Determination of the Effect of Fiber Volume Fraction on The Buckling Behavior of Ant-Symmetric Angle Ply Laminated Carbon Fiber, Boron Fiber and Glass Fiber Composite Plates.

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ABSTRACT: There have been numerous studies on the composite laminated structures which use for many applications in engineering fields namely aerospace, biomedical, civil, marine, sport goods, electronics materials and mechanical engineering because of their high strength and stiffness to weight ratio, ease of handling, good mechanical properties, low fabrication cost, excellent damage tolerance and impact resistance. Buckling behavior of laminated composite plates subjected to in-plane loads is an important factor specially in the design of Aerospace crafts and launch vehicle components.
The buckling behavior of the anti-systematic angle play, simply supported edges and application of a uniaxially compressive loads was considered. The buckling load of the plat was formulated using energy method and Classical lamination theory.
In this study, the influence of fiber volume fraction, ply orientation, and aspect ratio on the buckling behavior of simply supported reinforced glass fiber, carbon fiber and boron fiber laminated composite plates was analyzed theoretically and numerically by using MATLAB and ANSYS.

The result of the analysis shows, for any given fiber volume fraction the buckling resistance of composite materials decreases linearly within the range of orientation of 0 to 30 degree and increases linearly from 300 to 600 and decreases thereafter up to 900. In other cases, for any given angle of orientation, the buckling load increases with the increase in fiber volume fraction. The results show that the maximum value of the critical buckling load is found at 600 for all plates, while the minimum value of the critical buckling load is found at 300. To verify the results, Comparisons were made using MATLAB result and ANSYS for different layered and orientation angle of glass fiber, carbon fiber and boron fiber laminated plates.

Key Words: anti-symmetric, laminate, fiber volume fraction, orientation angle, glass fiber, carbon fiber, boron fiber, critical buckling, simply supported and uniaxial load.

INTRODUCTION

Composite materials are materials with two or more constituents combined together to form a material with different, better mechanical and physical properties than those of the individual constituents. Fiber reinforced composite plate is a combination of a series of fibers surrounded by a solid matrix. A layer of composite material is defined as a lamina and stacking laminae forms a laminate.
Composites used for typical engineering applications are advanced fibers or laminated composites, such as fiberglass, glass-epoxy, carbon-epoxy, graphite-epoxy, Kevlar and boron-epoxy etc.

Paul Davidson and Anthony M. Waasy (2012) Compression strength experiments were conducted on carbon fiber unidirectional specimens with defects of varying aspect ratios and corresponding misalignment angles. (12)
Luyang Shan (2007) investigated Explicit analyses of flexural-torsional buckling of open thin-walled FRP beams, local buckling of rotationally restrained orthotropic composite plates subjected to biaxial linear loading and associated applications of the explicit solution to predict the local buckling strength of composite structures (i.e., FRP structural shapes and sandwich
cores), and delamination buckling of laminated composite beams are presented (14)

Kyle Rosenow (2016) experimentally tested some High-powered rockets use thin walled carbon-fiber reinforced polymer (CFRP) tubes as the primary structure and the tubes experience compressive stress during flight, which is estimated at 18MPa. The tube laminate is an angle-ply orientation testing the winding angles 35°, 50°, 65°, and 80° and winding patterns 1/1 and 8/1 in combination using an unsupported parallel compression test. Coupons are one-inch in height, 2.5 inches in diameter and fail in buckling. (13)
Timoshenko (1961), was found the exact solutions of buckling properties of linear elastic isotropic of thin rectangular plates.

Ashton and Waddoups (1969) determined critical buckling loads for the general case of anisotropic for rectangular plates by using an approximate Rayleigh-Ritz solution.

Ashton and Whitney (1970) formulated approximate buckling load equations for laminated plates. They treated the specially orthotropic laminate case as equivalent to homogeneous orthotropic plates.

Khdeir (1989) investigated the stability of anti-symmetric angle-ply laminated plates to see the influence of the number of layers, lamina orientation, and the type of boundary conditions using a generalized Levy type solution to determine the compressive buckling loads of orthotropic rectangular shaped plates.

Jawad Kadhim Uleiwi (2006) deals the estimation of critical load of unidirectional polymer matrix composite plates by using experimental and finite element techniques at different fiber angles and fiber volume fraction of the composite plate.

The different parts of an aerospace craft such as control surfaces, skin, web of ribs, engine bays, bulkheads, cockpit, windows, panels, fuel thanks some other areas are subjected to compressive stresses and this stresses cause buckle of those components.

The aim of performing this research is investigating the effect of fiber volume fraction on the buckling behavior of laminated glass fiber, carbon fiber and boron fiber composite plates which is subject to in plane compressive load. The analysis was carried out theoretically and numerically with different layer, orientation angle varied from 0 to 90 degrees in steps of 15 degrees for the given thickness of those materials.

METHODOLOGY

The methodologies used in this study were reviewed different literatures, driving equations of laminated plates for selected composite materials. using these equations, the buckling strength of different laminates were determined with varying fiber volume fraction, angle play and number of layers computed, analyzed and compared using ANSYS and MATLAB to justify the result is correct.

a. GOVERNING BUCKLING PRINCIPLES AND EQUATIONS

Classical Lamination Theory (CLT) is used to analyze a laminate based on the laminae that make-up the laminate. Using CLT, the stiffness matrices (A, B, D matrices) for a laminate to determine the response of a linear elastic laminate, using macro and micromechanics mainly the stress-strain relations of individual orthotropic lamina under a state of plane stress in principal material directions.

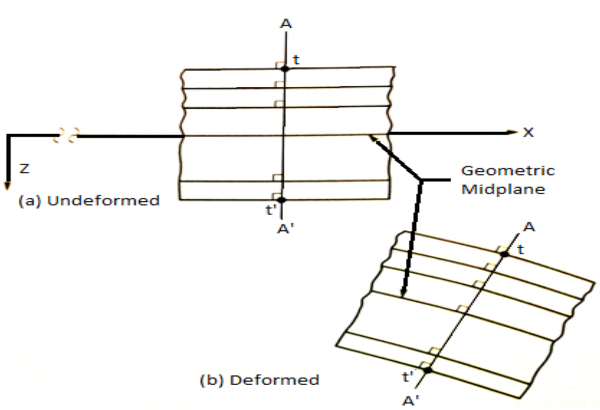


Fig.1. the un-deformed and deformed (source R.Jone)

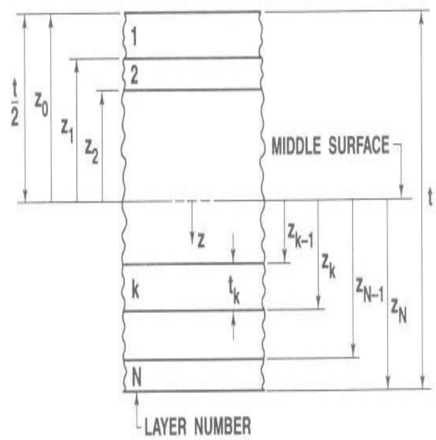


Fig.2. The Nth number of layered laminate shape of the plate (source R.Jone)

The effect of the number of layers on the buckling load is found by dividing a constant thickness, equal-weight angle-ply laminate into more and more laminae. The influence of bending-extension coupling is to reduce the buckling load for two-layered plates from the many-layered results.

b. ANALYSIS OF LAMINATED PLATE

Consider a laminate with N-layers. Each ply of the laminate made of fiber-reinforced material is assumed orthotropic with uniform material properties $E_1; E_2; G_{12}; and\ \nu_{12}$ where 1 and 2 refer to the axes along and perpendicular to the fiber. Following the usual notation as in R.Jones, the matrix of elastic stiffness coefficients for such a ply is given by:

$$[Q_{ij}] = \begin{bmatrix} Q_{11} & Q_{12} & Q_{16} \\ Q_{21} & Q_{22} & Q_{26} \\ Q_{61} & Q_{62} & Q_{66} \end{bmatrix} \quad \text{..................(1)}$$

Where;

$$Q_{11} = \frac{E_1}{1-\nu_{12}\nu_{21}}; \quad Q_{22} = \frac{E_2}{1-\nu_{12}\nu_{21}};$$

$$Q_{12} = \frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}} = \frac{\nu_{21}E_2}{1-\nu_{12}\nu_{21}}; \quad Q_{66} = G_{12} = \frac{G_m G_f}{V_m G_f + V_f G_m}$$

V_f and V_f are fiber and matrix volume fraction respectively

G_f and G_m are fiber and matrix shear modules respectively

$E_1 = V_f E_f + V_m E_m$; E_f and E_m are elastic modules of fiber and matrix respectively

$$Q_{66} = G_{12} = \frac{E_f E_m}{V_m E_f + V_f E_m}$$

$$G_{12} = \frac{G_m G_f}{V_m G_f + V_f G_m} \quad \text{.......... ....(2)}$$

$$V_f + V_m = 1$$

$$\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2} \quad \text{........................... (3)}$$

Where ν_{12} and ν_{21} are the poison's ratio

The matrix of elastic stiffness coefficients (eq.1) is referred to be orthotropy axes. However, if the fibers of such a ply are lie at an angle θ relative to the x-axis of the reference plane (fig.1), then the transformed ply stiffness matrix is given by:

$$\left[\overline{Q}_{ij}\right] = \begin{bmatrix} \overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16} \\ \overline{Q}_{21} & \overline{Q}_{22} & \overline{Q}_{26} \\ \overline{Q}_{61} & \overline{Q}_{62} & \overline{Q}_{66} \end{bmatrix} \quad \text{................ (4)}$$

c. STRAIN-DISPLACEMENT-CURVATURE RELATIONSHIPS

Considering the rectangular coordinate system shown in Figure 3 and the assumptions of classical thin laminated plate theory lead to the following displacement relations:

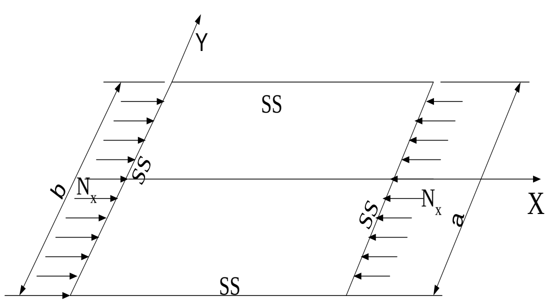


Fig.3. Simply supported plates subjected with

unidirectional force Nx

$$\left.\begin{aligned} u &= u^0(x,y) - z\frac{\partial w}{\partial x} \\ v &= v^o(x,y) - z\frac{\partial w}{\partial y} \\ w &= w(x,y) \end{aligned}\right\} \quad \text{................(5)}$$

The corresponding strain-curvature and the strain-displacement relations are

$$\left.\begin{aligned} \varepsilon_x &= \varepsilon_x^o + zk_x \\ \varepsilon_y &= \varepsilon_y^o + zk_y \\ \gamma_{xy} &= \varepsilon_{xy}^o + zk_{xy} \end{aligned}\right\} \quad \text{................(6)}$$

d. BOUNDARY CONDITIONS BY ENERGY APPROACH

Different types of simply supported and clamped edge boundary conditions are possible for the analysis of laminated plates. A general expression for the elemental strain energy is given by:

$$dV = \frac{1}{2}\left[\sigma_x\varepsilon_x + \sigma_y\varepsilon_y + \sigma_z\varepsilon_z + \tau_{xy}\gamma_{xy} + \tau_{yz}\gamma_{yz} + \tau_{xz}\gamma_{xz}\right]dxdydz = q(x,y)wdxdy \ \ldots \ldots (7)$$

Incorporating the general assumptions of classical thin plate theory and integrating over the thickness t, the strain energy of the plate is given by:

$$V = \frac{1}{2}\iint\left[N_x\frac{\partial u^o}{\partial x} + N_y\frac{\partial v^o}{\partial y} + N_{xy}\left(\frac{\partial u^o}{\partial y} + \frac{\partial v^o}{\partial x}\right) - M_x\frac{\partial^2 w}{\partial x^2} - M_y\frac{\partial^2 w}{\partial y^2} - 2M_{xy}\frac{\partial^2 w}{\partial x\partial y}\right]dxdy + \iint q(x,y)wdxdy \ \text{................ ....(8)}$$

N_x , N_x *and* N_{xy} are the in plane normal and shear forces and bending and M_x , M_x *and* M_{xy} twisting moments.

For simply supported boundary condition of anti-symmetric angle-ply laminates

$$\left.\begin{aligned} w &= 0, & M_x &= 0 \\ u^0 &= 0, & N_{xy} &= 0 \end{aligned}\right\} \ x = 0, a \quad \text{....... (9)}$$

i. ANTI-SYMMETRIC ANGLE-PLY LAMINATED PLATE

Symmetric of a laminate about the middle surface is often desirable to avoid coupling between bending and extension. However, many physical applications of laminated composite material require un-symmetric laminate to achieve design requirements.

An anti-symmetric angle-ply laminate has laminae oriented at $+\alpha$ degrees to the laminate coordinate axes on one side of the middle surface and corresponding equal-thickness laminae oriented at $-\alpha$ degree on the other side at the same distance from the middle surface.

In general, it has been noticed that anti-symmetric laminates tend to become orthotropic for $N \geq 8$.

The governing equation for an anti-symmetric angle-ply laminate can be derived as follows:

For anti-symmetric angle play laminate, the following value of the stuffiness matrix will be zero

A16=A26=B11=B12=B66=D16=D26=0 as a result the coefficient of the anti-symmetric angle play laminate H2=H4=H6=H8=0

Therefore, the question reduced to:

$$H_1 \frac{\partial^8 \emptyset}{\partial x^8} + H_3 \frac{\partial^8 \emptyset}{\partial x^6 y^2} + H_5 \frac{\partial^8 \emptyset}{\partial x^4 y^4} + H_7 \frac{\partial^8 \emptyset}{\partial x^2 y^6} + H_9 \frac{\partial^8 \emptyset}{\partial y^8} = q(x,y)$$
……………………………………………………………..(10)

Let $q(x,y) = -N_x \dfrac{\partial^2 w}{\partial x^2}$

For an anti-symmetric angle-ply laminated plate subjected to in-plane load N_x per unit width (figure 3), the governing equation (3.22) can be written as:

$$H_1 \frac{\partial^8 \emptyset}{\partial x^8} + H_3 \frac{\partial^8 \emptyset}{\partial x^6 y^2} + H_5 \frac{\partial^8 \emptyset}{\partial x^4 y^4} + H_7 \frac{\partial^8 \emptyset}{\partial x^2 y^6} + H_9 \frac{\partial^8 \emptyset}{\partial y^8} + N_x \left(H_7 \frac{\partial^6 \emptyset}{\partial x^6} + H_8 \frac{\partial^6 \emptyset}{\partial x^4 y^2} + H_9 \frac{\partial^6 \emptyset}{\partial x^2 y^4}\right)$$
………………(11)

The governing equation can be reducing for simply supported in all edge boundary condition assume a deflection or displacement at:

$$x = 0 \; and \; a : \partial w = 0 \; and \; \partial u = 0$$
$$y = 0 \; and \; b : \partial w = 0 \; and \; \partial v = 0$$
………… (12)

s Fig. 4. Coordinate Axes of plate

Substituting the expression for 'w' and for the values of ϕ for anti-symmetric angle-ply laminated plate, that satisfy the boundary conditions we found the following equation

$$Nx = \left[\frac{a}{m\pi}\right]^2 \left[T_{33} + \frac{2T_{12}T_{23}T_{13} - T_{22}T_{13}^2 - T_{11}T_{23}^2}{T_{11}T_{22} - T_{12}^2}\right]$$
….. (13)

Where;

$$T_{11} = A_{11}\left[\frac{m\pi}{a}\right]^2 + A_{66}\left[\frac{n\pi}{b}\right]^2$$

$$T_{12} = \left(A_{12} + A_{66}\right)\left[\frac{m\pi}{a}\right]\left[\frac{n\pi}{b}\right]$$

$$T_{13} = -\left[3B_{16}\left[\frac{m\pi}{a}\right]^2 + B_{26}\left[\frac{n\pi}{b}\right]^2\right]\left[\frac{n\pi}{b}\right]$$

$$T_{22} = A_{22}\left[\frac{n\pi}{b}\right]^2 + A_{66}\left[\frac{m\pi}{a}\right]^2$$

$$T_{23} = -\left[B_{16}\left[\frac{m\pi}{a}\right]^2 + 3B_{26}\left[\frac{n\pi}{b}\right]^2\right]\left[\frac{m\pi}{a}\right]$$

$$T_{33} = D_{11}\left[\frac{m\pi}{a}\right]^4 + 2\left(D_{12} + 2D_{66}\right)\left[\frac{m\pi}{a}\right]^2\left[\frac{n\pi}{b}\right]^2 + D_{22}\left[\frac{n\pi}{b}\right]^4$$

$$\left.\begin{aligned} A_{ij} &= \sum_{k=1}^{N} (\overline{Q}_{ij})_k (Z_k - Z_{k-1}) \\ B_{ij} &= \frac{1}{2}\sum_{k=1}^{N} (\overline{Q}_{ij})_k (Z_k^2 - Z_{k-1}^2) \\ B_{ij} &= \frac{1}{3}\sum_{k=1}^{N} (\overline{Q}_{ij})_k (Z_{k-1}^3 - Z_{k-1}^3) \end{aligned}\right\}$$
……..(14)

To compute the value of the buckling load for different fiber volume fraction, which is increasing from 0 to 1 by increment of 0.1 and for different layers arranging in different angle (0 to 90 degrees with increment of 15 degree) using the above formula (11). Materials considered in this study are glass fiber, carbon fiber and boron fiber with epoxy matrix.

RESULT AND DISCUSSION

i. Glass Fiber Reinforced Laminated Plate

Glass fibers are the most common of all reinforcing fibers of polymeric matrix composites (PMC). The principal advantages of glass fibers are light in weight low cost, high tensile strength, high chemical resistance, and excellent insulating properties.

Assume the plate dimensions are

a=0.9m, b=0.9m, t=0.003m

Vf = (0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

0.9 1.0)

The properties of the constitutes are:
E_f = 72.5x109N/m; E_m = 2.4x109N/m; and $V_m = 0.3$
$\nu_f = 0.22$

The density of Glass fiber, $\rho_f = 25000 \frac{N}{m^3}$ and

The density of epoxy matrix, $\rho_m = 11300 \frac{N}{m^3}$

Thus, the values of the buckling load for the respective fiber volume fraction V_f and fiber angle is represents in following the graph

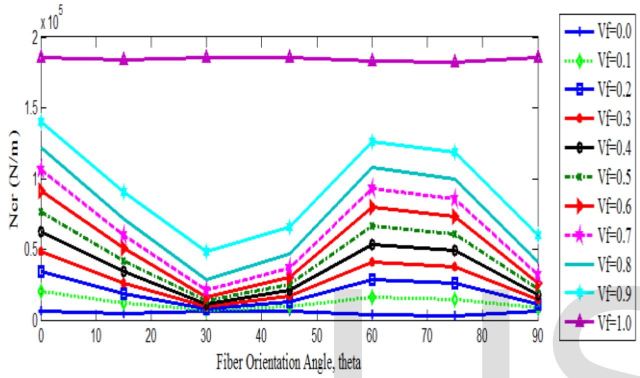


Fig.a

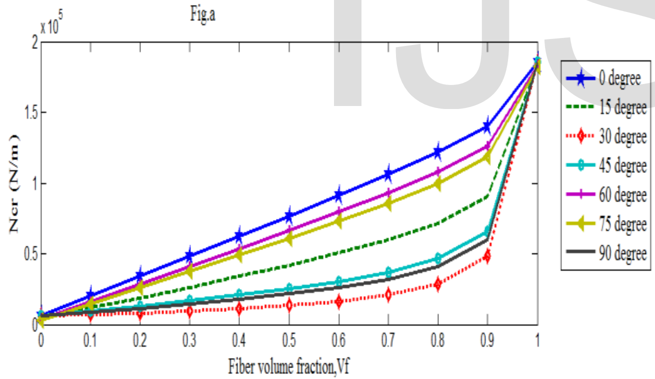


Fig.b

Fig.5.Variation of buckling load of two layered glass fiber-epoxy reinforced laminated plate with the (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

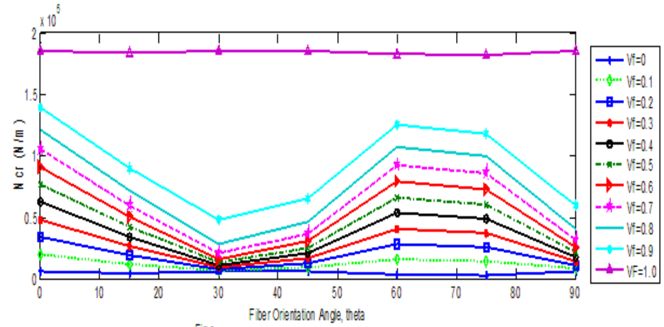


Fig.a

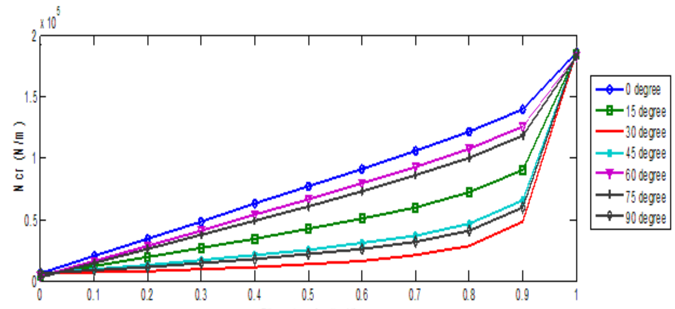


Fig.b

Fig.6 Variation of critical buckling load of four layered glass fiber-epoxy reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle.

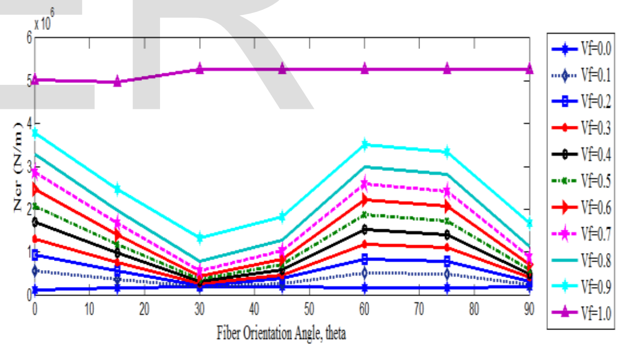


Fig.a

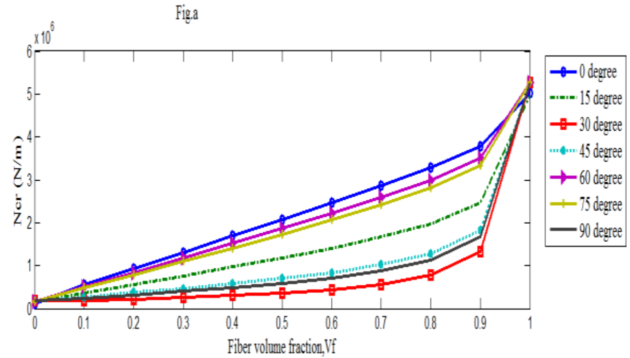


Fig.b

Fig.7 Variation of critical buckling load of two layered glass fiber-epoxy reinforced laminated plate with the (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

ii. **Reinforced Carbon Fiber Laminate**

Carbon fibers are commercially available with a variety of tensile modulus values ranging from 207GPa to 1035GPa. In general, the low-modulus fibers have lower density, lower cost, higher tensile and compressive strengths, and higher tensile strains-to-failure than the high-modulus fibers, high tensile strength–weight ratios, tensile modulus–weight ratios, very low coefficient of linear thermal expansion high fatigue strengths, and high thermal conductivity.

The dimension of the plate assumed are
a=0.9m ; b=0.9m ; t=0.003m

Typical properties of carbon fiber and epoxy resin are
E_f=228x109N/m ; E_m=2.4x109 N/m; V_f = 0.31; Vm =0.33

The value of fiber density, $\rho_f = 13800\frac{N}{m^3}$ and
the value of matrix density, $\rho_m = 11400\frac{N}{m^3}$

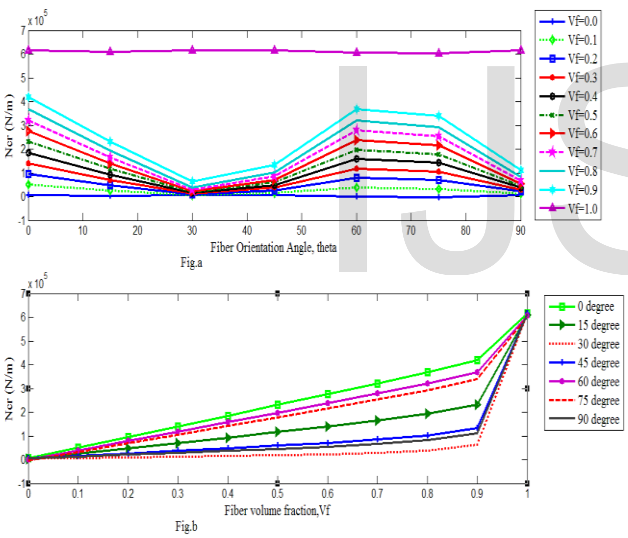
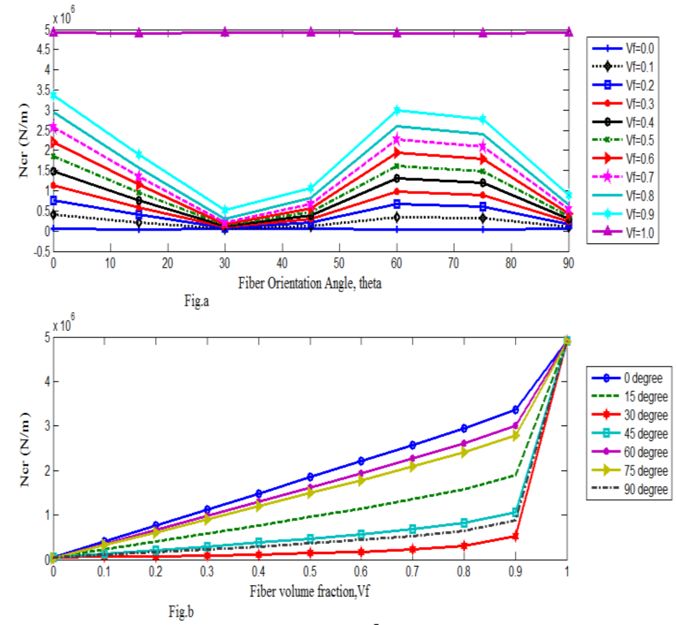


Fig.8 The variation of critical buckling load for two layered carbon fiber-epoxy-reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

Fig.9 Fig.8 The variation of cr



itical buckling load for four layered carbon fiber-epoxy-reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

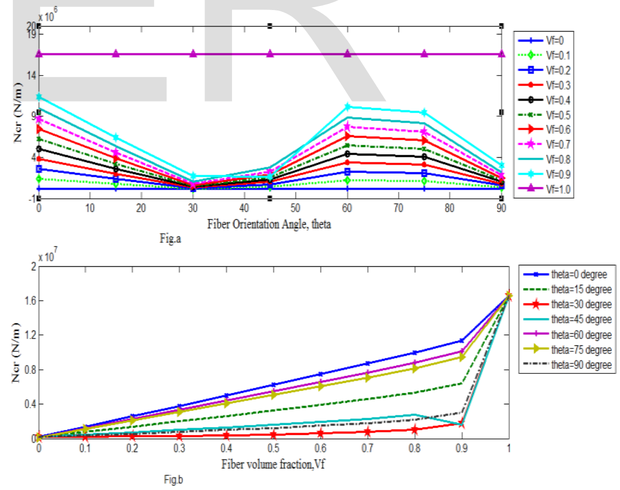


Fig.10. The variation of critical buckling load for six layered carbon fiber-epoxy-reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

iii. Reinforced Boron Fiber Laminate

The most prominent feature of boron fibers is their extremely high tensile modulus, which is in the range of 379–414GPa for this reason, its use at present restricted to a few aerospace applications. The principal disadvantage of boron fibers is their high cost, which is even higher than that of many forms of carbon fibers.

V_f = (0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0)

$E_f = 400\times10^9\ N/m$; $E_m = 2.4\times10^9\ N/m$;

$V_f=0.2$; $V_m=0.33$

The value of fiber density, $\rho_f = 25200\frac{N}{m^3}$ and the value of matrix density, $\rho_m = 11400\frac{N}{m^3}$

The value of fiber The geometric data is the same as with glass fiber laminate

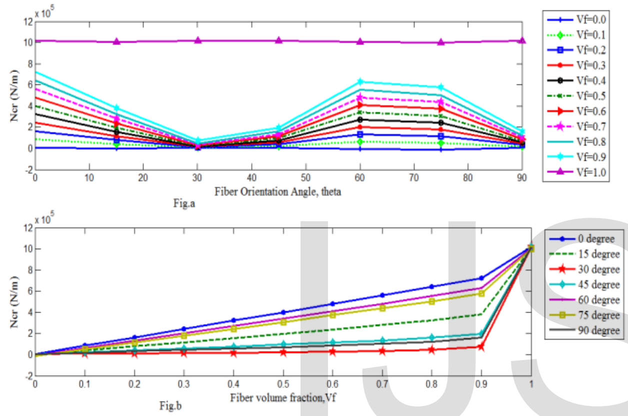


Fig.11 The variation of critical buckling load for two layered boron fiber-epoxy-reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

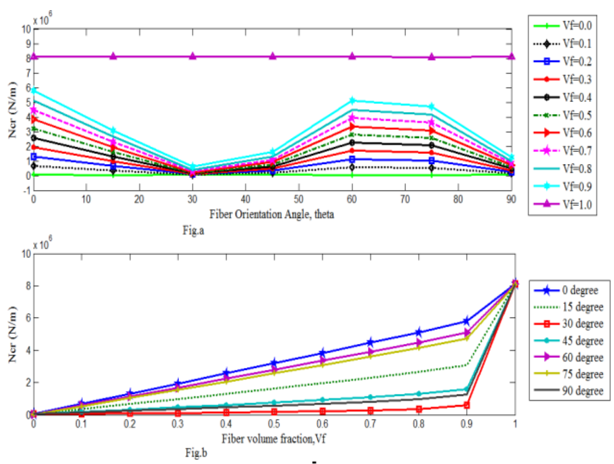


Fig.12. The variation of critical buckling load for four layered boron fiber-epoxy-reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

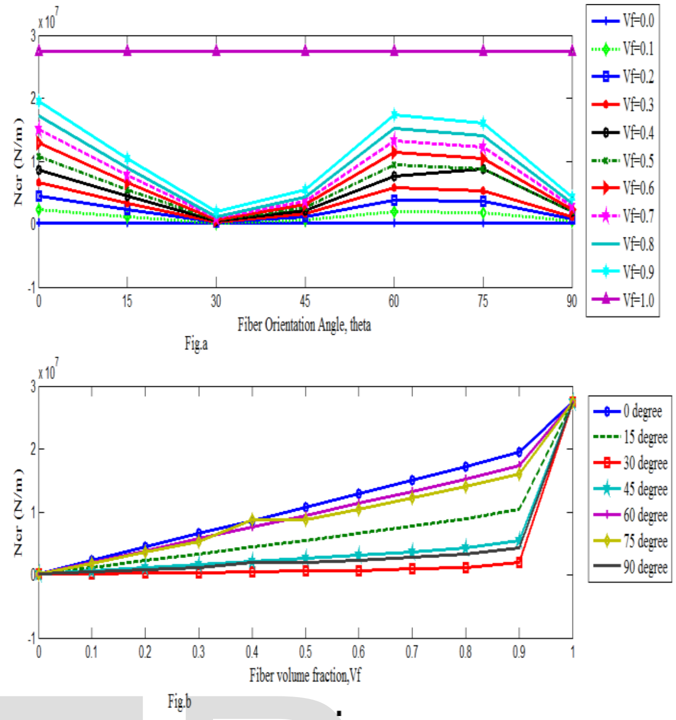


Fig.13. The variation of critical buckling load for six layered boron fiber-epoxy-reinforced laminated plate with (a) fiber angle and constant fiber volume (b) fiber volume fraction for constant orientation angle

NALYSIS OF CRITICAL BUCKLING LOAD OF LAMINATED PLATES USING ANSYS

Critical buckling loads of various plates were found using the commercially available finite element software, ANSYS, version 12. In this research, the eigenvalue buckling analysis is used because we want to show the general effect of fiber volume fraction on the buckling strength of a laminated plate. The plates have analyzed under the boundary conditions of simple-simple-simple-simple said simply supported and size of 0.9mx0.9mx0.003 composite laminate plate which is subjected to a uniformly distributed load in the longitudinal direction. In the analysis a sample of glass fiber, carbon fiber and boron fiber laminated plate has been considered. And the result will compare the MATLAB result.

i. Glass Fiber Reinforced Laminated plate

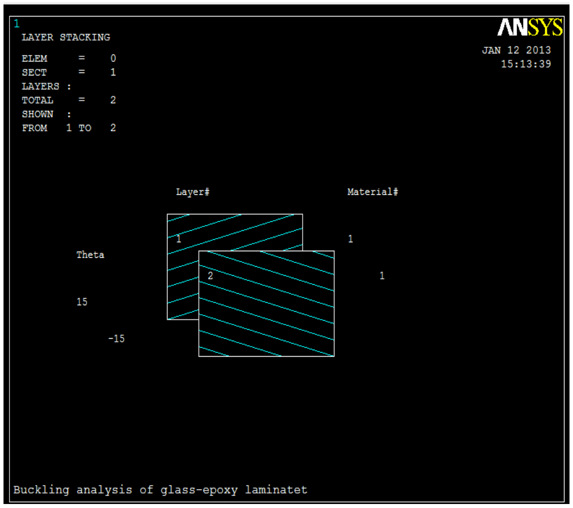


Fig.14. A two-layer Anti-symmetric laminate of glass fiber reinforced layup with different fiber volume fraction and 15 degrees is at critical buckling mode

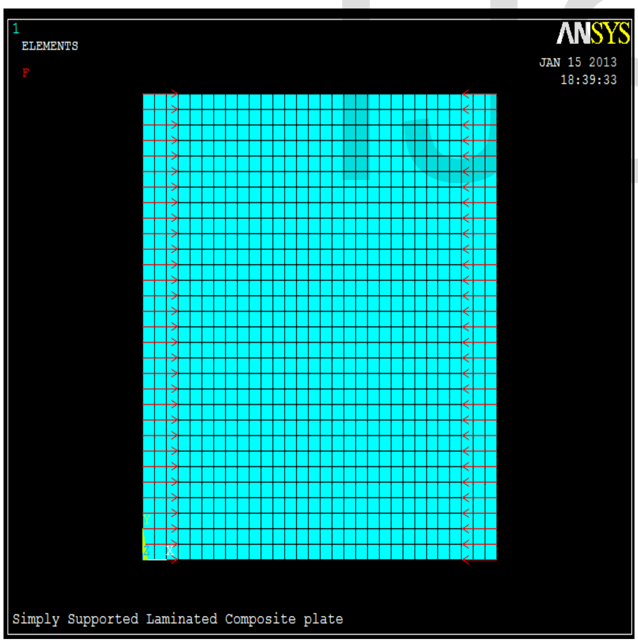


Fig.15. Simply Supported Laminated Composite Plate with The Application of Force, Nx at Two Edges of plate

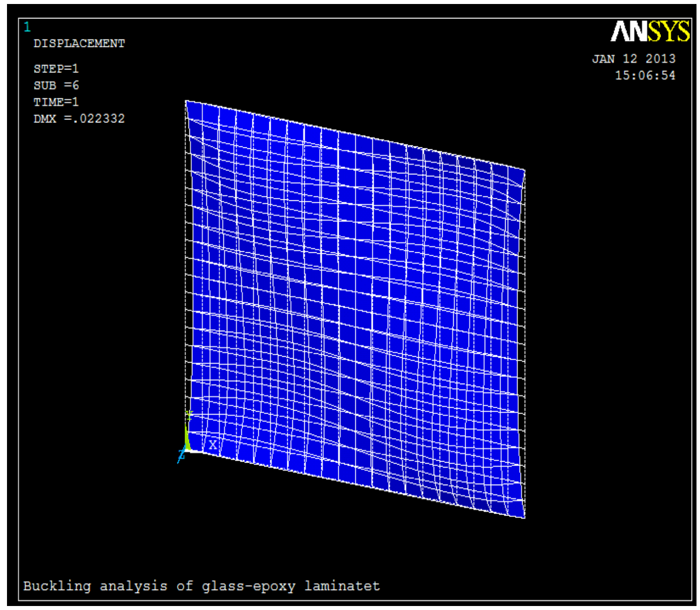


Fig.16. the buckling mode of a two layered glass fiber reinforced laminate

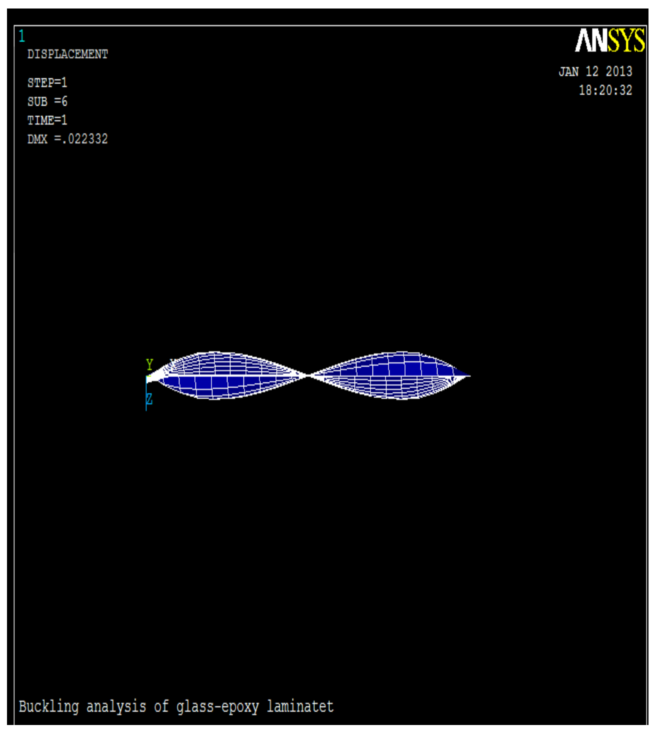


Fig.17. Edge view of buckled glass fiber reinforced laminate

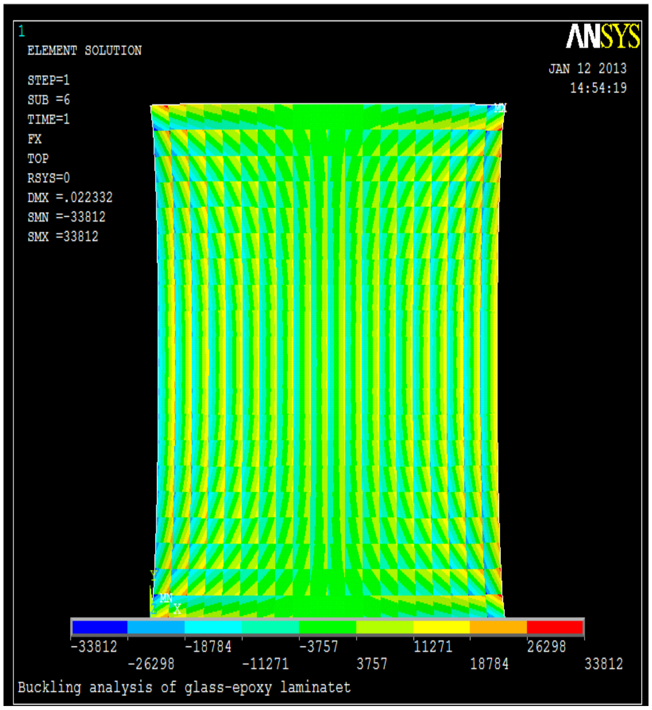


Fig.18. The buckling load distribution along the plate and this is at the state where the plate is at critical buckling mode

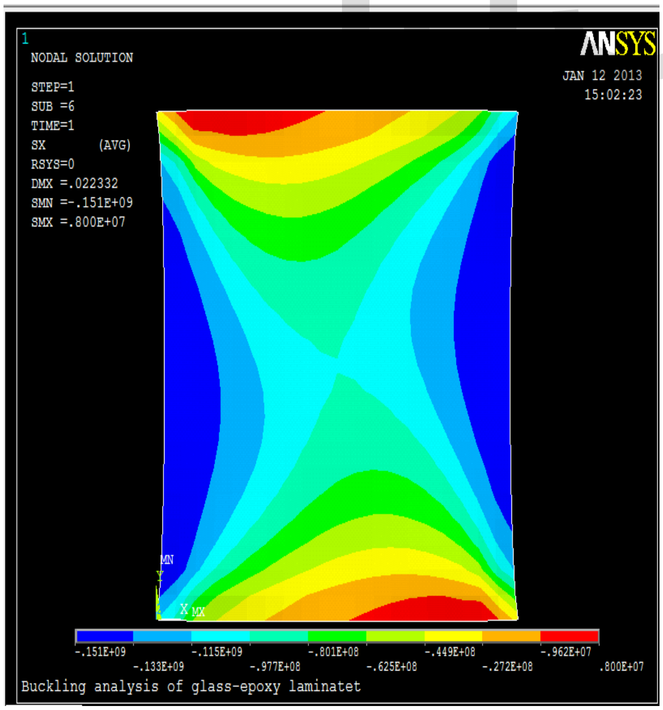


Fig.19 the stress distribution of two layered glass fiber reinforced laminate

ii. Reinforced Carbon Fiber Laminate Analysis

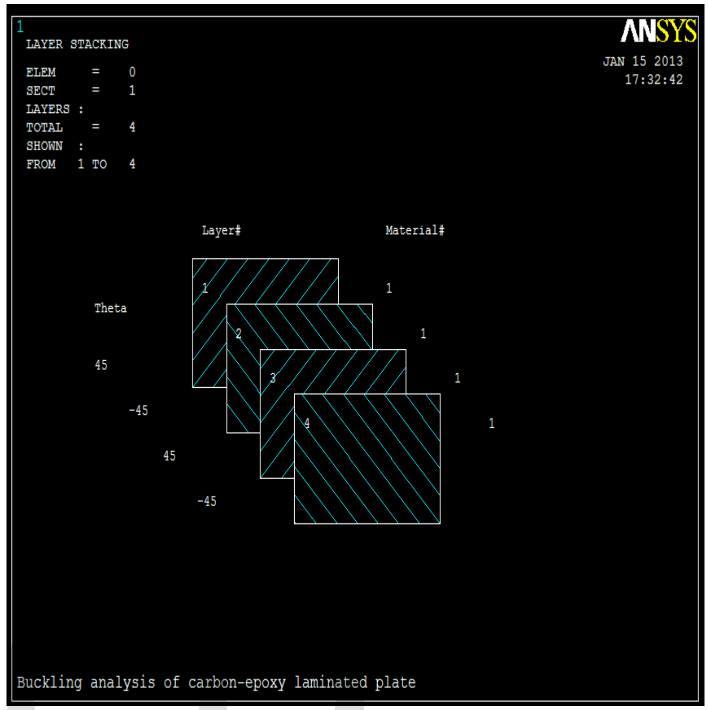


Fig.20. A four layered Anti-symmetric laminate of glass fiber reinforced layup with different fiber

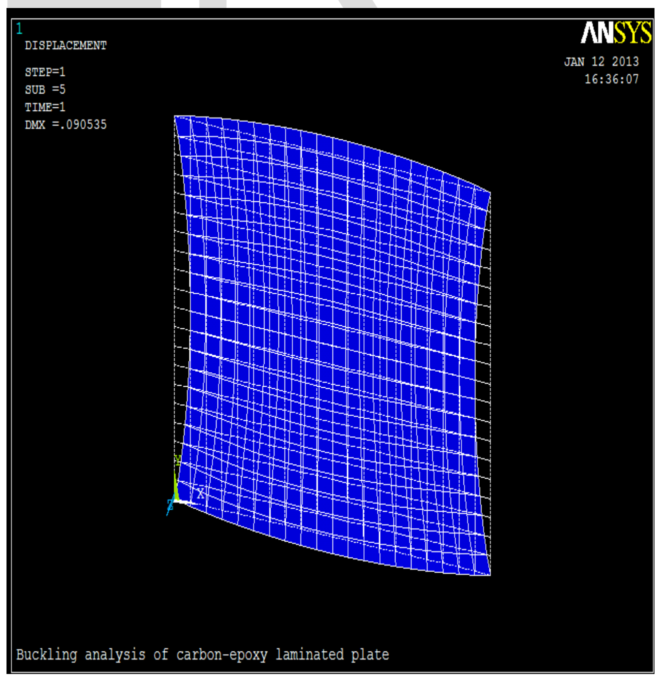


Fig.21. the buckling shape mode of for layered carbon-epoxy laminated composite plate

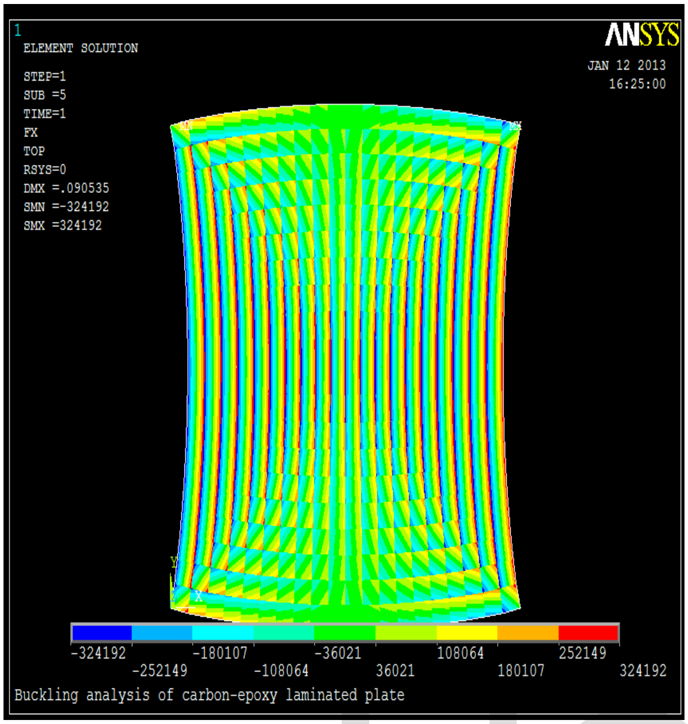


Fig.22. the buckling load distribution for a four-layered carbon fiber reinforced laminated composite plates with lay up 450

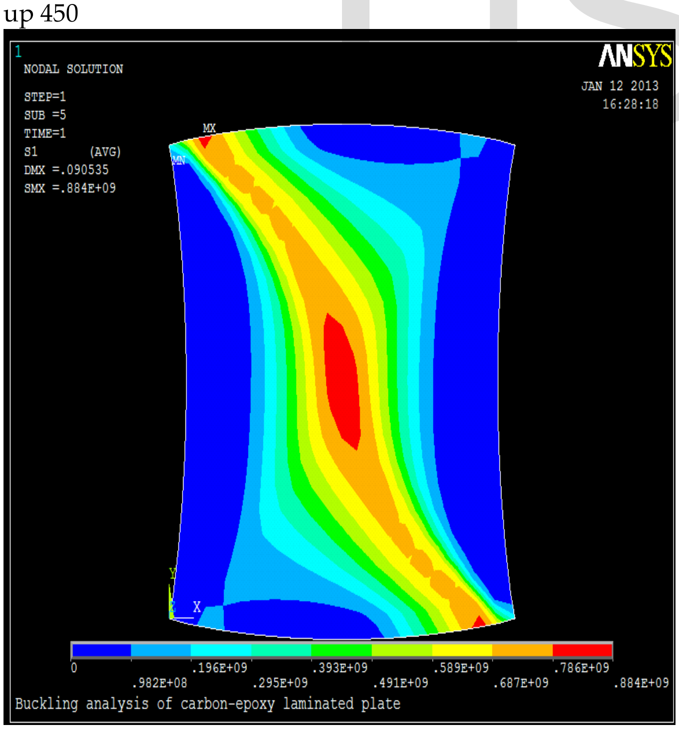


Fig.23. stress distribution throughout the four-layered anti-symmetric carbon fiber reinforced laminated plate

iii. A Six Layered Reinforced Boron Fiber Laminated Plate

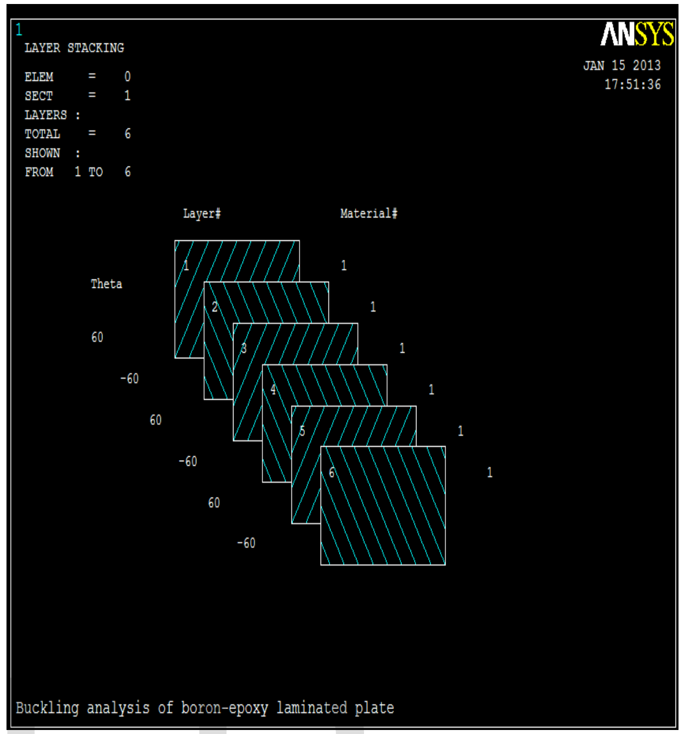


Fig.24. A six layered Anti-symmetric laminate of boron fiber reinforced layup with fiber orientation angle of 600

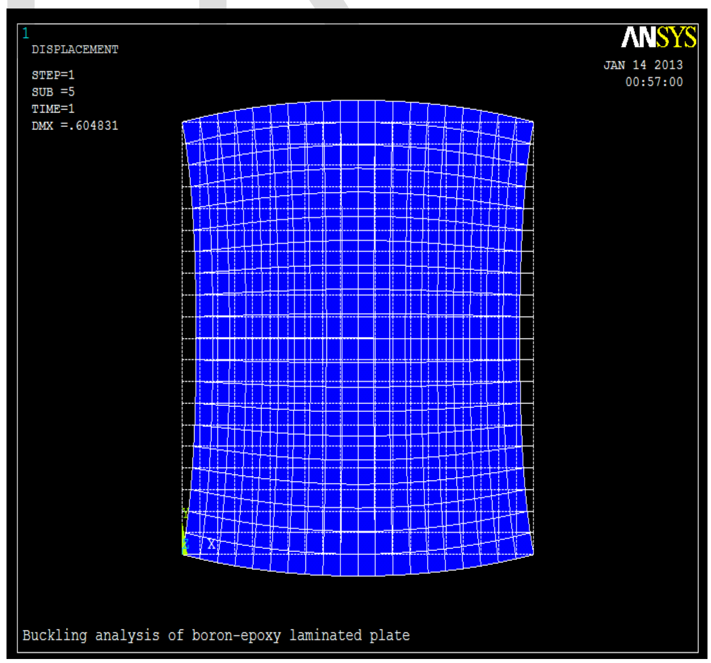


Fig.25. the buckling mode shape of a six-layered boron fiber reinforced laminated composite plate

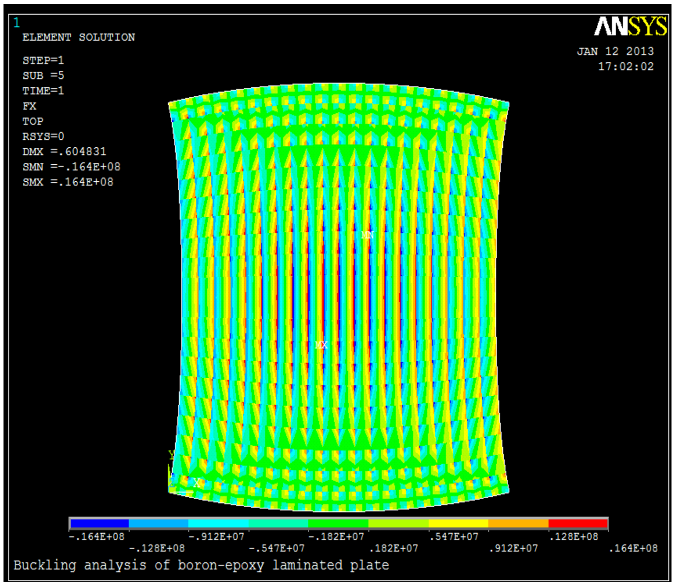


Fig.26. Buckling load distribution for six layered boron fiber reinforced laminated composite plate

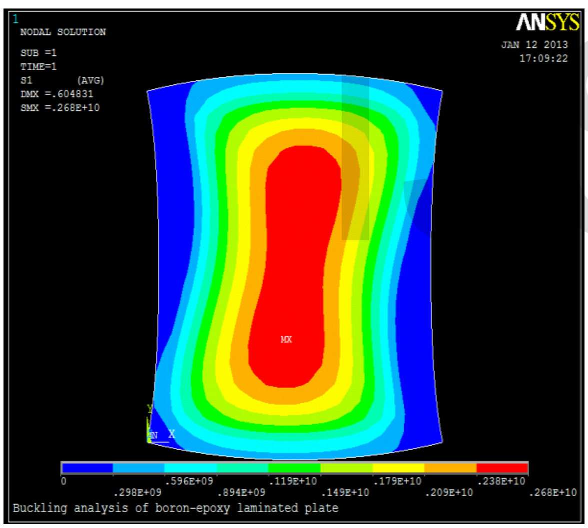


Fig.27. the stress distribution for six layered laminated boron fiber reinforced composite plate

COMPARISON OF MATLAB AND ANSYS RESULT

Since the MATLAB is used a theoretical formula and the result is consider as best fitted and used as a reference for the ANSYS value, which used a model computation. Thus, here the value obtained using MATLAB and ANSYS is compared to evaluate the modeling value with the theoretical value.

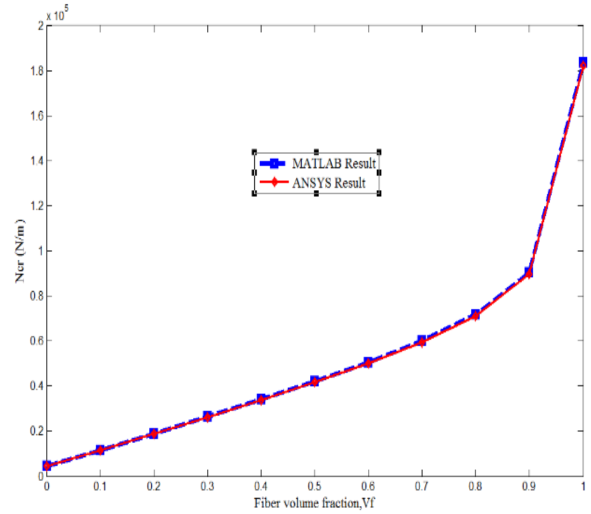


Fig.28. Comparison of MATLAB and NSYS for two Layered Reinforced Glass Laminated Plate N=2; $\theta = 15^0$

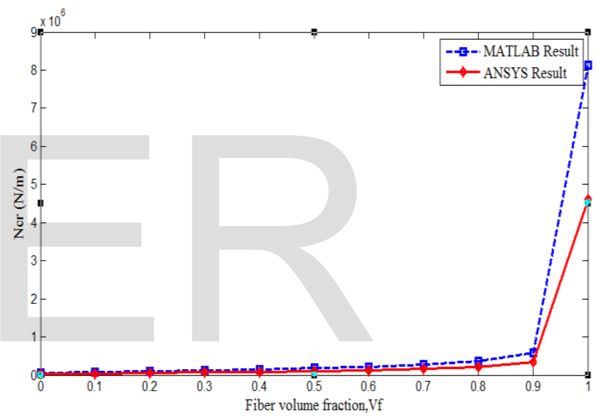


Fig.29. Comparison of MATLAB and ANSYS for two Layered Reinforced Carbon Fiber Laminated Plate N=2; $\theta = 15^0$

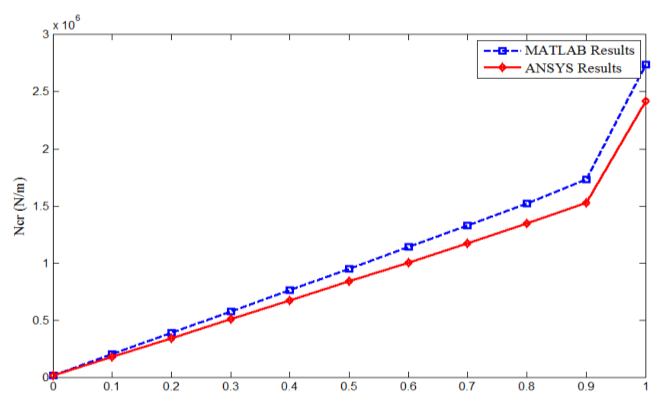


Fig.30. Comparison of MATLAB and ANSYS for two Layered Reinforced Boron Fiber Laminated plate Laminated Plate

$N = 6, \ \theta = 60^0$

CONCLUSIONS

An investigation on the response buckling strength of anti-symmetric composite laminate plate was conducted. ANSYS was utilized to model and analyze the response of a simply supported anti-symmetric plate subjected to a uniform load and used to validate the calculated values performed using MATLAB that invoked the classical lamination theory. The MATLAB calculations along with the ANSYS analyses were performed to investigate how fiber volume fraction, orientation, and lay-up sequencing affect the buckling load of a laminated plate.

It was noted that different fiber volume fraction affected the critical buckling load of the plate, the buckling load increases irregularly as the fiber volume increases. When the fiber volume is larger than 65% the rate of change of the buckling load is high. It is also observed that the different fiber orientation angles affected the critical buckling load, the fiber angle increases, the buckling load changes irregularly. The plate with [0/0 and60/-60]k lay-ups have the highest buckling load and the plate with [30/-30]k lay-ups have the lowest buckling load.

The MATLAB and finite element analysis for the given thickness and simply supported laminates with the number of layers (2,4 and 6) and orientation angles (00,150,300,450,600,750 and 900), the highest result for the critical buckling load was found at 00 and 600. However, it is better to take the value at 600 because the structure may require different strength in different directions. In other case the buckling load decreases at 45^0 due to the existence of bend-twist coupling, it decreases up to 43% in the range of 00 to 450 when compare with the other orientations.

It is also found that the variation of the buckling load is about 0.8% for 2-layer Glass fiber laminate, 43.2% for 4 layered carbon fiber and 6 layered for boron laminate 11.7%.

Generally, the virtually limitless combinations of ply materials, ply orientations and ply-stacking sequences increase the design flexibility of composite structures.

BIBLIOGRAPHY

1. Campbell, F.C. “Structural Composite Materials” ASM International. Copyright 2010
2. Hyer, Michael W. “Stress Analysis of Fiber-Reinforced Composite Materials”. Updated Edition. 2009.
3. Mane-6180 Mechanics of Composite Materials –Prof. R. Naik, Lecture Notes 2010.
4. Jones, Robert M. “Mechanics of Composite Materials”. First Edition. McGraw-Hill Book Company. Copyright 1975.
5. Barbero, E.J. and Tomblin, J., “Local Buckling Experiments on FRP Columns”, Thin-Walled Structures 18, pp. 97-116., 1994.
6. Barbero, E.J., Introduction to Composite Material Design, Taylor & Francis, Philadelphia, PA., 1998.
7. Berg, K., “Today’s Structural Fiberglass Reinforced Plastics (FRP), Structural Engineer Vol. 3, No. 1, pp.44-49. 2002.
8. Timoshenko, S.P., Theory of Elastic Stability, McGraw-Hill, New York.2-963, 1961.
9. Ashton, J.E. and Waddoups, M.E., “Analysis of Anisotropic Plates”, Journalof Composite Materials, Vol. 3, pp. 148-165, 1969.
10. Ashton, J.E. and Whitney, J.M., Theory of Laminated Plates, Technomic, Stamford, Conn., 1970.
11. Khdeir, A.A., “Stability of Antisymmetric Angle-Ply Laminated Plates”, Journal of Engineering Mechanics, Vol. 115, No. 5, pp.95 1989.
12. Effect of Fiber Waviness on the Compressive Strength of Unidirectional Carbon Fiber Composites, Paul Davidson_, Anthony M. Waasy Univeristy of Michigan 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference April 2012,
13. Buckling Strength in Carbon Fiber Polymer Matrix Composites Produced by Filament Winding for Structural use in Rockets the Faculty of Materials Engineering Department California Polytechnic State University, San Luis Obispo By Kyle Rosenow 2016.
14. Explicit buckling analysis of fiber-reinforced plastic (frp) composite structures by luyang shan department of civil and environmental engineering may 2007