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An Experimental Study of Circular Cutout Hole Effect of Kevlar/epoxy-Al_2O_3 Composite under Subjected to Quasi-Static Compressive and Tensile Loading

Ayad Abed Ramadhan
Department of Mechanical Techniques, Al-Hawija Technical Institute, Northern Technical University, Iraq

Abstract
This paper has presented an experimental study of quasi-static compressive and tensile loading of cutout hole on multi-layer of Kevlar-29/epoxy-Al_2O_3laminated composite. The experimental procedure has been developed to study the performance of (50%, 55% and 60%) volume fraction (vf) and ($0^o/90^o$ and $+45^o/-45^o$) fiber orientation angle effects of these composites under quasi-static compressive and tensile load using a servo-hydraulic testing machine. It was concluded that the maximum load bearing capacity increases as volume fraction increases in tensile test. While, the maximum load bearing capacity increases with the decrease of volume fraction in compression test. Hence, from the results obtained it can considered the 55% volume fraction of composite panels is a good value for tensile and compression applications.

Keywords: Experimental study, Cutout, Composite materials and Tensile and compressive load.

دراسة عملية لتأثير الفجوات دائرية الشكل على متراكب كفلر/ايبوكسي - الومنا تحت تأثير احمال السحب والضغط الاستاتيكي

الخلاصة
تم في هذا البحث دراسة عملية لأحمال الشد والضغط الاستاتيكي للمواد المركبة متعددة الطبقات المصنوعة من مادة كفلر/ايبوكسي – الومينا ذات الثقب الدائري ومركزي الموقع. وقد تم في هذا البحث كذلك دراسة تأثير النسب الحجمية لخلط تلك المواد (50%، 55%،60%) و بزوايا تدوير لألياف الكفلر (90/0 ، -45/+45) تحت تأثير احمال الشد و الضغط الاستاتيكي باستخدام جهاز ماكنة هيدروليكية الاداء. لقد تم الحصول على القيم العليا للحمل المسلط على العينات حيث ازدادت تلك القيم مع ازدياد النسب الحجمية في حالة شروط اجهادات الشد او السحب بينما بينت النتائج ازدياد في السعة التحملية للعينات مع نقصان النسب الحجمية في حالة الانضغاط. لهذا يمكن اعتبار ان نسب الخلط عند القيمة (55%) للمواد المركبة المصنوعة من تلك المواد هي مناسبة للتطبيقات و التصاميم التي تتعرض لكلا الحالتين (الشد والانضغاط) لتلك المواد تحت نفس الشروط والظروف التي تم التطرق اليها في هذا البحث.

الكلمات الدالة: الدراسة العملية، الفجوات، المواد المركبة، احمل الشد والانضغاط

Introduction
Composite materials have such an influence on our lives that many researches invested a great deal of time and effort for a better understanding of their behavior. Composite materials have been used for a

while in many industries such as: aerospace, automotive, marine and civil engineering applications. One can say that composite materials usage is limited by the individual imagination. Development of new applications using composites is increasing due to the requirement of materials with unusual combination of properties that cannot be met by conventional monolithic materials. Actually, composite materials are capable of covering this requirement in all means because of their heterogeneous nature. Properties of composite arise as a function of its constituent materials, their distribution and the interaction among them and as a result an unusual combination of material properties can be obtained. One type of composite materials is cross-ply laminated plates with cutouts, where cutouts are introduced for accessibility reasons or to just lighten the structure. Such plates are vulnerable to buckle when subjected to various types of in-plane loadings; therefore, it is of great importance to fully understand the effects of various parameters on its buckling load[1].There are few studies on optimal design of simply supported rectangular plates laminated to composite material and subjected to uniaxial compressive loading[2,3]. Numerical results are presented for optimal-design plates laminated of glass/epoxy, boron/epoxy, and carbon/epoxy composite materials. Initially, few studies were made on thin-walled structures which have high strength coupled with the ease of manufacturing and the relative low weight. However, thin-walled structures have the characteristic of susceptibility to failure by instability or buckling. It is therefore important to the design engineer that accurate methods are available to determine the critical buckling strength[4]. It is well known that laminated composite materials are increasingly used in aircraft structures for their great potential to achieve structural design tailoring in specific stiffness and strength, weight saving and desirable mechanical behavior against applied loads. However, cutouts are often necessary in the construction of aircraft structures for lightening holes, passages for wire bundles, hydraulic and fuel pipes, control linkages, accessibility for final assembly and maintenance inspections. In the construction, cutout usages are categorized and the most noticeable feature of cutout for metallic structure is the rounding of the corners to prevent excessively high stress concentrations[5]. The problems of stress concentration and bucking behavior due to cutouts in laminated composite plates have been studied by a number of researchers since the early 1970s[6,7], and there is an excellent review of research work in these areas[8]. According to Freitas and Reis[9], impact loading in composite plates leads to a damage to matrix cracking, inter-laminar failure and eventually fiber breakage for higher impact energies. Even when no visible impact damage is observed at the surface on the point of impact, matrix cracking and inter-laminar failure can occur, and the carrying load of the composite laminates is considerably reduced.

The effect of cross-ply laminated plates with circular cutouts due to plane shear loading with various parameters was also investigated. For example Al Qablan et al.[10], studied some parameters for comparison reasons which include; cutout size, cutout location or eccentricity, fiber orientation angle and type of loading. Three types of in-plane loading were considered; namely, uniaxial compression, biaxial compression and shear loading. The reduction in the buckling load due to the increase of cutout size was significant in the case of shear loading as compared to uniaxial and biaxial compression. For relatively small size cutouts, a better performance will be achieved if the cutout is kept close to the edge of the plate, however, for relatively large size cutouts, a higher buckling load will be achieved if the cutout is kept in the middle of the plate. Several other imperative findings based upon the various parameters are also presented in this study.

Baba[11], Baba and Baltaci[12], studied the effect of support conditions on the buckling load of laminated plates with circular in semicircular cutouts under axial compression. They found that the buckling load of clamped-clamped plates is 75% higher than the buckling load of simply supported plates, and 50% for the case of clamped-pinned boundary condition. Also, an increase of the length/thickness ratio by 50% increases the buckling load in the range of 75%. The effect of fiber orientation angle was studied by Al Qablan et al.[10] and Vandenbrink and Kamat[13], they also found that the buckling load of composite plates with large holes begins to increase above that of the corresponding solid plate for fiber orientation angle of 60^o. Stress and load-displacement analysis of fiber reinforced composite laminates with a circular hole under compressive load is presented by Manoharan and Jeevanantham[14].

This paper focuses on the analysis of stress-strain and displacement for compressive and tensile load capacity on the circular cut-out holes of kevlar-29/epoxy-Al_2O_3 composite laminated plates. The influence of adding alumina powder (Al_2O_3) on epoxy resin, volume fraction and fiber orientation on this composite panel have been studied in this work. Three different volume fractions (50%, 55% and 60%) and orientations of fibers (0^o/90^o and +45^o/-45^o) have been analyzed in detail and their results have been compared.

Methodology

Experimental Work (Materials Selection and Specimen Fabrication)

Materials selection has been done after several surveys of the previous studies and thesis's recommendations that studded[9-16] the composite plate panels that are made from a reinforcement and resin. Woven roving Kevlar-29 fiber with 82% epoxy resin (EP-A215C1) mixed with 15% Alumina powder (Al_2O_3) and 3% hardener resin (EP-B215) have been selected to fabricate the composite specimens. Hand lay-up method into glass mold has been used in this work to fabricate all the specimens as shown in Figure (1). Woven roving Kevlar-29 fiber is winded manually using an open mold, and epoxy-Al_2O_3.

Fig. 1. Glass's mold of hand Lay-Up Process

Two kinds of Kevlar-29 fiber orientations (0^o,90^o) and (+45^o,-45^o) with 50%, 55% and 60% volume fraction (V_f) of Kevlar-29 of panels/epoxy- Al_2O_3 composite laminated plates with (38mm) cutout circular hole diameter centrally located have been selected to fabricate the composite laminated plates in this paper. All specimens have the same geometry with specimens length of 320 mm as presented specimens' specifications in Table 1. The active length has been 210 mm (unclamped) will carry the tensile or the compression load (as shown in Figure (2)) until failure occurs in the compression test by bulking, so 12 specimens are needed. While failure around the holes by stress concentration generated by the tensile test (free force applied) would lead to fractures and delimitations in the center of the specimen.

Table 1. shows specimen specifications Kevlar-29/epoxy-Al_2O_3 composite plate panels with cut holes

No.	Fiber orientation	Volume Fraction	Average Specimen Dimensions (mm)			No. of Kevlar-29 layers
			Length (L)	Width (W)	Thick (t)	
1	0^o, 90^o	50%	320	60	4	8
2	+45^o, -45^o	50%	320	60	4	8
3	0^o, 90^o	55%	320	60	4	9
4	+45^o, -45^o	55%	320	60	4	9
5	0^o, 90^o	60%	320	60	4	10
6	+45^o, -45^o	60%	320	60	4	10

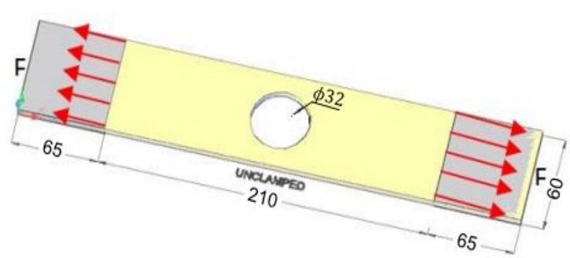

Fig. 2. Specimen dimensions in (mm) with cut holes of Kevlar-29/epox- Al_2O_3composite plate

Laminated plates have been subjected to uniform uni-axial compression and tensile load, F with orientation (0^o, 90^o and +45^o, -45^o) fiber angles. Experimentally, Hydro machine

(E.H-Machine, china assembled) shown in Figure (3) has been used to achieve the static mechanical performance tests such as tensile and compression tests that is connected with computer to get the results.

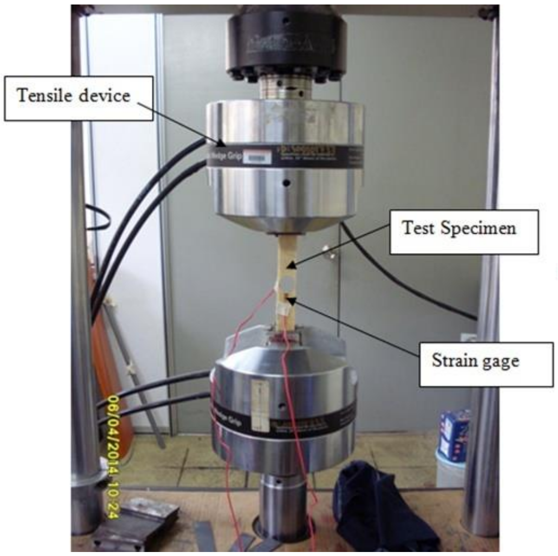

Fig. 3. Clarifies specimen under test which cut out hole

Theoretical Work

Laminated composites are gaining wider use in mechanical and aerospace applications due to their high specific stiffness and high specific strength. Fiber-reinforced composites are used extensively in the form of relatively thin plate, and consequently the load carrying capability of composite plate against buckling has been intensively considered by researchers under various loading and boundary conditions[15]. Hand lay-up technique is used in many industries applications that are increasingly demanding as well as aerospace, automotive, marine, wind energy systems (blades), furniture, telecommunications, transportation and etc.[16-17].

The mass of the composite (M) is presented in Equation (1) below:

$$M = M_f + M_m \quad \ldots\ldots(1)$$

Where Mf and Mm are mass of fiber and mass of matrix respectively.

$$\rho v = \rho_f v_f + \rho_m v_m \quad \ldots\ldots(2)$$

Volume fraction of fiber $(V_f) = \frac{v_f}{v}$ and of matrix ($V_m = \frac{v_m}{v}$)

So, the total volume fraction as presented in Equation (3) below:

$$V_f + V_m = 1 \quad \ldots\ldots(3)$$

The composite panel is subjected to the longitudinal tensile force as shown in Figure (4). It can be supposed in this work that the longitudinal extensions resulting from the tensile force F are the same in the composite, fibers and matrix, which can be presented in Equation (4):

$$\epsilon_1 = \epsilon_1^f = \epsilon_1^m \quad \ldots\ldots(4)$$

With the loading described above the transverse extensions of the fibers and matrix are equal to:

$$\epsilon_2^f = -\upsilon_f \epsilon_1 \quad \ldots\ldots(5)$$

$$\epsilon_2^m = -\upsilon_m \epsilon_1 \quad \ldots\ldots(6)$$

Where υ_f and υ_m represent poison's coefficients of the fiber and the matrix reprehensively.

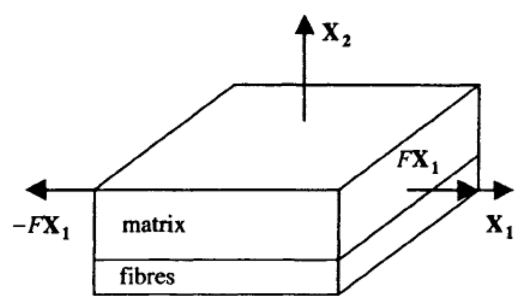

Fig. 4. Manifests Longitudinal tension

To determine the effective axial Poisson's ratio we consider the loading as in the case applied for determining the effective axial modulus. Here, for this loading we have stress in direction (1) isn't equal zero ($\sigma_1 \neq 0$) and other stresses are zero, so the effective axial

Poisson's ratio as υ12 of the composite is defined by Equation (7):

$$\upsilon_{12} = -\frac{\varepsilon_2}{\varepsilon_1} \quad \text{.....................................(7)}$$

From Equation (7) it can obtain the expression by following Equation (8):

$$\upsilon_{12} = V_f \upsilon_f + V_m \upsilon_m = V_f \upsilon_f + (1 - V_f)\upsilon_m \quad \text{...(8)}$$

The number of specimens used in this work is 12 specimens, 6 specimens for tensile tests with different volume fraction V_f and fiber orientation, and 6 specimens for compression test.

Results and Discussion

The experimental results presented of load-displacement curve for Kevlar-29/Epoxy-Al_2O_3 specimens with (60% volume fraction) and [0/90 and 45/-45] fiber orientation under tensile load as shown in Figure 5. The results show that the (0/90) fiber orientation of this composite panel is the highest value with the maximum value of 3720 N while for (-45/+45) fiber orientation is 3356 N. The results from stress and displacement shear loading cases are in very good agreement with those obtained from testing the composite panels with the selected cutout reinforcements. i.e the 9.78% deference value of load capacity in tensile test.

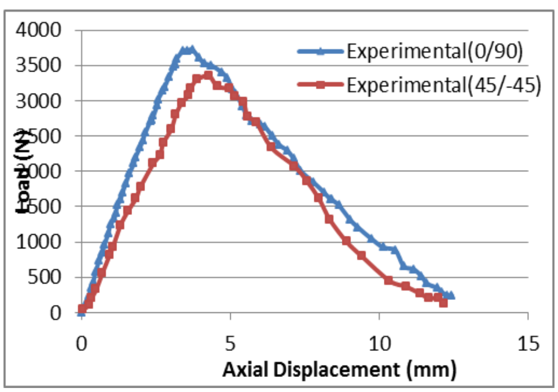

Fig. 5. Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 (Vf 60%)

The results that have been obtained for other Kevlar-29/Epoxy- Al_2O_3 composite panels under tensile test as shown that the (0/90) fiber orientation of this composite panel is the highest value with the maximum value of (3386 N and 2975N) while for (-45/+45) fiber orientation is (3084 N and 3386N)of (55% and 50%) volume fraction respectively as shown in Figures 6 and 7. The volume fraction has been selected in this type of material i.e.60% of tensile load capacity; it has been an optimum value compared with other volume fractions for fabricating the specimens.

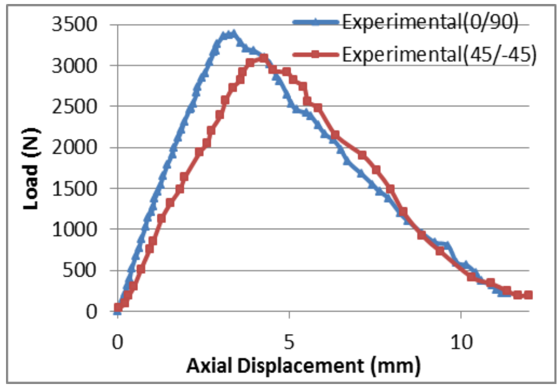

Fig. 6. Load-displacement curve for Kevlar-29/Epoxy-Al_2O_3(Vf 55%)

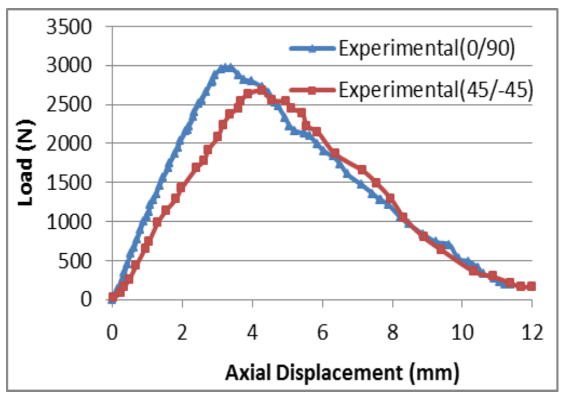

Fig. 7. Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 (Vf 50%)

The behavior of the experimental results has expressed the composite laminated with(0^o, 90^o) and ($+45^o$, -45^o) fiber orientation angles and the curves under compression test. The curves of the presented results shown in Figures (8), (9) and (10) suddenly drop for specimens with cut-out holes because of the stress concentrations around the holes.

The difference resulting of all composite panels from the above results is due to the different fiber orientation (0/90^o and 45/-45) which plays an important role in determining the load capacity.

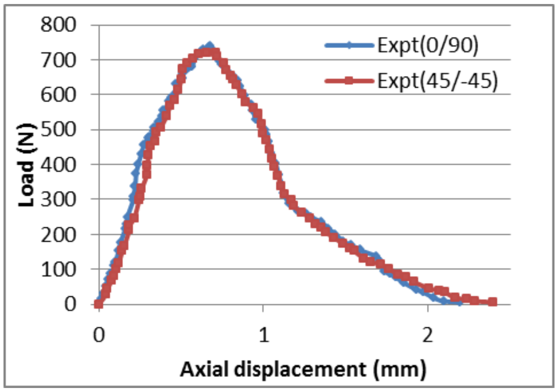

Fig. 8. Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 specimens with (60% volume fraction)

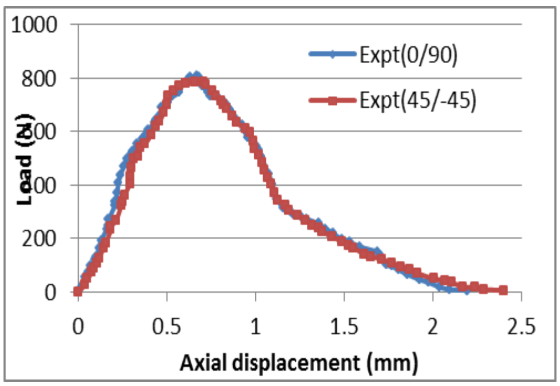

Fig. 9. Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 (V_f= 55%)

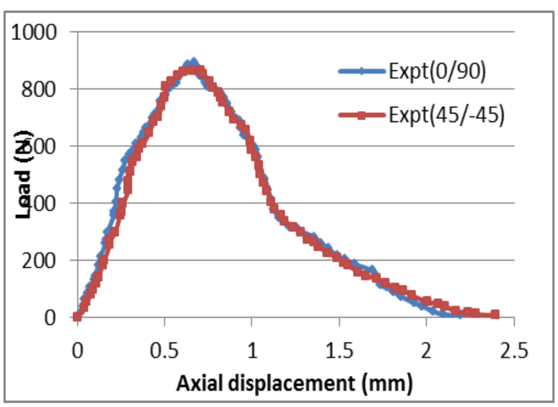

Fig.10. Load-displacement curve for Kevlar-29/Epoxy-Al_2O_3 specimens with (50% volume fraction)

The results obtained for other Kevlar-29/Epoxy- Al_2O_3 composite panels under compression test show that the (0/90) fiber orientation of this composite panel is the highest value with the maximum value of (739, 807 and 893N) while for (-45/+45) fiber orientation is (719, 788 and 863 N) of (60%, 55% and 50%) volume fraction respectively as shown in Figures (8), (9) and (10). The volume fraction has been selected in this type of material 50% of compression load capacity; it has been an optimum value compared with other volume fractions for fabricating the specimens.

From the above results, it can be considered that the optimum value for tensile load capacity obtained is increasing with the increasing value of volume fraction and the maximum value obtained at 60%. While for compression test the value of compression load capacity is decreasing with the increase of volume fraction, so the maximum value can be obtained in this work at 50% volume fraction.

The ultimate load test applied and displacement deformation of experimental results for the four panels are shown below in Tables (3) and (4). The results obtained from this work show that adding the alumina powder in kevler29/epoxy composites increases the values of load capacity of these composites in compression case if we compare these results with previous works.

Table 3. The ultimate tensile load verse displacement of panels (1-6)

Panel	Ultimate Tensile load (N)	Displacement (mm)	Time (s)
	Experimental	Experimental	
1	2975	3.39	14.3
2	2680	4.28	12.9
3	3386	3.93	15.6
4	3084	4.27	15.1
5	3720	3.71	16.3
6	3356	4.27	16.2

Table 4. The ultimate compression load verse displacement of panels (1-6)

Panel	Ultimate Compression load (N)	Displacement (mm)	Time (s)
	Experimental	Experimental	
1	893	0.668	0.045
2	863	0.710	0.044
3	807	0.667	0.039
4	788	0.712	0.033
5	739	0.681	0.034
6	719	0.656	0.031

Results of this work are in good agreement; for load capacity with previous work of Abu Talib et al.[18]. These findings suggest that this type of ply configuration is capable of absorbing large amounts of energy before fracture, where the energy absorbed is given by the area under the load–displacement curve. The compression load capacity of Kevlar-29/epoxy- Al_2O_3 studied in the present work has been found to be 7.05% and 10% higher than those for Kevlar-29/ epoxy[$0^o/90^o$] and [$+45^o/-45^o$] fiber orientation angle of 60% volume fraction that was presented in previous work as well as Abu Talib et al [18] as shown in Table (5).

Comparing the stress and buckling results between the constant stress and the constant displacement loaded panels has shown a good agreement. The FE results have been validated by experimental test data and the overall agreement between them is very good.

Table 5. The comparison of load-displacement of Kevlar-29/epoxy- Al_2O_3 and Kevlar-29/epoxy

Panel		Ultimate Compression load (N)		Difference	Displacement (mm)	
Vf	Fiber orientation	Kevlar-29/ epoxy- Al_2O_3	Kevlar-29/epoxy by [18]	%	Presented by this work	Presented by [18]
60%	$0^o/90^o$	893	830	7.05	0.668	0.263
60%	+45/-45	863	770	10.7	0.710	0.167

Conclusion

The load capacity resulting in this research shows that the specimens that have [$0^o/90^o$] fiber orientation angle is greater than in composite panels of [$+45^o/-45^o$] fiber orientation angle, as well as an increase in the load capacity for the specimens under pressure loads than they are in the case of tension.

The optimum value that was obtained from the experimental results showed that the increase in the value of the volume fracture leads to increase the load capacity in the case of tensile while the opposite in the pressure case of load capacity. The results difference are due to material Al_2O_3 powder which added to the mixture , which increases the value of carrying these materials for the case of compressibility.

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References

1- Katkhuda, H. and Dwairi, H., "Assessment of the Buckling Behavior of Square Composite Plates with Circular Cutout Subjected to In-Plane Shear", Jordan Journal of Civil Engineering, 3(2):184-195, 2009.

2- Pannok, R. and Singhatanadgid, P., "Buckling Analysis of Composite Laminate Rectangular and Skew Plates with Various Edge Support Conditions", The 20th Conference of Mechanical Engineering Network of Thailand, 2006.

3- Supasak, C. and Singhatanadgid, P. A., "Comparison of Experimental Buckling Load of Rectangular Plates Determined from Various Measurement Method", The 18th Conference of Mechanical Engineering Network of Thailand; 2002.

4- Fok, "Applied Theory of Thin Plates to Engineering Structures",1984

5- Niu, M. C. Y., "Airframe Stress Analysis and Sizing", 2nd ed. Hong Kong Conmilit Press Ltd, Hong Kong. Chapter 13, 2001.

6- Greszczuk, L. B., "Stress Concentrations and Failure Criteria for Orthotropic and Anisotropic Plates with Circular Openings", ASTM STP 497, 363-381, 1971.
7- Martine, James, "Buckling and Postbuckling of Laminated Composite Square Plateswit Reinforced Central Holes", PhD Diss., Case Western Reserve University, 1972.
8- Nemeth, M. P., "Buckling and Postbuckling Behavior of Laminated Composite Plates with a Cutout", NASA Technical Paper, 3587, 1996.
9- De Freitas, M. and Reis, L., "Failure Mechanisms on Composite Specimens Subjected to Compression After Impact", J. Compos Structure, 42: 365-366, 1998.
10- Baba, B., "Buckling Behavior of Laminated Composite Plates", Journal of Reinforced Plastics and Composites, 26 (16): 1637-1655, 2007.
11- Baba, B. and Baltaci, A., "Buckling Characteristics of Symmetrically and Antisymmetrically Laminated Composite Plates with Central Cutout", Applied Composite Materials;14:265-276, 2007.
12- Al Qablan, H., Katkhud, H., Dwairi, H., "Assessment of the Buckling Behavior of Square Composite Plates with Circular Cutout Subjected to In-Plane Shear", Jordan Journal of Civil Engineering; 3(20), 25-38, 2009.
13- Vandenbrink, D. J. and Kamat, M. P., "Post-Buckling Response of Isotropic and Laminated Composite Square Plates with Circular Hole", Finite Elements in Analysis and Design, 3:165-174, 1987.
14- Manoharan, R. and Jeevanantham, A. K., "Stress and Load-displacement Analysis of Fiber Reinforced Composite Laminates with a Circular Hole under Compressive Load", ARPN Journal of Engineering and Applied Sciences,6(4), 64-74, 2011.
15- Arun Kumar, R., "Buckling Analysis of Woven Glass Epoxy Laminated Composite Plate", National Institute of Technology Rourkela, Master, 2009.
16- Groppe, D. Robotic, “Layup of Composite Materials", Assembly Automation, 23(2), 153–158, 2003.
17- McGann, T. W. and Crilly, E. R., "Preparation for Cure", Composites, Engineered Materials Handbook, ASM International, Metals Park, 1, 642-644, 1987.
18- Abu Talib, A. R., Ramadhan, A. A., ,Mohd Rafie, A. S. R. Zahari, "Influence of Cut-out Hole on Multi-layer Kevlar-29/epoxy Composite Laminated Plates", Materials & Design, 43, 2013.