Effect of Hexagonal Cutout Orientation and Roundness of Edges on Stress Concentration in Plate

Mayuri Patil[1], Ajay More[2]

[1]*Student, Cummins College of Engineering, Pune, Maharashtra, India*
[2]*Mechanical Engineer (Design), Sidel India Pvt. Ltd. Pune, Maharashtra, India*

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Abstract - *The current study presents detailed finite element analysis on stress concentration in structured steel plate with hexagonal cutout. This research examines isotropic plate for the Stress Concentration Factor (SCF) with the central cutout of hexagonal shape in contrast with bluntness. Current approach explores stress concentration with respect to different cutout orientations. For calculating a stress concentration and its patterns, ANSYS, a finite element program, is utilized. Two parameters under consideration in this study are as follows: rotation of cutouts and bluntness. From the analytical modelling, it was concluded that, in general, increase in bluntness, increases the stress concentration. Study shows that stress concentration is reduced by 49% when bluntness is maximum. Vertical axis of symmetry of hexagon is rotated clockwise about x axis and stress concentration in plate was examined.It was observed that an angle of inclination was indirectly proportional to stress concentration for hexagonal cutout. This study emphasizes that the orientation of cutout is also a important design factor which affects stress concentration. While analyzing the hexagonal cutout, vertical axis of symmetry of the hexagonal cutout to the applied tensile forces must be parallel. It was found that stress concentration was reduced by when vertical axis of symmetry of the hexagonal cutout is parallel to the applied tensile forces. It was observed that to reduce the stress concentration in component we must align polygonal cutouts properly.*

***Key Words*: Stress concentration analysis, Finite element analysis, Cutout orientation, Bluntness, Stress concentration points.**

1. INTRODUCTION

Though wholly homogenized stress field is desired in mechanical component design,in practical environment there are limitations due to design constraints which induces disorders.Such disorder in stress field, affects the equal stress distribution in component.Such points with maximum stress concentration are known to be Stress concentration points (SCP).Stress concentration is affected by abrupt changes in cross section of component,damage likes cracks and scratches.Fatigue and various types of failure are negatively affected by stress concentration. Hence it is imperative for designers to reduce the stress concentration at SCP. Extensive research has been carried out to reduce stress concentration in mechanical component.These Studies can be classified into two major categories namely,Reinforcing methods and shape optimization.Study conducted by Giare and Shabahang [1] was aimed to reduced stress concentration around a hole by adding composite reinforcing rings. Sburlati, Atashipour et al. [2], undertaken a study where SCF in a plate with a hole was examined.They experimented on loading conditions such as uni-axial, bi-axial. They achieved reduction in SCF along with reinforced FGM layer.

While using reinforcing methods extra material is added at SCP,increasing component weight. Weight reduction is also desired design parameter as it reduces cost.Reinforcing methods can not address these problems effectively.It is imperative to use shape optimization methods where weight is design constraint. Flat plates with notches and circular holes were studied by G.N. Savin, he examined stress concentration[4]. While D.Y. Kim, D.H. Shim, and M.J. Choi, etc examined stress concentration with respect to perforated plates of circular nature[5]. In a two-dimensional plate with triangular and square shaped cutout,optimum shape for minimum stress concentration factor was found out[6]. Since shape optimization is efficient for simple geometrical changes,it minimizes stress concentration.

2. FINITE ELEMENT ANALYSIS

Finite element analyses of steel plates with hexagonal cutouts was done for evaluating stress concentration.The structured steel plates having dimensions of 150 mm(x direction) ,150 mm(y direction) and 5.0 mm in(z direction) are used.Material properties are shown in Table 1 and location of cutout is at center of plate. While studying an elastic ranged stress concentration, plate modelling is as linear elastic material. While loading conditions are, uni-axial tensile force of 2000N at right end and plate is fixed at left end.

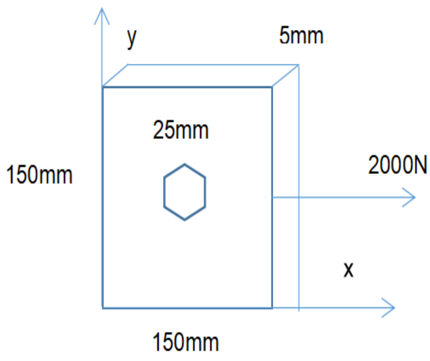

Fig -1: Basic model of problem

Since element size is being critical for analysis, to find out suitable element size, mesh convergence study was done. The result of mesh convergence study are shown in figure 2.

Table -1: Material properties of Structured steel

Material properties	
Material Property	**Values**
Young's modulus (GPa)	200
Poisson ratio	0.3
Tensile yield strength (MPa)	250
Tensile ultimate strength (MPa)	460

For each mesh size, maximum stress was obtained and and compared with next finer mesh and plotted on convergence study. Size of element was chosen as 0.01 mm along edges of plate. Total number of element for finer mesh are 73067.

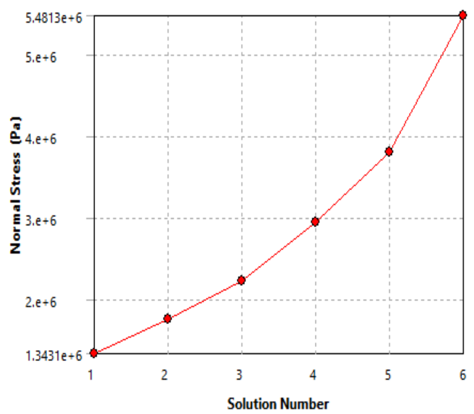

Fig -2: Mesh convergence study

3. CUTOUT ROUNDNESS AND ROTATION

Method of inscribed circle was used to compare with circular cutout. Radius of inscribed circle is 21.5 mm. To reduce stress concentration at edges, edges are rounded. Roundness of edges is physical terminology. Radius ratio is defined as ratio of radius (r) to the inscribed circle radius (R).

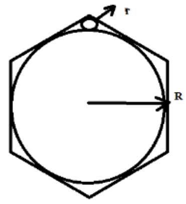

Fig -3: Radius ratio (r/R) defined by edge radius (r) and Inscribing circle radius (R)

In other words, the degree of roundness decreases as r/R increases. We have considered a six different degrees of roundness which includes 0.0, 0.3, 0.5, 0.7, 0.9, 1.0 with respect to hexagonal holes.

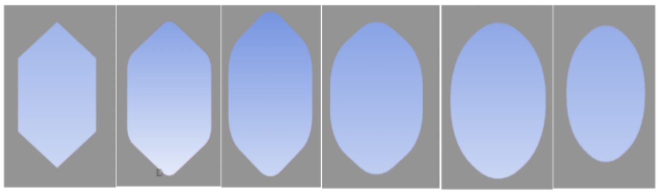

Fig -4: Experimented hexagonal cutout by applying value r/R = 0.0, 0.3, 0.5, 0.7, 0.9, 1.0.

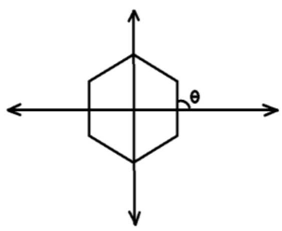

Fig -5: Rotation of cut-out

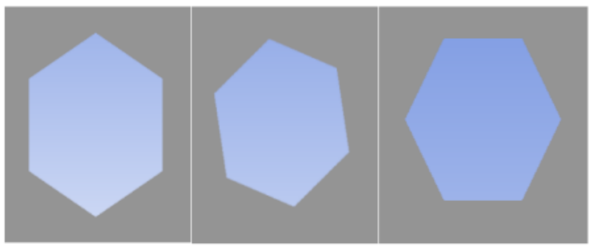

Fig -6: Hexagonal cut-out with θ = 90° (left), 110° (centre), and θ=120° (right)

4. RESULTS

After constraining the design variables -cutout roundness and cutout rotation .The stress concentration pattern, the maximum von-Mises stress were obtained.These results are as shown in the following sections.

4.1 Cutout Roundness

As mentioned previously, study observed a single cutout shape which is hexagon. While considering roundness a total of six radius ratios are considered: r/R = 0.0,0.3, 0.5, 0.7, 0.9,1.0.This section discusses the relationship of stress concentration with respect to the roundness.. All of the other design parameters are kept same, for example the uni-axial tensile forces are fixed at 2000N.

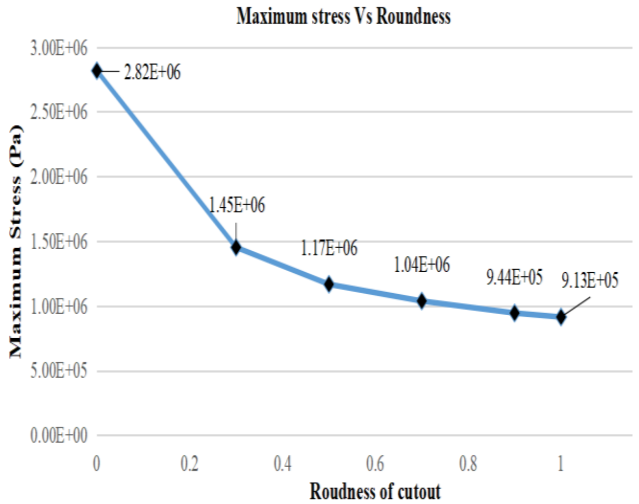

Fig -7: Maximum stress Vs roundness of cutout(r/R)

Following Table illustrates roundness and Maximum stress correlation. As roundness increases maximum stress increases.

Table -2: Maximum stress with respect to roundness(r/R)

Maximum stress and Roundness	
r/R	**Maximum Stress (Pa)**
0.0	2.82E+06
0.3	1.45E+06
0.5	1.17E+06
0.7	1.04E+06
0.9	9.44E+05
1.0	9.13E+05

When the roundness of cutout is 1, It generated maximum stress of 9.13 MPa while the stress concentration factor approximated at 3. Earlier studies indicates that, the maximum stress is about three times the tensile force[3]. Since our tensile force is 2.86 MPa, the magnitude of 9.13 MPa is precisely concurring with the previously observed results. Shown in Table 2, depending on roundness of cutout the value of maximum von-Mises stresses varies.

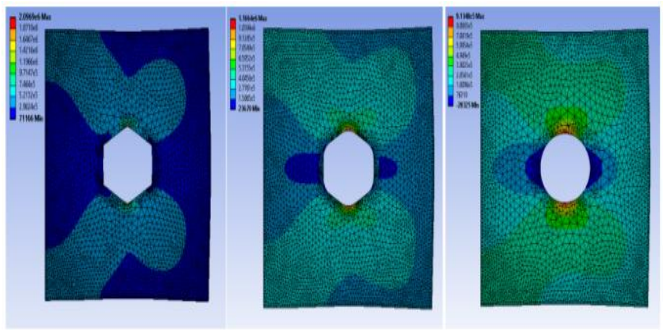

Fig -8: Stress contour of plate with Hexagonal cutout r/R = 0.0(left), 0.3(Center), 1.0(Right)

For the stress patterns visualization , three stress contours are shown in Fig.8.illustrate the stress contour in the case of the Hexagonal cutout with different roundness.Stress concentration is maximum at vertical axis of symmetry of hexagon. Though roundness of hexagonal cutout is changed, point of maximum stress concentration is same.Significant changes are observed in maximum value of stress.It is evident from stress contours that maximum stress decreases exponentially,and attains the minimum value and becomes constant.It is interesting to note that maximum stress is decreased by 48% when roundness to 0.3 from sharp hexagonal edges. Rate of change Maximum stress decreases as roundness increase. When roundness is increased from 0.3 to 0.5, change in maximum stress is 19%.

This findings emphasize that roundness of cutout helps in reducing stress significantly hence being important design parameter.

4.2 Cutout Orientation

This section explains stress analysis of a single hexagonal cutout with different orientations.All of the other design parameters are kept same, for example the uni-axial tensile forces are fixed at 2000N.In the cases of the hexagonal cutout, Five rotation angles are considered, 90°, 100°, 110°, 120°and 180°.

Below table shows the Maximum stress for the steel plates with hexagonal cutouts, which have the five rotations. In the case of the θ=90°(i.e Axis of symmetry of hexagonal cutout is perpendicular to x axis) , the maximum stress is 2.82 MPa.

Table -3: Maximum stress with respect to Orientation(θ)

Maximum stress and Cutout Orientation (θ)	
Cutout Orientation (θ)	**Maximum Stress (Pa)**
90	2.82E+06

100	2.19E+06
110	1.86E+06
120	1.46E+06
120	1.42E+06

As shown in Table 3, the maximum stresses changes depending on the cutout orientation(θ). In the case of θ=1800 (i.e Axis of symmetry of hexagonal cutout is parallel to x axis) ,the maximum stress is 1.42 MPa. Maximum stress is reduced by 49% only by changing cutout orientation and other variables like roundness of cutout was constant.

As a result, we can see that many differences occur in the maximum stresses, depending on the rotation angle. However, for all of the cases consistently, the stresses increase as the rotation angles increase.

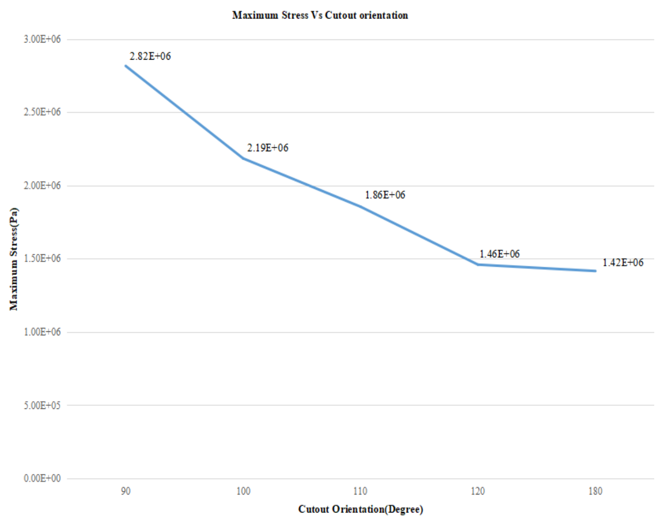

Fig -9: Maximum stress (Pa) Vs Cutout orientation (θ)

It is observed that the maximum stresses differs , depending on the rotation angle. Stress in plate is maximum when angle of symmetry is perpendicular to direction of applied force. It is evident that angle of rotation of hexagonal cutout in inversely proportional to maximum stress. It is evident from stress contours that maximum stress decreases exponentially when orientation of cutout is increased form 900 to 1800. Stress is minimum when angle of symmetry of hexagonal cutout is parallel to applied force.

It is interesting to note that maximum stress is decreased by 23% when rotation of cutout is increased by 10° from 90°.

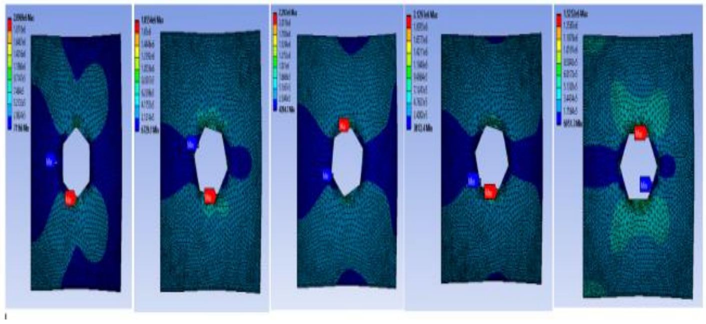

Fig -10: Stress contour of plate with Hexagonal cutout with θ =90°, 100°, 110°, 120°and 180°.

5. CONCLUSIONS

This study analyses interdependence of design factors on maximum stress in plate.Two major design factors considered were roundness of hexagonal cutout and orientation of cutout with x axis. Earlier studies indicates that, the maximum stress is about three times the tensile force in plate with circular hole.

After conducting finite element analyses, the following observations are reported.Earlier mentioned design factors affect the maximum stress. In general, as roundness increases, the stress concentration decreases. A noteworthy observation is that the stress concentration is reduced when the cutouts become further oriented from the x - axis. While the direction of the applied tensile force is parallel to the x - axis, demonstrating that the orientation(θ) is a relatively significant design factor which reduce stress concentration.

As study has shown shape optimization method plays prime role to reduce maximum stress. In general study found that maximum stress in plate was reduced by 50% without significant design changes.

REFERENCES

[1] G.S. Giare, R. Shabahang, The reduction of stress concentration around the hole in an isotropic plate using composite materials, Eng. Fract. Mech., 32(5) (1989) 757-766.

[2] R. Sburlati, S.R. Atashipour, S.A. Atashipour, Reduction of the stress concentration factor in a homogeneous panel with hole by using a functionally graded layer, Compos. Part B: Eng., 61 (2014) 99-109.R. Nicole,

[3] W.D. Pilkey, D.F. Pilkey, and R.E. Peterson, Peterson's Stress Concentration Factors, John Wiley and Sons, New York (2008).

[4] G.N. Savin, Stress Concentration around Holes, Pergamon Press, New York (1961).

[5] D.Y. Kim, D.H. Shim, and M.J. Choi, A Stress Concentration Analysis Model for a Plate in the Aircraft Surface using Energy Method, Spring Conference of Korean Society for Precision Engineering, (2007), 553-554.

[6] Z. Wu, Optimal hole shape for minimum stress concentration using parameterized geometry models, Struct. Multidiscip. Optim, 37(6) (2009) 625- 634.