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Finite Element Analysis of Laminated Plates with Circular Holes

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Abstract: A composite material is composed of fiber and matrix. Hence a component having two or more distinct constituent material or phases may be considered as a composite material. Fibre-reinforced composites are most commonly used in the recent time due to their higher strength to weight ratio. The objective is to produce a material that possesses higher performance properties than its constituent parts. Some of these properties are mechanical strength, corrosion resistance, high-temperature resistivity, heat conductivity, stiffness, durability, lightness and appearance. Thus it is very essential to study the behavior of composites along with the design and mechanical properties. The present study reports the finite element analysis of a laminated plate with central concentric holes under uniform pressure for stresses and deflection. Four layered rectangular angleply and crossply has been used. The practice involves the use of S-glass/Epoxy and Graphite/Epoxy. The parameter used for the analysis is central hole diameter to plate side ratio (D/W) varying from 0.15 to 0.6. The thickness of the laminated layers in the plate are kept equal. The orientation angle of the layers is varied in the study from 0^0 to 90^0 varying with the increment of 30^0. The stresses and deflections are discussed under the boundary conditions of simply supported case and clamped case on all four sides. The graphs are made between the symmetric, antisymmetric, crossply and stresses or deflection for D/W ratio.

The effect of change in angle of fiber on maximum stresses and maximum deflection for all layers is discussed for simply supported condition D/W ratio 0.15 maximum stress in x direction occurs in antisymmetric crossply for both laminate and the stress is maximum in graphite/epoxy than s-glass/epoxy whereas the deflection is maximum in s-glass/epoxy than graphite/epoxy except for the ratio 0.6. The finite element method is performed with the help of ANSYS 15.0 software.

Introduction

In recent years the three fibre materials i.e. fibre-glass, carbon fibre and kevlar are increasingly used for composite materials. Whereas in the case of matrix most commonly used resins are polyester-resin, vinyl-resin and epoxy-resin in many engineering and civilian applications have increased, ranging from the fuselage of an aeroplane to the frames of a simple tennis racket. They are becoming more and more important in the construction of aerospace structures as their application is very widespread and almost more than 50% of the structures are made up of composites. The area of interest in the use of composites is their parameter of bearing load to a greater threshold. The primary advantages of composite materials are high strength, relatively low weight, and corrosion resistance.

Fiber reinforced composite materials contain high strength and modulus. Fibers in a matrix material are principal load bearing members and matrix material keeps the fibers together. It acts as a load transfer medium between fibers and protects them from being exposed to the environment.

In a composite material, the matrix material serves a few important functions like holds the fibers together, protects them from environment, enhances transverse properties of a laminate, carry interlaminar shear. It improves impact and fracture resistance of a component etc as well.

The aim of this 3-dimensional composition is to obtain a property which none of the constituent's posses. The target is to form a material that possesses higher performance properties for a particular purpose. Some of these properties-mechanical strength, corrosion resistance, high-temperature resistance, heat conductibility, stiffness, lightness, and appearance. In accordance with this definition, several conditions must be satisfied by the material. It must have at least two different materials with different chemical components. The material must behave as one entity, *e.g.* the fiber and the matrix material (material surrounding the fibers) must be perfectly bonded.

Literature Review

The Literature reviews explain the various aspects of plates and their applications to various areas of expertise. The main area of discussion in this part is on the plate with holes and how holes in the plate can create an effect on the stresses in the plate under loads. The plates with holes with different dia., shape and orientations are worked for the analysis. The expected outcome is a reduction of stresses by introducing the holes in the plates.

Kam, T.Y. and Chang, R.R (1993):- The study explained the effect of material properties, plate aspect ratio, length to thickness ratio, number of layers and lamination angle on the mechanical behavior of laminated composite plate is investigated. The best arrangement of layers for laminated composite plates was found. The study found the optimum angles and number of layers for maximizing the buckling loads of symmetrically laminated plates with different material properties, aspect ratios by the design technique by kam and snyman.

C.H., Chen (1995:- presented the easy and accurate method for the stress distributions in laminated composite plates with an elliptical hole. The various results showed that the special finite elements to model critical regions around a hole are very accurate and easy. It can also be used to reduces modelling efforts in the analysis of laminated structures.

Paul, T.K. and Rao, K.M. (1995:- showed the finite element displacement method along with the LoXhristensen-Wu high order bending theory for calculating in-plane stresses and concentration in thick FRP finite laminated plates containing hole under transverse loading. The results for the stress concentration factor of an infinite isotropic plate with a circular hole at the centre, under pure bending loading, obtained by the present theory is compared with the exact values of Alblas and Reissner.

Ukadgaonker, V.G and Rao, D.K.N. (2000):- Advised the extension of becker's solution for elliptical hole problem for unsymmetrical laminates. The study on the circular, triangular, elliptical, square and rectangular was done. It was found that the effect of whole geometry, type of loading and laminate geometry on stress resultants and plate moments around the hole need to be considered. In the study the usefulness of various regular and irregular holes was discussed and how it can be achieved by using the mapping function, orientation angle and biaxial loading factor for the type of loading and laminate stiffness.

Manoharan, R. and Jeevanantham, A. K (2011):- Discussed the stress strain and displacement for the compressive load on the fibre reinforced composite laminates.

Kawadkar, D.B. et. al. (2012):- Performed the study for the effect of cut-outs and bluntness with various cut-out orientation on the stress concentration. For finding the stress concentration the finite element program ANSYS is used.

Rathi, S. et al. (2017):- Presented the behavior of rectangular laminated composite plate with a central circular hole and without hole under transverse loading. The results were discussed critically based on the variation of D/H versus stresses and D/H versus deflection.

It is concluded from the above studies that different techniques of analysing plates have been studied. Research has been done on the plate with a square, rectangular, circular hole for different parameters such as comparison with a different type of material laminate, deflections and stresses under concentrated load influencing the characteristics of plates. But there has been no work done to study the comparison of concentric holes in s-glass/epoxy and graphite/epoxy plate behaviour under uniform pressure.

So, it has been decided to work on the analysis of the comparison of concentric holes in s-glass/epoxy and graphite/epoxy plate behaviour under uniform pressure using FEM.

METHODOLOGY

The methodology adopted in the present study involves the comparison of s- glass/epoxy and graphite/epoxy plate with concentric holes on the maximum stress and deflections. An antisymmetric, symmetric, crossply with various boundary conditions under uniform pressure has been analysed using FEM to study the changes that occur in stresses and deflections by varying D/W ratio. ANSYS has been used to perform the analyses. Results obtained are plotted in the tables and graphs are formed to compare the stresses and deflections at various D/W ratio. The highlighted points of the study are:-

- A four-layer rectangular laminate (+θ/-θ/-θ/+θ) in a symmetrical arrangement, (+θ/-θ/+θ/-θ) in anti-symmetrical, (00/900/900/00) in symmetrical crossply and (00/900/00/900) in antisymmetrical crossply stacking sequence has been analysed. Thickness of each layer of the laminate is taken as uniform.

- Boundary conditions considered are all sides clamped and all sides simply supported.

- A uniform pressure of magnitude 50 Kn/mm2 has been analysed through software ANSYS 15.0.

- Material taken are s-glass/epoxy and graphite/epoxy its properties are defined as linear orthotropic as stated in th table below.

PARAMETER USED

S-glass/epoxy properties	
E1	55×10^{6} kN/m^{2}
E2	16×10^{6} kN/m^{2}
E3	16×10^{6} kN/m^{2}
G12	7.6×10^{6} kN/m^{2}
G23	7.6×10^{6} kN/m^{2}
G13	7.6×10^{6} kN/m^{2}
μ12	0.28
μ23	0.28

μ13	0.28
ρ	2 kN/m2
Graphite/epoxy properties	
E1	145×10^{6} kN/m^{2}
E2	10×10^{6} kN/m^{2}
E3	10×10^{6} kN/m^{2}
G12	4.8×10^{6} kN/m^{2}
G23	4.8×10^{6} kN/m^{2}
G13	4.8×10^{6} kN/m^{2}
μ12	0.25
μ23	0.25
μ13	0.25
ρ	1.58 kN/m^{3}
P (Uniform pressure)	50 kN/m^{2}
h (thickness of each layer)	5 mm
t (overall thickness)	20 mm

- The of D/W ratio varying from 0.15 to 0.6 with an increment of 0.15 has been studied on maximum stresses (σx,σy,τxy,τyz,τxz) and maximum deflection (Uz) for θ varying from 00 to 900 with an increment of 300 for all layers.
- A four noded structural shell element (SHELL181) has been selected.
- Each node has six degrees of freedom which are three translations in x, y, and z axes respectively, and three rotations about x, y, and z respectively.

Plate selected for the study with the dimension as shown in Table.

Dimensions of plates

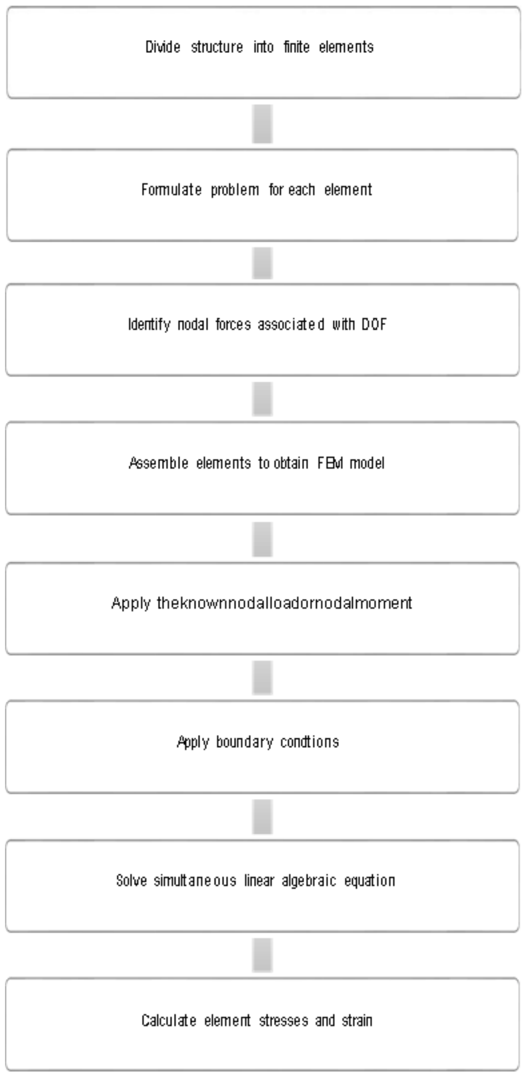
Length (a)	1800 mm
Breadth (b)	600 mm
Thickness (t)	20 mm

FEM and its importance

FEM is a numerically based approach which is utilized in solving many engineering problems such as structural analysis, heat transfer, fluid flow, mass transport and electromagnetic potential. The finite element detailing of the problem results in the arrangement of synchronous algebraic equations for a solution instead of requiring the result of differential equations. In the finite element method, instead of solving the problem for the whole body in a single operation, we form the equations for every finite element and combine them to get the solution of the entire body. There are three types of finite elements:

1. One-dimensional element
2. Two-dimensional element
3. Three-dimensional element

Various steps involved in solving problems using FEM are as under:



Various Shell elements used to analyse plate and shells

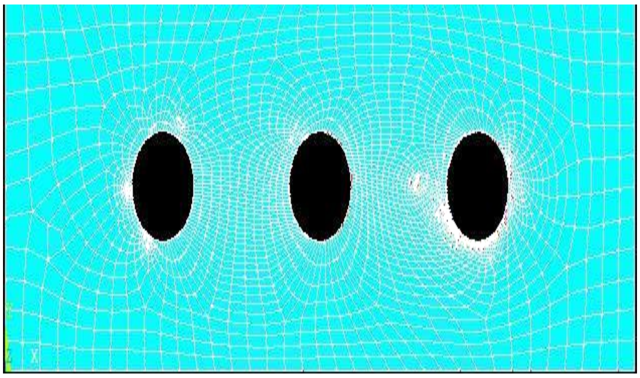
- SHELL 61 = 2-node, axisymmetric shell – 4 DOF/node (3 translations and one rotation)
- SHELL 208 = like 61, but finite strain

- SHELL 209 = like 208, but with midside node (3-node element)
- SHELL 28 = shear twist panel – 3 DOF/node (3 translation or 3 rotation)
- SHELL 41 = 3-D quad or triangle with membrane only
- SHELL 43 = 4-node shell with 6 DOF/node (plastic)
- SHELL 63 = 4-node shell with 6 DOF/node (elastic only)
- SHELL 93 = Like 63, but with midside nodes
- SHELL 150 = 8-node p-element
- SHELL 181 = 4-node, finite strain SHELL 281 = 8-node, finite strain

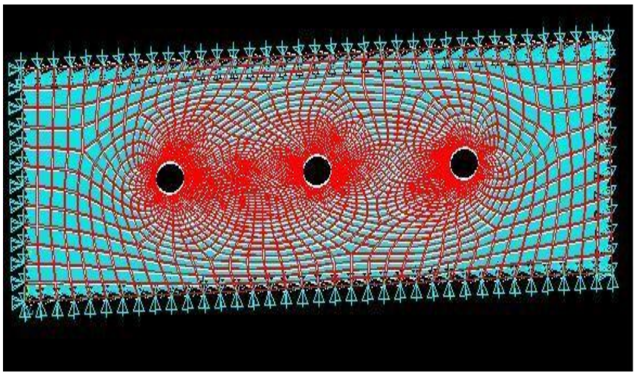
Modeling in ANSYS

ANSYS is a finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. It enables us to solve complex engineering problems and make better faster design decisions. ANSYS is a very useful and widely accepted engineering tool which is used to solve many problems involving electronics aviation atomic and automobile. ANSYS is one of the best finite element computer software which includes all the aspects of FEM. It is capable of performing static, fluid flow dynamic and electromagnetism and heat transfer analysis. It is used throughout the industry to enable engineers to optimise their product designs and reduce the costs of physical testing.

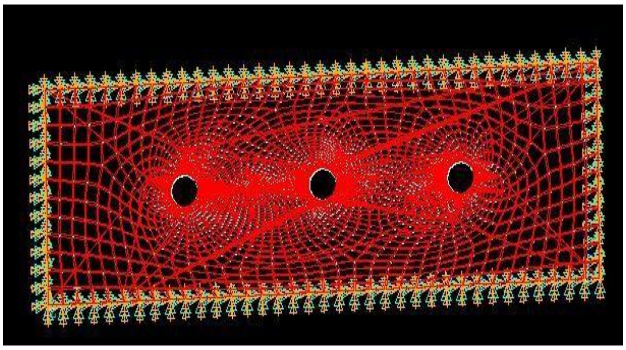
Model of Plate

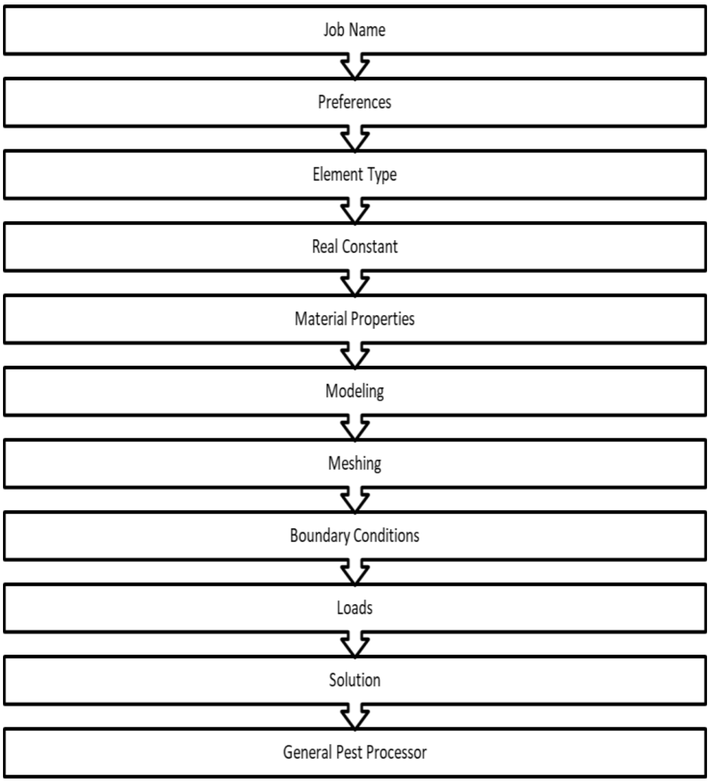


Rectangular laminate with ss boundary conditions on all four sides



Rectangular laminate with clamped boundary conditions on all four sides





RESULTS AND DISCUSSION

1) Clamped boundary condition

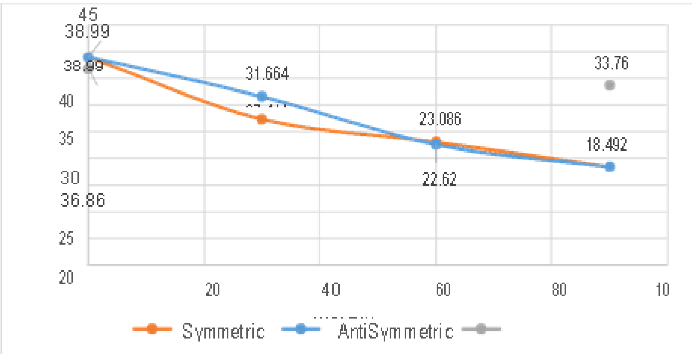
For this condition, the result of s-glass/epoxy and graphite/epoxy finite element analysis are discussed below.

2) Clamped rectangular s-glass/epoxy laminate with concentric circular hole ratio d/w 0.15 under transverse uniform pressure load

For this case, the maximum stresses (+θ/-θ/-θ/+θ) in a symmetrical arrangement, (+θ/-θ/+θ/-θ) in anti-symmetrical, (00/900/90 0/00) in symmetrical crossply and (00/900/00/900) in anti-symmetrical crossply stacking sequence are listed in Tables.

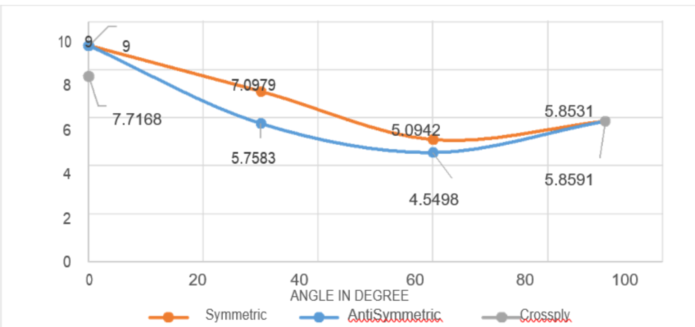
Max. Stresses (σx) in clamped rectangular laminate

Angle	0	30	60	90
Symmetric	38.99	27.411	23.086	18.492
AntiSymmetric	38.99	31.664	22.62	18.492
Crossply	36.86			33.76



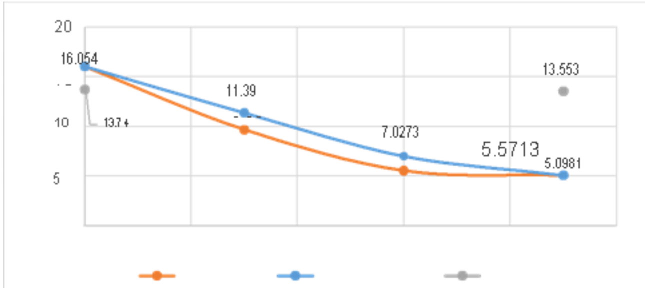
Max. Stresses (σy) in clamped rectangular laminate

Angle	0	30	60	90
Symmetric	9	7.0979	5.0942	5.8535
AntiSymmetric	9	5.7583	4.5498	5.8531
Crossply	7.7168			5.8591



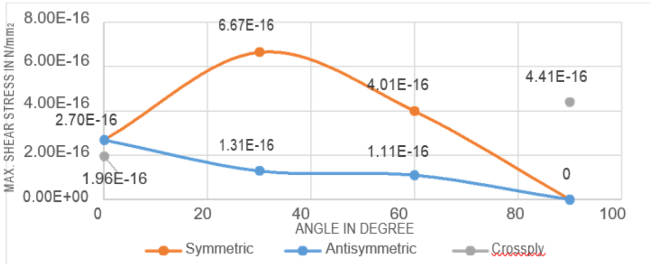
Max.in plane shear stresses (τxy) in clamped rectangular laminate

Angle	0	30	60	90
Symmetric	16.054	9.69	5.5713	5.0981
Antisymmetric	16.054	11.39	7.0273	5.0981
Crossply	13.74			13.553



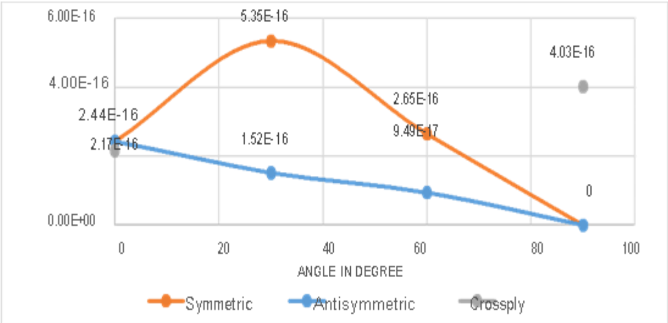
Max. in plane transverse shear stresses (τyz,) in clamped rectangular laminate

Angle	0	30	60	90
Symmetric	0.26975E-15	0.66748E-15	0.40086E-15	0
Antisymmetric	0.26975E-15	0.13074E-15	0.11087E-15	0
Crossply	0.19597E-15			0.44106E-15



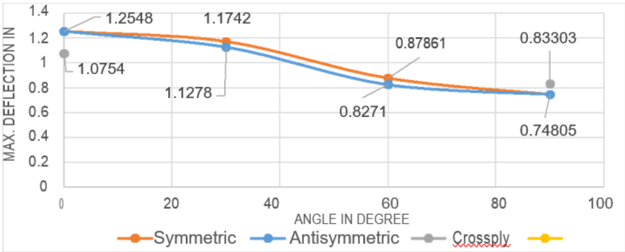
Max.in plane transverse shear stresses (τxz) in clamped rectangular laminate

Angle	0	30	60	90
Symmetric	0.24364E-15	0.53451E-15	0.26505E-15	0
Antisymmetric	0.24364E-15	0.15226E-15	0.94881E-16	0
Crossply	0.21672E-15			0.40278E-15



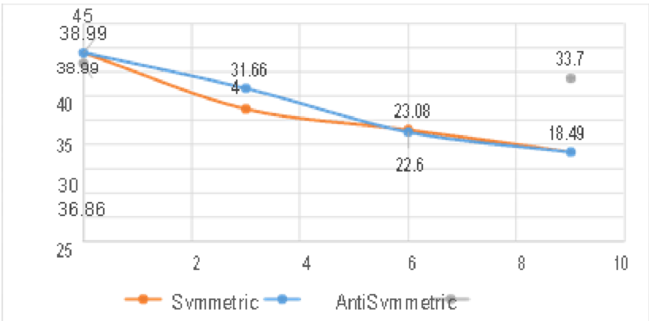
Max deflection (Uz) in clamped rectangular laminate

Angle	0	30	60	90
Symmetric	1.2548	1.1742	0.87861	0.74805
Antisymmetric	1.2548	1.1278	0.8271	0.74805
Crossply	1.0754			0.83303



3) Maximum normal stress (σx)

The variation of maximum normal stress (σx) with respect orientation of fiber with constant D/W ratio 0.15 is shown in following graph:



Clampped when ratio is 0.15

1. The stresses in x direction in s-glass/epoxy antisymmetric case varies from 38.99 Mpa to 18.492 Mpa and stresses in graphite/epoxy antisymmetric case varies from 75.956 Mpa to 22.22 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric case is more than the s-glass/epoxy antisymmetric case.

2. The stresses in y direction s-glass/epoxy symmetric case varies from 9 Mpa to 5.8535 Mpa and stresses in Graphite/epoxy symmetric case varies from 19.624 Mpa to 8.3477 Mpa. Mainly the stresses in y direction in graphite/epoxy symmetric case is more than s-glass/epoxy symmetric case.

3. The shear stresses in xy plane in s-glass/epoxy antisymmetric case varies from 16.054 Mpa to 5.0981 Mpa and stresses in Graphite/epoxy antisymmetric case varies from 35.544 Mpa to 9.1972 Mpa. Mainly the stresses in xy plane in graphite/epoxy antisymmetric case is more than the s-glass/epoxy antisymmetric case.

4. The deflection in z direction in s-glass/epoxy symmetric case varies from 1.2548 mm to 0.74805 mm and deflection in graphite/epoxy symmetric case varies from 1.5204 mm to 0.5451 mm. Mainly the deflection in z direction in s-glass/epoxy symmetric case is more than the graphite/epoxy symmetric case except for 0^0 case.

Clampped when ratio is 0.3

1. The stresses in x direction in s-glass/epoxy antisymmetric crossply case is 45.86 Mpa and stresses in graphite/epoxy antisymmetric crossply case is 53.66 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric crossply case is more than the s-glass/epoxy antisymmetric crossply case.

2. The stresses in y direction in s-glass/epoxy antisymmetric case varies from 8.1146 Mpa to 12.555 Mpa and stresses in graphite/epoxy symmetric case varies from 10.354 Mpa to 10.933 Mpa. Mainly the stresses in y direction in s-glass/epoxy antisymmetric case is more than the graphite/epoxy symmetric case except at 0^0 and 60^0

3. The shear stresses in xy plane in s-glass/epoxy symmetric case varies from 15.016 Mpa to 4.6674 Mpa and stresses in graphite/epoxy symmetric case varies from 17.555 Mpa to 7.824 Mpa. Mainly the stresses in xy plane in graphite/epoxy symmetric case is more than the s-glass/epoxy symmetric case.

4. The deflections in z direction in s-glass/epoxy symmetric case varies from 1.0241 mm to 1.267 mm and deflection in graphite/epoxy symmetric case varies from 0.58033 mm to 1.0332 mm. Mainly the deflection in z direction in glass/epoxy symmetric case is more than the raphite/epoxy symmetric case.

Clampped when ratio is 0.45

1. The stresses in x direction in s-glass/epoxy antisymmetric case varies from 40.002 Mpa to 15.094 Mpa and stresses in graphite/epoxy antisymmetric case varies from 56.27 Mpa to 18.669 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric case is more than the s-glass/epoxy antisymmetric case.

2. The stresses in y direction in s-glass/epoxy symmetric case varies from 7.8521 Mpa to 6.4707 Mpa and stresses in graphite/epoxy antisymmetric case varies from 9.0929 Mpa to 4.6886 Mpa. Mainly the stresses in y direction in s-glass/epoxy symmetric case is more than the graphite/epoxy antisymmetric case except in case of 0^0.

3. The shear stresses in xy plane in s-glass/epoxy antisymmetric crossply case is 13.11 Mpa and stresses in graphite/epoxy antisymmetric crossply case 16.498 Mpa. Mainly the stresses in xy plane in graphite/epoxy antisymmetric crossply case is more than the s-glass/epoxy antisymmetric crossply case.

4. The deflection in z direction s-glass/epoxy symmetric case varies from 1.1284 mm to 0.95296 mm and deflection in graphite/epoxy symmetric case varies from 0.96011 mm to 0.63758 mm. Mainly the deflection in z direction in s-glass/epoxy symmetric case is more than the graphite/epoxy symmetric case.

Clampped when ratio is 0.6

1. The stresses in x direction in s-glass/epoxy antisymmetric case varies from 18.298 Mpa to 12.674 Mpa and stresses in graphite/epoxy antisymmetric case varies from 36.558 Mpa to 15.893 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric case is more than s-glass/epoxy antisymmetric case.

2. The stresses in y direction in s-glass/epoxy symmetric case varies from 3.3388 Mpa to 3.1765 Mpa and stresses in graphite/epoxy symmetric case varies from 5.2905 Mpa to 3.1765 Mpa. Mainly the stresses in y direction in graphite/epoxy symmetric case is more than s-glass/epoxy symmetric case except in case of 60^0.

3. The shear stresses in xy plane in s-glass/epoxy symmetric case varies from 6.2393 Mpa to 2.9237 Mpa and stresses in graphite/epoxy symmetric case varies from 14.385Mpa to3.7131 Mpa. Mainly the stresses in xy plane in graphite/epoxy symmetric case is more than s- glass/epoxy Symmetric case.

4. The deflection in z direction in s-glass/epoxy symmetric case varies from 0.74386 mm to 0.61214 mm and deflection in graphite/epoxy symmetric case varies from 0.80432 mm to 0.56424 mm. Mainly the deflection in z direction in s-glass/epoxy symmetric case is more than graphite/epoxy symmetric case except for 0^0 case.

Simply supported when ratio is 0.15

1. The stresses in x direction in s-glass/epoxy antisymmetric crossply case is 103.10 Mpa and stresses in graphite/epoxy antisymmetric crossply case is 172.87 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric crossply case is more than s-glass/epoxy antisymmetric crossply case.

2. The stresses in y direction in s-glass/epoxy symmetric case varies from 25.18 Mpa to 19.91 Mpa and stresses in graphite/epoxy symmetric case varies from 45.706 Mpa to 36.105 Mpa. Mainly the stresses in y direction in graphite/epoxy symmetric case is more than s-glass/epoxy symmetric case.

3. The shear stresses in xy plane in s-glass/epoxy antisymmetric crossply case is 40.301 Mpa and stresses in graphite/epoxy antisymmetric case varies from 77.198 Mpa to 36.499 Mpa. Mainly the stresses in xy plane in s-glass/epoxy antisymmetric crossply case is more than graphite/epoxy antisymmetric case.

4. The deflection in z direction in s-glass/epoxy symmetric case varies from 5.0207 mm to 4.6921 mm and deflection in graphite/epoxy symmetric case varies from 6.2986 mm to 4.6334 mm. Mainly the deflection in z direction in s-glass/epoxy symmetric case is more than the graphite/epoxy symmetric case except for 0^0 case.

Simply supported when ratio is 0.3

1. The stresses in x direction in s-glass/epoxy antisymmetric crossply case is 171.84 Mpa and stresses in graphite/epoxy antisymmetric crossply case is 197.38 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric crossply case is more than s-glass/epoxy antisymmetric crossply case.

2. The stresses in y direction in s-glass/epoxy symmetric case varies from 29.465 Mpa to 43.585 Mpa and stresses in graphite/epoxy antisymmetric case varies from 32.99 Mpa to 37.399 Mpa. Mainly the stresses in y direction in graphite/epoxy antisymmetric case is more than the s-glass/epoxy symmetric case except for 60^0 and 90^0

3. The shear stresses in xy plane in s-glass/epoxy antisymmetric crossply case varies is 58.21 Mpa and stresses in graphite/epoxy antisymmetric crossply case

is 66.623 Mpa. Mainly the stresses in xy plane in graphite/epoxy antisymmetric crossply case is more than the s- glass/epoxy antisymmetric crossply case.

4. The deflection in z direction in s-glass/epoxy symmetric case varies from 5.673 mm to 8.0272 mm and deflection in graphite/epoxy symmetric case varies from 4.2141 mm to 6.7739 mm. Mainly the deflection in z direction in s-glass/epoxy symmetric case is more than graphite/epoxy symmetric case.

Simply supported when ratio is 0.45

1. The stresses in x direction in s-glass/epoxy antisymmetric crossply case is 187.37 Mpa and stresses in graphite/epoxy antisymmetric crossply case is 215.58 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric crossply case is more than s-glass/epoxy antisymmetric crossply case.

2. The stresses in y direction in s-glass/epoxy symmetric case varies from 28.286 Mpa to 42.012 Mpa and stresses in graphite/epoxy antisymmetric case varies from 23.884 Mpa to 31.388 Mpa. Mainly the stresses in y direction in s-glass/epoxy symmetric case is more than the graphite/epoxy antisymmetric case.

3. The shear stresses in xy plane are shown in s-glass/epoxy antisymmetric crossply case is 63.78 Mpa and stresses in graphite/epoxy antisymmetric crossply case is 75.661 Mpa. Mainly the stresses in xy plane in graphite/epoxy antisymmetric crossply case is more than s-glass/epoxy antisymmetric crossply case.

4. The deflection in z direction in s-glass/epoxy symmetric case varies from 6.3873 mm to 8.5082 mm and deflection in graphite/epoxy symmetric case varies from 3.8954 mm to 6.9442 mm. Mainly the deflection in z direction in s-glass/epoxy symmetric case is more than the Graphite/epoxy symmetric case except for 0^0 case.

Simply supported when ratio is 0.6

1. The stresses in x direction in s-glass/epoxy antisymmetric crossply case is 90.411 Mpa and stresses in graphite/epoxy antisymmetric crossply case varies from 134.07 Mpa to 127.67 Mpa. Mainly the stresses in x direction in graphite/epoxy antisymmetric case is more than s- glass/epoxy antisymmetric crossply case.

2. The stresses in y direction in s-glass/epoxy symmetric case varies from 10.356 Mpa to 10.601 Mpa and stresses in graphite/epoxy symmetric case varies from 19.624 Mpa to 8.3477 Mpa. Mainly the stresses in y direction in graphite/epoxy symmetric case is more than s-glass/epoxy symmetric case.

3. The shear stresses in xy plane in s-glass/epoxy antisymmetric crossply case varies is 26.206 Mpa and stresses in graphite/epoxy antisymmetric crossply case is 56.137 Mpa. Mainly the stresses in xy plane in graphite/epoxy antisymmetric crossply case is more than s-glass/epoxy antisymmetric crossply case.

4. The deflection in z direction in s-glass/epoxy symmetric case varies from 5.9776 mm to 6.8959 mm and deflection in graphite/epoxy symmetric case varies from 6.0981 mm to 8.5929 mm. Mainly the deflection in z direction in graphite/epoxy symmetric case is more than s-glass/epoxy symmetric case except for 30^0 case.

Outcome of result and discussion

For clamped when D/W ratio is 0.15, we observe that

i. σx s-glass is maximum for θ = 0^0, 30^0, 60^0 and 90^0 antisymmetric angleply respectively.

σx graphite is maximum for θ = 0^0, 30^0, 60^0 and 90^0 antisymmetric angleply respectively.

σx graphite > σx s-glass

ii. σy s-glass is maximum for θ = 0^0, 30^0, 90^0 and 60^0 symmetric angleply respectively.

σy graphite is maximum for θ = 0^0, 30^0, 90^0 and 60^0 symmetric angleply respectively.

σy graphite > σy s-glass

iii. τxy s-glass is maximum for θ = 0^0, 30^0, 60^0 and 90^0 antisymmetric angleply respectively.

τxy graphite is maximum for θ = 0^0, 30^0, 60^0 and 90^0 antisymmetric angleply respectively.

τxy graphite > τxy s-glass

iv. τyz s-glass is maximum for θ = 30^0, 60^0 ,0^0 and 90^0 symmetric angleply respectively.

τyz graphite is maximum for θ = 30^0, 90^0, 0^0 and 60^0 symmetric angleply respectively.

τyz graphite > τyz s-glass

v. τxzs glass is maximum for θ = 30^0, 60^0 ,0^0 and 90^0 symmetric angleply respectively.

τxz graphiteis maximum for θ = 0^0, 90^0 ,60^0 and 30^0 antisymmetric angleply respectively.

τxz graphite > τxzs glass

vi. Uzs-glass is for θ = 0^0, 30^0, 60^0 and 90^0 symmetric angleply respectively.

Uzgraphite is for θ = 0^0, 30^0, 60^0 and 90^0 symmetric angleply

respectively.

Uz s-glass >Uz graphite

Similarly it can analysed for

For clamped when D/W ratio is 0.3,
For clamped when D/W ratio is 0.45
For clamped when D/W ratio is 0.6
For simply supported when D/W ratio is 0.15
For simply supported when D/W ratio is 0.3
For simply supported when D/W ratio is 0.45
For simply supported when D/W ratio is 0.6

CONCLUSION AND FUTURE SCOPE

In the present work, finite element analysis of four layered rectangular symmetric (+θ/-θ/-θ/+θ) and antisymmetric (+θ/-θ/+θ/-θ) laminate with equal thickness of layer, clamped and simply supported on all the four sides under transverse uniform pressure load of 50 kN/mm^2 have been analysed using software ANSYS 15.0. The effect of D/W ratio varying from 0.15 to 0.6 with increment of 0.15 has been studied on maximum stresses (σx,σy,τxy,τyz,τxz) and maximum deflection (Uz) for θ varying from 0^0 to 90^0 with increment of 30^0 for all layers.

Conclusions

The maximum σx, max. σy and max. τxy occurs at top and bottom surface of the laminate; max. τyz and max. τxz occurs at middle surface of the laminate; max. Uz occurs at different locations along the periphery of the circular hole depending upon the D/W ratio. For both the laminates, the following conclusions have been observed:-

For Simply supported:

- Stresses in x directions is mostly maximum in antisymmetric crossply in both the laminate and is always maximum for graphite/epoxy laminate than s-glass/epoxy laminate.
- Stresses in y directions in graphite/epoxy is only greater when the D/W ratio is 0.15 and 0.6 otherwise its value is less.
- The shear stresses in xy plane is maximum in antisymmetric crossply and shear stresses in xy plane in graphite/ epoxy laminate is more than s-glass/epoxy laminate except when the ratio is 0.15.
- The shear stresses in yz plane is maximum in s-glass/epoxy laminate than graphite /epoxy laminate except when the ratio is 0.15.
- The shear stresses in zx plane is maximum in graphite/ epoxy laminate than s-glass/epoxy laminate
- The deflection in z direction is maximum in s-glass/epoxy laminate than graphite /epoxy laminate except when the ratio is 0.6.

For Clamped edges:

- Stresses in x directions is maximum for graphite/epoxy laminate than s- glass/epoxy laminate.
- Stresses in y directions in graphite/epoxy is greater than s-glass/epoxy laminate except when the D/W ratio is 0.3.
- The shear stresses in xy plane is maximum in graphite/ epoxy laminate than s-glass/epoxy laminate.
- The shear stresses in yz plane is maximum in s-glass/epoxy laminate than graphite /epoxy laminate except when the ratio is 0.3and 0.45.
- The shear stresses in zx plane is maximum in graphite/ epoxy laminate than s-glass/epoxy laminate except when ratio is 0.45
- The deflection in z direction is maximum in s-glass/epoxy laminate than graphite /epoxy laminate except when ratio is 0.6.

Thus from the above results, we can say that graphite/epoxy plate with D/W ratio upto 0.45 and all sides clamped is best suited for application because small deflections and stresses are observed in this case. It is suitable to use at the places where such type of assembly is required. Thus, plate can be used in the places such as aeroplane, car body, space station, subjected to high pressure.

Scope for future

The suggestions for the extension of present work are as follows:

1. The laminates with arbitrary boundary conditions may be analysed.

2. The analysis may be carried out for plates with varying thickness.

3. The analysis may be carried out for point loading, axial loading, cyclic loading, impact loading and sinusoidal loading.

4. The laminates with holes of various shapes may be analysed.

5. The laminates with different materials may be analysed.

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