movement in x,y and z axis and rotation about x ,y and z axis). The dynamic analysis covered parametric studies on a composite laminated plate (square plate) to determine its effect on the natural frequency of the plate. The parametric study was represented by a set of changes (layer number, boundary conditions, layer orientation, and the symmetry of layer orientation) and the plates were simulated by using ANSYS package 12. The boundary conditions considered in this study, at all four edges of the plate, are simply supported and clamped boundary condition. The results obtained from ANSYS program show that the natural frequency for both simply supported increase through increasing the number of layers. And it is observed that the natural frequency of a composite laminated plate will change with the change of ply orientation.

Keywords: Laminated Plate, Orthotropic Plate, Square Plate, (Free Vibration) Natural Frequency, Composite (Graphite/ Epoxy)

1. Introduction

Technological progress results in the continuous expansion of structural material types and in an improvement of their properties. The most frequently used structural materials can be categorized into four primary groups: metals, polymers, composites, and ceramics. One of the clearest manifestations of such an interrelated process is the development and application of composite materials. The needs of the aerospace industry and high rise building drive to the use and improvement of composite materials. The progress in the industrialization process and technology of composites materials has improved the use of the composites from secondary structural components to such a primary component.

Through the last decade plates made by composite materials are being progressively used in many engineering purposes. The high stiffness/weight ratio coupled with the flexibility of the chosen of the lamination sketch which can be sewed to match the design demand makes the laminated plate an interesting structural component for many manufacturers. The grown use of laminated plates in different areas has encouraged the use of plates as a constructional element for the present research. The results of the analysis of natural frequency for the laminated composite plates in the structural designing are so remarkable to avoid the resonant action of the laminated structures. Also, whether the use of composite materials is in civil, aerospace, and marine, they are applied to dynamic loads.

2. Review of Literature

The natural frequencies and mode shapes of the number of Graphite/ Epoxy and Graphite/Epoxy - Aluminum plates and shells were experimentally determined by Crawley (1979). Kim and Gupta (1990) investigated the effects of lamination and extension–bending coupling, shear and twist-curvature couplings on the lowest frequencies and corresponding mode shapes for free vibration of laminated anisotropic composite plates using a finite element method with quadratic interpolation functions and five degrees of freedom (DOF). Narita and Leissa (1990) presented an analytical approach and accurate numerical results for the free vibration of cantilevered, symmetrically laminated rectangular plates. The natural frequencies are calculated for a wide range of parameters: e.g., composite material constants, fiber angles and stacking sequences.

Qatu and Leissa (1991) analyzed free vibrations of thin cantilevered laminated plates and shallow shells by Ritz method. Convergence studies are made for spherical circular cylindrical, hyperbolic, paraboloidal shallow shells and for plates. Results are compared with experimental value and FEM. The effect of various parameters (material number of layers, fiber orientation, and curvature) upon the frequencies is studied.

Koo and Lee (1993) used a finite element method based on the shear deformable plate theory to investigate the effects of transverse shear deformation on the modal loss factors as well as the natural frequencies of composite laminated plates. The complex modules of an orthotropic lamina were employed to model damping effect. Soares, Moreira, Pedersen, and Araujo (1993) described an indirect identification technique to predict the mechanical properties of composites which makes use of eigenfrequencies, experimental analysis of a composite plate specimen, corresponding, numeri-caleigen value analysis and optimization techniques.

3. Materials & Methodology Composite Materials

A composite material can be defined as a combination of a matrix and a reinforcement, which when combined give properties superior to the properties of the individual components. In the case of a composite, the reinforcement is fiber and used to fortify the matrix in terms of strength and stiffness. A reinforcement material called fiber and a base material called matrix to achieve better engineering properties than the conventional material. Composite materials are ideal for structures that require high strength to weight and stiffness to weight ratios. The positive characteristic of using composite material is the control capability of fiber alignment by changing the fiber orientation and layers according to the required properties (strength and stiffness). For the present study, it has been considered a square orthotropic plate consists of graphite/epoxy material, accumulate series are considered for the laminates [ϴ/ϴ], with the change of the angle (ϴ). The composite plate is simulated for various stacking series for two boundary conditions, simply supported and fixed.

Detail of the plate:

Table 1: Geometric properties of the plate

Dimension	No. of Layer	Stacking sequence angle	
Length = 1m	2	[-15/15]	Symmetric
width = 1m	4	[-30/30]	
thickness = 0.01 m	6	[-45/45]	Un-symmetric
	8	[-60/60]	
	10	[-75/75]	
	14	[-90/90]	
	16	[0/90]	

Material properties are:
E1 = 175 e9 N/m^2, E2 = 7 e9 N/m^2, E3 = 7 e9 N/m^2
V12 = V13 = 0.25, V23 = 0.01,
G12 = G13 = 3.5 e9 N/m^2, G23 = 1.4 e9 N/m^2
Unit weight= 1550 kg/m^3.

3.1 Free Vibration

Free vibration means the motion of a structure without any external forces (dynamic force) or support motion. The linear SDF systems motion without damping can be specialized to

$$m\frac{d^2u}{dt^2} + ku = 0 \quad (1)$$

Free vibration is initiated by disturbing the system from its static equilibrium position by imparting the mass some displacement u (0) and velocity ů (0) at time zero, and the motion is initiated

u = u(0), ů = ů(0)

So, solution to the equation is obtained by standard methods:

$$u(t) = u(0)cos\omega_n t + \frac{\dot{u}(0)}{\omega_n}\sin\omega_n t \quad (2)$$

where natural circular frequency of vibration in unit radians per second is

$$\omega_n = \sqrt{\frac{k}{m}} \quad (3)$$

The time required for the undamped system to complete one cycle of free vibration is the natural period of vibration of the system. Natural cyclic frequency of

$$T_n = \frac{2\pi}{\omega_n} \quad (4)$$

vibration is denoted by Fn= 1/ Tn, unit in Hz (cycles per second).

3.2 Mode Shape

The free vibration undamped system in one of its natural vibration modes can be described by

$$u(t) = q_n(t)\emptyset_n \tag{5}$$

Where$\emptyset_n$ does not vary with time.
The time variation of the displacements is described by the simply harmonic function

$$q_n(t) = A_n \cos\omega_n t + B_n \sin\omega_n t \tag{6}$$

An, Bn are constants of integration. Combining the two equations, there will be

$$u(t) = \emptyset_n(A_n \cos\omega_n t + B_n \sin\omega_n t) \tag{7}$$

Putting in equation of undamped free vibration, we have

$$[-\omega_n{}^2 m\emptyset_n + k\emptyset_n]q_n(t) = 0 \tag{8}$$

Either, $q_n(t) = 0$, →u(t) = o, trivial solution. Or, $k\emptyset_n = \omega_n{}^2 m\emptyset_n$. This is called matrix eigenvalue problem. This equation can be written as:

$$\lfloor k - \omega_n{}^2\, m \rfloor\emptyset_n = 0 \tag{9}$$

A set of "n" homogeneous algebraic equations is obtained. This set has always the trivial solution $\emptyset_n$=0, which implies no motion. The nontrivial solution is:
det$\lfloor k - \omega_n{}^2\, m\rfloor = 0$, which so called as frequency equation.

3.3 Ansys Modeling

By using ANSYS 12.0 package, the dynamic analysis has been done. For layered applications of a structural shell model, the element SHELL99 can be used. So, the element SHELL99 linear layer is used to model the laminated composite plates. SHELL99 goes ahead up to 250 layers. This element has 6-DOF in every node: displacement in the x, y, and z directions and twist about the nodal x, y, and z-axes.

4. Results and Discussion

The natural frequency of laminated composite plates is investigated for various numbers of layers and ply orientation with symmetric and un-symmetric stacking sequences (with the same thickness) in the laminated composite plates. Different cases of boundary conditions were analyzed (simply supported and fixed). The cases investigated during the present study are defined below.

4.1 Case 1: graphite/epoxy composite laminated plate with two cases of boundary conditions (simply supported and fixed) has been investigated in this study. The natural frequency has been studied for various numbers of layers for the composite plate for the same thickness.

Table 2: Natural frequency of a fixed symmetry angle-ply [45 / 45-]s
Square composite laminated plate

	Natural Frequency				
No. of layer	mode 1	mode 2	mode 3	mode 4	mode5
2	67.05	134.58	134.58	211.51	232.25
4	99.65	176.11	219.21	268.91	334.75
6	104.95	195.73	222.04	308.11	355.21
8	106.11	201.25	221.3	319.33	359.48
10	106.81	204.85	220.69	326.39	362.22
12	107.1	206.75	219.98	330.06	363.27
14	107.32	208.18	219.51	332.65	364.15
16	107.44	209.13	219.01	334.32	364.55

From Table 2, it is observed that the natural frequency increased clearly when the number of layers increased for same plate thickness and boundary condition, which was fixed, but the amount of increase in natural frequency will be unremarkable for all mode shapes after augmenting layer numbers above 10 layers for the same thickness. So, it can be deduced from that the maximum natural frequency for this plate by using 10 layers for a symmetric clamped composite laminated plate. The effects of a number of the layer in the laminate are clearly shown in Figures 1 and 2.

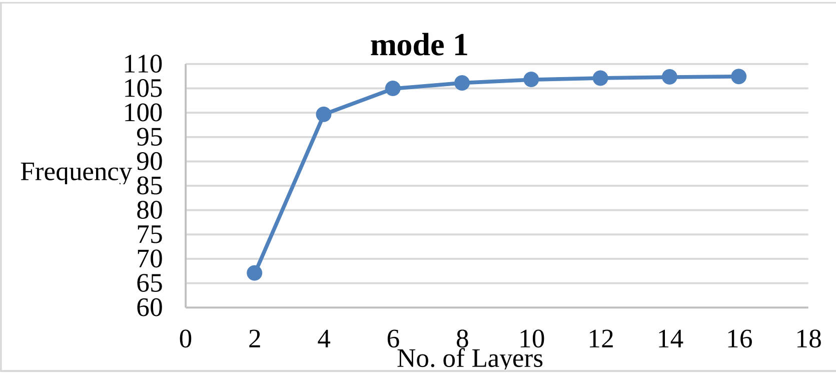

Figure 1: Natural frequency (first mode shape) of fixed composite laminated plate with various numbers of layers

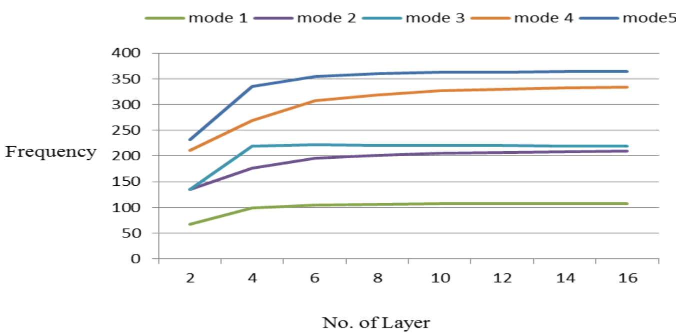

Figure 2: Natural frequency (first five mode shape) of fixed composite laminated plate with various numbers of layers

Table 3: Natural frequency of a symmetry angle-ply [-45 / 45] s
Simple supported square laminated composite plate

	Natural Frequency				
No. of layer	mode 1	mode 2	mode 3	mode 4	mode5
2	51.25	105.79	105.79	179.26	181.48
4	59.83	129.88	157.82	199.19	256.5
6	64.73	137.35	160.64	234.99	275.01
8	65.87	142.41	160.25	245.6	279.2
10	66.5	145.61	159.68	252.33	281.61
12	66.79	147.35	159.13	255.96	282.67
14	66.99	148.62	158.68	258.5	283.43
16	67.1	149.48	158.29	260.23	283.84

From Table 3, it is observed for a plate with the same thickness that by increasing the number of layers the natural frequency will increase significantly at the beginning, then the amount of increment for all mode shapes will reduce after increasing layer numbers above 10 layers for the same thickness. So the maximum natural frequency can be obtained by using 10 layers for a symmetric clamped composite laminated plate. The effects of a number of the layer in the laminate are clearly shown in Figures 3 and 4.

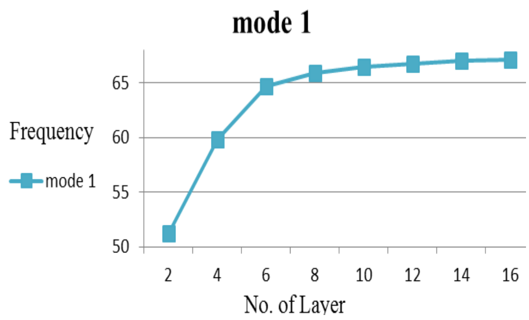

Figure 3: Natural frequency (first five mode shape) of simply supported composite laminated plate with various numbers of layers

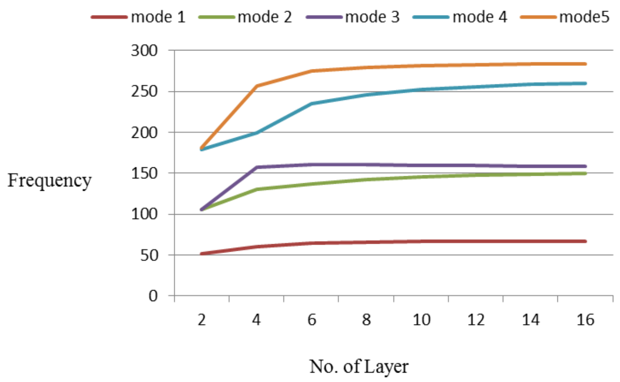

Figure 4: Natural frequency (first five mode shape) of simply supported composite laminated plate with various numbers of layers

4.2 Case 2: The natural frequency of asymmetry and un-symmetric angle-ply square laminated composite plate for 10 layers were studied. The two boundary conditions (simply supported and fixed) have been considered for the graphite/epoxy composite laminated plate. In this case, the natural frequency has been studied for various layers orientation for the composite laminated plate.

Table 4: Natural frequency of a 10-layer fixed symmetry angle-ply square laminated composite plate

Angle of layers	mode 1	mode 2	mode 3	mode 4	mode5
[-15/15/-15/15/-15]s	110.53	140.55	193.63	269.21	285.42
[-30/30/-30/30/-30]s	107.97	170.99	254.72	262.69	329.57
[-45/45/-45/45/-45]s	106.81	204.85	260	326.39	362.22
[-60/60/-60/60/-60]s	107.97	170.99	254.72	262.69	329.57
[-75/75/-75/75/-75]s	110.53	140.55	193.63	269.21	285.42
[-90/90/-90/90/-90]s	111.76	128.74	168.16	232.6	296.42
[0/90/0/90/0]s	112.02	205.64	251.29	308.78	368.13

Table 5: Natural frequency of a 10-layer fixed un-symmetry angle-ply square laminated composite plate

angle	Mode1	Mode 2	Mode 3	Mode 4	Mode5
[-15, 15]	109.86	140.54	194.08	270.18	282.98
[-30,30]	107.54	171.58	252.79	264.60	329.06
[-45,45]	106.55	212.39	212.39	336.58	361.90
[-60,60]	107.54	171.58	252.79	264.60	329.06
[-75,75]	109.86	140.54	194.08	270.18	282.98
[-90,90]	111.76	128.74	168.16	232.6	296.42
[90,0]	110.67	226.95	226.95	305.30	417.31

From Tables 4 and 5, it is observed that the natural frequency for 10-layer cross-ply and angle-ply composite laminated plate with clamped boundary condition in the symmetric and un-symmetric arrangement of layers decreases when the angle of ply changes from 0° to 45°, then it increases up to 90°. So, the maximum value of natural frequency for both cases and for all mode shapes will be at angles 0/90 of ply orientation. And the natural frequency for the un-symmetric arrangement is slightly less than the symmetric arrangement as shown in Figure 5. It is also observed that the natural frequency in case of angles 15° and 75° is the same, and for 30 and 60, it is the same.

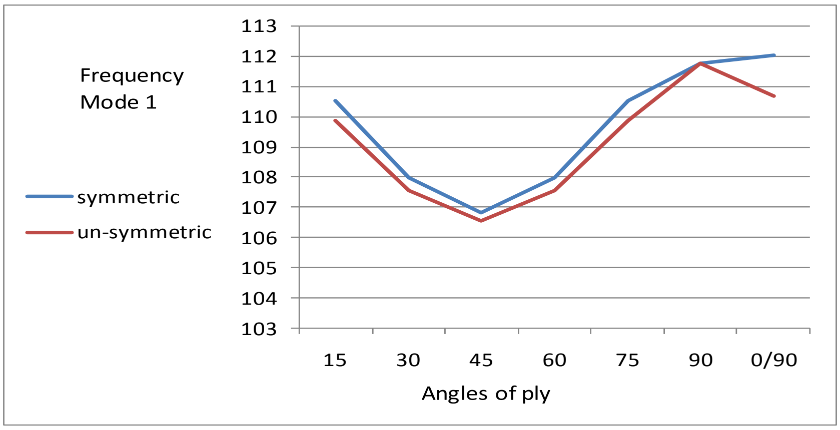

Figure 5: Natural frequency (first mode shape) of fixed composite laminated plate with various layer orientations

Table 6: Natural frequency of a 10-layer simply supported symmetry angle-ply square laminated composite play

Angle of layers	mode 1	mode 2	mode 3	mode 4	mode5
[-15/15/-15/15/-15]s	55.62	86.79	138.1	189.46	209.45
[-30/30/-30/30/-30]s	63.134	120.48	176.53	202.08	250.52
[-45/45/-45/45/-45]s	66.5	145.61	169.68	252.33	281.61
[-60/60/-60/60/-60]s	63.134	120.48	176.53	202.08	250.52
-[75/75/-75/75/-75]s	55.62	86.79	138.1	189.46	209.45
-[90/90/-90/90/-90]s	51.32	68.56	108.81	171.90	193.64
[90/0/90/0/90/0]s	51.344	127.82	161.25	204.13	270.09

Table 7: Natural frequency of a 10-layer simply supported un-symmetry angle-ply square laminated composite plate

Angle	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
[-15 , 15]	55.76	87.29	138.92	188.51	210.56
[-30,30]	63.58	121.92	175.64	204.98	251.01
[-45,45]	67.01	153.19	153.19	264.42	281.99
[-60,60]	63.58	121.92	175.64	204.98	251.01
[-75,75]	55.76	87.29	138.92	188.51	210.56
[-90,90]	51.32	68.56	108.81	171.90	193.64
[90,0]	51.23	143.89	143.89	201.93	309.74

From the Tables 6 and 7, it is observed that the natural frequency for 10-layer cross-ply and angle-ply composite laminated plate with simply supported boundary condition in the symmetric arrangement of layers increases when the angle of ply changes from 0° to 45°, then it decreases up to 90°. So, the maximum value of natural frequency for all mode shapes will be at angle 45° of ply orientation. And the natural frequency for the un-symmetric arrangement is slightly more than the symmetric arrangement as shown in Figure 6. It is also observed that the natural frequency in case of angles 15 and 75 is the same, and for 30 and 60 also, it is the same.

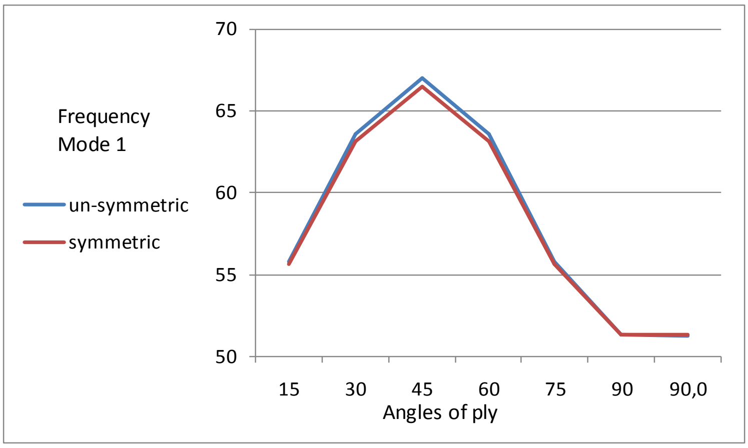

Figure 6: Natural frequency (first mode shape) of simply supported composite laminated plate with various layer orientations

5. Conclusion

1- It is found that the natural frequency for the composite laminated plate in simply supported boundary condition is less than in clamped boundary condition for the same plate.
2- For both simply supported and fixed boundary conditions, it is observed that by increasing the number of layers of the laminated plate for the same thickness the natural frequency will increase and the maximum natural frequency can be obtained using 10 layers laminated plate.
3- The maximum natural frequency for angle-ply simply supported composite plate can be obtained using angle [-45/45] for fiber orientation, and using cross-ply [0/90] fixed composite plate.
4- There is a small difference in the natural frequency between asymmetric and un-symmetric arrangement of ply for both clamped and simply supported boundary condition.
5- The natural frequency for the symmetric fixed composite plate is little more than the un-symmetric, and the natural frequency for un-symmetric simply supported composite plate is little more than the symmetric.

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