Experimental Investigation of Stress Concentration Factor in an Isotropic and Orthotropic Plate with Multiple Circular Holes

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***Abstract*— Stress concentration around holes is an important problem for mechanical engineering and civil engineering and used in various engineering applications. Abrupt change in geometry of component is known as stress concentration. In this paper, stress concentration of rectangular isotropic and orthotropic plate with multiple circular holes are calculated in tensile loading on computerized Universal Testing Machine (UTM) and Strain gauge indicator. The material used for the plate is Mild steel in isotropic nature and Carbon epoxy in orthotropic nature. Experimental results are compared with finite element ANSYS software.**

***Index Terms*— Finite element analysis, Multiple circular holes Stress concentration, Universal Testing Machine.**

I. INTRODUCTION

This study is concerned with the synergistic effects of multiple holes on the stress concentration in isotropic plates and composite plates. Many researchers have studied the effects of single hole in isotropic plates and composite plates; little information exists to aid the designer in dealing with the effects of multiple holes. Multiple holes are an important design consideration in aerostructures and other applications, where the holes are needed for access, weight reduction and other reasons.

For design of plates with hole, accurate knowledge of deflection, stresses and stress concentration are required. Stress concentration arises from any abrupt change in geometry of plate under loading.

The location and magnitude of maximum stress will vary depending on a number of factors such as the size of discontinuity, shape of the discontinuity, number of discontinuity, location of discontinuity [6].

Mild Steel (Isotropic) Plates with holes are widely used in various Industries aerospace industry and vehicle industries etc. In order to anticipate problems of corrosion resistance and to reduce weight of products Carbon epoxy (Composite) material plates with holes are studied. Holes in composites will create stress or strain concentrations and hence will reduce the mechanical properties [11]. Woven fabric composites are orthotropic composites.

The computerized Universal Testing Machine (UTM) and Strain gauge indicator are used to find Stress concentration near multiple holes experimentally. The advantages of the strain gauge indicator technique are accurate and strain near holes (in the micron meter range), are indicated.

The aim of this paper is to investigate the stress concentration in rectangular isotropic and orthotropic plates with multiple circular holes. Stresses around holes are calculated from the strain concentration and then stress concentration is calculated.

II. EXPERIMENTAL

A. *Materials*

Stress concentration investigation on rectangular plates with multiple holes, was carried on Mild Steel (Isotropic) and (composite) woven carbon fiber epoxy resin (0°/90°).

For Composite materials, there are basic two phase of composite material, in which one is known as matrix material and another one is called reinforcing material. The reinforcing material is embedded over matrix material.

In this paper carbon is reinforcing material and epoxy is matrix material. Carbon fibers have high elastic modulus exhibiting high stiffness at low elongation. Carbon fibers are not moisture absorbent and resist chemical actions. Their fatigue strength is excellent and do not get stressed and corroded easily. Carbon fibered composites are ideally suited for applications where strength, chemical inertness, stiffness, weightlessness, high damping and fatigue characteristics are the inevitable requirements.

Epoxy is a very versatile resin system, allowing for a broad range of properties and processing capabilities. It exhibits low shrinkage as well as excellent adhesion to a variety of substrate materials. Epoxies are the most widely used resin materials and are used in many applications, from aerospace to sporting goods.The matrix consisted of resin LY556 and hardener HY951. LY556 resin is a bifunctional epoxy resin.

B. Specimen Preparation

First to prepare samples for Mild steel plate with different dimension and thickness. Required composite material was manufactured by Hand Layup Method to form plates of required thickness. Test laminates of 300 mm X 300 mm were initially fabricated to prepare test specimens by hand lay-up technique. The final thickness of the laminate was 2 mm. The weight ratio of the fabric and the matrix was maintained at 65% and 35% by weight respectively. The matrix consisted of resin LY556 and hardener HY951. The weight ratio of resin to hardener was maintained at 10:1 – [3].

The fabric roll was spread on the flat surface and required dimension of 300 mm x 300 mm was marked using the marker pen on the spread fabric and cut using a scissor manually. Required number of layers of fabric was cut to get the required thickness of laminates. The resin and the hardener of required quantities were taken in a previously weighed empty bowl. They were mixed properly in the bowl using a paintbrush. The mixture was used immediately in the preparation of the laminate which otherwise would form gelation. A highly polished flat wood mould was cleaned and wiped dry followed with Polyvinyl Acetate (PVA) wax for about 20 minutes to dry. The wax is applied in order to form a thin film. A small quantity of resin system was coated on the mould surface and then a layer of the fabric already cut was placed on that. The resin system was applied on the fabric to wet it and then the next layer of fabric was placed. The same procedure was followed till the required number of layers were placed ensuring adequate impregnation – [4].

Fig-1: Wood mould used for hand lay up technique

After completion of hand lay up technique, layers of carbon and epoxy required pressure till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mould plate which is then kept on the stacked layers and the pressure is applied with the help of C clamps.

Laminates were prepared for 0°/90° and were cut to the required size and shape in accordance with ISO 527 or NF T57-301 standards to undergo tensile tests – [9].

C. Tensile Test set up

The fig.2 shows complete experimental setup. It shows a Computerized Universal Testing Machine of 100 Tonne capacity. Plate is clamped between the two jaws of UTM. Two strain gage of 90° rosette is connected to the instrument "10 Channel Strain Gage Indicator". Two computers are used, one for operating the UTM and another used for recording the strain gage data. The UTM having two operating valves, the left valve is used to release the hydraulic oil pressure after conducting every test and the right valve is used to gradually increase the hydraulic oil pressure.

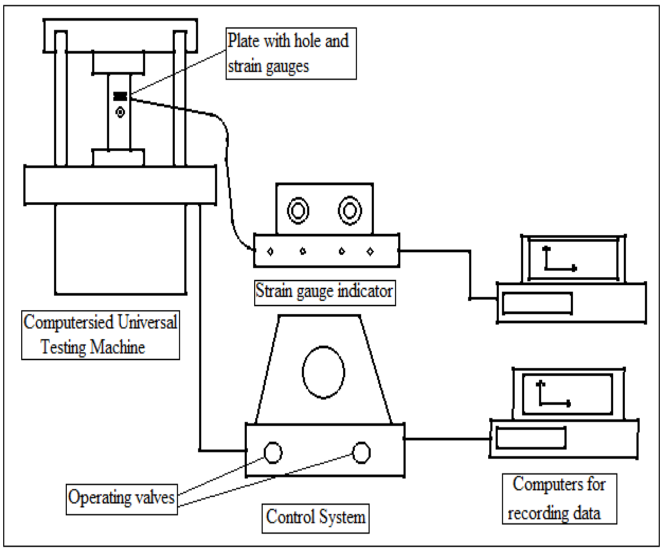

Fig-2: Tensile Experimental setup

After Plate is clamped wires from gages are connected to the 10 Channel strain gage indicator. Plate is clamped on UTM in such a way that connections to 10 Channel strain gage indicator should not disturb.

Before applying load on the plate, the strain gage reading units of the 10 Channel strain gage indicator are made to zero. The UTM test input data is entered in the right side computer and alternately the strain gage data is recording in the other computer. By checking all the connections the test is started by gradually opening the right side valve. The strain in each direction is going to change and data is recorded in micron meter.

III. PROBLEM DEFINITION

Rectangular Isotropic and orthotropic plates with multiple circular holes under tensile load has been considered. The properties of Isotropic (MS) Material for calculation of Stress Concentration factor shown in table 1.

The geometrical aspect of the tensile test specimens were performed in accordance with ISO 527 or NF T57-301 standards which are applied to plate [2]. For test specimens length of 250 mm and width of 25 mm with a circular hole of diameters d1 = 2 mm d2 = 4mm, d3=6mm at centre.

E (GPa)	μ	Thickness (mm)
210	0.3	2

Table 1 Tensile Properties for MS Plate

The properties of orthotropic composite (Carbon epoxy) Material for calculation of Stress Concentration factor shown in table 2.

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Table 2 Tensile Properties for Carbon epoxy Plate

E11 (GPa)	E22 (GPa)	γ12	G12 (GPa)	Thickness (mm)
58.33	45.08	0.06	3.24	2

IV. NUMERICAL APPROACH

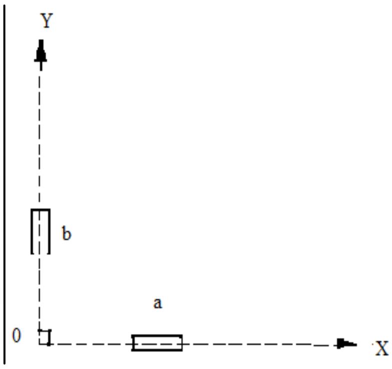

Fig.3 a MS Plate with 1hole

Fig.3 b Two gauge strain rosette (90°)

Fig. 3 Two strain gauge rosette (90°)

Fig.3 a shows two strain gauge rosette (90°) pasted on plate with hole. Fig.3 b shows two strain gauge rosettes (90°). For this rosette gauges angles -

$\phi a = 0°$ $\phi b = 90°$

Two gages are attached to the plate in different angles as indicated fig. 3. Any rotated normal strain is a function of the coordinate strains εx and εy which are unknown in this case therefore two strains εa and εb are required along directions a and b to determine state of a strain at a specific point on plate Thus, if two different gages are all rotated, that will give equations, with unknowns εx, εy.

These equations are,

$$\varepsilon a = \frac{1}{2}(\varepsilon x + \varepsilon y) + \frac{1}{2}(\varepsilon x - \varepsilon y)\cos 2\phi a + \frac{1}{2}\gamma xy(\sin 2\phi a)$$

$$\varepsilon b = \frac{1}{2}(\varepsilon x + \varepsilon y) + \frac{1}{2}(\varepsilon x - \varepsilon y)\cos 2\phi b + \frac{1}{2}\gamma xy(\sin 2\phi b)$$

$$\varepsilon c = \frac{1}{2}(\varepsilon x + \varepsilon y) + \frac{1}{2}(\varepsilon x - \varepsilon y)\cos 2\phi c + \frac{1}{2}\gamma xy(\sin 2\phi c)$$

..(equation 1) - [12]

A. *Strain Gage Pasting on Plate*

A strain gage bonding is very important for accurate results. A strain gage bonded to the piece in such a manner that the strain experienced by gage grid is precisely the same as the strain of the test specimen.

For pasting of strain gage on the specimen necessary steps are - Surface preparation, gage preparation, adhesive preparation, gage installation, lead wire connections. While pesting of strain gauge on carbon epoxy plate a care should be taken, carbon epoxy laminate will not damage.

Fig.4.1 MS Plate without strain gauge and Plate with two strain gauge rosette

Fig.4.2 Carbon epoxy Plate without strain gauge and Plate with two strain gauge rosette

Fig.4.1 and Fig. 4.2 shows MS and Carbon epoxy plates without strain gauge and MS and Carbon epoxy plates pasted with strain gage. For pasting of the strain gauge the contact surface should be very smooth, clean and dust proof. Small solder tabs was used to connect lead wires.

As strain gauge grid is delicate, so care should be taken to connect strain gauges with lead wires. The gauge is pasted on strain gauge in direction where strain is measured. As shown in fig.4.1 and fig. 4.2 in similar way two gauge strain rosette pasted on MS and Carbon epoxy plates with multiple circular holes.

As $\phi a = 0°$ $\phi b = 90°$ put in equation 1

We get, $\varepsilon a = \varepsilon x$

$\varepsilon b = \varepsilon y$

Hence $\varepsilon_1 = \varepsilon a$ and $\varepsilon_2 = \varepsilon b$ ..(equation 2) - [12]

By using above equations we can find out the strain values i.e. εx and εy.

From equation 2 we get values of and ε1 and ε2

Hence we get stresses σ1 and σ2

$$\sigma 1 = \frac{E}{(1-\mu^2)}(\varepsilon 1 + \mu\varepsilon 2)$$

$$\sigma 2 = \frac{E}{(1-\mu^2)}(\varepsilon 2 + \mu\varepsilon 1)$$

..(equation 3) - [12]

The analysis of result is based on load according to the deformation for Isotropic and Orthotropic plate. The strain data is obtained from 10 channel strain gauge indicator. For finding Stress Concentration factor for Isotropic plate first to find out the nominal stress because the Stress Concentration Factor (Kt) is equal to Maximum Stress divided by Nominal Stress. The maximum stress is the stress occur at the edge of the hole and Nominal stress is just the gross stress in the same element under the same loading conditions without holes, notches.

$$Kt = \frac{\sigma\ maxmium}{\sigma\ nominal} \qquad ..(equation\ 4)$$

Stresses around the hole in composite plate can be calculated from the measured strain field ε11 and ε22 using the following equation.

$$\sigma 11 = \frac{E11\ \varepsilon 11}{(1-\mu^2)(E22/E11)} + \frac{E22\ \varepsilon 22}{(1-\mu^2)(E22/E11)}$$

..(equation 4) - [9]

Nominal stress for Carbon epoxy plate is calculated as follows

$$\sigma^* = \frac{P}{(w-d)*t}$$

Where σ^* nominal stress w is is width of plate, d is diameter of hole and t is the thickness.

V. Analytical Approaches

For Analytical Finite element analysis (FEA) is used to calculate stress concentration in Isotropic and in Orthotropic Composite plates with multiple circular holes subjected to uniaxial tension.

For Isotropic (MS) Plates with 1 hole, 2holes and 3holes results are -

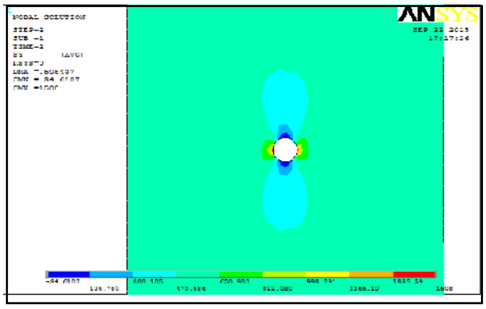

Fig-5: sample 1 MS plate with 1 hole

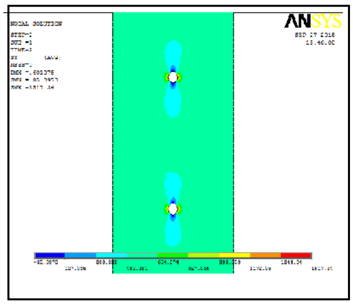

Fig-6: sample 2 MS plate with 2 holes

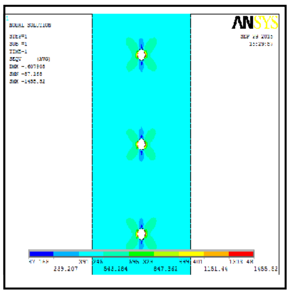

Fig-7: sample 3 MS plate with 3 holes

For MS Plates

Fig. 8,9 and 10 shows Von mises stress for 1,2 and 3 holes. Von mises stress for MS plate 3 holes is maximum than MS Plates with 1 hole and 2 holes.

Von mises stress is maximum stress hence Stress Concentration is calculated by using equation 4.

For Carbon epoxy plates

Fig. 8,9 and 10 shows Von mises stress for 1,2 and 3 holes. Von mises stress for Carbon epoxy plate 1 hole is maximum than Carbon epoxy Plates with 2 holes and 3 holes.

Von mises stress is maximum stress hence Stress Concentration is calculated by using equation 4.

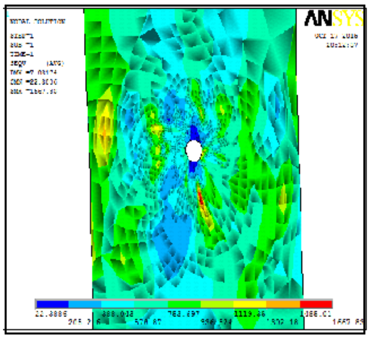

Fig-8: sample 1 for Carbon epoxy plate with 1 hole

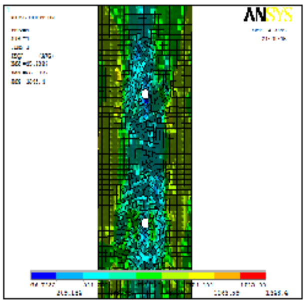

Fig-9: sample 2 for Carbon epoxy plate with 2 holes

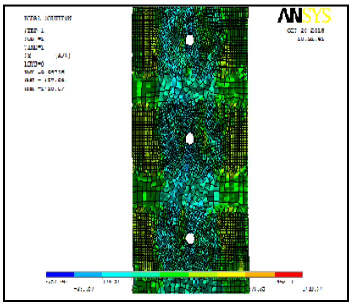

Fig-10: sample 3 for Carbon epoxy plate with 3 holes

VI. Result and Discussion

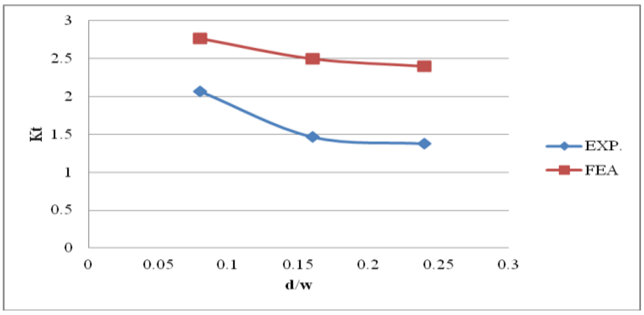

Fig-11: Graph of 1 hole ms plate

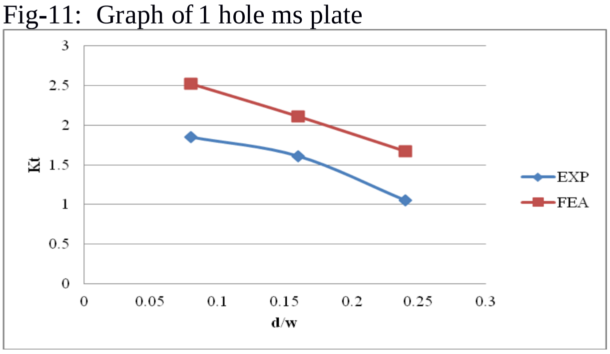

Fig-12: Graph of 2 hole ms plates

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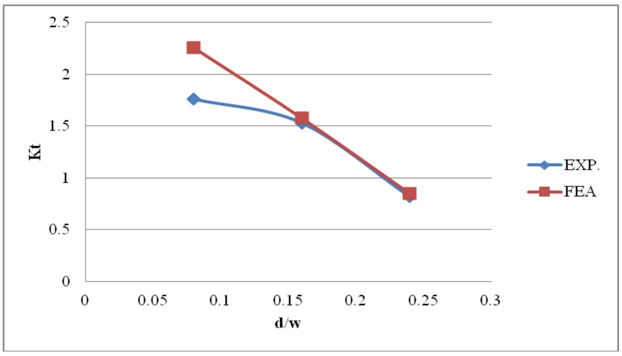

Fig-13: Graph of 3 hole ms plates

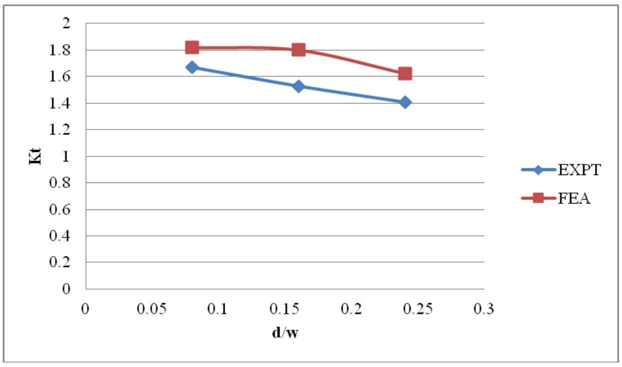

Fig-14: Graph of 1 hole carbon epoxy plate

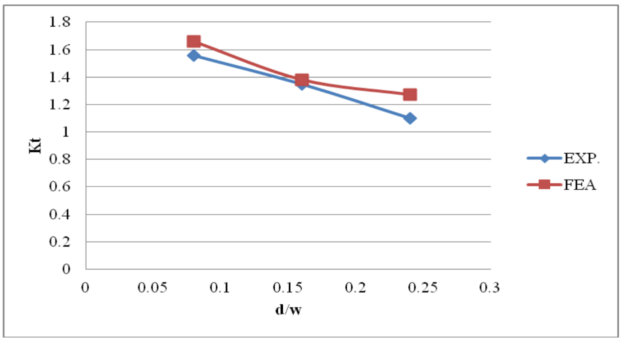

Fig-15: Graph of 2 hole carbon epoxy plates

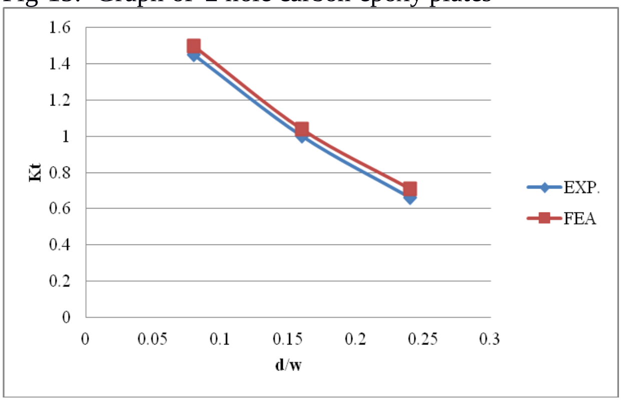

Fig-16: Graph of 3 hole carbon epoxy plates

Fig. 11, 12 and 13 shows Comparison for Kt Vs d/w between Experimental (Blue Line) and Finite element analysis (Red Line) for Ms plates with 1,2 and 3 holes.
Fig. 14, 15 and 16 shows Comparison for Kt Vs d/w between Experimental (Blue Line) and Finite element analysis (Red Line) for Carbon epoxy plates with 1, 2 and 3 holes.

From above results of Kt Vs d/w shows that Kt values of Experimental and Finite element analysis are near to each other.

VII. CONCLUSION

The precision of experimental results explains value of stress concentration factor in Isotropic (MS) plates and Composite (Carbon epoxy) plates is lower compared to the analytical results. The stress concentration in plate with holes is influenced by the loading direction. We conclude that as diameter of the hole changes, the stress concentration factor is also changes with respect to dimensions of plate. The behaviour of the maximum stress for plates with one center hole is the same with the plates with two holes but there is a sensitive difference in the values between them.
The maximum stress concentration factor is more in Isotropic (MS) plate than Composite (Carbon epoxy) plate with multiple circular holes.

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