International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

Mechanical and Thermal Buckling Analysis of Laminated Composite Plates

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Abstract - Composite laminated structures have many application fields such as aerospace, biomedical, civil, marine, transportation and mechanical engineering because of their ease of handling, good mechanical properties. Buckling behavior of laminated composite plates subjected to in-plane loads is an important consideration in the preliminary design of aircraft and launch vehicle components. Also these element may expose to high temperature fields (while launching or re-entry) which also cause for failure due to thermal buckling. Composite laminated plates with holes and other openings are used as structural members in aerospace industry. The buckling behavior of such plates has always received much attention. In this study buckling analysis was carried out of a laminar composite plate with a hole. In the analysis, finite element method (FEM) was applied to perform parametric studies on various plates based on the shape and position of the hole. ANSYS has been used as a platform for buckling analysis.

Key Words: Composite Laminated Plates, Buckling Analysis, FEM, ANSYS

1. Introduction

Composite materials are very flexible and operate in a broad range of applications. It is completed by integrating two materials which are reinforcement (fiber) and matrix (resin). Application fields of composite materials are continuously expanding from traditional application areas to the various engineering fields. There are a large application range of composite materials such as for electrical and electronics, buildings and public work, transportation (road, rail, marine, air and space), sports and recreation, general mechanical applications and aerospace industry. Nowadays, the application of composite materials in aerospace industry is growing up. Composite materials provide a completely high strength-to-weight ratio in addition to the capability to produce large and integrated structure. Composite materials are one such class of materials that play a significant role in current and future aerospace components. For instance, one component of composite materials is able to change ten or more conventional metal parts which may impressively reduce manufacturing time and cost. A true understanding of their structural behavior is required such as the deflections, buckling loads and modal characteristics, the through thickness distributions of stresses and strains, the large deflection behavior and of extreme importance for obtaining strong, reliable multi-layered structures, the failure characteristics.

2. Problem Definition and Objectives

2.1 Problem Definition

Due to the excellent stiffness and weight characteristics, composites have been receiving more attention from engineers, scientists, and designers. During these applications the composite laminate plates are commonly subjected to compression loads that may cause buckling if overloaded. Hence, structural instability becomes a major concern in safe and reliable designs of the composite plates. Hence their buckling behaviors are important factors in safe and reliable design of these structures.

Laminated composite is often employed to replace traditional metal for the skin panels of aircraft wings and fuselage in order to reduce the weight of flight vehicles. In the design of composite skins for aircraft wings, one of the important issues is buckling of the panels. High-speed aircraft structural panels are subjected not only to aerodynamic loading, but also to aerodynamic heating and solar radiation heating. The temperature rise may buckle the plate and exhaust the load carrying capacity. In certain cases, the thermal load turns out to be the primary one and controls the design. Thermal gradients are built up across wall thickness. Due to boundary constraints, compressive stresses are induced by thermal loads, which may cause buckling, especially in thin-walled members.

2.2 Objectives and Scope of Study

A lot of studies were carried out on buckling analysis of laminated composite plate. Some works concentrated on the plates with circular or rectangular cut outs. But very few were concentrated on other cut out shapes. The current study focuses on the buckling analysis of laminated composite plates with other shaped hole at the centre of the plate using FEM. The buckling loads were calculated for different orientations and sizes of the hole.

Thermal buckling behavior of laminated composite plate is also studied. Effect of different boundary conditions, orientation and thickness on critical buckling temperature will also be analyzed in this study.

3. Methodology

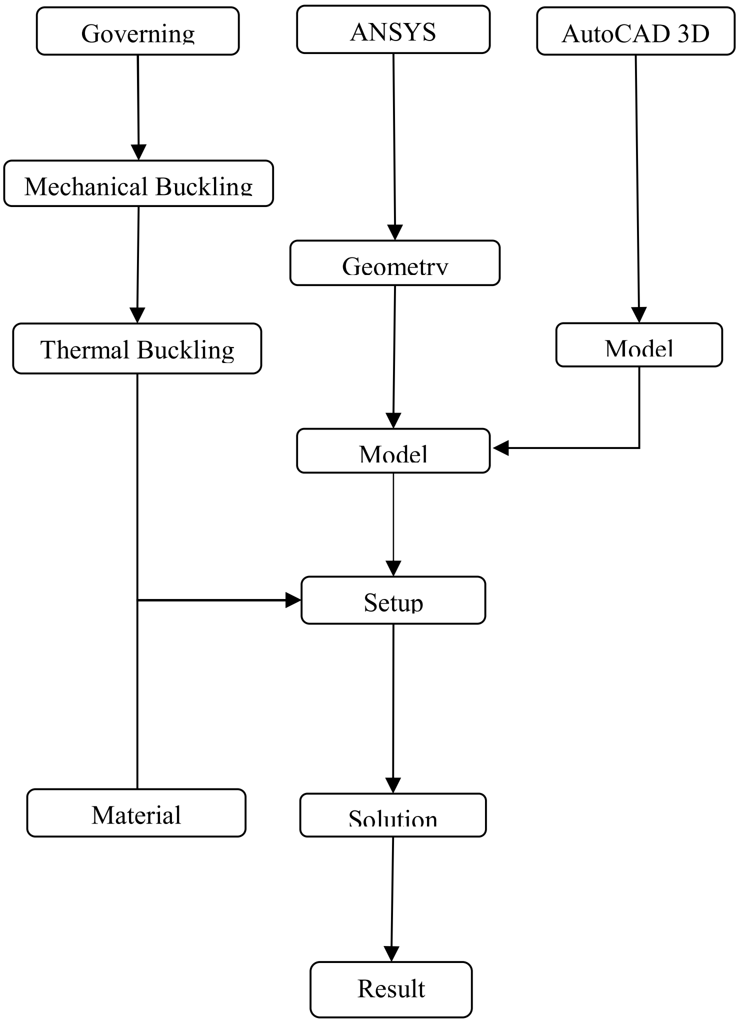


Fig -1: Methodology

3.1 Laminated Composites

In materials science, a composite laminate is an assembly of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion.

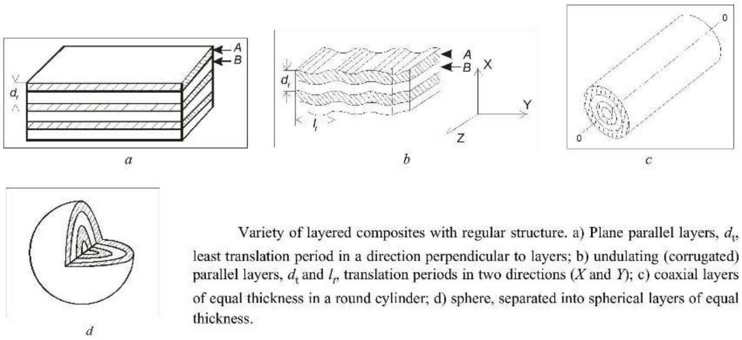
The individual layers consist of high-modulus, high-strength fibers in a polymeric, metallic, or ceramic matrix material. Typical fibers used include cellulose, graphite, glass, boron, and silicon carbide, and some matrix materials are epoxies, polyimides, aluminium, titanium, and alumina.

Layers of different materials may be used, resulting in a hybrid laminate. The individual layers generally are orthotropic (that is, with principal properties in orthogonal directions) or transversely isotropic (with isotropic properties in the transverse plane) with the laminate then exhibiting anisotropic (with variable direction of principal properties), orthotropic, or quasi-isotropic properties. Quasi-isotropic laminates exhibit isotropic (that is, independent of direction) in plane response but are not restricted to isotropic out-of-plane (bending) response. Depending upon the stacking sequence of the individual layers, the laminate may exhibit coupling between in plane and out-of-plane response. An example of bending-stretching coupling is the presence of curvature developing as a result of in-plane loading.

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called **multilayer (angle-ply) composite.**

3.1.1 Multilayer composite

Multilayer composites are a broad and important group of structural and functional materials whose properties may vary over a very wide range. The possibility of combining in one monolithic material layers of a different nature that exhibit markedly different physical properties makes it possible to construct materials for very different functional purposes, including impact and high temperature, heat- and erosion-resistance, heat conducting, and heat-protective. From the point of view of strength properties there is most interest in composites within which high-modulus brittle, or low-ductility layers (ceramics, refractory metals, intermetallics) alternate with ductile metal layers. The main aim of creating these composites is a significant increase in the specific work for failure, i.e. an increase in impact strength with retention of the surface properties of ceramics, i.e. hardness, wear resistance, and heat resistance.
Examples of the classification of layered structures with respect to geometry are given in Fig -2. Naturally they do not exhaust all of the many possible multilayer systems.



Variety of layered composites with regular structure. a) Plane parallel layers, d_t, least translation period in a direction perpendicular to layers; b) undulating (corrugated) parallel layers, d_t and l_t, translation periods in two directions (X and Y); c) coaxial layers of equal thickness in a round cylinder; d) sphere, separated into spherical layers of equal thickness.

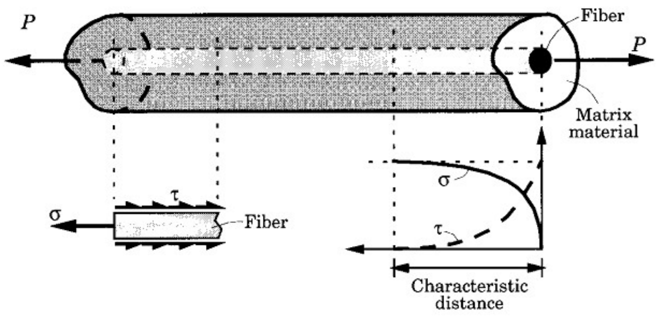
Fig -2: Classification of layered structure

3.2 Theoretical Formulation

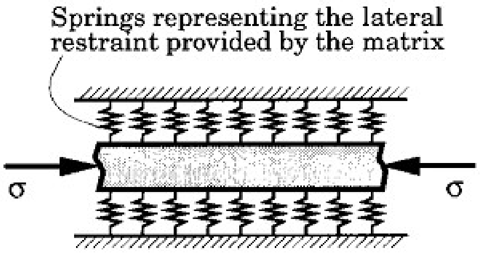
The buckling of a plate involves two planes, namely, xz, yz and two boundary conditions on each edge of the plate. The basic difference between plate and column lies in the buckling characteristics. The column, once it buckles, cannot resist any additional axial load. Thus, the critical load of the column is also its failure load. On the other hand, a plate, since it is invariably supported at the edges, continues to resist the additional axial load even after the primary buckling load is reached and does not fail even when the load reaches a value 10-15 times the buckling load.

3.2.1 Load transfer in a single fiber embedded in matrix

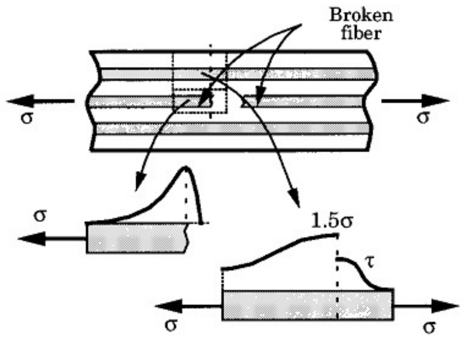
The load transfer mechanism in a single fiber embedded in matrix is explained by J.N. Reddy [20]. The stiffness and strength of fibrous composites come from fibers which are stiffer and stronger than the same material in bulk form. The matrix material keeps the fibers together, acts as a load-transfer medium between fibers, and protects fibers from being exposed to the environment. The basic mechanism of load transfer between the matrix and a fiber can be explained by considering a cylindrical bar of single fiber in a matrix material as figure -3(a). The load transfer between the matrix material and fiber takes through shear stress. The applied load *P* on the matrix is tensile, shear stress τ develops on the outer surface of the fiber, and its magnitude decreases from a high value at the end of the fiber to zero at a distance from the end. The tensile stress σ in the fiber cross section has the opposite trend, starting from zero value at the end of the fiber to its maximum at a distance from the end. The two stresses together balance the applied load, P on the matrix. When a compressive load is applied on the matrix, the stresses in the region of characteristic length are reversed in sign; in the compressive region, i.e., rest of the fiber length, the fiber tends to buckle, much like a wire subjected to compressive load. At this stage, the matrix provides a lateral support to reduce the tendency of the fiber to buckle. Fig -3(b) shows how the matrix gives lateral support for fibers. When a fiber is broken, the load carried by the fiber is transferred through shear stress to the neighboring two fibers which is explained in fig -3(c).



(a)



(b)



(c)

Fig -3: Load transfer and stress distributions in a single fiber embedded with matrix material and subjected to an axial load

3.3 Buckling Behavior of Laminated Composite Plate

In laminated composites, failure of one layer does not necessarily imply failure of the entire laminate; the laminate may, in fact, be capable of sustaining higher loads despite a significant change in stiffness. An analogy to this phenomenon is the ability of an in-plane loaded plate to carry loads higher than the buckling load, but at an increase in the amount of deformation per unit of load (a decreased stiffness) as in fig -4 and -5

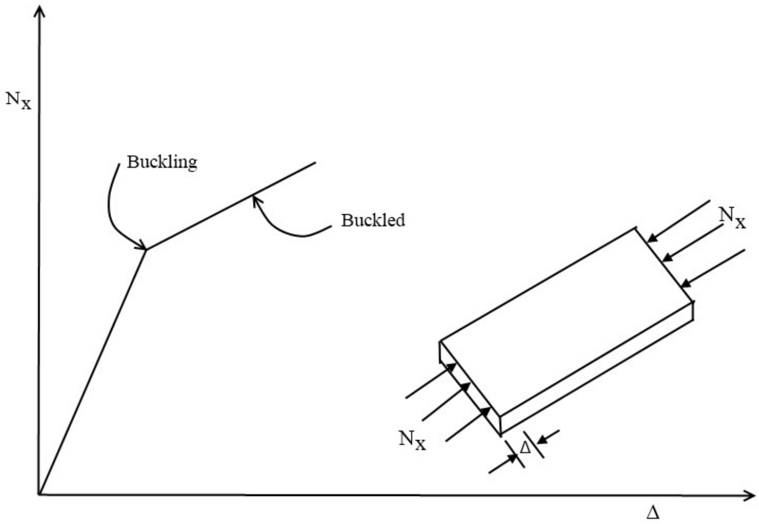


Fig -4: Load-deformation behavior of plate

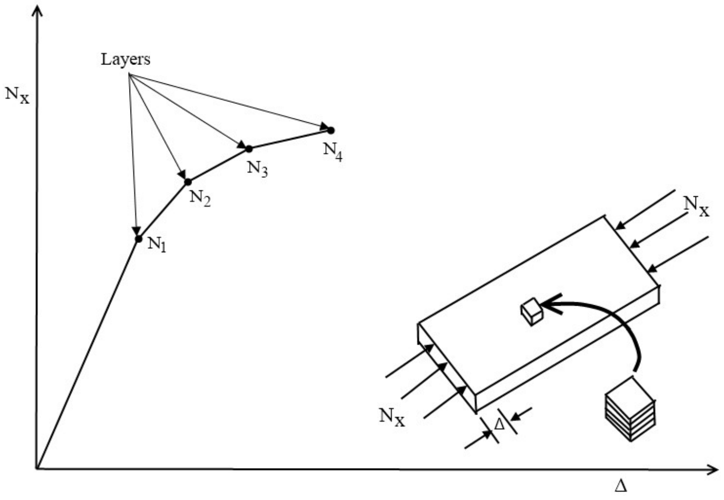


Fig -5: Load-deformation behavior of laminate

All strength theories for composite materials depend on the strength in the principal material directions, which likely do not coincide with principal stress direction. Therefore, the strength of each lamina in a laminate must be assessed in a co-ordinate system that is likely different from those of its neighbouring laminae. This co-ordinate mismatch is but one of the complications that characterises even amacroscopic strength theory. The main factors that are peculiar to laminate strength analysis are:

- Laminae strength
- Laminae stiffnesses
- Laminae coefficient of thermal expansion
- Laminae orientation
- Laminae thickness
- Stacking sequence

3.4 Theory of Bending of Thin Plates

The theory for thin plates is similar to the theory for beams. In pure bending of beams, the stress distribution is obtained by assuming that cross-sections of the bar remain plane during bending and rotate only with respect to their neutral axes so as to be always normal to the deflection curve. For a thin plate, bending in two perpendicular directions occur. A rectangular plate element is shown fig -5

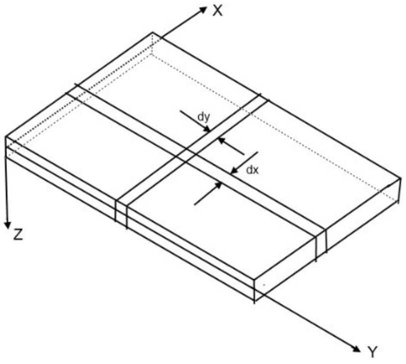


Fig -6: Thin plate notation

The basic assumptions of elastic plate bending are

1. Perfectly flat plate and of uniform thickness.
2. The thickness of the plate is small compared with other dimensions. For plate bending, the thickness, t, is less than or equal to ¼ of the smallest width of the plate. For plate buckling equations, the thickness, t, should be 1/10 of the smallest width of the plate.
3. Deflections are small, i.e., smaller or equal to 1/2 of the thickness.
4. The middle plane of the plate does not elongate during bending and remains a neutral surface.
5. The lateral sides of the differential element, in the above figure, remain plane during bending and rotate only to be normal to the deflection surface. Therefore, the stresses and strains are proportional to their distance from the neutral surface.
6. The bending and twisting of the plate element resist the applied loads. The effect of shearing forces is neglected.

3.5 Buckling of Composite Plate

Composite materials consist of two or more materials which together produce desirable properties that cannot be achieved with any of the constituents alone. Fiber-reinforced composite materials, for example, contain high strength and high modulus fibers are the principal load carrying members, and the matrix material keeps the fibers together, act as a load transfer medium between fibers from being exposed to the environment. The layup sequence of unidirectionally reinforced plies as indicated in fig -3. Each ply is typically a thin sheet of collimated fibers impregnated with an uncured epoxy or other thermosetting polymer matrix material. The orientation of each ply is arbitrary, and the layup sequence is tailored to achieve the properties desired of the laminate.

Fiber reinforced composite materials for structural applications are made in the form of a thin layer, called lamina. A lamina is a macro unit of material whose material properties are determined through appropriate laboratory tests. Structural elements such as bars, beams and plates are then formed by stacking the layers to achieve desired strength and stiffness. Fiber orientation in each lamina and stacking sequence of the layers can be chosen to achieve desired strength and stiffness.

4. Software Analysis

4.1 AutoCAD 3D

Computer-aided design is one of the many tools used by engineers and designers and is used in many ways depending on the profession of the user and the type of software in question.

CAD is one part of the whole digital product development (DPD) activity within the product lifecycle management (PLM) processes, and as such is used together with other tools, which are either integrated modules or stand-alone products, such as:

- Computer-aided engineering (CAE) and finite element analysis (FEA, FEM)
- Computer-aided manufacturing (CAM) including instructions to computer numerical control (CNC) machines
- Photorealistic rendering and motion simulation.
- Document management and revision control using product data management (PDM)

4.2 Finite Element Method

Finite element method (FEM) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc.

4.2.1 ANSYS

ANSYS is a general purpose finite element modelling package for numerically solving a wide variety of mechanical problems. These problems include: static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electromagnetic problems.

In general, a finite element solution may be broken into the following three stages.

1. Pre-processing: defining the problem; the major steps in pre-processing are given below:

- Define key points/lines/areas/volumes
- Define element type and material/geometric properties
- Mesh lines/areas/volumes as required

The amount of detail required will depend on the dimensionality of the analysis (i.e. 1D, 2D, axi-symmetric, 3D)

2. Solution: assigning loads, constraints and solving; here we specify the loads (point or pressure), constraints (translational and rotational) and finally solve the resulting set of equations.

3. Post processing: further processing and viewing of the results; in this stage one may wish to see

- Lists of nodal displacements
- Element forces and moments
- Deflection plots
- Stress contour diagrams

5. Buckling Analysis

5.1 Mechanical Buckling Analysis

5.1.1 Model and Material Properties

In this study, the effects of elliptical hole on the buckling load of laminated composite plates have been investigated numerically. The composite plate was considered as a square with dimensions of (a*a) 120 mm * 120 mm. The thickness of plate is 1.6 mm. Nonetheless, the cut out shape was assumed an elliptical hole (c/b) 30mm/60mm centred in the square plate in this work. The hole was also positioned according to α angle rotated about z-axis as 0^0, 15^0, 30^0, 45^0, 60^0, 75^0 and 90^0. The diameters of the major and minor axes' dimensions of ellipse are represented by b and c respectively. In other words, the width is b and height is c. The parameters b and c are changed according to selected ratios; hence the eccentricity of the ellipse is also varied. Fig -7 shows the geometry of the model.

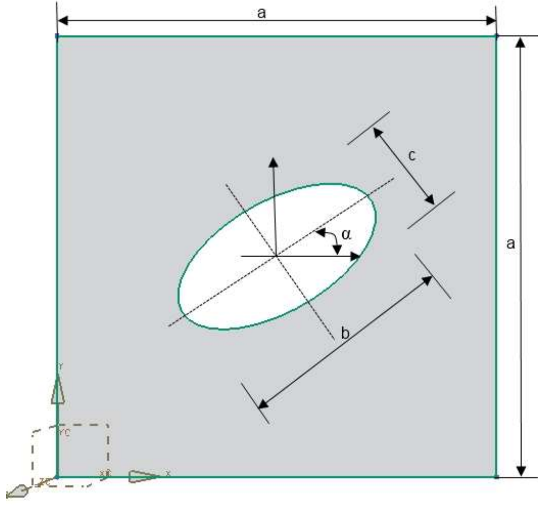


Fig -7: Geometry of the model

For the analysis material properties of graphite/epoxy laminate (CU-125NS) is used. Table -1 shows the material properties of graphite/epoxy laminate.

Table -1: Material properties of graphite/epoxy laminate (CU-125NS)

E_1	E_2, E_3	G_{12}, G_{13}	G_{23}	υ_{12}, υ_{13}	υ_{23}
134.5 GPa	9.6GPa	4.8GPa	3.2GPa	.31	.52

Briefly, buckling analysis was performed for various elliptical holes in terms of created different models. Four different composite plates based on stacking sequences namely cross-ply $[0/90]_S$ and angle-ply $[15/-75]_S$, $[30/-60]_S$, $[45/-45]_S$ were analyzed. Consequently, four different composite plates based on stacking sequences were analyzed. In this manner, the effects of orientations of laminated composite plates on the buckling loads were also analyzed.

5.1.2 SOLSH190 Element Description

SOLSH190 is used for simulating shell structures with a wide range of thickness (from thin to moderately thick). The element possesses the continuum solid element topology and features eight-node connectivity with three degrees of freedom at each node: translations in the nodal x, y, and z directions and has plasticity, hyperelasticity, stress stiffening, creep, large deflection, and large strain capabilities. SOLSH190 is used for layered applications such as modelling laminated shells or sandwich construction. Accuracy in modelling composite shells is governed by the first order shear deformation theory (also known as Mindlin-Reissner shell theory). The geometry, node locations, and the element coordinate system for this element are shown in fig -8

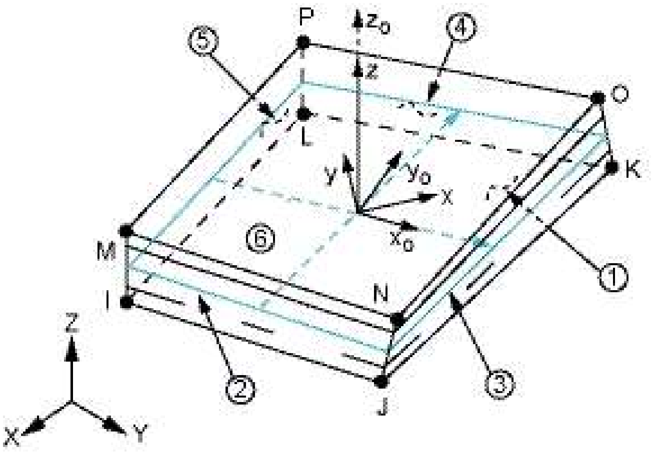


Fig -8: SOLSH190 geometry (courtesy: ANSYS 10)

Because of the different hole dimensions and angles, the different models and mesh structures were made. Sample mesh structure, boundary conditions and loading of the model for the analysis are illustrated in fig -9.

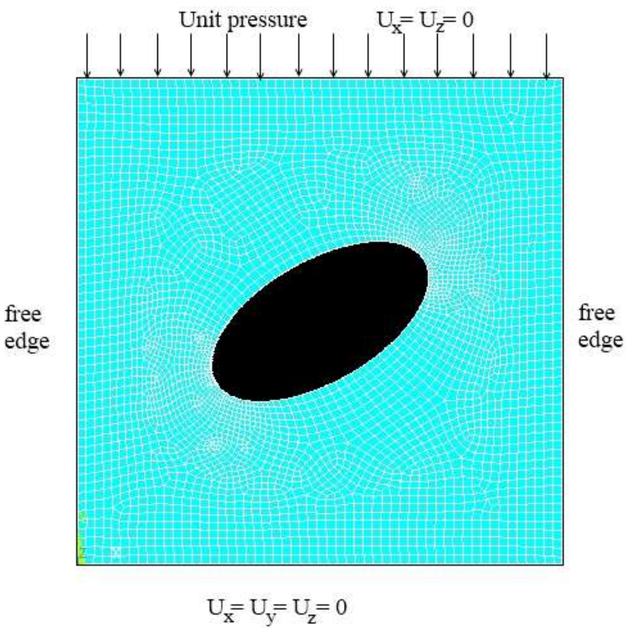


Fig -9: Sample mesh and boundary conditions

In this boundary condition, all degree of freedoms are constraint in one edge. The adjacent sides kept free. In the opposite side, displacement in the direction of X and Z are constraint and load applied in Y direction. The boundary conditions are shown in fig -9.

5.2 Thermal Buckling Analysis

5.2.1 Model and Boundary Conditions

Model used for thermal analysis is same as used for the mechanical buckling analysis. Square plate with dimensions of (a*a) 120 mm *120 mm and thickness of plate is 1.6 mm with elliptical hole. Material properties of graphite epoxy composite (CU-125NS) is used whose thermal expansion coefficients are
$\alpha_1 = 21.6\times10^{-6}/^0C$; $\alpha_2 = .018\times10^{-6}/^0C$

The element used for thermal analysis is SOLSH190.

Two types of boundary conditions are used for the analysis. 4 sides fixed condition and 2 sides fixed and 2 sides free. The boundary conditions used for the analysis is shown in fig -10 and 11

Since the selected element has only three degree of freedom on nodes, they are translational in X, Y and in Z direction, no need to consider the rotational degree of freedom.

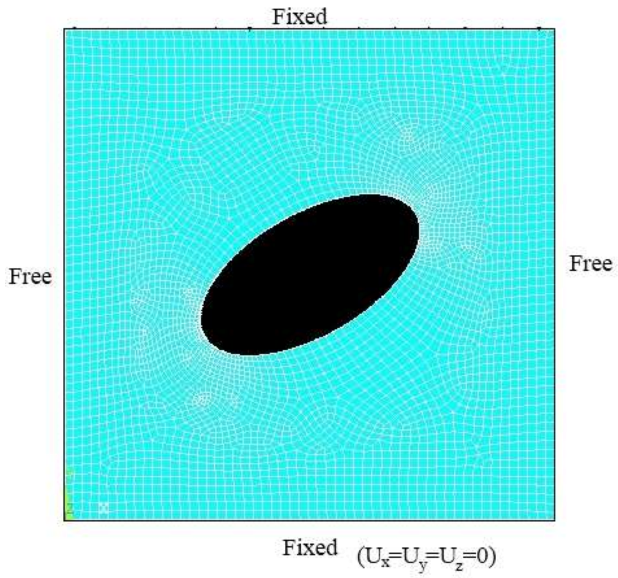


Fig -10: Two sides fixed and two sides free boundary condition

In 2 sides fixed and 2 sides free condition, two opposite sides are kept fixed and other two sides are kept free. The displacement in all direction is constraint in fixed sides. In 4 sides fixed condition, displacement in all direction is constraint in all sides.
For fixed edge $U_x= U_y= U_z= 0$

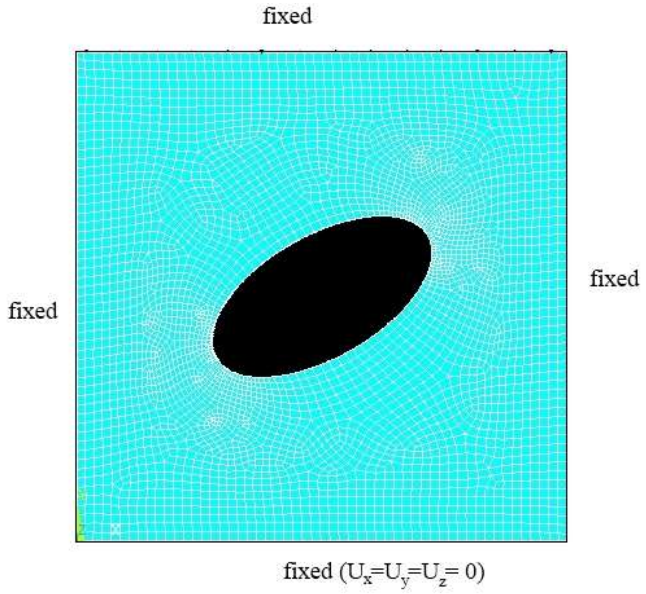


Fig -11: Four sides fixed boundary condition

5.2.2 Thermal Load (Uniform Temperature Profile Heating)

Uniform temperature loading case is used for the analysis. fig -12 explains the method of uniform temperature profile heating.

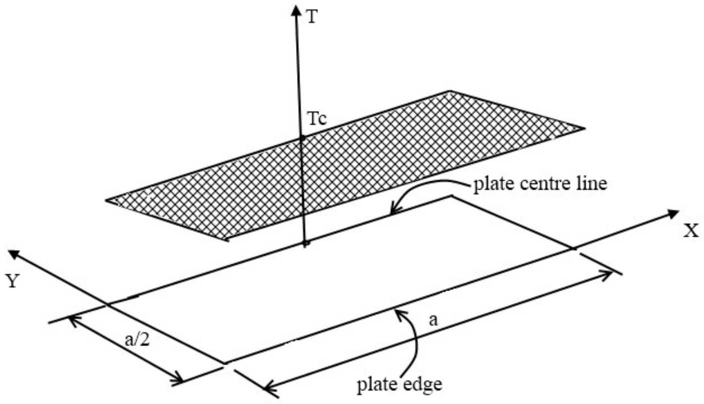


Fig -12: Uniform Temperature Profile Heating

Temperature load of 1ºC is chosen as input to all nodes of the finite-element model so that the eigen value calculated from ANSYS will give the buckling temperature Tc, namely

$$T_c = \lambda_c \times 1 = \lambda_c$$

Where λc is the eigen value which multiplies the applied temperature to give critical buckling temperature.

Critical buckling temperatures for different orientation of ellipse and for different values of c/a were found in this study. The variation of critical buckling temperature with increasing plate thickness also studied.

6. Results and Discussion

6.1 Mechanical Buckling Analysis Results

This study mainly focused on the variation of buckling load with the change in orientation of elliptical hole at the centre of the composite laminated plate. Also the variation of buckling load with c/a (ratio of minor diameter to the edge length of the plate) also studied. The results are shown in the following sections.

6.1.1 Variation of Buckling Load for Various Composite Layup with Change in Ellipse Angle α

b/a; c/a	Ellipse angle 'α'	Buckling Load (MPa) for different composite lay up			
		[0/90]$_S$	[15/-75]$_S$	[30/-60]$_S$	[45/-45]$_S$
0.5; 0.15	0°	74.25	70.22917	59.29167	49.96875
	15°	76.5625	75.63021	57.80208	52.1875
	30°	81.46875	74.41146	60.80208	54.4375
	45°	89.70313	86.78646	69.35938	64.85417
	60°	94.08854	91.23438	72.53125	65.875
	75°	95.625	93.34375	71	65.73438
	90°	99.79688	92.74479	75.82292	72.15625
0.5; 0.3	0°	65.26563	61.03646	56.99479	53.25
	15°	72.16146	64.79167	61.42188	57.29167
	30°	72.38021	67.92188	62.31771	58.25521
	45°	73.95833	67.64063	63.375	59.60938
	60°	74.35417	68.28125	64.76042	61.17188
	75°	76.40625	72.51563	65.75	61.69271
	90°	76.72396	73.38542	66.57292	61.63542
0.5; 0.45	0°	63.22917	59.55729	48.91146	47.36979
	15°	64.47396	60.75521	49.77083	51.26042
	30°	65.56771	58.54167	50.58854	50.64063
	45°	68.10417	60.76563	51.91146	51.60417
	60°	65.36458	61.63021	52.48958	51.42708
	75°	65.52083	61.25	51.90104	51.94792
	90°	64.71875	60.24479	50.01563	46.63021

Table -2: Buckling load for different ellipse angle

Here the ellipse angle is changed for different composite layups, taking one at a time and the buckling load is calculated by linear Eigen value buckling analysis. Table -2 gives the critical buckling loads obtained for different orientation and for different lay-ups.

Using the above values of buckling load the following three graphs were plotted. fig -13 shows the variation of buckling load with change in ellipse angle α for different lay-ups when b/a= 0.3 and c/a= 0.15.

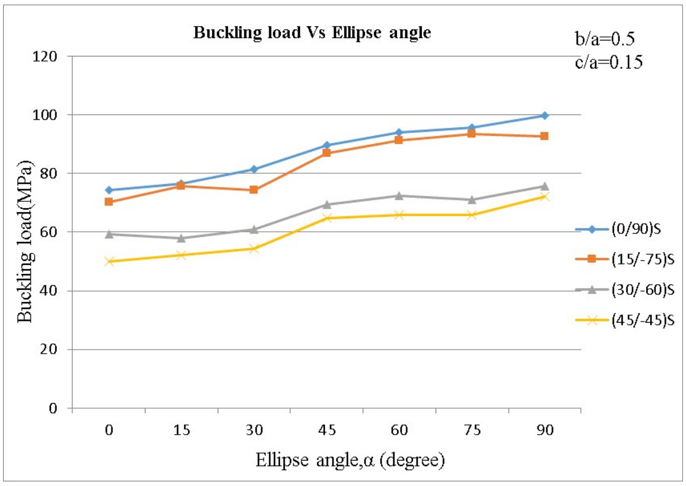


Fig -13: Variation of buckling load with change in ellipse angle for different composite layups (when b/a=0/5 and c/a=0.15)

The fig -13 shows that the buckling load increases when the value of ellipse angle increases. The maximum buckling load obtained for an ellipse angle $\alpha=90^{0}$.

The effect of ellipse angle on buckling load when b/a=0.5 and c/a=0.3 is shown in fig -14. Similarly the variation when b/a=0.5 and c/a=0.45 is shown in fig -15.

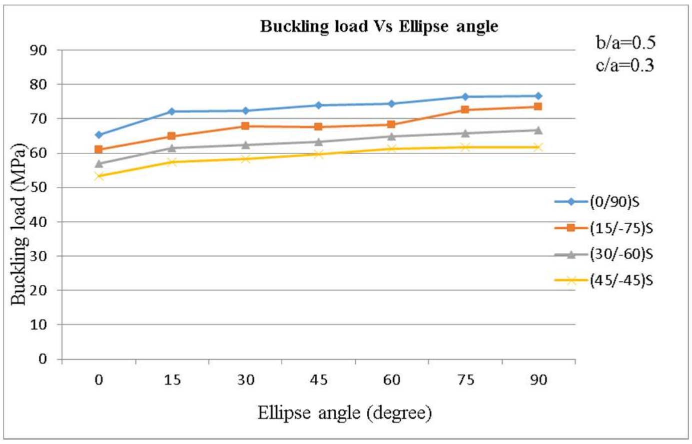


Fig -14: Variation of buckling load with change in ellipse angle for different composite layups (when b/a=0/5 and c/a=0.3)

In fig -14, c/a ratio used is 0.3 and b/a is 0.5. Here also the trend of variation in buckling load with ellipse angle is similar to the figure -13. But the rate of increase in variation is less in fig -14 compared to fig -13.

Fig -15 shows the variation in buckling load with ellipse angle when b/a=0.5 and c/a=0.45. As c/a ratio reaches the value 0.45, the variation is very less compared to the cases when c/a=.15 and c/a=.3. From these three figures it's clear that the variation of critical buckling temperature decreases as the value of c/a increases.

In fig -13, 14 and 15, the maximum buckling load is for cross ply laminate $[0^{0}/90^{0}]_{s}$ followed by angle ply $[15^{0}/-75^{0}]_{s}$, $[30^{0}/-60^{0}]_{s}$ and minimum buckling load is for $[45^{0}/-45^{0}]$. So from the analysis it is clear that cross ply laminate is stronger and weakest is $[45^{0}/-45^{0}]$ among the analyzed laminates.

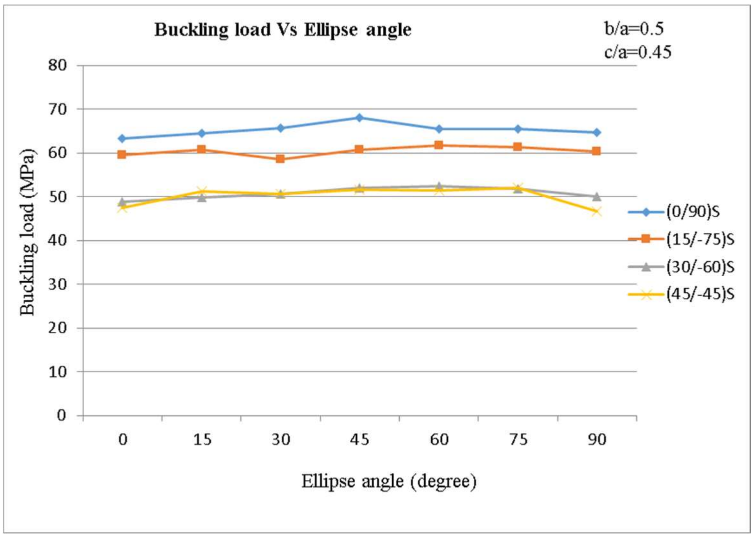


Fig -15: Variation of buckling load with change in ellipse angle for different composite layups (when b/a=0/5 and c/a=0.45)

6.1.2 Effect of 'c/a' ratio on buckling load

The variation of buckling load with minor axis, keeping major axis as a constant is also studied. The ratio of minor axis(c) to the edge length (a) is used for the study. The variation plotted in fig -16 is for an ellipse angle 45°. The fig -16 shows that the rate of variation of buckling load decreases as the value of c/a increases.

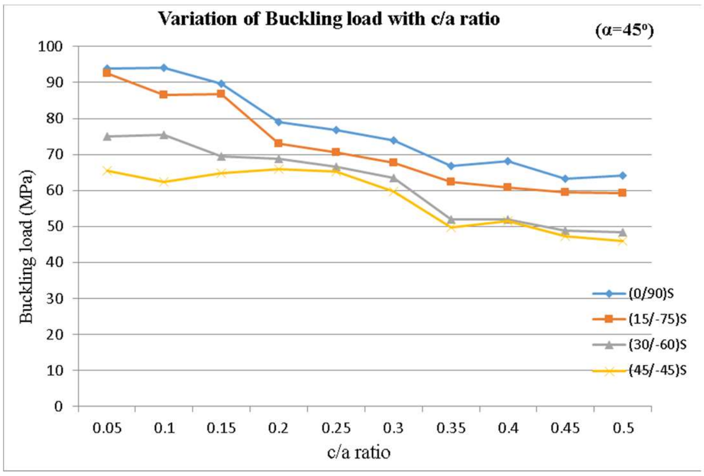


Fig -16: Variation of buckling load with c/a ratio (α=45°)

The buckling load shows decreasing behavior as the value of c/a increases. When c/a crosses the value 0.35 the decreasing rate of buckling load is less. When the minor axis is close to the value of major axis, the variation in buckling load with the orientation of ellipse is less.

6.1.3 Variation of buckling load with c/b ratio

The variation of buckling load with c/b ratio (minor axis to major axis) is calculated for a cross ply laminate [0/90]S. When c/b=1, the hole become circular. The area of the ellipse is maintained constant (π*30*60) and major and minor axis is varied for different c/a ratios. The buckling load is calculated for different c/a ratio (0.2, 0.4, 0.6, 0.8 and 1) for constant ellipse angle 0^0. The variation of buckling load with c/b ratio is shown in fig -17.

Table -3: Buckling loads for different c/a ratio

c/b ratio	0.2	0.4	0.6	0.8	1
Buckling load (MPa)	60.51563	116.3177	128.8802	139.724	128.8802

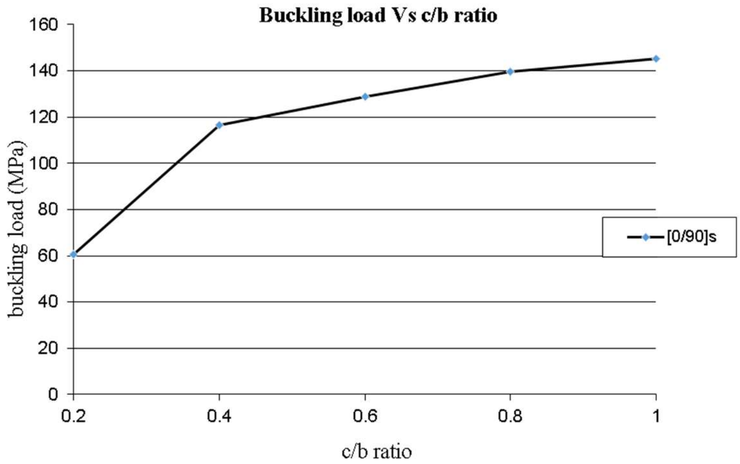
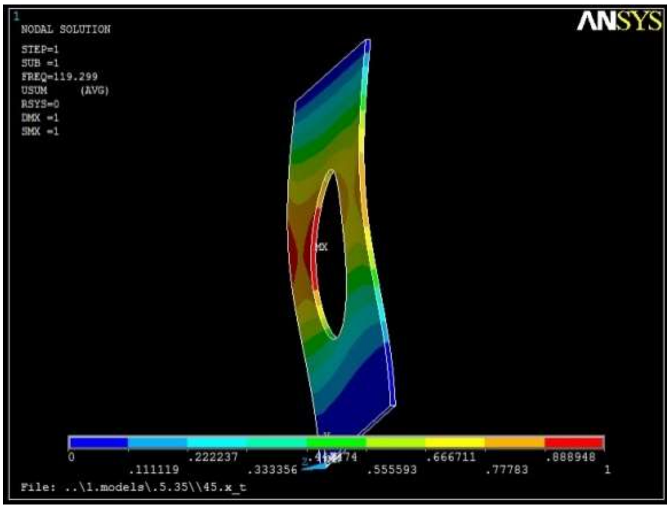


Fig -17: Variation of buckling load with c/b ratio

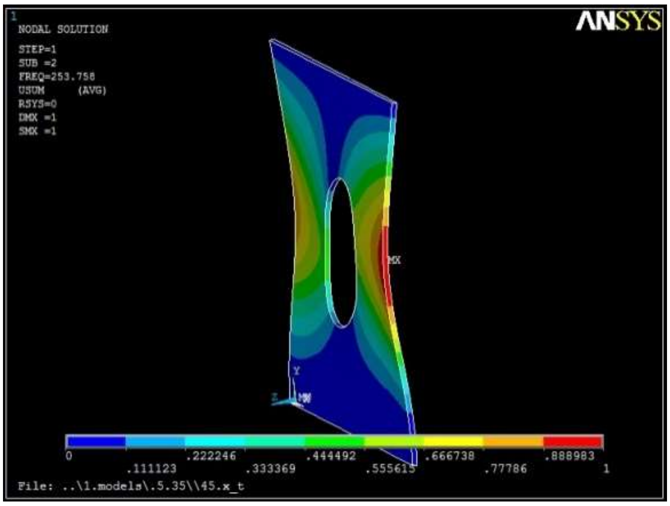
The fig -17 shows that as c/b ratio increases, the value of buckling load increases. Thus as the elliptical hole transforms into circle, it withstands higher buckling load. The maximum buckling load is for maximum when c/b=1, ie, when ellipse becomes perfectly circle. The rate of increase in buckling load is very high, when the value of c/b increases from 0.2 to 0.4.

6.1.4 Mode Shapes

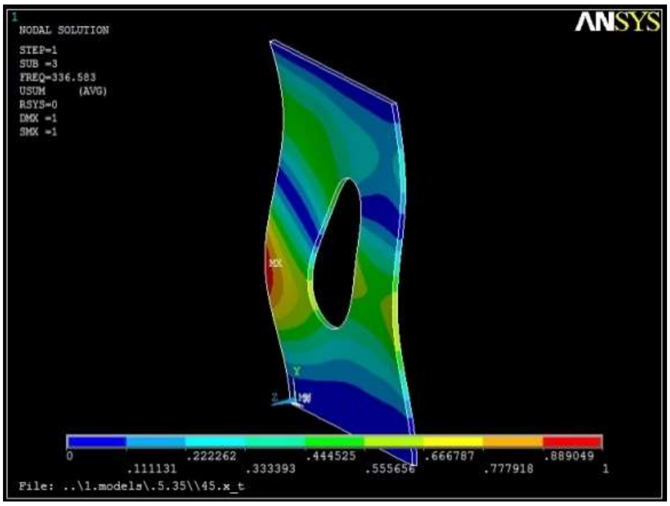
The mode shapes of buckling can be plotted using ANSYS. Buckling mode shapes of composite laminate plate $[45/-45]_S$ (When b/a=0.5 and c/a=0.35) are shown in fig -18 a,b,c,d and e .



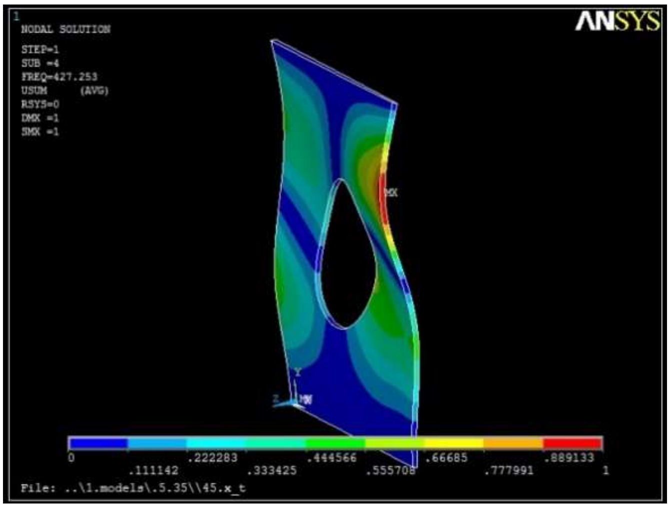
(a)



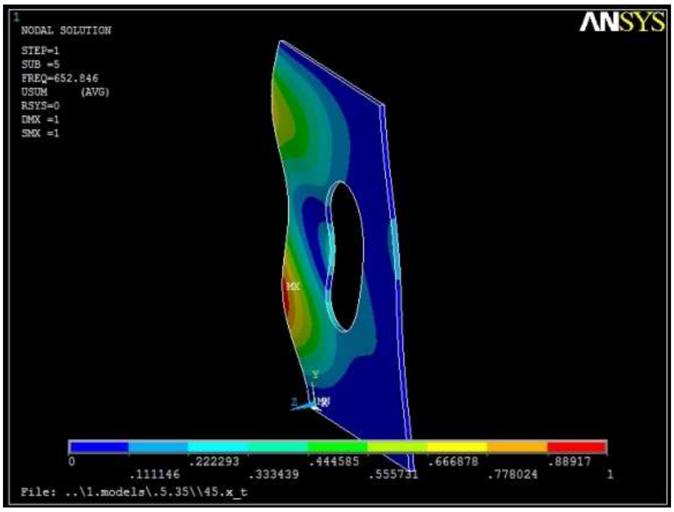
(b)



(c)



(d)



(e)

Fig -18: Mode shapes.

6.2 THERMAL BUCKLING ANALYSIS RESULTS

Thermal buckling analysis has been carried out with two different boundary conditions as mentioned in section 5.2.1. Four sides fixed condition and two sides fixed and two sides free condition.

6.2.1 Four sides fixed condition

In this boundary condition the variation of critical buckling temperature with the orientation of ellipse, increasing thickness and increasing diameter have been analyzed.

6.2.1.1 Variation of critical buckling temperature with the orientation

The variation of critical buckling temperature with the orientation of ellipse (α) is calculated for cross ply and angle ply laminates. The critical buckling temperatures for different orientation of ellipse are given in table -4

Table -4: Variation of buckling temperature with ellipse angle for different lay-ups.

Ellipse angle	Buckling temperatures for different lay-ups (°C)			
	$[0/90]_S$	$[15/-75]_S$	$[30/-60]_S$	$[45/-45]_S$
0°	39.74	41.32	41.65	41.52
15°	39.42	41.6	40.17	39.7
30°	38.87	37.98	38.24	38.01
45°	39.81	39.51	39.3	37.41
60°	38.11	38.37	38.53	37.69
75°	38.13	39.87	40.53	39.7
90°	39.68	41.19	41.21	41.47

Fig -19 shows the variation of buckling temperature with ellipse angle for different lay-ups.

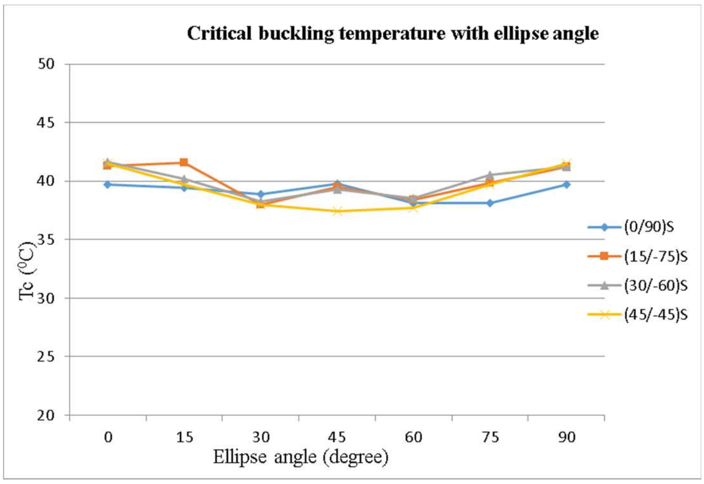
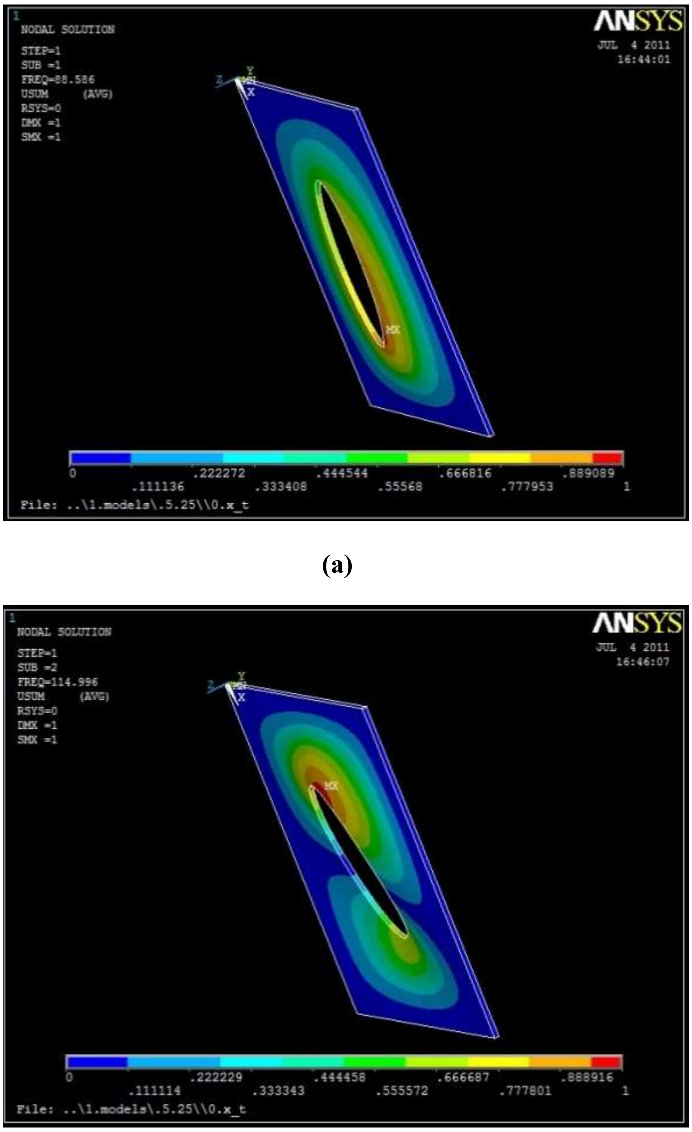


Fig -19: Variation of critical buckling temperature with change in ellipse angle for 4 sides fixed condition

The fig -19 shows that the variation of buckling temperature with ellipse angle is very less in four sides fixed condition. The variation is in the order of 2 °C - 4°C. Also the buckling temperature for different lay-ups is almost similar.

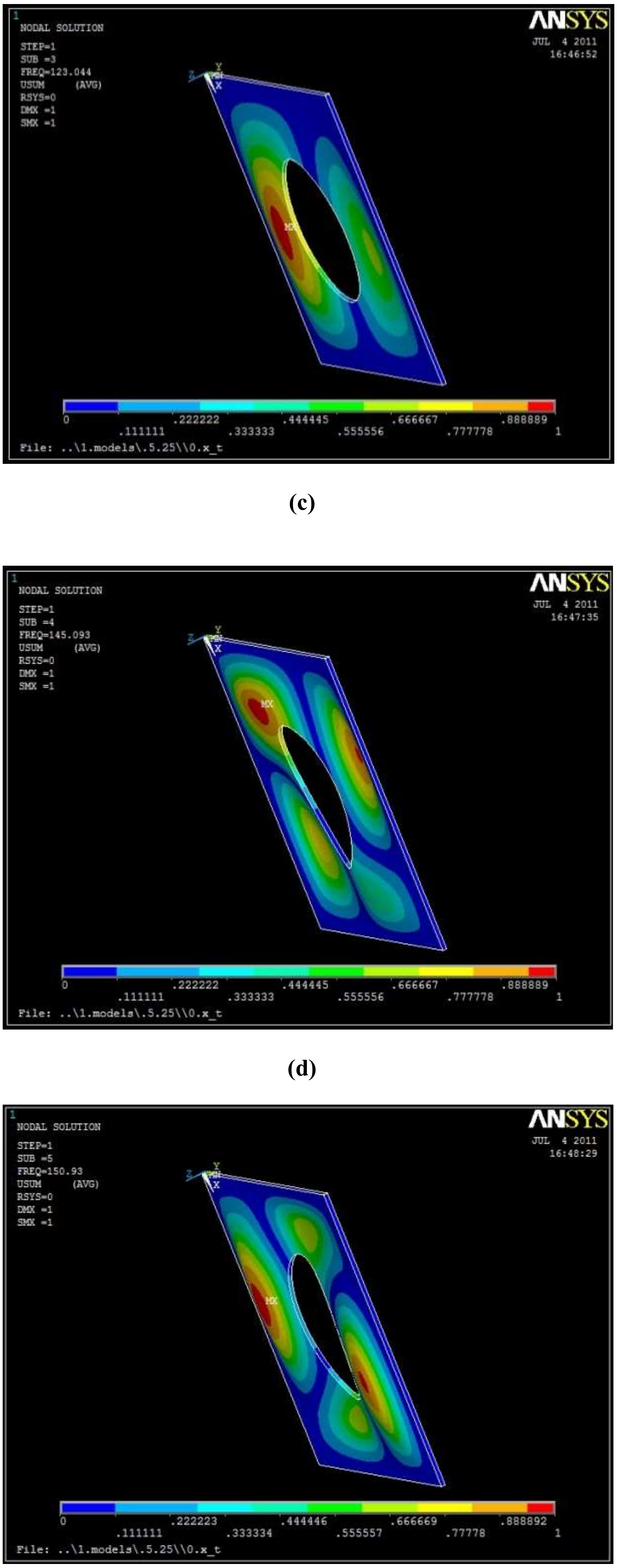
6.2.1.2 Mode shapes

The fig -20 a,b,c,d,e and f represents the buckling mode shapes of 4 sides fixed plate with elliptical hole at the centre.



(a)

(b)



(c)

(d)

(e)

Fig -20: Mode shapes for buckling of 4 sides fixed plate.

6.2.2 Two Sides Fixed and Two Sides Free

In this analysis two opposite sides kept fixed and other two sides kept free. Uniform temperature distribution is used as thermal load. Here also variation of buckling temperature with ellipse angle are analyzed.

6.2.2.1 Variation of buckling temperature with ellipse angle (α)

The variation of buckling temperature with the orientation of elliptical hole for different lay-ups is given in table -5 and the values plotted are shown in fig -21.

Table -5: Variation of buckling temperature with ellipse angle for different lay-ups in two sides fixed and two sides free boundary condition

Ellipse angle	Buckling temperatures for different lay-ups (°C)			
	$[0/90]_S$	$[15/-75]_S$	$[30/-60]_S$	$[45/-45]_S$
0°	32.3	33.9	34.4	34.55
15°	32.16	36.33	35.65	35.5
30°	28.66	35.2	30.42	30.87
45°	25.35	30.37	27.45	30.04
60°	26.34	31.45	27.93	32.9
75°	30.2	29.88	31.34	28.43
90°	29.13	28.77	29.69	28.04

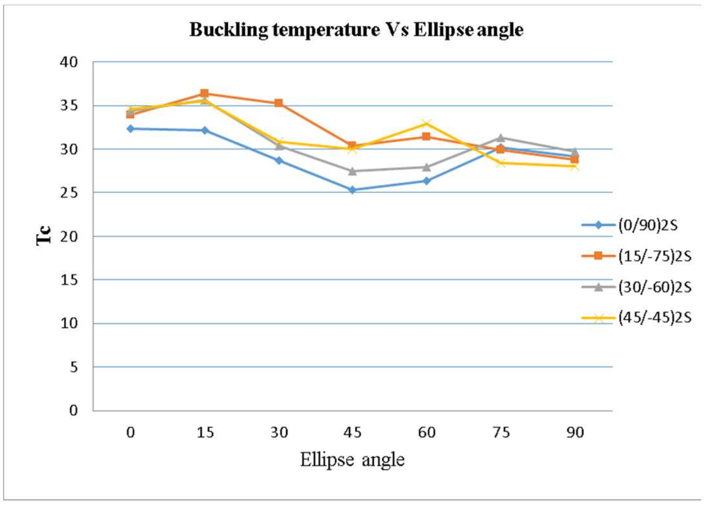


Fig -21: Variation of buckling temperature with ellipse angle

In the above figure buckling temperature variation with ellipse angle is shown. Buckling temperature decreases as the value of ellipse angle increases. But the change is very less and response of each lay-up shows different response in variation of buckling load.

7. Conclusions

The buckling response of a graphite epoxy composite laminated square plate with centred elliptical hole is investigated in this study. Both mechanical buckling and thermal buckling analysis has been done. In mechanical buckling analysis, the elliptical hole is positioned according to various angles from $\alpha=0^o$ to 90^o. Additionally, the effect of 'c/a' and 'c/b' on buckling loads are calculated. Models were created by using AutoCAD 3D software and solution is done with FEM using ANSYS. From the present study, the following conclusions can be made. Firstly, the magnitudes of buckling loads are decreased by increasing c/a ratio. This means that as the size of the hole increases the strength of the plate decreases. The increasing of hole positioned angle cause to decrease of buckling loads. The cross ply $[0/90]_S$ composite laminate plates are stronger than other angle ply ($[15/-75]_S$, $[30/-60]_S$, $[45/-45]_S$) laminated plates. Meanwhile, the $[45^o/-45^o]_S$ laminated plate is observed as the weakest angle-ply plate.

In thermal buckling analysis, two types of boundary conditions are used. Four sides fixed condition and the other is two sides fixed and two sides free condition. In 4 sides fixed case critical buckling is higher compared to the two sides fixed and two sides free boundary condition.

Future scope

Experimental analysis can be performed to validate the results obtained. Buckling analysis of laminated composite plates with different boundary conditions, materials and cut outs can be carried out. Delamination effect and post buckling behavior of laminated composite plate, thermal buckling analysis with different thermal loads can be studied.

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