Use of Strain Gauge Rosette to Investigate Stress concentration in Isotropic and Orthotropic Plate with Circular Hole

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Abstract - ***Rectangular plate with circular holes are used in engineering applications. The understanding of the effect of hole and stress concentration of plate is very important in design of components. Abrupt change in geometry of component is known as stress concentration. In this paper, stress concentration of rectangular isotropic and orthotropic plate with circular hole are calculated in tensile loading on computerized Universal Testing Machine (UTM) and Strain gauge indicator. The influence of diameter to width ratio (d/w) on stress concentration is also studied. Experimental results are compared with finite element ANSYS software.***

Key Words: *Finite element analysis, Stress concentration, Two circular holes, Universal Testing Machine.*

1. INTRODUCTION

In design of any mechanical product, study of stress concentration factor is important to avoid failure of product. The presence of holes or notches in the product cause stress concentration. There are various numerical analysis methods like Finite Element Method, Finite Difference Method and Boundary Element Method for stress analysis to find stress concentration.

This study includes rectangular isotropic plate and orthotropic plate with circular hole under longitudinal tensile loading. MS plate cutout is more useful and gives greater efficiency than Al plate [2]. Rectangular plate with hole have found widespread applications in various fields of engineering such as aerospace, marine, automobile and mechanical.

Holes in composites will create stress or strain concentrations and hence will reduce the mechanical properties [9]. Composite laminates were fabricated using hand lay-up technique for woven fabric (0°/90°) for 2 mm laminate thickness. The computerized Universal Testing Machine (UTM) and Strain gauge indicator are used to find Stress concentration near the hole experimentally. The advantages of the Strain gauge indicator technique are accurate and strain near hole (in the micron meter range), is indicated.

2. STRAIN GAGE APPLICATION ON PLATE

Strain gauge gives simple and accurate value of strain (in the micron meter range), even slight deformation of surface. There is no instrument which gives value of stress at cutout locations. Strain of location can be measured with two common techniques extensometer and strain gage indicator.

Strain gages are constructed from a single wire that is wound back and forth. The gage is attached to the surface of plate near hole with wires in the direction where the strain is to be measured.

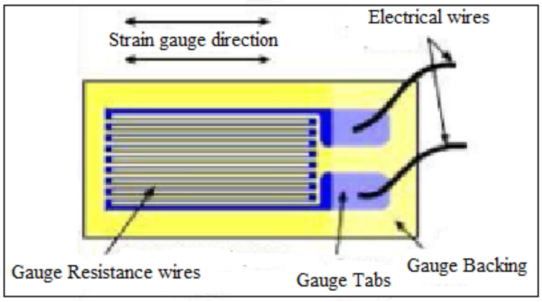

Fig.1 Strain gage

Fig.1 shows the basic strain gage. In electrical resistance strain gauges strain is measured as a function of resistance change produced by the displacement in gauging circuit.`

Single strain gauge is used to measure the strain in one direction, two gauges are needed to determine strain in X and Y direction, at one location on a stressed object known as two gauge strain rosette.

3. NUMERICAL APPROACH

Fig.2 a MS Plate with hole

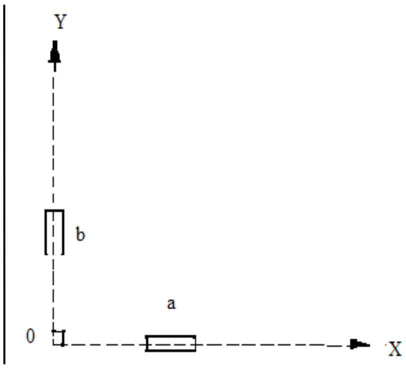

Fig.2 b Two gauge strain rosette (90°)

Fig. 2 Two strain gauge rosette (90°)

Fig.2 a shows two strain gauge rosette (90°) pasted on plate with hole. Fig.2 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. 2. 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) - [10]

3.1 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.

Fig.3.1 MS Plate without strain gauge and Plate with two gauge strain rosette

Fig.3.2 Carbon epoxy Plate without strain gauge and Plate with two gauge strain rosette

Fig.3.1 and Fig. 3.2 shows MS and Carbon epoxy plates without strain gauge and MS and Carbon epoxy plates pasted with strain gage. For pasting of the strain gage 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 $\phi a = 0°$ $\phi b = 90°$ put in equation 1

We get, εa = εx

εb=εy

Hence ε1 = εa and ε2 = εb ...(equation 2) - [10]

By using above equations we can find out the strain values i.e. εx and εy. The two rosette gage covers smaller area hence will give more results in a region in which the strains are varying. In gauge rosette distance from the neutral axis is very important, will shows error if different distance from the neutral axis.
From equation 2 we get values of and ε1 and ε2

Hence we get stresses $\sigma 1$ and $\sigma 2$

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

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

..(equation 3) - [10]

4. EXPERIMENTAL

The fig.4 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.

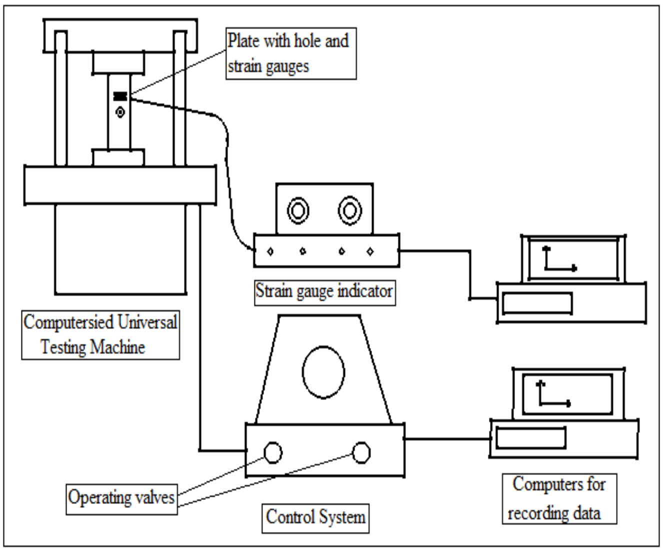

Fig.4 Experimental setup

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.

5. PROBLEM DEFINITION

A Isotropic rectangular plate with circular hole under tensile load has been considered. The numerical simulation is carried out for calculation of Stress Concentration factor shown in table 1.
The geometrical aspect of the 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.

Table 1 Tensile Properties for MS Plate

E (GPa)	μ	Thickness (mm)
210	0.3	2

The present work for Orthotropic material carried out with woven carbon fabric and epoxy resin. The matrix material was Araldite Epoxy Resin LY556 and hardener HY951 mixed in appropriate ratio (10:1).
The geometrical aspect of the test specimens were performed in accordance with ISO 527 or NF T57-301 standards which are applied to carbon fiber composites [7]. 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.

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

6. RESULT AND DISCUSSION

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.

$$K_t = \frac{\sigma \text{ maxmium } (\sigma 1)}{\sigma \text{ nominal } (\sigma 2)}$$

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) - [7]

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.

6.1 Stress concentration calculated from the strain Measurements

Experimental data is obtained from tensile tests of rectangular specimens containing holes of different sizes.

$$Kt = \frac{\sigma \text{ maxmium } (\sigma 11)}{\sigma \text{ nominal } (\sigma^*)}$$

The local variations in the mechanical properties are neglected and values of stress concentration factor (SCF) for woven fabric composites on-axis tensile loading are calculated.

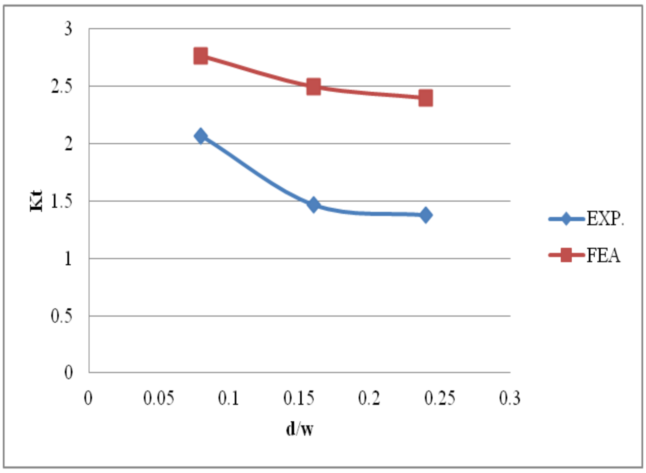

Fig. 5 Comparison for Kt Vs d/w between Experimental and Finite element analysis for Isotropic Plate

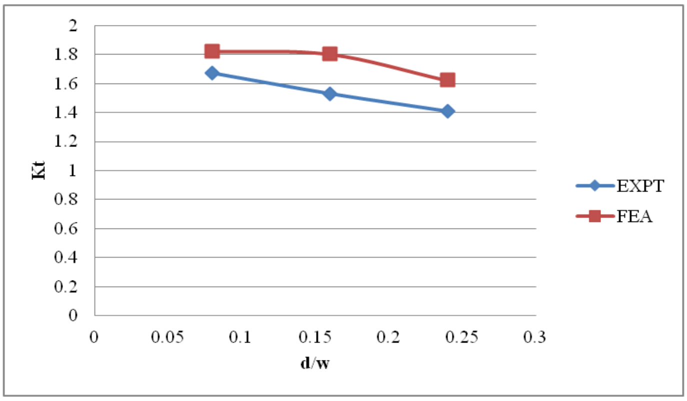

Fig. 6 Comparison for Kt Vs d/w between Experimental and Finite element analysis For Composite Plate

The above Fig.5 and Fig.6 shows the comparative difference for Kt Vs d/w between experimental (Blue Line) and finite element analysis (Red Line). The maximum value of stress concentration factor with d/w ratio 0.08 for isotropic plate is 2.77 and for Composite plate is 1.82.
The results from Fig. 5 and Fig. 6 show the experimental and Ansys results for stress concentration analysis for Isotropic Plate and Composite Plate which are near to each other.

7. CONCLUSION

This stress concentration characterization study of Mild steel and carbon epoxy has been carried out. The precision of experimental results explains value of stress concentration factor in Isotropic (MS) plate and Composite (Carbon epoxy) plate 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 maximum stress concentration factor is more in Isotropic (MS) plate than Composite (Carbon epoxy) plate.

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