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Analysis and validation of Stress Concentration through Various Cutout Orientation in Plates

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Abstract: *Perforated plates with cutouts(or holes) are extensively used in structural members. These cutouts give stress con centration in plates. expansive studies have been carried out on stress attention in perforated plates, which consider cutout shapes, boundary conditions, plainness of cutouts, and more. This study presents stress attention analyses of perforated plates with not only colorful cutouts and plainness but also different cutout exposures. Especially, the effect of cutout exposure on stress attention is emphasized since structural members have come more complicated lately. To gain stress attention patterns, a finite element program, ANSYS, is used. For the designated thing, three parameters are considered as follows the shapes of polygonal cutouts(circle, triangle, and square), plainness(a counter measure of compass rate, r/ R), and gyration of cutouts(θ). From the analyses, it's shown that, in general, as plainness increases, the stress attention increases, regard lower of the shape and gyration. A more important finding is that the stress attention increases as the cutouts come more acquainted from the birth, which is the positive vertical axis(x). This fact demonstrates that the exposure is also a fairly significant design factor to reduce stress attention. By aligning those polygon cutouts duly, we can reduce stress concentration.*

Keywords: Stress Concentration, Optimization, CAE, Ansys, FEM

I. INTRODUCTION

The structural analysis should inform the design of various structural components, such as those found in spacecraft, aircraft parts, or pressure vessels, instilling a high level of confidence in their integrity. This analysis must be a fundamental aspect of the design process, as it helps to reduce both effort and time by preventing the need for redesigns that may arise from failures during structural verification testing. One significant advantage of conducting stress analyses is the ability to identify design sensitivities and perform trade studies. This leads to effective structural optimization, improving reliability while simultaneously lowering costs and weight. Openings or cut-outs are incorporated into structures to meet specific service requirements, but they can compromise strength. In practice, different shapes of openings are utilized for various applications; for instance, the manhole of a pressure vessel is typically circular or elliptical, while an airplane's window or door features a rectangular opening with rounded corners. These openings act as stress concentrators, potentially resulting in structural or component failure. Therefore, accurately predicting stress concentration around both regular and irregular openings is a crucial element of stress analysis. Irregularities in hole shapes may arise from chemical degradation, where external loads and chemical processes can lead to the formation of atypical shapes. Understanding the stress distribution around such irregularly shaped holes is essential for assessing their evolution. Stress concentration refers to the localization of elevated stresses primarily caused by discontinuities in the material, abrupt changes in cross-section, and contact stresses. To analyze the effects of stress concentration and the magnitude of localized stresses, a dimensionless factor known as the Stress Concentration Factor (SCF), represented as Kt, is employed.

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II. PROBLEM DEFINITION

Plates and shells of colorful designs serve as essential structural factors in aerospace, mechanical, and civil engineering operations. lately, the growing demand for featherlight and effective structures has urged advancements in structural shape optimization .To minimize system weight and grease access to other structural rudiments, colorful cut- eschewal shapes are needed in these factors. It's extensively honored that the preface of a cut- eschewal or hole in a stressed-out member results in largely localized stress attention around the cut- eschewal area.The stress attention factor(SCF) is defined as the rate of the outside stress at the edge of the cut- eschewal to the nominal stress.Understanding how abbreviated- outs affect the cargo- bearing capacity and stress attention in these plates is pivotal for effective structural design.

III. METHODOLOGY

Creation of Geometry for Plate with different shaped cut-outs.
Importing the geometry for meshing.
Solving for the meshed model with constraints and boundary conditions.
Viewing the results during post-processing.
Interpretation over the results.

IV. MATERIAL SELECTION

The plate is made from aluminum alloy, a material commonly utilized in the aerospace industry due to its lightweight properties. This makes it suitable for applications such as space shuttles and airplanes.The dimensions of the plate are 360 mm × 75 mm × 3 mm.

Table 1. Properties of Aluminium Alloy

1.	Young's Modulus (GPa)	71.0
2.	Tensile Yield Strength (MPa)	280
3.	Tensile Ultimate Strength (MPa)	310
4.	Poisson's Ratio	0.33

V. EXPERIMENTATION

The experimental setup includes a loading frame designed to apply force to a specimen. The load is introduced through a screw mechanism, as illustrated in the accompanying figure, which presents a CATIA model of the experimental arrangement. Another figure depicts the actual experimental setup. The specimen is crafted from an aluminum alloy plate measuring 360 x 75 x 3 mm, featuring centrally located square, elliptical, and circular cutouts, as demonstrated in the subsequent figure.

Figure 1:Experimental setup for elliptical cutout (Electrical Strain Gauge Method)

Preparation of Specimen (Ellipse Cutout):-

The plate is constructed from aluminum alloy, a material commonly utilized in aerospace applications due to its lightweight properties, as seen in space shuttles and airplanes. The dimensions of the plate are 360 mm x 75 mm x 3 mm. Two circular holes, each with a diameter of 10 mm, are drilled near the edge of the plate for clamping purposes. A centrally located elliptical hole is created using a Wire Electrical Discharge Machining (W-EDM) machine, featuring a major axis of 20 mm and a minor axis of 10 mm, with the major axis aligned parallel to the applied force. This method helps to minimize internal residual stress around the cutout, which is negligible in this instance. Subsequently, strain gauges with a resistance of 120 Ω are installed in the area identified as having high localized stress, based on results obtained from ANSYS, to measure the corresponding strain values. The procedure for mounting the strain gauges follows the same protocol as previously described for the square cutout, and the final specimen with the mounted strain gauges is illustrated in the following figure. Experiments can be conducted to assess the Stress Concentration Factor (SCF) for various cutouts and orientations, including circular, square, triangular, and elliptical shapes, by adjusting the radius ratio and orientation angle. Initial experimentation can be performed using ANSYS software.

In the course of experimentation, the parameters of radius ratio and notch orientation can be adjusted as outlined below:

1) Bluntness (r/R): Ranging from 0.1 to 1.0
2) Orientation of the cut-out: From 0° to 90° (Dependent on the configuration of the cut-out/notch)
3) The cut-out shapes will include: Circular, square, triangular, and elliptical.

VI. RESULTS AND DISCUSSION

Through experimentation with various shaped cutouts, the following results were obtained using the Finite Element Analysis (FEA) method.

Table 2.SCF for Square Cutout with w=0.1

Angle of rotation (˚)	Maximum Stress(Pa)	SCF
0	3263364.50	3.26336450
15	4954324.85	4.95432485
30	6651487.27	6.65148727
45	7375160.83	7.37516083
60	6508823.73	6.50882373

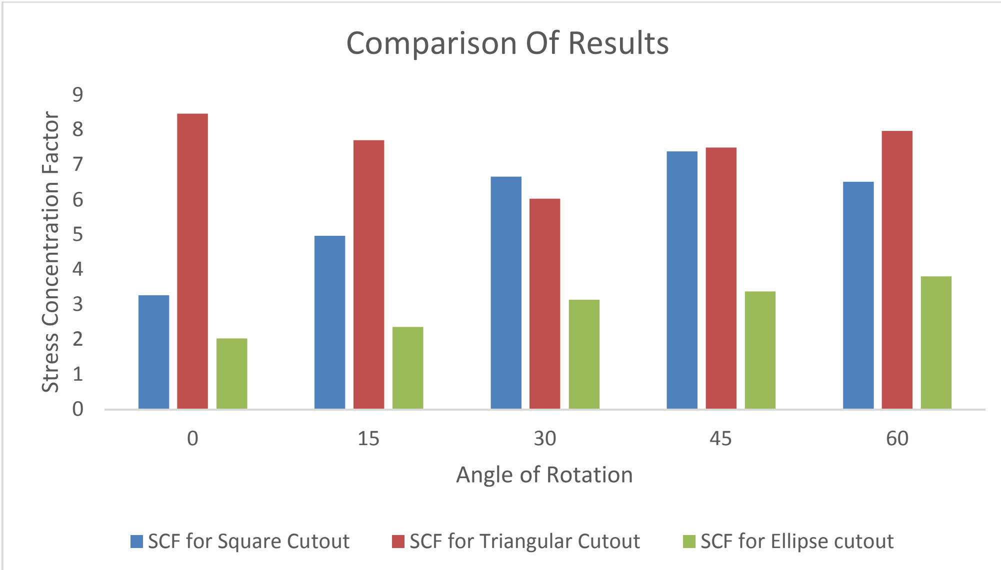
Table 3. SCF for Triangular Cutout withw=0.1

Angle of rotation (˚)	Maximum Stress (Pa)	SCF
0	8456707.81	8.45670781
15	7697420.52	7.69742052
30	6022483.88	6.02248388
45	7483808.52	7.48380852
60	7966380.76	7.96638076

Table 4.SCF for Ellipse cutout

Angle of rotation (˚)	Maximum stress (Pa)	SCF
0	2017326.05	2.01732605
15	2356442.41	2.35644241
30	3128847.60	3.12884760
45	3370634.04	3.37063404
60	3802453.34	3.80245334

From above readings the graph is plotted SCF vs Angle of rotation for square, triangular and elliptical cutout as shown in following Graph



Graph 1: SCF vs Angle of rotation

VII. CONCLUSION

The experiments conducted demonstrate that the Stress Concentration Factor (SCF) can be influenced by adjusting parameters such as bluntness, cutout shape, and the orientation of the cutout relative to the applied force.

For a square cutout, the highest SCF value recorded is 7.37 (using Finite Element Analysis) when the bluntness is set at 0.1 and the angle θ is 45 degrees. Typically, the SCF value for a circular cutout is 3. However, the experiments indicate that the SCF for a square cutout can be reduced to 3 when the bluntness values are 0.25, 0.3, 0.5, 0.75, or 0.9, provided that θ is either 0 or 90 degrees. This implies that for optimal conditions, two opposite sides of the square should be aligned parallel to the applied force, resulting in the minimum SCF for any bluntness value.

In the case of a triangular cutout, the maximum SCF value observed is 8.45 when the bluntness is 0.1 and θ is 0 degrees. The findings reveal that the SCF for a triangular cutout cannot be reduced to 3 at any bluntness level; however, it can approach 3 if one side of the triangle is positioned perpendicular to the applied force. Under these conditions, the SCF reaches its minimum for all bluntness values, except for bluntness values of 0.75 and 0.9.

For an elliptical cutout, the maximum SCF value is 4.9 when the major axis is oriented perpendicularto the applied load. It is important to note that the minimum SCF value, which is 2.01 (as per Finite Element Analysis), is lower than that of a circular cutout when the major axis is aligned parallel to the appliedload.

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