Journal of Advances in Science and Technology
Vol. 12, Issue No. 25, (Special Issue) December-2016, ISSN 2230-9659

Analysis of Stress Concentration Effect around Countersunk Hole in Composite Plate under Transvers Loading

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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 stress concentration around hole in different plate sizes and changes in hole with different loading conditions using FEA to reduce the need and expenditure of experimental testing by developing procedures that allow the use of FEA to simulate experimental stress test For comparison purposes, a structure having similar identical geometry and material properties are used. The FEA results and experimental results are compared and discussed with respect to different loads. 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 Hole Stress concentration Factor, Universal Testing Machine, Carbon Epoxy Plate.

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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 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 −60oC and 125oC. 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

We have considered the hex dominant method for element having size 7.8 mm throughout the FFA analysis for all specimens. Figure 2.5 states that we get desirable results for optimum element size with dimension 7.8 mm. It is to be noted that by decreasing size of the element we get proper results but it consumes much times for processing. Hence in all specimens the element size is preferred to be 7.8 mm.

3. EXPERIMENTAL AND FEA WORK

3.1 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 3.1.

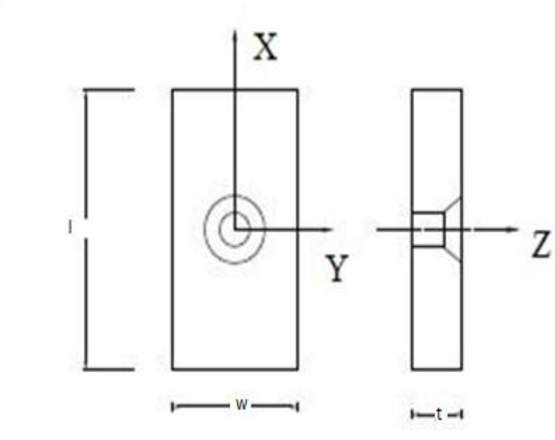

Figure 3.1 Work specimen.

Different dimensions of the specimen are shown in table no. 3.1 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.

Tabl 3.1 Dimensions of Specimen

Specimen no.	l	w	t	d	C_s	Θ_c
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)

C_s = Countersunk depth (mm)

Θ_c = Angle of countersunk hole

3.2 Model

Meshing option helps to select number of elements in which model is to be subdivided and selection of meshing type depending upon accuracy required. The solid model is imported into ANSYS Workbench for analysis. The material of the model is carbon epoxy. Formulation of elements in Finite element analysis is an important factor that can influence the simulation results considerably. All the types of plate with countersunk hole are meshed using Hex Dominant method with Quad/ tri mesh type having mesh size 7.8 mm with fine relevance as shown in Figure 3.2.

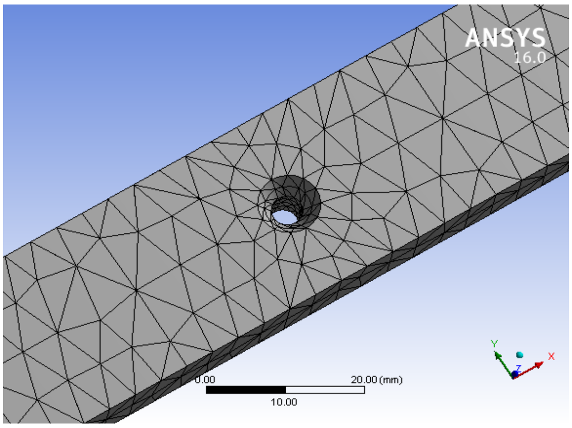

Fig. 3.2 Meshing of Solid Model

3.3 Mesh Refinement

We have considered the hex dominant method for element having size 7.8 mm throughout the FFA analysis for all specimens. Figure 3.3 states that we get desirable results for optimum element size with dimension 7.8 mm. It is to be noted that by decreasing size of the element we get proper results but it consumes much times for processing. Hence in all specimens the element size is preferred to be 7.8 mm.

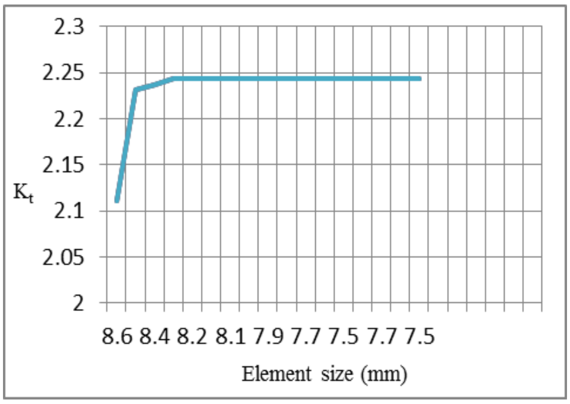

Fig. 3.3 Mesh Refinement.

3.4 Material Properties of Plate

Material properties of Carbon epoxy plate **(**LY-556 & HY-951) used are shown in Table 3.2.

Table 3.2 Material properties of carbon epoxy plate.

Density	1464.9 Kg/m^3
Modulus of Elasticity	270 GPa
Poisson's ratio	0.25
Bulk modulus	180 GPa
Shear modulus	108 GPa

4. ANALYTICAL APPROACH

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

Mathematical Calculations,

Formulae's for stress concentration around countersunk hole,

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 K_t 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, Өc =45°, E = 270000 MPa etc.

K_t = ?

Here,

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 (σ_{max}) = 16.39 N/mm^2

Then,

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

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

$$\sigma_{nom} = 15.87 \text{ N/mm}^2$$

So,

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

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

Stress concentration factor for first specimen = 1.032.

5. COMPARISON EXPERIMENTAL RESULTS WITH FEA RESULTS

The value of Kt in FEA and Experiment for specimen 1, 2 and 3 with load 5000N, 7500N and 10000N is shown in table no. 5.1, 5.2 and 5.3 respectively. The graph consist variation in Kt factor according to diameter of the specimen is shown in figure 5.1, 5.2 and 5.3.

Table 5.1 FEA and Experimental Results For 5000 N Load.

Specimen no.	FEA (K_t)	Experimental (K_t)
Specimen 1	1.06	1.032
Specimen 2	1.01	1.034
Specimen 3	1.08	1.055

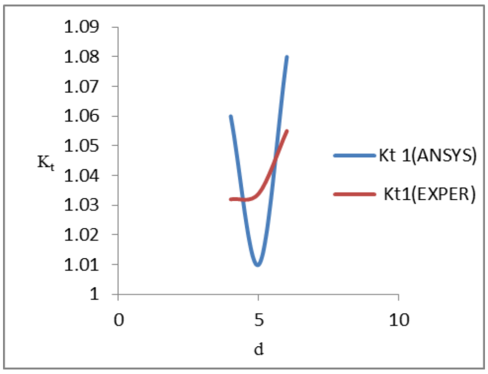

Fig. 5.1 Diameter Vs Kt For 5000N

From the graph of diameter Vs Kt for 5000N, it is concluded that as diameter increases value of Kt also increases, for load 5000N for both FEA results and Experimental results.

Table 5.2 FEA and Experimental Results For 7500 N Load.

Specimen no.	FEA (K_t)	Experimental (K_t)
Specimen 1	0.89	1.033
Specimen 2	0.925	1.034
Specimen 3	1.1	1.055

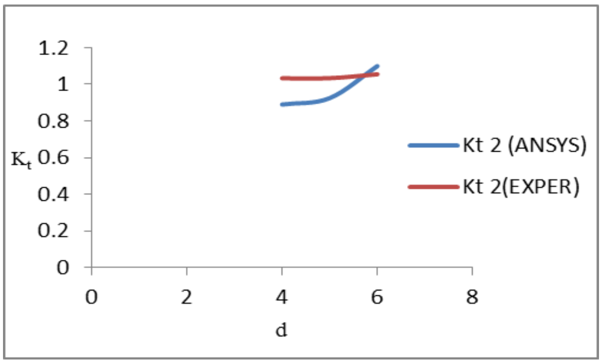

Fig.5.2 Diameter Vs Kt For 7500N

From the graph of diameter Vs Kt for 7500N, it is concluded that as diameter increases value of Kt also increases, for load 7500N for both FEA results and Experimental results.

Table 5.3 FEA and Experimental Results For 10000 N Load.

Specimen no.	FEA (K_t)	Experimental (K_t)
Specimen 1	1.063	1.032
Specimen 2	1.05	1.034
Specimen 3	1.1	1.055

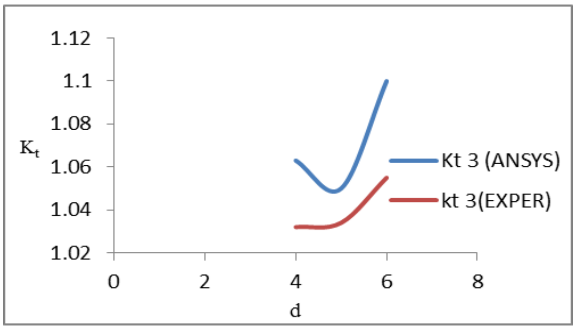

Fig 5.3 Diameter Vs K_t for 10000N

From the graph of diameter Vs Kt for 10000N, it is concluded that as diameter increases value of Kt also increases, for load 10000N for both FEA results and Experimental results.

CONCLUSION

It is concluded that as the stress concentration increases as the diameter increase. The stress concentration factor varies in the same fashion for the three loads. The FEA results and experimental results are compared and discussed with respect to different loads ranging from 5000N to 10000N.

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