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Linear Buckling Behaviour of Composite Laminate [(Θ/-Θ)] With Various Shaped Cutout Using Fem

Somasundaram K, Pandiarajan P, Kathiresan M, Baskaran PG, Rajkumar I

***Abstract:** In this paper, the buckling behavior has been investigated on square laminate made of Woven-glass-polyester composite with various shaped cutouts (i.e., circle, square, vertical rectangle, horizontal rectangle, vertical ellipse, horizontal ellipse) numerically. The composite laminates have been arranged in asymmetrical order as [(θ/-θ)]. The laminated plate that is subjected to uniaxial compression has been emphasized on the laminate along with the effect of layer orientation, effect of cutout ratio and effect of cutout angle. The result shows that the minimum buckling load is obtained at 45° and the maximum buckling load attained at 0° and 90°for all laminates by increasing the layer orientation. For cutout ratio, the maximum and minimum load is obtained for the smallest and largest cutout ratio in all cutout shapes. Increasing the cutout angle, the square cutout exhibits the minimum load at 60°. In elliptical cutouts, the load is decreasing and increasing gradually while they are aligned in along and perpendicular to the loading directions. The rectangular cutouts positioned vertically and horizontally the load is decreasing up to 30° and 60°and then increasing up to 90°.*

***Keywords:** Buckling, Composite, Laminate, Anti symmetric, ANSYS.*

I. INTRODUCTION

The composite laminates with cutouts are widely used in civil, automobile and aerospace applications. The cutouts are essential for providing the ports for the hydraulic and electrical lines in aircraft wings. The cutouts are being used as doors and windows in aircraft structures and for damage inspection in structural components. Besides they are reducing the weight of the structure and also affecting the structural stability of the laminated plates. The true cutout; aspect ratio, rigidity ratio, side to thickness ratio, loading & boundary conditions that are needed for their proficient understanding of buckling behaviour of the plate with cutouts depends on different ply orientation, angle & size of the design. Many studies have been carried out about the stability of the laminated square plates under cutout shape and size, boundary and loading conditions and orientation of the cut outs in cross ply and angle ply laminates.[1-2].

Jain and Kumar [3] have investigated the post buckling behaviour of the square laminates with and without centrally positioned circular and elliptical cutouts with uniaxial compression in Quasi-isotropic laminates by Mindlins plate theory and von Karman's assumptions to incorporate the geometric non linearity. N.G.R Iyengar and Chakraborty [4] have studied the resisting behaviour of thin laminates without cutout subjected to inplane uniaxial and shear loading by Simple higher order shear deformation theory in anti-symmetric laminates. They identified that the buckling load decreases by decreasing in length/thickness ratio and increasing the aspect ratio. Anil et al [5] have addressed the Stability effect of square symmetrical angle ply laminate with and without rectangular cutout by applying the in plane compressive and bi axial loading using Simple higher order shear deformation theory. Dinesh Kumar & Singh [6, 7, 8, 9, 10] have analysed the buckling behaviour of the square Quasi-isotropic laminate with various shaped cutouts (circle, square, diamond, horizontal ellipse and vertical ellipse) with different inplane and flexural boundary and uniaxial compression, inplane shear and combined loading conditions by computer program based on FEM using First Order Shear Deformation Theory FSDT. Hamani et al. [11] have determined the effect of fibre orientation on the critical buckling load of symmetrical laminated composite plates having a crack emanating from a circular notch. They have pointed out that the critical buckling loads attain important maximum values when the fibres are oriented in the range of 50o to 90o whereas the minimum values have been obtained when the fibres are perpendicular to the applied pressure. Djamel ouinas and Achour [12] have taken the boron epoxy laminated square plates arranged in (0°/-0°) under uniaxial compression and they identified that the buckling load decreases by increasing the geometric ratio of the elliptical cutout. From the above literature, the considerable work has been carried out for buckling behaviour of the circular, elliptical cut out under uniaxial, biaxial and combined loads. Some of researches include the study of the buckling behaviour in rectangular cut out but that is limited to only in the vertical orientation.

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* Correspondence Author (s)
Somasundaram K*, Department of Mechanical Engineering, Theni Kammavar Sangam College of Technology, Theni, India. Email: sundarsubi@gmail.com
Pandiarajan P, Department of Mechanical Engineering, Theni Kammavar Sangam College of Technology, Theni, India. Email: pandi1427@yahoo.com
Kathiresan M, Department of Mechanical Engineering, Thiagarajar College of Engineering, Madurai, India. Email: umkathir@yahoo.com
Baskaran PG, Department of Mechanical Engineering, Sri Venkateswara College of Engineering and Technology, Thiruppachur, Thiruvallur, India. Email: baskarmdu@gmail.com
Rajkumar I, Department of Mechanical Engineering, Kalasalinagm Academy of Research and Education, Krishnankoil, Virudhunagar, India. Email: irajkumarilango@gmail.com

Nomenclature

a	Side of the square plate
b	Diameter of the circular cut out
c	Dimension of the square cut out
d and e	Dimensions of the rectangular cut outs
g and f	Dimensions of the elliptical cut outs
θ	Layer orientation angle

This work has addressed the investigation of buckling characteristics of the square laminate with different cutouts arranged in asymmetrical order as [(θ/-θ)]. In this present work the effect of the size and position of the various cutouts under compressive loading conditions.

II. FINITE ELEMENT MODELING

The SHELL 91 as shown in figure-1 has been selected for the reason of small ply thickness rather than compared to the other dimensions of square plate. The plane stress analysis has been carried out. It can be suitable for layered application up to 100 different laminates. This element has 8 nodes with six degrees of freedom at each node (Translation in X, Y & Z directions and rotations about nodal X, Y & Z axis). The buckling analysis has been carried out for centrally positioned cutouts according to the layer orientation, size, shape and position of the cutouts under mono axial compression.

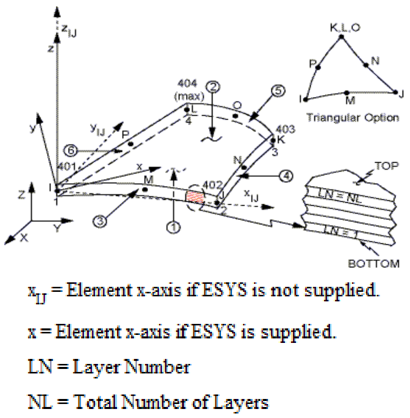

Fig.1. Shell 91 Element Geometry [13]

III. MATERIAL PROPERTY AND GEOMETRIC MODEL

The side of the square plate is assumed as “a”. The dimensions of square plate are 120mm x120mm and the total layer of the laminate is eight with the ply thickness of 0.2mm.The material property of the composite laminate is given in Table I [2]. The various cutout shapes and their dimensions are shown in Table II and the notations are shown in Figure 2.

Table- I: Mechanical Properties [2]

Mechanical properties	Values
E1=E2	31610 [MPa]
G12	3220 [MPa]
V12	0.206

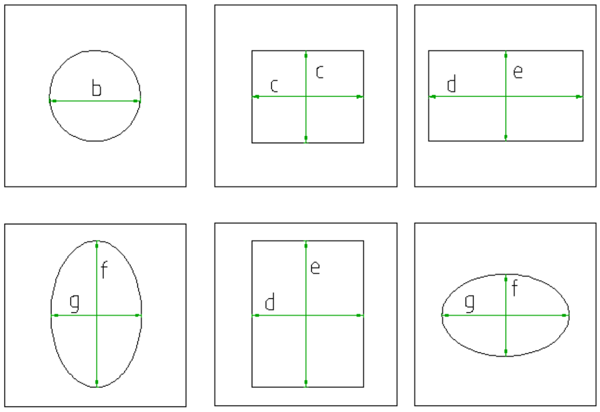

Fig. 2. Notations of square plate with horizontal ellipse, vertical ellipse, square, circle, vertical rectangle and horizontal rectangle.

Table- II: Details of cut out shapes and their dimensions

Cut out shape	Ratio	Value
Circle	b/a	0.5
Square	c/a	0.5
Vertical Rectangle	d/a	0.25
	e/a	0.5
Horizontal rectangle	d/a	0.5
	e/a	0.25
Vertical Ellipse	f/a	0.5
	g/a	0.25
Horizontal Ellipse	f/a	0.25
	g/a	0.5

IV. MESHING, BOUNDARY AND LOADING CONDITIONS

The different model and mesh structures have been created for the different dimensions and angles of the various dimensions and angles. The samples of mesh structure with refined for vertical rectangular cutouts under horizontal compression load is shown in Figure 3. The boundary and loading conditions are same as in reference [2].

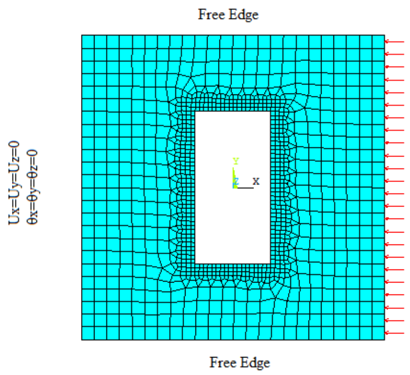

Fig. 3. Mesh structure of the model

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A. Convergence study

To fix the mesh size the convergence study has been carried out. The details of the converged study are in Table-3. From the Table-3 it is confirmed that 49 x49 mesh size gives the suitable converged values.

Table- III: Converged study

Element edge length	Mesh Size	Load (N)
3	81x81	17.537
4	61x61	17.583
5	49x49	17.556
6	41x41	17.537

b. Validated Study

The commercial FEA software ANSYS has been used for the present study. In order to find the accuracy of the software results, it has been corroborated by comparing the results with those available in literatures [7-10].

Table- IV: Validated study for buckling load and non-dimensional buckling loads.

References	Results	Present study
Ghonnadpur etal [1]	13.79	13.77
	6.8	5.9
Aydin komur et al [2]	16	16.151
	28	28.4
N.G.R.Iyengar et al [4]	7	7.535
V.Anil et al [5]	4	4.583
Dinesh et al [7]	17.7	18.620
Dinesh et al [8]	16.4	16.360
Dinesh et al [9]	11.7	11.615
Dinesh et al [10]	16.5	16.756
Djamel ouinas et al [12]	40	40.571

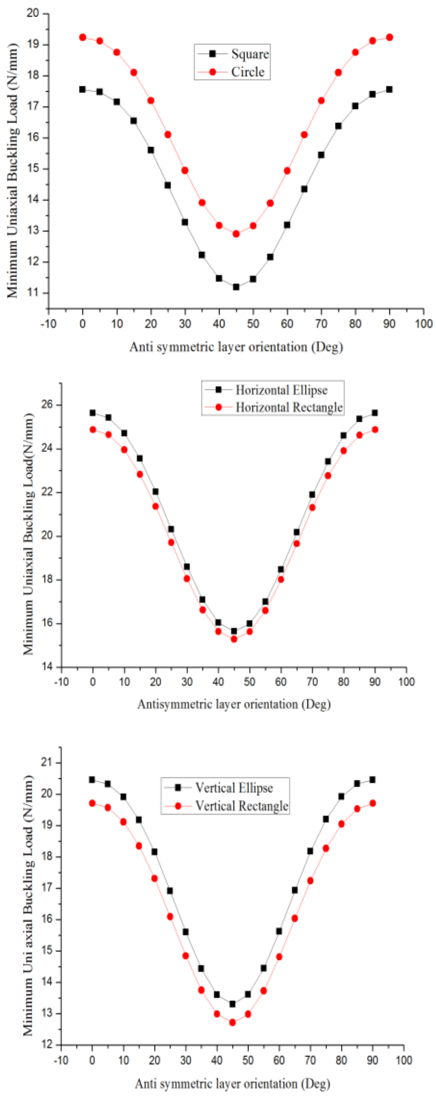

Fig. 4. Effect of layer angle (θ/-θ) in various shaped cutouts

V. RESULTS AND DISCUSSION

A. Effect of layer orientation

The effects of the position of layer orientation on buckling loads with various shaped cutouts are shown in figure.4. From this figure, all cutouts exhibit the same value in either cases of aligned in parallel & perpendicular ply orientation to the loading directions. This is because of the Bi-directional layer.

Other than this orientation, the load decreases either by increasing and decreasing the layer position from along and perpendicular to the loading directions. By comparing the buckling behavior in elliptical and rectangular cutouts, elliptical cutout is higher than the rectangular cutout irrespective of cutout orientation. This is due to the stress concentration in rectangular cutouts. Finally from the effect of layer angle in various shaped cutouts the horizontal ellipse cutout is having the highest stability and square cutout is having the lowest stability irrespective of the ply orientation.

B. Effect of the cutout ratio

The buckling behaviors for various cutout ratios are shown in figure.5. The laminated composite material is analyzed in this case with [(0°/-0°)] orientation. From this figure.5, it can be pointed out that the load decreases by increasing cutout ratio in all cutout shapes. In comparing the circle and square cutout, the load difference is small for the b/a and c/a from 0 to 0.3. The difference in load increases from 1.272 to 2.848 for b/a and c/a ratio 0.4 to 0.9.

In vertical rectangular (VR) cutout the ratio of e/a=0.9 is constant and d/a is increasing from 0 to 0.9. In vertical elliptical (VE) cutout the ratio of f/a=0.9 is constant and g/a is varying from 0 to 0.9. In horizontal elliptical (HE) cutout the ratio of g/a=0.9 is constant and f/a is varying from 0 to 0.9. In horizontal rectangular (HR) cutout the ratio of d/a=0.9 is constant and e/a is changing from 0 to 0.9.

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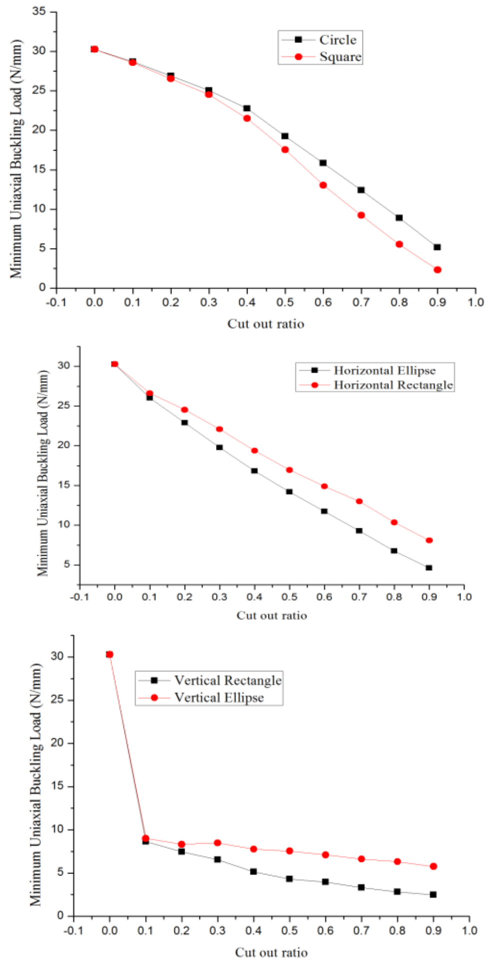

Fig. 5. Effect of cutout ratio

In the vertical cutouts (VE and VR) the load decreases suddenly at 0 to 0.1. The load is same in 0.1 and then the load is decreasing with smaller value. The load differences in vertical cutouts (VE and VR) increases from 1.947 to 3.293 when the cutout ratio (g/a and d/a) increases from 0.3 to 0.9. For the horizontal cutouts (HE and HR) the load linearly decreases when cutout ratio (f/a and e/a) increases from 0 to 0.9. It is also found that when the cutout ratio increases the difference in load increases from 1.65 to 3.4733. In case of elliptical cutouts (VE and HE), the horizontal elliptical cutouts is higher than the vertical elliptical cutout in all cutout ratio and the cutout ratio increases from 0.1 to 0.9 the difference in decreasing load decreases from 17.626 to 2.319. In rectangular cutouts (VR and HR) the horizontal rectangular cutout is higher than the vertical cutout irrespective of the cutout ratios. It is also found that when the cutout ratio increases from 0.1 to 0.9, the difference in load is decreases from 15.434 to 2.139. Finally by comparing the vertical (VE and VR) and horizontal (HE and HR) cutouts the vertical rectangular (VR) and horizontal ellipse (HE) are having the lowest and highest buckling capacity in all cutout ratios because of stress concentration are presence in sharp edges.

C.Effect of the cutout angle

The effects of cutout angle on the buckling load are shown in the following Figure.6. The laminated composite material studied in this case is [(θ°/-θ°). From the following Figure.6, for square cutout the buckling load has the same and maximum value when the cutout positioned in horizontal and vertical direction. For the vertical rectangle in the range of 0° to 30° the buckling strength is decreasing.

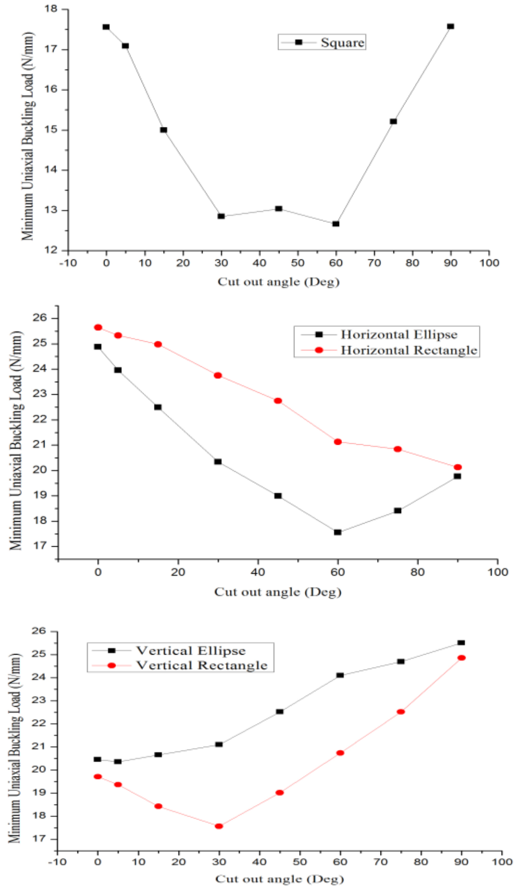

Fig.6. Effect of cutout angle

After this cutout angle the load is suddenly increasing by increasing the cutout angle up to 90°. For the horizontal rectangle cutout the buckling strength is decreasing up to cutout angle 60°. After this cutout angle the load is linearly increasing by increasing the cutout angle up to 90°. In vertical elliptical cutout the stability of cutout linearly increases by increasing the cutout position. For horizontal ellipse the load is decreasing from 0° to 90° cutout position. Moreover the stability of the vertical and horizontal rectangle at 45o is almost equivalent and it is same for the both vertical and horizontal ellipse.

VI. CONCLUSION

In this present work, the buckling behavior of a Woven-glass –polyester composite laminate were arranged in anti-symmetric order with centrally positioned cutouts of various shapes have been analyzed. The various cutouts are positioned with different orientations from 0o to 90o. In addition to the buckling reactions the effects of cutout ratios have also been investigated. The analysis has been done by the commercial Finite Element Analysis package ANSYS and, the following conclusions can be drawn.

1) By increasing the layer orientation from 0° to 90° the same and highest buckling loads are obtained due to high resisting stiffness (withstanding the deformation) for 0° and 90° ply orientations and 45° ply orientation has the lowest buckling load irrespective of the shape of the cutout.
2) Introducing the cutout shapes and increasing the cutout ratio the buckling load decreases in all cutouts. This means the large cutout size carries the low compressive loads only in all shape of cutouts. Circular and Vertical rectangle cutouts are carrying the high and low buckling loads in all cutout size ratios.
3) For increasing the angle of the cutouts the minimum and maximum loads are obtained in vertical cutouts (VE and VR) while they aligned in along and perpendicular to the loading directions. The same is reverse in the case of horizontal cutouts (HE and HR).

Irrespective of the layer orientation and cutout angle the square cutout exhibits low resistance than all other cutouts that had been taken for analysis

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AUTHORS PROFILE

Somasundaram K, working as an associate professor in Theni Kammavar Sangam college of Technology, Theni, He has completed doctorate in the faculty of mechanical engineering in Anna University, Chennai. He has published 4 international journals.

Pandiarajan P, working as an associate professor in Theni Kammavar Sangam college of Technology, Theni, He has completed doctorate in the faculty of mechanical engineering in Anna University, Chennai. He has published 5 international journals.

Kathiresan M, working as an assistant professor in Thiagarajar college of Engineering, Madurai. He has completed doctorate in the faculty of mechanical engineering in Anna University, Chennai. He has published more than 20 international journals.

Baskaran PG, working as an associate professor in Sri Venkateswara college of Engg. and Technology, Thiruvallur. He has completed doctorate in the faculty of mechanical engineering in Anna University, Chennai. He has published 2 international journals.

Rajkumar I, pursuing Ph.D in Kalasalingam University, Krishnankovil. He has published 3 international journals.

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