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Elasto Buckling Behaviour Of Gfrp Laminated Plate With Central Holes

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Abstract—In various cases, it is roughly unavoidable to have holes in the plate elements for inspection, maintenance, and service purposes. In such cases, the presence of these holes redistributes the membrane stresses in the plates and may reduce their stability significantly. The buckling of such perforated plates has received the attention of many researchers over the past years. This paper deals with the buckling analysis of symmetrically and laminated composite plates under two sides simply supported and two sides free boundary condition. The effects on buckling load by various cut out shapes (circular, square and elliptical) and sizes are investigated. It was observed that the plate with the circular cutout yielded the greatest critical buckling load when compared with the square and elliptical cutouts.

Keywords-Buckling, Cutouts, Load, Composite

I. INTRODUCTION

The mechanical behavior of composite structures is of particular interest to engineers in modern technology. Buckling of plates is a well-established branch of research in composite structures. It has a wide range of applications in engineering science and technology. Plates with circular, elliptical and other holes are extensively used as structural members in aircraft design. The buckling behavior of such plates has always received much concentration by investigators. Ghannadpour et al [1] found that plates that have a cutout can buckle at loads higher than the buckling loads for corresponding plates without a cutout. Kremer et al[2] studied the influence of the shape of optimised cut-outs on the buckling behaviour. Besides the critical load the under-critical and post-critical behaviour of geometrical imperfect orthotropic composite plates is analysed. Methods that prevent local buckling under tensile stresses are discussed in order to provide the full advantage of optimised cut-outs. Tercan et al[3] studied the cutout shape effects on the buckling behavior of 1 * 1 rib knitting glass/epoxy laminated plates in three different knitting tightness levels as low, medium and high. They showed that the buckling loads depend on the cutout area and the level of tightness. Eryigit et al[4] investigated the effects of hole diameter and hole location on the lateral buckling behaviour of woven fabric laminated composite cantilever beams. In the experimental studies, They concluded that the effects of the hole diameter and hole location on the lateral buckling behaviours is very important, especially for the short beams. Komur et al[5] studied the buckling analysis of a woven–glass polyester laminated composite plate with a circular/elliptical hole, numerically. The results show that buckling loads are decreased by increasing c/a and b/ratios. Kumar et al[6] observed that the cut-out shape has considerable effect on the buckling and postbuckling behaviour of the quasi-isotropic laminate with large size cut-out. They also observed that the direction of shear load and composite lay-up have substantial influence in strength and failure characteristics of the laminate.

II. SPECIMENS PREPARATION

The specimens were prepared from glass fiber in the form of rovings and epoxy resin. Araldite LY556 Hardener HY951 in the ratio 10:1 by weight was used as a matrix material. The reinforcement material used was E-glass fiber. Specimens were fabricated by hand layup technique developed in the laboratory. A layer of mix was applied on the die and a layer of rovings. The fibers were impregnated with help of a brush. The required thickness of the specimen was built up putting one layer over another. The thickness of the specimen was controlled by introducing spacers. Volume fraction could be controlled by squeezing out the excess resin. Squeezing would also remove the air bubbles. After this male die was inserted over it and clamped. The section was removed after 12 hours. The specimens were then cured at 80°-100° C for about 2 hours. Then the specimens were cut with considering the proper precautions about actual dimensions and smooth edges. The buckling specimens were drilled with various types of the holes at the center. The hole types were circular, square and elliptical. For circular hole, the diameter of the hole was varied from 1cm to 5 cm with an increment of 1cm. Similarly, the square cutouts were followed with side variation of 1cm to 5 cm with an increment of 1cm. and elliptical holes had followed the variations of 1cm to 5cm with an increment of 1 cm in its minor axis. During drilling special precautions were taken about the drilling effect on the edges of the holes, so oils were poured into the drilling tips and after drilling the edges were patched up epoxy resin for smooth boundary walls of the holes.

III. SPECIMENS TESTING

The servo Hydraulic Universal Testing Machine having a maximum capacity of 20000 kg was used for the experimental measurements. The machine was properly calibrated before using. Tensile tests and buckling tests were carried in the same machine and elastic properties like E_L, E_T .Ultimate strength and critical buckling load were determined from stress-strain values and buckling studies.

A. Tensile Test

During the tensile test, the ASTM standard (3039-D)specimens as mentioned above was striped at two fixtures of the machine and load was applied as per the ASTM standard recommends till the sample was failed into two segments. During the process, the load Vs. deflection was recorded in the machine and converted into the stress strain diagram. This stress strain diagram gave the elastic modulus, Poisson's ratio and ultimate tensile strength of the specimen.

B. Buckling Test

The specimens were tested with the boundary condition two sides simply supported and two sides free. After fixing the plate inside the fixture the lateral deflection were recorded in the machine and the load was increased with the constant interval of time. After aligning the axis of test section with loading axis of the machine the load was increased. At the point of the critical load, the specimen were unable to carry anymore load and finally developed several cracks at the surface. This was recorded as the ultimate buckling load of the tested sample.

IV. RESULTS AND DISCUSSIONS

The buckling behavior of laminated plates with and without cutouts is studied and results are analyzed in terms of experimental obtained data.

A. Effect of Cutout Shape

The effect of cut outs on the buckling load of the GFRP rectangular plates are analyzed in this section. There are three types of cutouts considered for the present investigation. One is circular, second is square and another one is elliptical cutout. The results obtained for various cut-out are shown in the Figure.1 through Figure.6.

From Figures, it has been observed that the buckling load have shown the different type of trend compare to normal expectation, i.e. in case of circular and elliptical cutouts buckling load first decreased and then increased and afterwards finally goes on decreasing with increasing dimension of the cutout. But, in case of square cutouts, the buckling load has decreased continuously with increasing dimension of the cutout although the decreasing trend is not uniform. Based on this observation about the difference and decrease in buckling load in presence of cutout, the possible cause may be outlined due to two effects,

a. Stress concentration effect
b. Material removal effect

And accordingly various zones of decreasing buckling load may be classified as,

a. Stress dominant zone
b. Stress concentration and material removal dominant zone
c. Material removal dominant zone and
d. Web dominant zone

In stress concentration zone buckling load decreased due to stress concentration at the boundary of the cutout. In this zone how much material has been removed is almost immaterial and buckling load decreases mainly due to stress concentration effect. Of course, this effect goes on decreasing as radius of curvature of the cutout increased.

In the second zone, the buckling load decreased due to stress concentration effect as well as the material removal effect. Material removal effect increased due to increase in the areas of the cutout which in turn increased the radius of curvature in case of circular and elliptical cutouts. Hence, as material removal effect increased, the stress concentration effect decreased. However, in case of square cutout stress concentration at the corners remained almost same irrespective of the cutout dimension and hence stress concentration effect did not decrease with increase in a material removal effect. In material removal dominant zone, stress concentration is either reduced to a greater extent or it remained constant and thus further decreased in buckling load. This may be attributed mainly due to material removal effect. In web dominant zone, due to large dimension of the cutout the width of the side web is reduced to such an extent that they are not able to provide sufficient buckling resistance and hence the buckling load of the plate decreased very sharply.

In Figures.1 to 3, the zone in between no cutout to cutout dimension (diameter or minor diameter) 1cm may be considered as first zone in which the buckling load decreased very sharply due to stress concentration effect caused by low radius of curvature. The zone in between 1cm to 2cm may be considered as second zone, in which, the buckling load increased due to decrease in stress concentration. This is caused by increase in radius of curvature and decreased due to increase in material removal effect. Since, in this zone, the decrease in stress concentration is more effective, as a combine effect of the two buckling load increment. The zone in between cutout dimension 2cm to 4 cm may be considered as third zone in which stress concentration effect has been reduced to a greater extent due to large rise in radius of curvature but on the other hand material removal effect has become dominating which increased continuously and consequently buckling load. The buckling load goes on decreasing continuously as well as more or less uniformly. The zone in between cutout dimension 4cm to 5cm may be considered as fourth zone in which the buckling load is mainly controlled by the side webs. Since at such a large dimension of the cutout with respect to the plate dimension the buckling resistance provided by the side webs is very less. The buckling load decreased sharply in this zone.

In Tables 1 to 3 percentage variation of buckling loads of experimental for different dimension of circular cutout have been presented. These values have also been plotted in Fig. 4 to 6. Percentage buckling loads of central cut-out specimens have been compared considering buckling load of a simple glass fiber reinforced composite plate having no cutouts as 100 percent. In the Fig. 4 to 6, it has been observed that the maximum loss of buckling load takes place in the first zone i.e. the zone in between no cutout to cutout dimension 1cm. From this observation it can be concluded that stress concentration effect is more important than the material removal effect.

In Table 4 maximum, minimum and average percent losses of bucking load of experimental and computational observation for different cutouts have been shown. Average loss has been calculated on the basis of losses for different cutout dimension (1cm to 5 cm). In this table, it is observed that for each size of cutout, all types of losses are maximum for square cutout, minimum for circular cutout and intermediate for elliptical cutout.

In the Table-5 loss of buckling load for different types and dimensions of cutouts have been given. These values have also been plotted in Fig. 7. In the above Table and Figure, it has been found that loss of buckling load is maximum for square cutout, intermediate for circular cutout and minimum for elliptical cutouts. Thus it can be concluded that elliptical cutout should be given first preference for making lightening holes, inspection holes, windows etc. If the structure is to be made up of the material under investigation, circular cutouts should be given second preference and if no alternative is left then only we should proceed for square cutouts.

V. CONCLUSIONS

From the present analysis, the following conclusions can be made.

1. The reduction of the buckling load due to the presence of a cutout is found to be significant. It is noted that the presence of cutout lowers the buckling load and it varies with the cutout shape. The plate with circular cutout yielded the greatest critical buckling load.
2. Presence of cutout reduces the buckling load due to stress concentration effect and material removal effect.
3. Stress concentration effect remains almost same with increasing side of square cutout.
4. Material removal effect goes on increasing with increasing dimension of the cutout in all three circular, elliptical and square cutouts.
5. Side web effect is maximum for circular cutouts, minimum for square cutouts and intermediate for elliptical cutouts.
6. Stress concentration effect is more important than the material removal effect provided that the dimension of the cutout is not so large with respect to the plate dimension that side web becomes dominant.
7. In laminated plates, there is a reduction of intensity towards the centre of the plate. This reduction is more pronounced at higher aspect ratios. It may be observed for a/b=1 the stress value in most of the central region is constant, whereas, for a/b=3 there is a rapid reduction in the value of stress intensity in central region.

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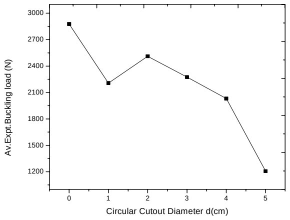

Figure1. Experimental Buckling Load with respect to Circular Cutouts with Different Diameter

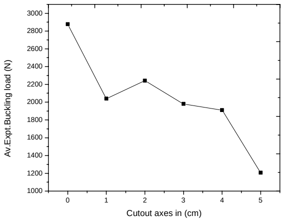

Figure2. Experimental Buckling Load with respect to Circular Cutouts with Different Diameter

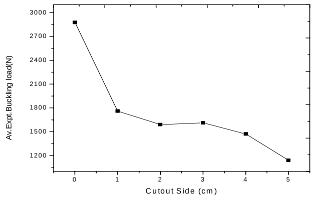

Figure 3.Experimental Buckling Load with respect to Square Cutouts with Different Side Length.

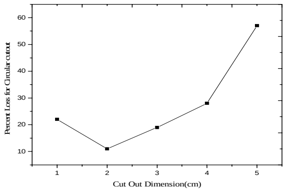

Figure 4Percentage Loss of Buckling Load with Increasing Dimension of Circular Cut-Out

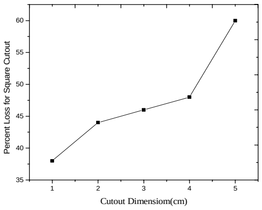

Figure 5 Percentage Loss of Buckling Load with Increasing Dimension of Square Cut-Out

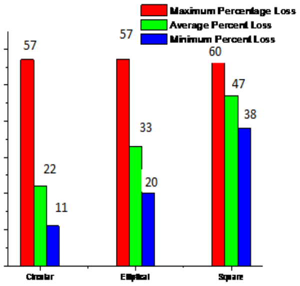

Figure 7 Maximum, Average and Minimum loss of Buckling loads due to cutout

TABLE 1 DECREASE IN EXPERIMENTAL BUCKLING LOAD WITH INCREASE IN SIZE OF CIRCULAR CUTOUT

S. No.	Circular Cutout Diameter d (in cm)	Expt. Buckling load (in N)	Percent Buckling load for 100% for no cut out	Percent Decrease
1	0	2877	100	0
2	1	2256	78	22
3	2	2550	89	11
4	3	2305	81	19
5	4	1961	72	28
6	5	1209	43	37

Table2 Decrease in Experimental Buckling Load with Increase in Size of Elliptical Cutout

Sl. No.	Cutout axes in cm (2a,2b)	Expt. Buckling load (in N)	Percent Buckling load for 100% for no cut out	Percentage of deviation
1	0.0, 0.0	2877	100	-
2	1.5, 1.0	2040	72	28
3	3.0, 2.0	2242	80	20
4	4.5, 3.0	1981	70	30
5	6.0, 4.0	1910	68	32
6	7.5, 5.0	1206	43	57

Table 5 Buckling Loads in Presence of Various Cutouts

Sl. No.	Cutout Dimensions(cm)			Average Buckling load (N)		
	Circular	Elliptical	Square	Circular	Elliptical	Square
1	1	1.5, 1.0	1	2207	2040	1760
2	2	3.0 , 2.0	2	2511	2242	1590
3	3	4.5, 3.0	3	2275	1980	1612
4	4	6.0, 4.0	4	2030	1910	1472
5	5	7.5, 5.0	5	1206	1206	1140

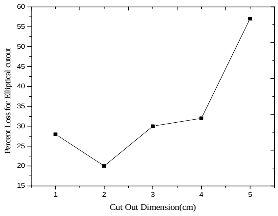

Figure. 6Percentage Loss of Buckling Load with Increasing Dimension of Elliptical Cut-Out

Table 3 Decrease in Experimental Buckling Load with Increase in Size of Square Cutout

Sl. No.	Cutout Side (in cm)	Expt. Buckling load (in N)	Percent buckling load for 100% for no cut out	Percent Decrease
1	0	2811	100	-
2	1	1760	62	38
3	2	1590	56	44
4	3	1612	54	46
5	4	1472	52	48
6	5	1140	40	60

Table 4 Maximum Average and Minimum Percent Loss of Buckling Load Due To Cutouts

Cut Out Nature	Maximum Percentage Loss	Average Percent Loss	Minimum Percent Loss
Circular	57	22	11
Elliptical	57	33	20
Square	60	47	38