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Vibration Analysis of Laminated Composite Plates with Holes

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Abstract

Fiber reinforced composite materials are widely used in variety of engineering applications due to its superior properties than the conventional materials. In this investigation free vibration analysis of four layered angle-ply symmetric laminated plates with various lamination angles ($\pm 0^\circ$ to $\pm 90^\circ$), of laminas with different hole locations were presented. The analyzed laminated plates have been made from composite materials: the reinforcement fibers were Graphite and the matrix material is Epoxy. Composite structures may sometimes provided with holes for the purpose of assembling the components, for passing the cables, for inspection and maintenance etc. The ANSYS13.0 software was used for modeling and analysis of the laminated plates under clamped boundary conditions. The eight noded shell99 was used throughout the analysis. Length to height ratio considered is 40 and 200. The ratio of hole area to the plate area is maintained constant throughout the analysis as 0.05. From the analysis it is inferred that the fundamental frequency of laminated composite plates decreases with increase in L/h ratio.

Keywords: Free vibration, laminated composite plate, Finite Element Analysis, Lamination angles.

Introduction

Laminated composite structures are being increasingly used in aerospace, automotive, marine, and civil areas. This is primarily due to their large values of specific strength and stiffness and the advantage that their properties can be tailored to meet practical requirements. The composite structures may some times be provided with different types of holes for the purpose of assembling the components inside the structure, for passing the cables and control mechanisms, for inspection, maintenance etc. The stresses and deformations of steep gradient are induced around these cutouts. The influence of the thickness parameter is inherent at higher modes of vibration. In this paper the effect of cutouts on vibration response of a laminated composite plates were investigated. Depreciation of the internal mechanism of composite plates are dependent on their own frequencies, estimating the specific characteristics is also difficult because of the non-isotropy of the materials [1, 2, 3]. Jwalamalini, et al.[4] have investigated the stability of a simply supported square plate with openings under in-plane loading is analyzed using a Finite Element program BUCSAP (Buckling Structural Analysis Program). The openings are considered as square and central for

the main study but rectangular and central for comparison with other work. Different magnitudes of tension and compression are assumed as initial pre-stress in the transverse direction before the longitudinal stress is applied. Myung Jo Jhung, et al. [5] have studied the free vibration analysis of circular plate with eccentric hole submerged in fluid studied the natural frequencies and mode shapes of the structures due to the existence of hole. Especially if the hole is located eccentrically the vibration behavior of the structures is expected to deviate significantly from that of a plate with concentric hole. Lee and Lim [6] analyzed free vibration response of simply supported isotropic and orthotropic square plates with a square cutout subjected to an in-plane force using the Rayleigh method. They concluded that the in-plane tensile force increases the natural frequency where as increased compressive force decreases the natural frequency until the state of buckling is reached. Sabir and Davies [7] used finite element method to determine natural frequencies of flat square plates containing an eccentrically located square hole. Paramasivam [8] proposed a method to determine the effect of square openings on the fundamental frequency of square isotropic plates for

different boundary conditions using the finite difference method. Results were obtained for simply supported and clamped boundary conditions. Rajamani and Prabhakaran [9], [10] studied the effect of a centrally located square cutout on the natural frequencies of square, simply supported and clamped symmetrically laminated composite plates for free and forced vibration cases. Aksu and Ali [11] developed a theory to study the dynamic characteristics of isotropic and orthotropic rectangular plates with one or two rectangular cutouts. They employed a method based on the use of variational principles in conjunction with finite difference technique. Ghannadpour et al. [12] investigated the influence of a cutout on the buckling performance of rectangular plate made of polymer matrix composites,

The objective of the present investigation is to understand the effect of the presence of circular cutouts on the vibration response of a symmetric angle-ply laminated plate with various lamination angles (+α, -α, -α, +α) for the range of angles 0° to 90° were analyzed. The study also includes the effect of side to thickness ratio on natural frequencies of the laminate.

Materials and methods

The word ‘Composite’ means ‘Consisting of two or more distinct parts’. Thus a material having two or more distinct constituent materials or phases may be considered a composite material, whose performance characteristic is superior to that of the individual constituents taken separately. The most common composites used are laminated composite plates which are typically made of different layers bonded together. Basically, each layer is generally orthotropic and has different fiber orientation as shown in figure 1. The properties which can be improved by forming a composite were strength and weight reduction. The major advantage of the laminated composite is that required strength and stiffness properties to specific design conditions can possibly achieved.

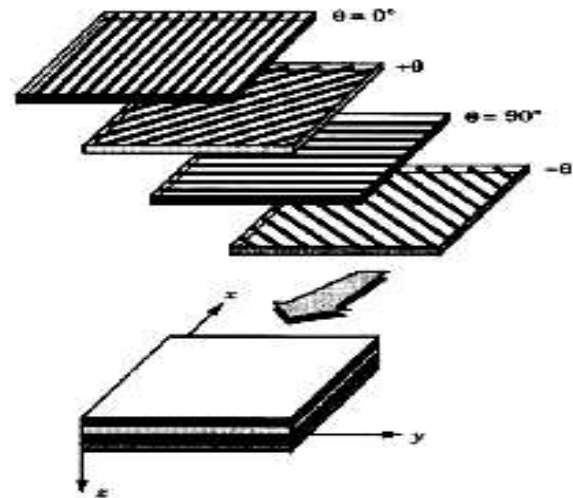


Figure 1. Laminated made up of lamina of different fiber orientation

Free vibration

Free vibration means the motion of a structure without any dynamic external forces or support motion. The motion of linear second order differential equation of motion without damping is presented in equation 1.

$$m \frac{d^2 u}{dt^2} + ku = 0$$

Free vibration is initiated by disturbing the system from its static equilibrium position by imparting the mass some displacement $u(0)$ and velocity $\dot{u}(0)$ at time zero, defined as the instant the motion is initiated : $u = u(0), \dot{u} = \dot{u}(0)$

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

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

Where natural circular frequency of vibration in unit radians per second:

$$\omega_n = \sqrt{\frac{k}{m}} \text{ rad/s}$$

Natural frequency of vibrations is denoted by

$$f_n = \frac{\omega_n}{2\pi} \text{ Hz.}$$

Finite Element Analysis

The equation of motion of a discredited undamped elastic structure undergoing small deformation can be expressed as:

$$[M]\{\ddot{u}\} + k\{u\} = 0$$

Eigen vectors can be determined from the following equation:

$$|[D] - \lambda [I]| = 0$$

Where $[D]$ = Dynamic matrix, $[k]$ = Stiffness matrix, $[M]$ = Mass matrix

$$[D] = [M]^{-1} [k], \text{ Eigen vector } \lambda = \omega^2$$

In this investigation eight noded iso-parametric plate bending element has been chosen to discretize the plates. The element is capable of incorporating the transverse shear deformation through the implementation of first order shear deformation theory as applicable to composites.

The element stiffness matrix can be expressed as:

$$[k] = \iint [B]^T \cdot [D] \cdot [B] \, dx \cdot dy \quad (2)$$

The consistent mass matrix is expressed as

$$[M] = \iint [N]^T \cdot [P] \cdot [N] \, dx \cdot dy \quad (3)$$

Finite Element Modeling

The model analysis has been done using ANSYS 13.0 software package. The laminated composite plates are modeled using the element SHELL 99 as shown in Figure 2. It has linear capabilities and has smaller element formulation time. It allows up to 250 layers. The element has six degrees of freedom at each node: translations in the nodal x, y and z directions and rotations about the nodal x, y, and z axes.

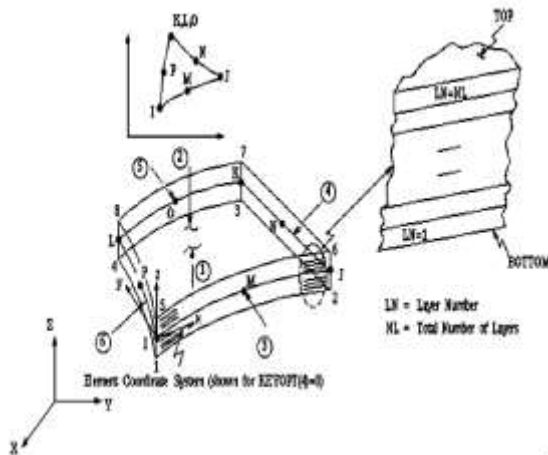


Figure 2. SHELL 99 linear layered structural shell

In the present investigation, the models of the angle ply symmetric layered composite plates with various lamination angles $(+\alpha, -\alpha, -\alpha, +\alpha)$ with gradual variation of α from $0^\circ \sim 90^\circ$ in steps of 15° were analyzed. The stacking sequence of the lamina are shown in figure 3. The observed models have been made up with four equal unidirectional lamina from the material: T300/5208 graphite /epoxy. The material properties of graphite/epoxy composite material is given in Table 1. In this present

investigation, the ratio of area of the hole to the plate is maintained constant as 0.05 and ratio of side to the thickness considered are 40 and 200. In the present study four different models have been considered are shown in figure 4 ~7: Model: 1. Laminated plate with no hole, Model: 2. Laminated plate with hole at centre, Model: 3. Laminated plate with a hole at the corner and Model: 4. Laminated plate with a hole at both corners. Clamped boundary conditions are applied at all four edges of the plate.

Table1. Mechanical Properties of a graphite/epoxy Composite

Longitudinal Modulus E_1	175 GPa
Transverse modulus $E_2 = E_3$	7GPa
Poisson's ratio	
$\nu_{12} = \nu_{13}$	0.25
ν_{23}	0.01
Shear modulus	
$G_{12} = G_{13}$	35GPa
G_{23}	1.4GPa
Density	1550kg/m ³

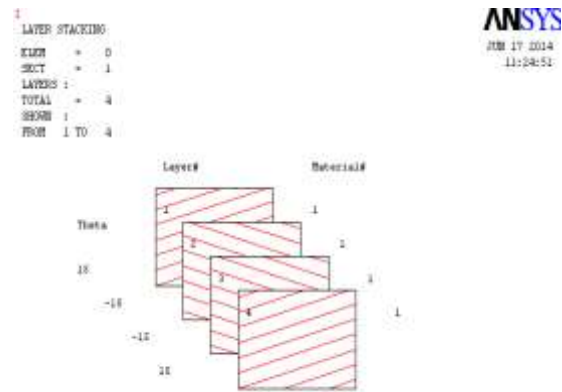


Figure 3. Lamination angles

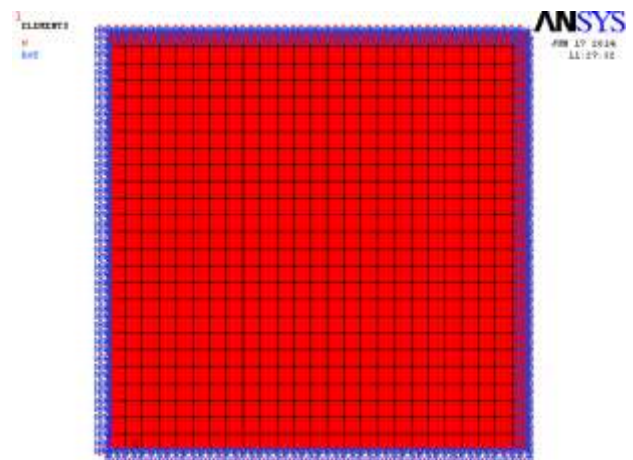


Figure 4. Plate with no Hole

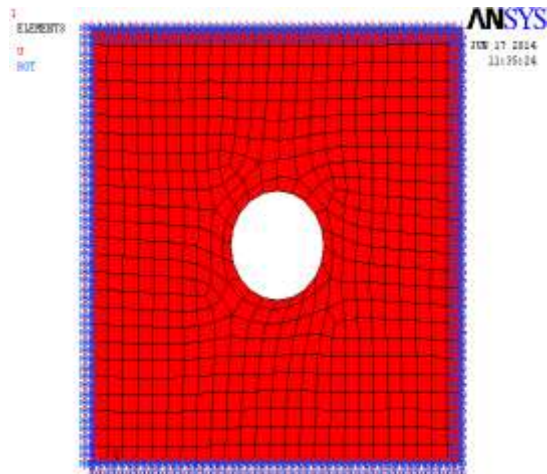


Figure 5. Plate with a hole at the centre

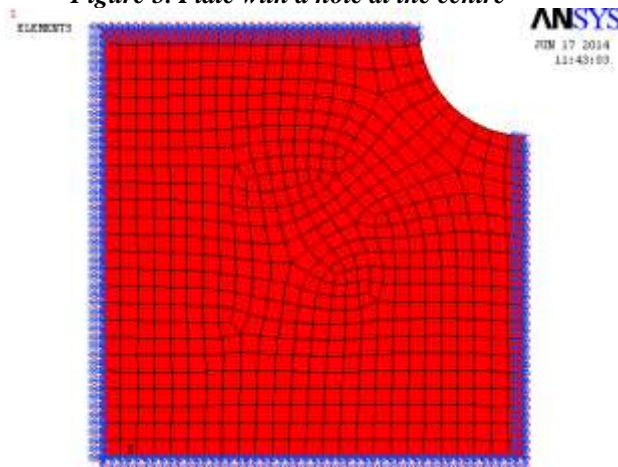


Figure 6. Plate with a hole at the corner

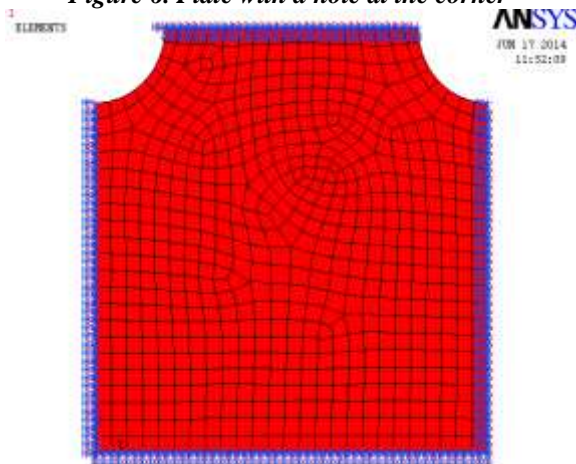


Figure 7. Plate with a hole at both corners

Results and discussion

The composite plates with arbitrary geometries and boundary conditions subjected to different loading conditions have got an important role to play as the structural elements in aerospace

and other engineering structures. The plate and shell structures subjected to dynamic loading cause non-uniform stress field which greatly affects the stability and dynamic behavior of structures. In this investigation the symmetric layered angle ply laminated composite plates with various lamination angles $(+\alpha, -\alpha, -\alpha, +\alpha)$ with gradual variation of α from $15^\circ \sim 90^\circ$ were analyzed. The plates of same geometry having size $1.0 \times 1.0\text{m}$ having a hole area ratio 0.05 and side to thickness ratio 50 and 200 were analyzed. The increase in frequency in any case is due to increase in stiffness of the plate or due to decrease in mass of the plate for any change in the plate geometry of the plate. The decrease in frequency at any position is due to the decrease in stiffness of the plate.

(i) **Laminated Composite whose side to thickness $(L/h = 40)$**

Model analysis of four layered symmetric $(\pm \alpha)_s$ laminated composite plates having thickness 25mm with different fiber orientation angles ranging from $15^\circ \sim 90^\circ$ and with different hole location were performed using ANSYS 13.0 software package. Clamped boundary conditions were applied at all the four sides of the plate i.e., $u=v=w=\theta_x=\theta_y=\theta_z=0$. The variation of natural frequency with respect to the fiber orientation angle for the four different cases considered in this investigation is illustrated in figure 8.

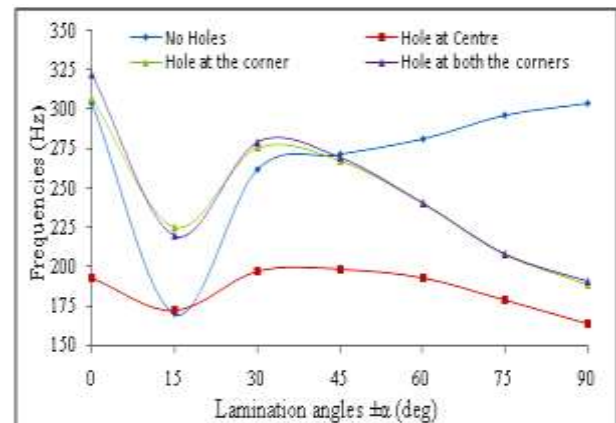


Figure 8. Variation of frequencies with respect to the lamination angles $(L/h=50)$

From the above figure it is inferred that maximum frequencies were observed for the four cases of $(\pm 0^\circ)_s$ symmetric layered laminated composite plate. Lower values of frequencies were noted for a plate with a centre hole for all the range of lamination angles. Laminated composite plate with no hole showing better performance from the range of fiber orientation angles $(\pm 30^\circ \text{ to } \pm 90^\circ)$, it is

followed by laminated plate with a hole at the corner and a laminated plate with hole at both the corners. In all the four cases of geometrical configuration better performance is noted at $(\pm 30^\circ)$, symmetric four layered laminated composite plates.

(ii) *Laminated Composite whose side to thickness (L/h =200)*

Model analysis has been carried out on a symmetric $(\pm \alpha)$, four layered laminated composite whose side to thickness ratio is 200 at different geometrical configurations using ANSYS 13.0 software package. The total thickness of the laminate is 5mm. Clamped boundary conditions were applied at all the four sides of the plate i.e., $u=v=w=\theta_x=\theta_y=\theta_z=0$. The variation of natural frequency with respect to the lamination angles for the four different cases considered in this investigation is illustrated in figure 9.

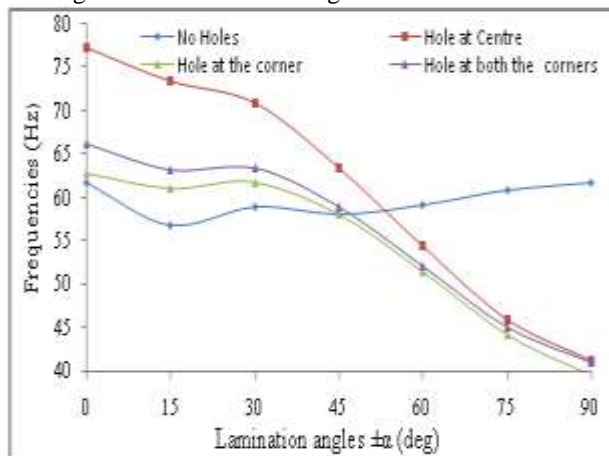


Figure 9. Variation of frequencies with respect to the lamination angles (L/h=200)

From the above figure it is inferred that lower frequency values were observed for the four cases considered in this investigation. The decrease in the natural frequency of the laminated structure is due to decrease in the stiffness or increase in the mass of the structure. From the graph it is inferred that, Plate with no hole shows stable natural frequencies for the range of lamination angles considered in this investigation. Plate with centre hole exhibits higher frequencies for the range of lamination angles $0^\circ \sim 30^\circ$, thereafter natural frequency decreases with increase in lamination angles. Similar trend has been observed for other two models considered in this investigation.

Conclusion

In this study, the free vibration response of a symmetric angle-ply laminated composite plates with and without circular holes investigated. The modeling process and solutions were done using finite element

analysis software package ANSYS13.0. The conclusions that can be drawn from the present study are summarized as follows.

1. The fundamental natural frequency of vibration decreases with increasing L/h ratio.
2. For the laminated plate with no hole and whose L/h ratio is 50 shows better results for range of lamination angles $\pm 30^\circ$ to 90° .
3. Laminated plate with centre hole whose L/h ratio is 50 shows lower fundamental frequencies for range of lamination angles $\pm 0^\circ$ to 90° .
4. The higher fundamental frequencies were observed when there is hole at the centre of laminated plate whose L/h ratio is 200 for the range of symmetric lamination angles $\pm 0^\circ$ to 30° and there after decreases with increase in lamination angles.
5. Laminated plate with no hole and whose L/h ratio is 200 shows stable fundamental frequencies for the range of lamination angles considered in this investigation.

From the present investigation, it is concluded that the best location of the hole in the laminated plate whose L/h ratio is 50 is hole at the corner as well as hole at both corners for lamination angles $\pm 0^\circ$ and $\pm 30^\circ$. When L/h ratio is 200 the best location of the hole is at the centre for the symmetric angle ply laminate for the range of lamination angles of $\pm 0^\circ$ to $\pm 30^\circ$.

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