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*Research Article*

# Experimental Investigation of Stress Concentration Factor around Countersunk Hole in Composite Plate

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### *Abstract*

*Stress concentration around countersunk hole is an important problem for mechanical engineering, used in various engineering applications. Abrupt change in geometry of component is known as stress concentration. The aim of this work is to investigate the stress concentration factor around countersunk hole in composite plate experimentally. The material used is carbon epoxy. And stress concentration is determined under tensile loading by using universal testing machine and strain indicator. The investigations are carried out by varying the tensile load and diameter of the hole. This paper includes mathematical analysis for calculating average strain from which stress is calculated for each specimen according to applied conditions. The calculated parameters such as stress concentration factor, stress, nominal stress are also graphically represented to get summary of the result.*


***Keywords****: Countersunk holes, Stress concentration factor, Universal Testing Machine, Carbon epoxy plate*

## 1. Introduction

The use of composites is increasing in engineering industrial application, because of their high strength to weight ratio, high stiffness, low density and long fatigue life. As the application of composite to commercial product has increased, so the need for design aspects for structural components increased. The mechanical joint is the best choice for detachable assembly of components in structures and machines to maintain integrity in fastened structure. The prime reason behind selection of mechanical joints is due to their high reliability, strong load bearing capacity, easy maintenance and inspection at low cost. The mechanical joints with countersunk holes are preferred for flush joint rather than lap joint as they offer good aesthetic with high strength. Countersunk hole when applied in composite plate generate stress concentration and need to be analyzed. So it is necessary to analyze the deflection, stresses and stress concentration factors for design of plates with countersunk joints under different loadings. The plates with discontinuities like circular or elliptic holes exist in all metal structure. Those areas represented dangerous zones because of the multiplication of the stresses values under the effect of the stress concentration phenomenon. So stress concentration zones are often areas of crack initiation. The loading conditions allow the brutal propagation of the cracks and then promote the rupture. Stress concentration arises from any abrupt changes in geometry of plate under loading. Stress distribution is not uniform throughout the cross section. Failure such as fatigue cracking and plastic deformation frequently occur at point of stress concentration. Hence for the design point of view the plate with different hole shapes plays an important role and accurate knowledge of stress. For the study detailed literature review is conducted. Parveen K. Saini, (2014) investigated the stress concentration around countersunk hole in isotropic plate under transverse loading.

The investigation of the effect of countersunk depth, plate thickness, countersunk angle and plate width on the stress concentration around countersunk hole is carried out with the help of finite element analysis. Hardik Acharya, (2014) investigated the stress reduction using semi elliptical slots in axially loaded plate having circular hole. The work is related to study the effect of semi-elliptical slot on each side of the hole and the maximum stress induced in a isotropic plate with circular hole. Using finite element analysis method, stress calculation is carried out in ANSYS. Dharmendra S. Sharma (2011) investigated the stress concentration around circular /elliptical /triangular cutouts in infinite composite plate general stress functions for determining the stress concentration around circular, elliptical and triangular cutouts in laminated composite infinite plate subjected to arbitrary biaxial loading at infinity are obtained using Muskhelishvili's complex variable method. Mohammed

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Diany (2013) investigated the effects of the position and the inclination of the hole in thin plate on the stress concentration factor, the stress concentration factors are widely used to predict the maximum stress value above which the mechanical structure can be destroyed. Lotfi Toubal (2005) investigated the stress concentration in a circular hole in composite plate, A non-contact measurement method, namely electronic speckle pattern interferometer (ESPI), was used to investigate the tensile strain field of a composites plate in the presence of stress concentrations caused by a geometrical defect consisting of circular hole. C. K. Cheung (2000) investigated the composite strips with a circular stress concentration under tension. A series of tensile experiments were performed on S2 glass/toughened epoxy composite strips with a center hole or a pin joint at various temperatures within the range of −60°C and 125 °C. J. Rezaeepazhand , M. Jafari (2008) investigated the stress analysis of composite plates with non-circular cutout. The high stress concentration at the edge of a non-circular shaped cutout is of practical importance in designing of the engineering structures. Moon Banerjee (2013) investigated stress concentration in isotropic & orthotropic composite plates with center circular hole subjected to transverse static load. Nitin Kumar Jain (2009) investigated analysis of stress concentration and deflection in isotropic and orthotropic rectangular plates with central circular hole under transverse static loading. The effect of D/A ratio (where D is hole diameter and A is plate width) upon stress concentration factor (SCF) and deflection in isotropic and orthotropic plates under transverse static loading was analyzed. Patel Dharmin (2012) investigated a review on stress analysis of an infinite plate with cut-outs, in this paper an effort is made to review the investigations that have been made on the stress analysis of an infinite plate with cut-outs.

From the literature review it is found that majority of research is concerned with the stress concentration in circular hole with isotropic material plate but only few studies are reported in composite plate and there is scope in studying the stress concentration around the countersunk hole in composite plates.

## 2. Problem definition

The increasing use of composite material in the design of structural parts with high mechanical performance requires a better understanding of the behaviour of these structures. Countersunk hole in composite structure creates stress concentration and hence will reduce mechanical properties which may further lead to failure of structure at joints. Therefore it is essential to investigate the effect of different parameters of countersunk hole on stress concentration around countersunk hole.

## 3. Experimental work

*3.1 Carbon Epoxy Specimen Preparation*

Solution of LY-556 with the hardener of HY-951 was used as epoxy (matrix) material which was available in liquid form. These two constituents were heated in oven and mixed with proper proportion. After cooling it was converted in to solid and that solid was used as epoxy model for testing.

*a. Mould Preparation for Epoxy*

Transparent acrylic sheet was used for mould preparation and thickness of this sheet was 2 mm. The plates were cut from the sheet according to mould size. Mould size was selected for the epoxy specimen 230 X 15 X 25 mm. These plates were cut by some tolerance was kept for finishing. All sides of plates were finished and made perpendicular. All sheets were joined by the feviquick and box was made with one open side. After tightening of the plates the mould was well cleaned. The wax or clay material was pasted in each joint to avoid the leakage. One side of the mould was kept open to pour the mixture. Thus mould was prepared & inspected it carefully for leak.

*b. Epoxy Solution Preparation*

Araldite solution of LY-556 with the hardener of HY-951 was separately heated in the oven for about 2 hours at a rate of 70 to 100 degree to remove moisture and air bubble. The heated solution was cooled slowly at room temperature. The hardener HY-951 was added slowly to LY-556 & HY-951 mixture by weight is 100: 10.33. During mixing, mixture was stirred continuously in one direction for proper & thorough mixing. The mixture was stirred for about 20 min. Now it was ready for pouring into mould. The reaction between araldite & hardener is exothermic. Simultaneously acrylic mould was chemically cleaned. Then this mixture was poured in to mould very cautiously to avoid formation of air bubbles. The mould was completely filled by the mixture. At this position, the mould was kept for curing at room temperature for 24 hours. After that solution of hardener and resin becomes solid that solid formed can be easily removed from the mould. Thus solid model of epoxy or matrix material was prepared. That model was kept on plane surface for four days to become hard. After four day it was taken for test. Finished specimen of epoxy was taken. Dimensions and cross sectional area was measured. The marking of centre line along the length was done. From centre line 75 mm marking on both sides was done.

*3.2 Dimensions of Specimen*

Carbon epoxy plate was selected to conduct experiment to calculate stress concentration around countersunk hole. Plate size was selected as per the ISO 527 or NF T57-301 standard. Countersunk hole was drilled on rectangular plate. The dimensions of the specimen are represented in figure 1.

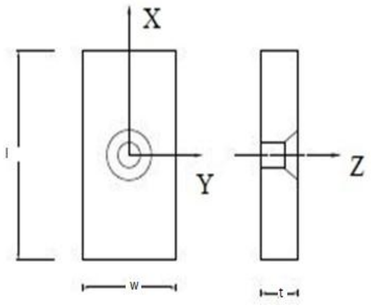


**Fig. 1** Work specimen

Different dimensions of the specimen are shown in Table 1 such as length, width, thickness, diameter etc. It is to be noted that diameter value is incremented from 4 mm to 6 mm and all other parameters are kept constant.

**Table 1** Dimensions of Specimen

| Specimen no. | l | w | t | d | Cs | Θc |
|---|---|---|---|---|---|---|
| Specimen 1 | 230 | 25 | 15 | 4 | 5 | 45 |
| Specimen 2 | 230 | 25 | 15 | 5 | 5 | 45 |
| Specimen 3 | 230 | 25 | 15 | 6 | 5 | 45 |

Where,

l = Length of the plate (mm)
w = width of plate (mm)
t = thickness of plate (mm)
d = Straight shank hole diameters (mm)
Cs = Countersunk depth (mm)
Θc = Angle of countersunk hole

*3.3 Material Properties of Plate*

Material properties of Carbon epoxy plate (LY-556 & HY-951) used are shown in Table 2.

**Table 2** Material properties of carbon epoxy plate.

| | |
|---|---|
| Density | 1464.9 Kg/m3 |
| Modulus of Elasticity | 270 GPa |
| Poisson's ratio | 0.25 |
| Bulk modulus | 180 GPa |
| Shear modulus | 108 GPa |

## 4. Experimental Set Up

The stress concentration in the specimen is determined by using computerized universal testing machine is shown in figure 2. The tensile capacity of this universal testing machine is 1200 KN. It consists of two control valves, to maintain desired pressure in the specimen. Jaw length of universal testing machine is 40 mm. Inputs and outputs are recorded on computer. Foil type strain gauge is used to measure the strain around the hole. This setup also consist strain gauge indicator to record strain in the component.

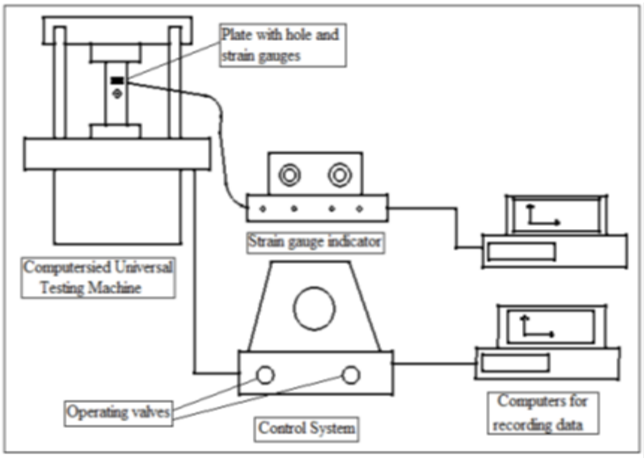


**Fig. 2** Experimental Setup

*4.1 Experimental Test Procedure*

The basic procedure to conduct experiment is given below,

1. Standard specimen was selected and a countersunk hole is drilled at center.
2. Strain gauge was pasted near the countersunk hole by using adhesive.
3. The plate was clamped between the two jaws of universal testing machine.
4. Suitable connections were made to get required readings through computer.
5. The control panel of universal testing machine has two operating valves at both ends to maintain required oil pressure.
6. As per the load condition, initially 5000 N tensile load was applied on the plate and strain was measured through strain gauge indicator.
7. The same procedure was repeated for 7500 N, 10000 N load for the plate having hole diameter 4 mm.
8. The average value of strain for each load was determined and noted in observation table.
9. Experiment setup was taken to the initial condition ( i.e zero load condition).
10. The above procedure was repeated for 5mm and 6 mm diameter of the countersunk hole to measure strain variation.
11. By using formulae of modulus of elasticity and recorded strain, the stress of corresponding diameters was precisely calculated. The results were noted in the observation table indicated below.

## 5. Analytical approach

Calculate stress concentration in Composite plates with countersunk holes subjected to UDL.

*Mathematical Calculations,*

Formulae's for stress concentration around countersunk hole,

$$\text{Modulus of elasticity} = \frac{\text{Max. stress}}{\text{Max.Strain}}$$

The nominal stress in the plate is,

$$\sigma_{nom} = \frac{P}{(w-d) \times t}$$

Where,
P = Tensile load (N).
w = Width of the plate (mm).
d = Diameter of the hole (mm).
t = Thickness of the plate (mm)

Stress concentration factor Kt is,

$$K_t = \frac{\sigma_{max}}{\sigma_{nom}}$$

Sample calculation for first specimen,
w = 25 mm , l = 230 mm, t = 15 mm, d = 4 mm, Cs =5 mm, ϴc =45°, E = 270000 MPa etc.
Kt = ?
Here,

$$\text{Modulus of elasticity} = \frac{\text{Max. stress}}{\text{Max.Strain}}$$

$$270000 = \frac{\text{maxi. stress}}{0.00006218}$$

Max. Stress = 270000 x 0.00006218

Max. Stress (σmax)= 16.39 N/mm2

Then,

$$\sigma_{nom} = \frac{P}{(w-d) \times t}$$

$$= \frac{5000}{(25-4) \times 15}$$

$\sigma_{nom}$ = 15.87 N/mm2

So,

$$K_t = \frac{\sigma_{max}}{\sigma_{nom}}$$

$$= \frac{16.39}{15.87} = 1.032$$

Stress concentration factor for first specimen = 1.032.

## 6. Result and discussion

The magnitude of Kt for specimen 1, 2 and 3 with load 5000N, 7500N, and 10000N is shown in Table 3. The graph consists of variation in Kt factor according to diameter of the specimen is shown in figure 3.

**Table 3** Kt for different loads

| | Kt for tensile loads | | |
|---|---|---|---|
| Specimen No. | 5000N | 7500N | 10000N |
| Specimen 1 | 1.032 | 1.033 | 1.032 |
| Specimen 2 | 1.034 | 1.034 | 1.034 |
| Specimen 3 | 1.055 | 1.055 | 1.055 |

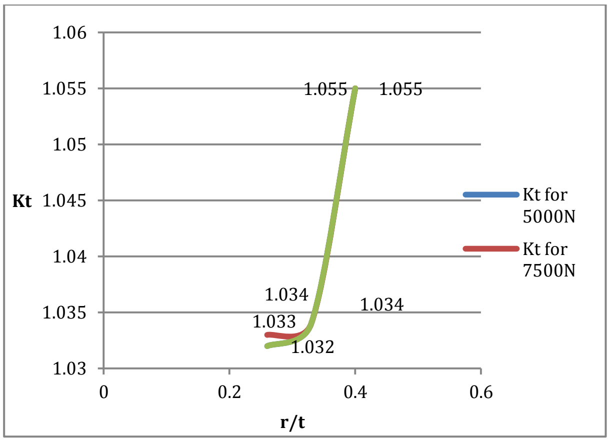


**Fig 3** Kt v/s r/t for different tensile load

From the graph of Kt v/s r/t for different loads, it is concluded that as r/t increases value of Kt also increases, for each load.

## Conclusions

The experimental work is carried out to investigate the stress concentration factor in composite (Carbon epoxy) plates under UDL. It is concluded that as the stress concentration increases as the r/t ratio increase. The stress concentration factor varies in the same fashion for the three loads.

## References


Parveen K. Saini, Tarun Agarwal ,(2014),Stress Concentration around Countersunk Hole in Isotropic Plate under Transverse Loading, *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, Vol.8, pp. 1967- 1973.

Hardik Acharya ,(2014),Stress reduction using semi elliptical slots in axially loaded plate having circular hole, *IJMET*,Vol.5 ,pp. 374-378.

Dharmendra S. Sharma, (2011), Stress Concentration around Circular/Elliptical/ Triangular Cutouts in Infinite Composite Plate, *Proceedings of the World Congress on Engineering, London , U.K*, Vol. 3.

Mohammed Diany, (2013), Effects of the Position and the Inclination of the Hole in Thin Plate on the Stress Concentration Factor, *IJERT*, Vol. 2, pp. 8-12.

Lotfi Toubal, Moussa Karama, Bernard Lorrain, (2005), Stress concentration in a circular hole in composite plate, *Composite Structures*, Vol.68, pp. 31–36.

C. K. Cheung, B. M. Liaw and F. Delale,B. B. Raju, (2000), Composite strips with a circular stress concentration under tension, *International conference, U.S. Army research center, Michigan.*

J. Rezaeepazhand, M. Jafari, (2008), Stress Analysis of Composite Plates with Non-circular Cutout, *Key Engineering Materials* Vol. 2, pp. 365-368.

Moon Banerjee,(2013),stress concentration in isotropic & orthotropic composite plates with centre circular hole subjected to transverse static load, *IJME,* Vol. 3(1), pp. 374-378.

Nitin Kumar Jain, (2009), Analysis of Stress Concentration and Deflection in Isotropic and Orthotropic Rectangular Plates with Central Circular Hole under Transverse Static Loading, *World Academy of Science, Engineering and Technology*, Vol.3 pp. 12-22.

Patel Dharmin, Panchal Khushbu, Jadav Chetan, (2012), A Review on Stress Analysis of an Infinite Plate with Cut-outs, *International Journal of Scientific and Research Publications*, Vol. 2. Issue 11, pp.1-7.