STUDYING THE EFFECT OF CUTOUTS ON THE COMPOSITE LAMINATE PLATES

Mr. Arz Y. R.

Mechanical Engineering Department

University of Anbar

ABSTRACT

The aim of current work is to investigate the tensioned composite plates with two types of cutouts. Many industrial applications use composite matrix with reinforcement fiber to obtain better properties. The objective of this work is divided into two parts, first the experimental work covers the measuring of the normal strain (ε_x) at the edges of (circular & square) holes that are perpendicular to the direction of the applied loads with different number of layers and types of cutouts of composite materials by using strain gages technique under constant tensile loads to compare with the numerical results. The second part is numerical work, which involves studying the static analysis of symmetric square plates with different types of cutout (circular – square). In static analysis, the effect of the following design parameters on the maximum stress (σ_x), strain (ε_x) and deflection (U_x) is studied. This part of investigation was achieved by using the software finite element package (ANSYS 5.4).

KEYWORDS: Composite Material, Cutout, Laminate, Composite Plate, Normal Strain, Tensile Load.

1. INTRODUCTION

In practical engineering design, deflections and stresses are very important criteria in reliability and serviceability evaluations of structures [1]. A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale. For example, concrete is made up of cement, sand, stone and water. If the composition occurs on a microscopic scale (molecular level), the new material is then called an alloy for metals or a polymer for plastic.

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and / or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material [2].

Basic ply or lamina of a composite structure can be considered as orthotropic with two principal material directions or natural axes – parallel and perpendicular to the direction of the filaments. By bonding these laminas to form a multi-lamina composite laminate, the designer has a material in which he can change the directional properties by changing the orientation of the various laminas, thus he is able to design a structure with a material that precisely matches the directional loading requirements at the considered point of the structure [3].

Composites are used to increase stiffness, toughness compact strength and strength or dimensional stability, increase heat deflection and temperature mechanical damping, reduce permeability to gases and liquids and reduce costs, modify electrical properties (e g. Increase electrical resistivity) and decrease thermal expansion and increase chemical and corrosion resistance [4].

It is very important for an engineer to be aware of these effects of stress raisers such as notches, holes or sharp corners in his/her deign work. Stress concentration effects in machine parts and structures can arise from internal holes or voids in the casting or forging process, which maybe found in many industrial applications, such as, missile cases, fiber-glass boat hulls, aircraft wing panels, tennis rackets, golf club shafts, etc..

Fiber composite offers many superior properties. Almost all high-strength / high stiffness materials fail because of the propagation of flaws. A fiber of such materials is inherently stronger than the bulk form because the size of a flaw is limited by the small diameter of the fiber [5].

The response of composite materials to the presence of holes, notches depends on the fiber geometry and material properties. The laminated composite plates used in the construction of aircraft, automobiles, ships and chemical vessels are sometimes provided with circular holes to meet functional or design requirements. In course of their service laminates get fractured and developed cracks. These cracks and holes act as stress raisers.

Knowledge of the behavior of the laminated composite plates with opening (cutout) is an important factor in the design of many types of aeronautical, mechanical, and civil structures. An evaluation of the stress concentrations near the cutout is necessary for better understanding of how the hole (cutout) size and shape affects the overall strength of composite.

One of the first investigations in this field was reported by Forchet, M. M. [6], where the stress concentration factor for holes, grooves and fillets were determined by using different loading (pure tension, compression and bending) and using photoelasticity method for determining the maximum value of stress from the change in photometric properties of certain solids due to the external load applied on the body under elastic conditions.

Waddoups [7] considered the problem of predicting the reduction in strength of a composite laminate static strength of composite laminate containing circular holes subjected to uniaxial loading which is reduced to a much higher degrees than in metals where local stress redistribution due to plastic deformation may occur at the notch boundary. Conversely, notched strength of composite laminates is not reduced in proportion to the stress concentration factor.

2. MACRO MECHANICS OF LAMINA

From control surfaces of modern aircrafts, to hulls and keels of yachts, to racing car, bodies, to tennis rockets, fishing rods, golf shafts and heads, laminate fiber reinforced composite is one of the most widely used composites in industry.

Unless otherwise noted, the following assumptions are made in our discussion of the macro-mechanics of laminated composites:

1.The matrix is homogeneous, isotropic, and linear elastic.

2.The fiber is homogeneous, isotropic, linear elastic, continuous, regularly spaced and perfectly aligned.

3.The lamina (single layer) is macroscopically homogenous, macroscopically orthotropic, linear elastic, initially stress-free, void-free and perfectly bonded.

4.The laminate is composed of two or more perfectly bonded lamina to act as an integrated structural element.

3. STRESS-STRAIN RELATIONS FOR PRINCIPAL DIRECTIONS

Before discussing the mechanics of laminated composites, we need to understand the mechanical behavior of a single layer – lamina. Since each lamina is a thin layer, one can treat a lamina as a plane stress problem. This simplification immediately reduces the 6x6 stiffness matrix to a 3x3 one as shown in Fig. (1).

Since each lamina is constructed by unidirectional fibers bounded by a metal or polymer matrix, it can be considered as an orthotropic material. Thus, the stress-strain relations on the principal axes can be expressed by the compliance matrix [s] such that

$$[e]=[s]\quad[s] \tag{1}$$

$$\text{Or}\ \begin{Bmatrix} e_1 \\ e_2 \\ g_{12} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_1} & -\frac{n_{12}}{E_1} & 0 \\ -\frac{n_{21}}{E_2} & \frac{1}{E_2} & 0 \\ 0 & 0 & \frac{1}{G_{12}} \end{bmatrix} \begin{Bmatrix} s_1 \\ s_2 \\ s_{12} \end{Bmatrix} \tag{2}$$

Or by the stiffness matrix [c] such that:

$$[s]=[c]\quad[e] \tag{3}$$

$$\text{Or}\ \begin{Bmatrix} s_1 \\ s_2 \\ s_{12} \end{Bmatrix} = \begin{bmatrix} \frac{E_1}{1-n_{12}n_{21}} & -\frac{n_{12}E_2}{1-n_{12}n_{21}} & 0 \\ -\frac{n_{21}E_1}{1-n_{12}n_{21}} & \frac{E_2}{1-n_{12}n_{21}} & 0 \\ 0 & 0 & G_{12} \end{bmatrix} \begin{Bmatrix} e_1 \\ e_2 \\ g_{12} \end{Bmatrix} \tag{4}$$

Note that the engineering shear strain γ is used in the stress–strain relations, and, the notation [s] for the compliance matrix and [c] for the stiffness matrix are not misprints.

Both stiffness and compliance matrices are symmetric [2], i.e.,

$$\frac{n_{12}}{E_1}=\frac{n_{21}}{E_2} \tag{5}$$

Only four of E_1, E_2, G_{12}, υ_{12}, and υ_{21} are independent material properties. Again, the shear modulus G_{12} corresponds to the engineering shear strain γ_{12} which is twice the tensor shear strain ε_{12}.

Note that there can be many fibers across the thickness of a lamina and these fibers may not arrange uniformly in most industrial practice. However, the combination of the matrix and fibers forms an orthotropic and homogeneous material from a macro mechanics standpoint. Some literature therefore schematically illustrates a lamina with only one layer of uniformly distributed fibers as shown below [8].

The method is used to measure the strain in the direction of the applied loads at the edge of holes that perpendicular to the applied loads. The present work is divided into two stages. The first stage includes the preparation of the mould and moulding the specimen of polyester resin and composite material. The second stage is conducting the tensile test.

Random glass fiber (E-glass) is used to reinforce the composite materials to produce materials with suitable mechanical properties, which are applied in the present structural application.

4. REINFORCED MATERIALS

Glass fibers (E-glass) are widely used as they enjoy good strength, toughness and availability in addition to the properties listed in Table (1) [9]. The main functions of the fibers in a composite are to carry most of the load applied to the composite and provide stiffness. For this reason, fiber materials have high tensile strength and a high elastic modulus [10]. The effect of the fiber is to increase both the tensile strength modulus; the

amount of changes depends on both the form the fibers take and the amount of the fiber [10]. Fig. (2) Shows the random glass fibers (E-glass) used in the present work.

5. EXPERIMENTAL PROCEDURE:

5.1 Specimens Geometry

The specimens used in this study can be classified into two groups depending on the number of layers. The first group includes two specimens made of random glass fibers with mass per unit area (420 g/m2), which consists of four layers. The first specimen contains a central circular hole and the second contains a central square hole as shown in Fig. (3).The second group includes two specimens made of random glass fibers with mass per unit area (420 g/m2) and consists of eight layers. These specimens contain a central circular and square hole as shown in Fig. (4).

5.2 Material and specimen:

Polyester resin was used with random glass fiber (E-glass) to manufacture different number of layers. Fig. (5) shows the main steps of work from sample preparation process until samples testing operation is completed for the composite materials. Table (2) shows the descriptions of specimens used in the experiment work.

6. RESULTS AND DISCUSSION

By utilizing the strain- gauges technique, the strain (ε_x) in the perpendicular direction of applied load is measured. These values of strain are compared with values that are obtained by the software (ANSYS). Table (3) shows the comparison between the experimental results and theoretical results of a symmetric composite plate with different types of cutouts and materials. Increasing the number of layer decreases the value of (ε_x) at the edge of circular and square holes as shown in Table (3) between random glass fibers (4-layers) and (8-layers). Finally it is noted that the value of strain (ε_x) at the edge of square hole is greater than value of (ε_x) at the edge of circular hole. Figs. (6 and 7) and Figs. (8 and 9) shows the specimens before and after test respectively.

Changing the angle of laminate is seen to affect the stiffness of the laminated plate. Also, changing the number of layers affects the stiffness of laminate plate. The fibers carry the applied load when put at (θ^o) equal to (0^o), while the matrix carries the load when put at (θ^o) equal to (90^o). For a symmetric square plate subjected to uniaxial constant applied load, the maximum value of normal stress (σ_x) occurs at lamination angle (30°) for both specimens with and without circular holes. Als, the maximum value of normal stress (σ_x) occurs at lamination angle (80°) for square hole as shown in Fig. (10). Increasing the number of layers decreases the maximum value of normal stress (σ_x). The maximum value of strain (ε_x) is affected by changing the lamination angle (θ^o) and the maximum value of strain occurs at lamination angle (50°) for symmetric square plate without hole. Also, it is noted that the rate of change of strain with (θ^o) is high between $\theta = 10^o$ and $\theta = 40^o$ for circular hole, but for square hole the maximum value of strain (ε_x) occurs at lamination angle (80°) as shown in Fig. (11). Moreover increasing the number of layers decreases the maximum value of strain.

The maximum value of (U_x) occurs at lamination angle (70°) for symmetric square plate without hole, also, the rate of change of deflection with (θ^o) is high between $\theta = 10^o$ and $\theta = 40^o$ for circular hole while the minimum value of (U_x) occurs at lamination angle (40°) for symmetric square plate with square hole as shown in Fig. (12). Increasing the number of layers decreases the value of the maximum deflection.

Table (4) shows the effect of presence of circular , square holes on the maximum values of stress, strain and deflection of a symmetric square plate subjected to uniaxial constant applied load

7. CONCLUSIONS:

From the previous discussion the following points can be concluded: -

1. Increasing the number of layers decreases the value of normal strain (ε_x) at the edges of (circular & square) holes of symmetric plates of different types of composite materials which consist of fibers and matrix.
2. The value of normal strain (ε_x) at the edge of square hole is greater than the value at the edge of circular hole of symmetric plates of different types of composite materials.
3. The lamination angle ply affects the maximum value of stress, strain and deflection of symmetric square plates subjected to uniaxial applied load. The maximum value of stress occurs at lamination angle (30^0) and the maximum value of strain and deflection occurs at lamination angle (70^0& 50^0), respectively.
4. The maximum value of the stress in a plate containing circular hole is (11.5) (MPa), while the value of the maximum stress in plate containing square holes is (13.2) (MPa). Also, the value of the maximum strain for circular hole is (0.38) (E-3), and for the square holes is (0.475) (E-3).

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Table (1): The set of properties for E-glass [9].

Properties	E-glass	Units
Diameter	8-14	µ m
Density	2.56	103 Kgm-3
Young's modulus	76	GNm-2
Poisson's ratio	0.22	/
Weight per unit area	420	g / m2

Table (2): Descriptions of specimens used in experiment work.

No. of layers	Type of hole	Total thickness (mm)	Hole dimensions D (mm)	Length to width ratio	Volume fraction of fibers	Volume fraction of matrix
4	Circular	2	4	3	0.55	0.45
4	Square	2	4	3	0.58	0.42
8	Circular	2	4	3	0.54	0.46
8	Square	2	4	3	0.65	0.35

* D: presented the diameter in circular hole and the length side in square hole.

Table (3): Experimental and numerical results of different types of composite materials.

No. of Layers	Type of hole	Experimental (ε_x)	Numerical (ε_x)	Discrepancy %(*)
4	Circular	0. 0189	0. 0177	6.35
4	Square	0. 019	0. 0209	10
8	Circular	0. 0165	0.0142	14
8	Square	0. 0193	0.0183	5.18

$$(*)\text{Discrepancy } (\%) = \frac{e_{x\exp.} - e_{x\,num.}}{e_{x\exp.}}$$

Table (4): The effect of presence of holes (with out, circular, square) on the maximum values of stress, strain and deflection of a symmetric square plate.

No. of layers	Total thickness (m)	Type of holes	Max. stress (σ_x) (Mpa)	Max. strain (ε_x)(*10-6)	Max. deflection (m) (*10-6)
4	0.006	-	10.528	196	12
8	0.006	-	5.264	98	5.9
4	0.006	Circular	11.51	380	8.4
8	0.006	Circular	2.72	198	5.3
4	0.006	Square	9.449	475	9
8	0.006	Square	4.724	240	4.5

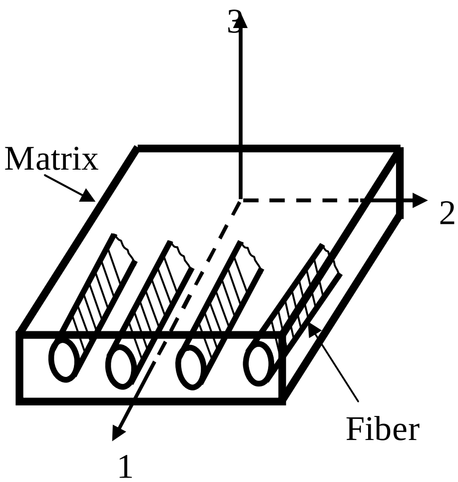

Figure (1):Unidirectional reinforced lamina.

Figure (2): Random glass fibers (420g/m2)

Figure (3): Random, 4-layers

Figure (4): Random, 8-layers

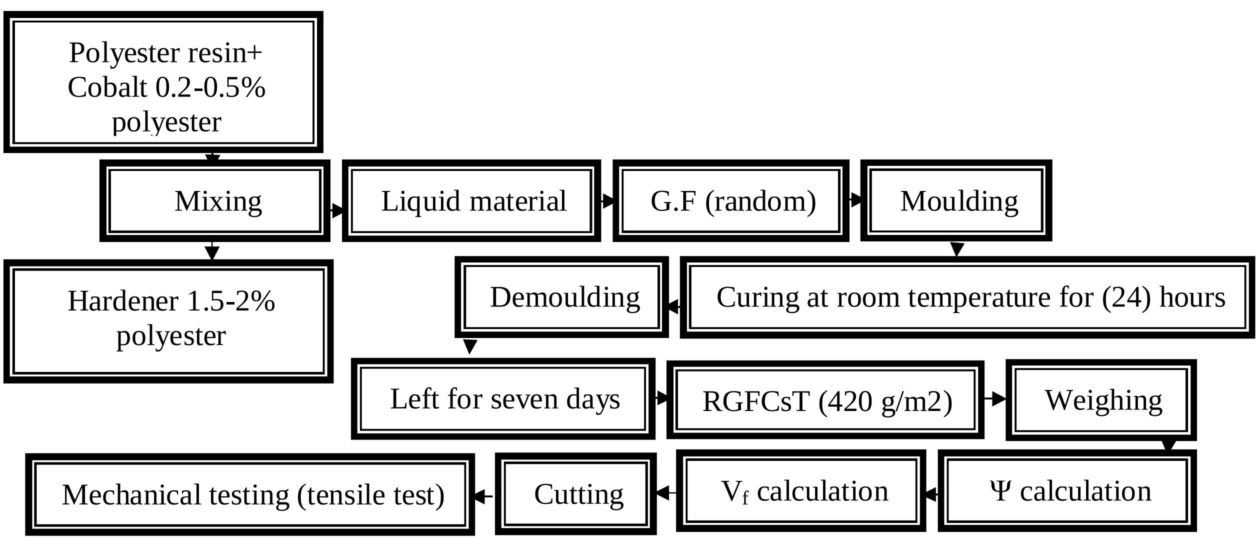

Figure (5): Block diagram of work from preparation process until samples testing performed for composite materials.

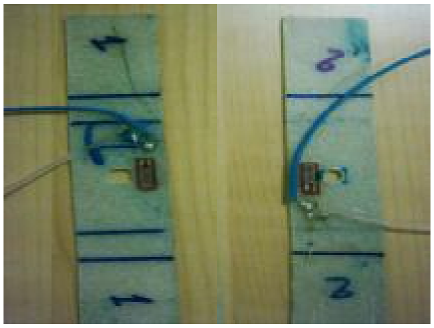

Figure (6): Random , 4-layers

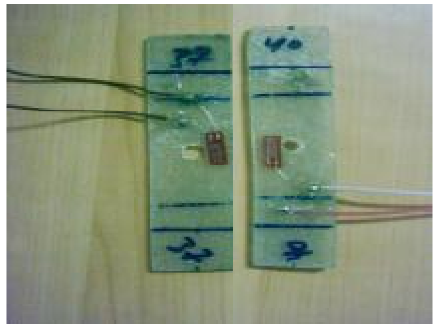

Figure (7): Random , 8-layers

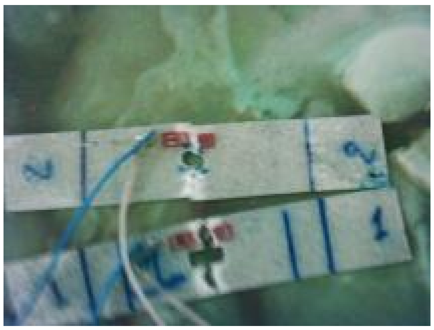

Figure (8): Random , 4-layers

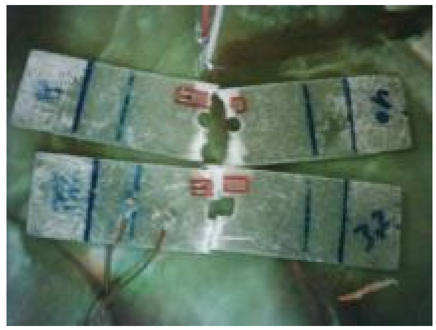

Figure (9): Random , 8-layers

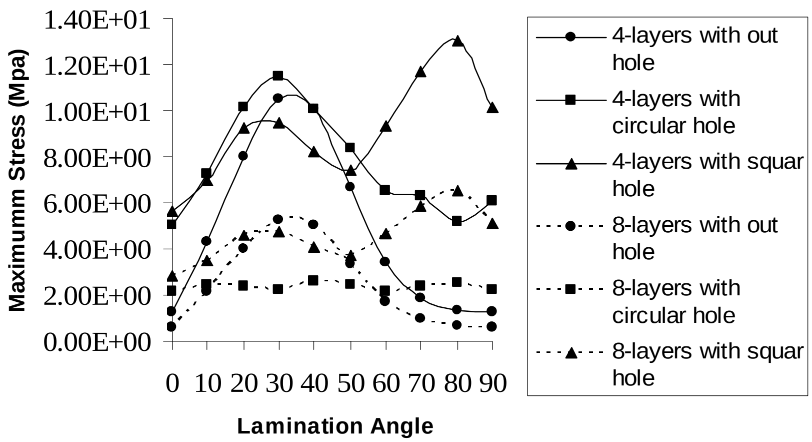

Figure (10): The effect of lamination angle on the maximum stress of a symmetric angle-ply laminates of square plate.

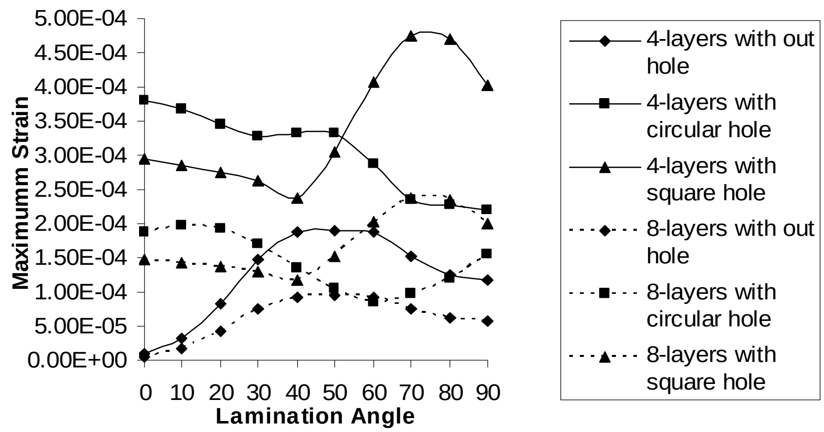

Figure (11): The effect of lamination angle on the maximum strain of a symmetric angle-ply laminates of square plate.

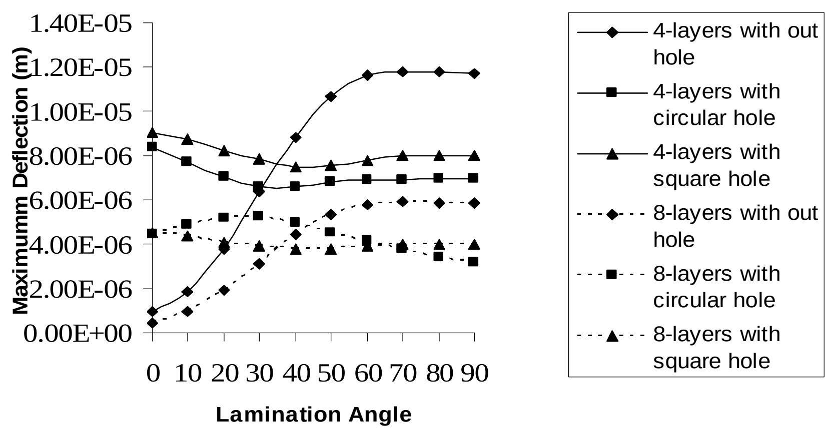

Figure (12): The effect of lamination angle on the maximum deflection of a symmetric angle-ply laminates of square plate.

دراسة تأثير الثقوب على الألواح المركبة

أرز يحيى رزيك
قسم الهندسة الميكانيكية - جامعة الانبار

الخلاصة

الهدف من العمل الحالي هو دراسة الألواح المركبة والمعرضة إلى أحمال استاتيكية (أحمال شد سكوني) وبوجود نوعين من الثقوب (دائرية و مربعة). يستعمل في العديد من التطبيقات الصناعية ألياف التقوية مع المواد الرابطة للحصول على أفضل الخواص. إن أهداف هذا العمل منقسم إلى قسمين، أولا الجزء العملي ويتضمن قياس الانفعالات عند حافة الثقوب (دائرية و مربعة) العمودية على اتجاه تسليط الأحمال للألواح المصنعة من مواد و ثقوب مختلفة و قد تم قياس الانفعالات باستخدام تقنية متحسسات الانفعال، لغرض مقارنتها مع بعض النتائج النظرية.ثانيا الجزء النظري والذي يتضمن دراسة القيم العظمى لكلا من الإجهاد والانفعال والانحراف والناتجة من تأثير الأحمال المسلطة على الألواح المربعة والمتماثلة وبوجود نوعين من الثقوب (دائرية و مربعة). إن الجزء النظري تم انجازه باستخدام البرنامج الهندسي المعروف(ANSYS 5.4) والذي يعتمد طريقة العناصر المحددة.