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Finite Element Analysis and Numerical Simulation of Composite Laminates

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***Abstract:** Minimization and miniaturization plays a major role in structural engineering design. The fiber reinforced composites finds suitable replacement of conventional materials. Apt aim of using the composite material is for high strength to weight ratio and to meet the applications with specific properties. In this work the buckling behavior of composite laminate plates is studied by varying the parameters like material for the plies, ply orientation angles, size of the plate etc., Finite element analysis is used for carrying out numeral cases of the buckling analysis. Numerical simulation for the two ply and three ply composite laminates was also carried out based on the first order plate theory and shear deformation theory to validate the obtained results. The variation in buckling behavior of the laminates vs. ply angles and material combinations were studied.*

***Keywords:** Buckling, Classical lamination theory, Fiber reinforced composites, Laminates.*

I. INTRODUCTION

Composite material is a macroscopic combination of two or more distinct materials having a recognizable with enhanced properties. Composites are not only used in structural applications, but also electrical, thermal and environmental applications. Apt aim of using the composite material is for high strength to weight ratio and to meet the applications with specific properties.

Plated structure is the basic common shape in structural engineering and all the applications too. Any structure that requires to cross section properties over and above those provides by rolled sections is built using plates and there by become plated structures. Some few applications of plates are Aerospace, Defenses, Sports and wherever the properties to be tailored.

When plates are subjected to the application of large inplane load either compressive or shear, they buckle. The phenomenon of buckling is actually a nonlinear one. Among the various materials Carbon epoxy and Graphite epoxy were used in more applications as its attention in pre-buckling and post-buckling characteristics.

The objective of this article is to present the buckling behavior of orthotropic three layer Carbon epoxy-graphite epoxy composite laminate plates. The ply angles are varied and their buckling loads are compared for various aspect ratios. For the chosen laminate configuration, the mid plane strain components are functions of the applied inplane loads as well as the fiber orientation angle. The analytical validation is done on comparing with the numerical simulation values and the results are available with this literature.

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II. LITERATURE REVIEW

Two dimensional finite element formulation for the consolidation process of thick thermosetting composites is presented and the corresponding finite element code is developed [1].The initial buckling loads of symmetrically laminated rectangular orthotropic plates under uniaxial compression are determined in a closed-form analytical manner. The considered laminates are simply supported at all edges and furthermore subjected to elastic rotational restraints at the unloaded edges [2]. The buckling of an orthotropic rectangular laminate with weak interfaces is investigated. The state-space formulations established directly from the 3D theory of elasticity are employed. The weak interfaces are treated in a unified way by adopting a linear spring-layer model [3]. The post-buckling response of the functionally graded materials plate, subjected to thermal and mechanical loadings, is obtained analytically, using fast converging finite double Chebyshev polynomials [4]. Post buckling analysis of piezoelectric laminated doubly curved shells is presented using finite element method. Post buckling responses of [±45°_/_45°_] laminated spherical, cylindrical and conoidal shell panels with piezoelectric layer are analyzed and the nonlinear load–deflection curves are presented. [5]. The effects of fiber orientation and aspect ratio distribution on the overall elastic properties of composites using the Mori–Tanaka's method, discussed [6]. The buckling resistance of fiber-reinforced laminated cylindrical panels with a given material system and subjected to uniaxial compressive force is maximized with respect to fiber orientations by using a sequential linear programming method together with a simple move-limit strategy. The significant influences of panel thicknesses, curvatures, aspect ratios, cutouts and end conditions on the optimal fiber orientations and the associated optimal buckling loads of laminated cylindrical panels have been shown [7]. The post buckling behavior of a flat, stiffened, carbon fibre composite compression panel has been studied, theoretically and experimentally. The panel has a collapse load three times excess of buckling load [8]. Nonlinear finite element analysis of laminated composite shell structures with smart material laminae is presented in the study. Third-order shear deformation theory is chosen for the shell formulation and it is used to study deflection suppression characteristics of laminated composite shells.

A number of parametric studies are carried out to understand the damping characteristics of laminated composite shells [9]. Carbon fibre Epoxy composite fracture characterization and failure analysis were carried out with the aid of scanning electron microscope [10]. Effect of thickness on the buckling of a perfect thick plane strain cross-ply ring (very long cylindrical shell) is investigated. A linearized version of a fully nonlinear finite element analysis, that employs a cylindrically curved 16-node layer-element, and is based on the assumption of layer-wise linear displacements distribution through thickness (LLDT), is utilized for computation of hydrostatic buckling pressure of the afore-mentioned cross-ply ring [11]. A class of problems of composite laminates and FGM under extension, twisting and bending is formulated in state space setting. Solution approach for analysis of deformation and the stress fields is developed. Solution for torsion of cross ply laminates derived [12].

III. DESCRIPTION OF THE BUCKLING ANALYSIS

The force acting on the composite plates is shared by the resin and the fiber simultaneously. The buckling is assumed to occur when a certain load level is reached. The surface of the plate is subjected to uniformly distribute compressive stresses resulting from the given compressive normal load.

A laminate is a stack of laminae bonded together to form an element having a desired stiffness and thickness. The laminae are stacked according to a pre-described sequence and due to some of the laminae being at various orientations, the laminate is able to resist loads in several directions. Macro mechanics is the study of a laminate's response to loading based on the properties of each lamina .Classical Lamination Theory (CLT) is used to analyze a laminate for buckling load.

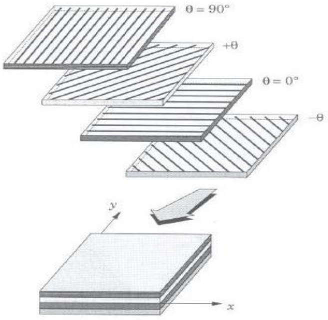

Fig.1 Layout of composite laminate with different orientation

Weight reduction with enhanced strength and other material properties are the prime concern in design engineering. Minimization and miniaturization are the requirements in novel engineering design. Hence newer materials are required to meet the above challenges.

In this paper an attempt is made to study the buckling behavior of three ply composite laminate plates by varying the parameters like ply orientation angles and aspect ratios.

Finite element analysis is used for carrying out buckling analysis for numeral cases and the tool classical lamination theory is used to validate the obtained results.

The following assumptions are followed in implementing Classical Lamination Theory

1) The laminate is assumed to consist of laminae that are perfectly bonded together.

The bonds are assumed to be infinitesimally thin as well as non-shear-deformable. Therefore, the displacements are continuous across lamina boundaries so that no Lamina can slip relative to another.

2) Deflections and strains are small compared to the thickness of the laminate.

3) Plane sections that are initially normal to the mid-plane of the laminate remain normal to the mid-plane after deformation requiring plane sections to remain plane is equivalent to ignoring the shear strains

4) The stress normal to the mid-plane is small compared to the other stress Components and can be neglected.

5) The strain perpendicular to the middle surface is ignored.

IV. NUMERICAL SIMULATION OF COMPOSITE LAMINATES

The critical buckling load of laminated plates can be

calculated from the following relation,

$$N_x = \prod^2 \left[D11(m/a)^2 + 2(D12 + 2D66) \times (1/b^2) + D22 \times (1/b^4)(a/m)^2 \right] \quad \ldots [1]$$

Where,

Q_{ij} = plane stress reduced stiffness, N/mm

D_{ij} = Bending stiffness, N/mm

M = Cross-ply ratio

F = Ratio of principal lamina thickness

t = total thickness of plate, mm

γ_{ij} = Poisson ratio

m = number of half wave in X direction

a = Length of the plate, mm

b = width of the plate, mm

E_1= Young's modulus in X-direction, N/mm^2

E_2 = Young's modulus in Y-direction, N/mm^2

Where

$$Q_{22} = \frac{E_2}{(1 - \gamma_{12} \times \gamma_{21})}$$

$$Q_{66} = G_{12}$$

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$$D_{11}=\frac{[(F-1)P+1]Q_{11}\times t^3}{12}$$

$$D_{12}=\frac{Q_{12}\times t^3}{12}$$

$$D_{22}=\frac{[(1-F)P+F]Q_{22}\times t^3}{12}$$

$$D_{66}=\frac{Q_{66}\times t^3}{12}$$

$$F=\frac{E_2}{E_1}$$

$$P=\frac{1}{(1+M)^3}+\frac{M(N-3)[M(N-1)+2(N+1)]}{(N^2-1)(1+M)^3}$$

$$t=t_1+t_2+t_3$$

$$M=\frac{t_1+t_3}{t_2}$$

$$Q_{11}=\frac{E_1}{(1-\gamma_{12}\times\gamma_{21})}$$

$$Q_{12}=\frac{\gamma_{12}\times E_2}{(1-\gamma_{12}\times\gamma_{21})}$$

V. FINITE ELEMENT FORMULATIONS

By expressing the equation of buckling during a compressive load, a three dimensional finite element formulation is presented in this section. The finite element method is a numerical analysis technique for obtaining approximate solution to varieties of engineering problems.

In the finite element analysis actual continuum or body of the matter like solid, liquid or gas is represented as an assemblage of subdivisions called finite element. These finite elements are connected at the nodes then the variations of the field variable inside the finite element can be approximated by the single function.

The approximating functions are defined in terms of the values of the field variables of the nodes. When the equations form the whole continuum is written the new unknowns will the nodal value of the field variables. By solving the field variables, the nodal values of the field variable will be found out. If the field variable found out, the approximating functions define the field variables throughout the assemblage of element. Solid 46 is a layered version of the 8 node, 3D solid element. It is designed to a nodal layered shell or layered solids and allows up to 250 uniform thickness layers.

The solid 46 element is chosen for discretization of the laminates. Plates with various orientations, aspect ratio were considered for the buckling analysis. The plate having length “a” width “b” and thickness “t” is chosen for analysis. Aspect ratio is the ratio between lengths of plate to width of plate. In this analysis length of plate is varied to obtain the aspect ratios 1.0, 1.25, 1.50, 1.75, 2.0

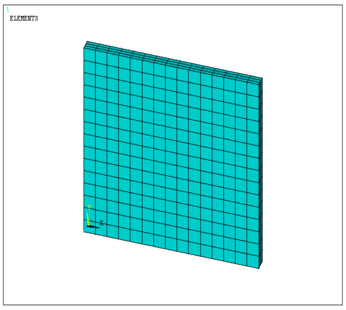

Fig.2. Finite Element mesh

During analysis initially the load and boundary conditions are kept constant and ply orientation and aspect ratio are varied and solved for the behavioral study of composite laminates. The boundary condition is, the four sides of the plates are fixed with 225 nodes, Aspect ratio: 1.5 (1000 mm * 500 mm) and 3 layered orthotropic plate.

Table 1.Material Properties

S.No	Material property with notations	Carbon epoxy	Graphite epoxy	unit
1	Youngs modulus in XY Direction(E_1)	142000	206842	N/ mm^2
2	Youngs modulus in YZ Direction(E_2)	10300	5171	N/ mm^2
3	Youngs modulus in XZ Direction(E_3)	10300	5171	N/ mm^2
4	Poisson ratio in X-Direction (γ_{12})	0.27	0.25	-
5	Poisson ratio in Y-Direction (γ_{21})	0.20	0.25	-
6	Poisson ratio in Z-Direction (γ_{13})	0.20	0.25	-
7	Shear modulus in XY-Plane(G_{12})	7200	2585	N/ mm^2
8	Shear modulus in YZ-Plane(G_{23})	4290	2585	N/ mm^2
9	Shear modulus in XZ-Plane(G_{13})	7200	2585	N/ mm^2

VI. NUMERICAL VALIDATIONS

Using the finite element formulation of orthotropic composite plates, the buckling analysis for the various aspect ratios is performed. In order to illustrate the accuracy of the proposed finite element formulation, it is assumed here that laminate thickness is constant ie $t_1 = t_2 = t_3$. For this numerical analysis a uniform compressive load of 1 KN is assumed to be applied over the surface of the plate.

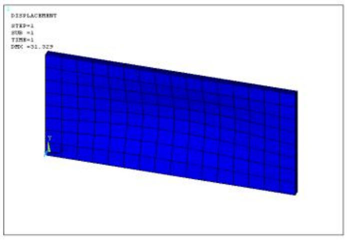

Fig .3 Deformed shape

Critical buckling loads of various plates were found using the commercially available finite element software, ANSYS.

Eigenvalue buckling analysis predicts the bifurcation point the critical buckling load) of ideal linear elastic structure.

Table 2. Result from ANSYS (The buckling loads specified by Newton)

S.No.	PLYANGLE	ASPECT RATIO				
		1.0	1.25	1.5	1.75	2.0
1	0°-30°-0°	16.33	15.423	14.498	12.105	14.116
2	0°-30°-45°	14.613	10.49	10.799	15.862	14.474
3	0°-45°-0°	17.785	16.727	16.692	13.916	13.843
4	0°-45°-30°	17.78	13.57	13.494	14.308	15.499
5	0°-(-30°)-(-45°)	14.46	10.496	10.798	15.748	14.116

Table 3.Comparison of result from laminated plate theory and ANSYS

S. No	Aspect ratio	Buckling load from laminated plate theory (1)	Buckling load from ansys (For uni plies) (2)	Error in %
1	1.0	16.0855	15.770	1.95
2	1.25	12.2559	11.512	6.06
3	1.50	10.7194	9.6171	10.28
4	1.75	10.3595	8.8460	14.6
5	2.0	10.7940	9.6281	10.8

VII. PLOTS OF BUCKLING LOAD VS ASPECT RATIO

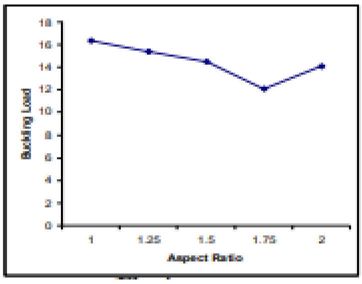

Fig.4

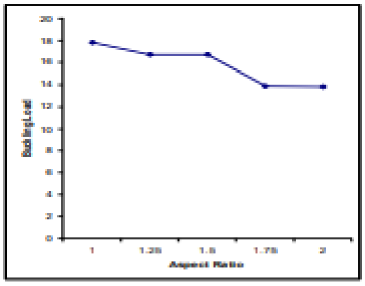

Fig.5

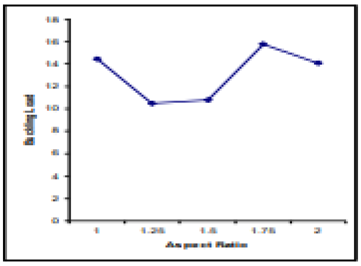

Fig.6

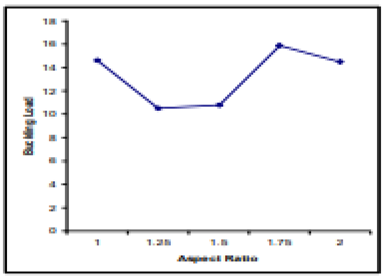

Fig.7

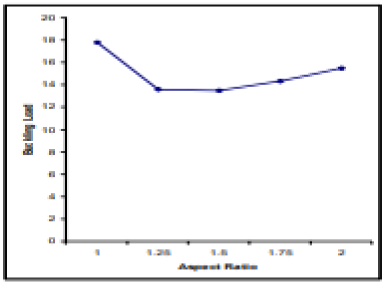

Fig.8

From the Figure 4 it is found that the buckling load for 0°-30°-0° oriented plates decreases, when the aspect ratio increases upto 1.75, for the given plate dimensions. After the increase in aspect ratio from 1.75 the buckling load also increases.

From the Figure 5 it is found that the buckling load for 0°-30°-45° oriented plates decreases, when the aspect ratio increases upto 1.25, for the given plate dimensions. After the increase in aspect ratio from 1.25 the buckling load also increases.

From the Figure 6 it is found that the buckling load for 0°-45°-0° oriented plates decreases, when the aspect ratio increases.

The increase in buckling load with respect to increase in aspect ratio was not noticed upto aspect ratio 2.

From the Figure 7 it is found that the buckling load for 0°-45°-30° oriented plates decreases, when the aspect ratio increases upto 1.5, for the given plate dimensions. After the increase in aspect ratio from 1.5 the buckling load also increases.

From the Figure 8 it is found that the buckling load for 0°-(-30)°-(-45)° oriented plates decreases, when the aspect ratio increases upto 1.5, for the given plate dimensions. After the increase in aspect ratio from 1.5 the buckling load also increases upto aspect ratio 1.75 and again decreases for the increase in aspect ratio.

6 Conclusion

From the analysis it is found that the ply orientation greatly influences the buckling load of three ply laminates. The buckling behavior for various ply orientations illustrates that the buckling load decreases with the increase in aspect ratio until a critical buckling load is reached and again it increases. The buckling load from laminated plate theory and ANSYS was compared in the table and the average error percentage was found to be 8.738%. Thus the result highlights that the orientation of plies plays key role in buckling behavior and minimization of aspect ratio enhances higher buckling load.

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