FINITE ELEMENT ANALYSIS: RECTANGULAR PLATE WITH AN ELLIPTICAL HOLE

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Abstract: In engineering design, the reliability of the product is driven by the factors including geometry, material and manufacturing process. Considering the fact that plates with complex geometry have a wide range of applications in the automobile and aerospace industry, an effort has been made to propose a procedure to select appropriate geometry with an acceptable range of design parameters. In this context, finite element analysis was performed for a mild steel – IS2062 material plate having an elliptical hole at the center, by altering the a/w ratio (normalized major radius ratio). The von mises stresses for a defined range of a/w ratios, when subjected to static loading were generated using the Finite Element Analysis package ANSYS, and analyzed to understand the influence in change in geometry of the cut outs on Von mises stress. A mathematical regression equation was further developed to realize the relationship between the a/w ratio and von mises stresses.

Keywords—Elliptical Hole, Plate, Von Mises Stress, Finite element analysis, Regression equation.

I. INTRODUCTION (*Heading 1*)

A plate is a planar structure (flat two-dimensional surface) with a very small thickness in comparison to the planardimensions.The resistance of the plate to the load being applied is achieved by twisting moment and bending intwo directions. In plate theory, the calculation of deformation and stresses becomes more important when it issubjected to loading [1].Plates have diverse applications in various domains like Automobiles, Space vehicles andcontainment Structures. Sometimes depending on requirements, it is needed to make holes in plates (as in spacevehicles and buildings) [2]. The strength and stiffness of the plate is influenced by the mere presence of holes onthe plates which also impacts the amount of stress and its distribution[3]. The holes in plates assuminghomogeneous, isotropic, and linear elastic material, the cause of this highly localized or accumulation of stressnear the change of cross section or clustering of stress lines at the point of discontinuity is termed as stressconcentration [4].Holes and openings give easy fastener access, reduce the weight and facilitate maintenancewhich is why they are a common sight in Engineering Structures [5]. Plates with elliptical holes find a wide rangeof applications in day-to-day life. Elliptical or circular holes made in plates are referred to as "Lightening Holes".The Engineering Structures are made lighter due to the introduction of Lightening Holes in various EngineeringDisciplines. Lightening holes are used in the aviation industry which makes the aircraft as light without having tocompromise with airworthiness and durability of the aircraft. A large chunk of cost expenses can be done awayby drilling holes, pressed stamping or machining [6].For the topic that we have chosen, we found it very necessary to go through relevant research conducted prior toours. Some of the papers that we have referred to are mentioned in this Section. Firstly, we referred to a report byWilliam L Kho from NASA [2] from which we got insights regarding the buckling and thermal properties ofplates with central cut-outs of different shapes. The paper by B. Mohammadzadeh et. al. was about determiningbuckling coefficients by conducting buckling analysis on plates with different thickness and different hole sizes.Next, we referred to the analysis carried out by Mallikarjun B et. al. [4].This analysis throws light on thedetermination of maximum stress using Stress Concentration Factor (SCF) as a multiplication factor forcylindrical holes with different obliquities on a flat plate. A Journal Paper by Ashish Patel et. al. [5] which gavea formula for tangential stress concentration factor around an elliptical hole in a large rectangular plate subjectedto linearly varying in-plane loading on two opposite edges. Further, we referred to another Journal Paper byBabulal K S et. al. [6] which gave us information about the effect of stretching of an isotropic rectangular platewith a centrally located circular hole under uniform tensile load. In the investigation carried out by DheerajGunwant et. al. [6] we see an FEA analysis on an Elliptical Hole on a plate of dimension 400mm x 100mm x10mm using a commercially available Finite Element Solver ANSYS. We referred a Journal paper by Ankur Joshi[9] which gave an analysis about an Elliptical hole on a Rectangular Plate done on ANSYS Package, and theStress Concentration and Stress Intensity Factors were calculated. Another paper by L. Q. Zhang et. al. – "Anefficient and accurate iterative Stress solution for an infinite elastic plate around two Elliptical holes, subjected touniform loads on the hole boundaries and at infinity" was referred. The takeaway from this paper was the methodfor calculating Stress Concentration Factors (SCF) analytically.The next paper was by V. G. Ukadgaonkar et. al.Manuscript2[10] which was about an elastostatic problem of two unequal holes on a rectangular plate subjected to internal

pressures and are solved analytically. G Mari Prabhu et. al. [11] paper showed us the stability of the web panel will reduce by having holes. The report by RaminSedaghati et. al. [12] showed us that lightening holes as

mentioned above, are used in the design of the web of the rib for mass reduction, accessibility and to form a

passage for wiring and fuel pipes. In broad, circular holes are used as lightening holes in rib webs of aircraft wings,structural components of other machines like ships, fighter jets, vehicles and even in buildings. Considering thedevelopments in the area of design criteria for a plate with cut outs of different geometry, an effort has been madeto propose a finite element analysis (FEA) for a plate with elliptical hole.

II. METHODOLOGY

The finite element analysis was performed on a plate having dimensions, 200mm length (2L), 80mm width (2W)and 5mm thickness. An elliptical cut out with a varying major axis dimension was introduced at the middle of theplate. Figure 1 shows the detailed drawing of the plate with an elliptical hole. The plate is fixed at one end and aload of 10,000N was applied at the other end (parallel to the major axis of the elliptical hole). The a/w ratio of theelliptical hole is varied from 0.275 to 0.500 in steps of 0.025. Table 1 shows the details of the a/w ratio for eachtrial. The plate was modelled with these specifications using the commercial FEA software, ANSYS. The platewith the elliptical hole was meshed using 4 node quadrilateral elements, and equivalent pressure was applied atthe loading edge. Von mises stress for a defined range of a/w ratio from finite element analysis were acquired and analysed to understand the influence of change in geometry of the cut outs on Von mises stress.

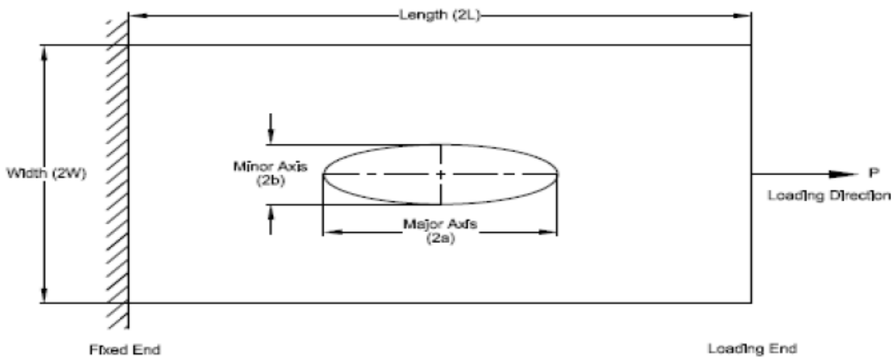

Fig.1: Detailed Drawing of the Plate.

TABLE 1: a/w Ratio for Each Trial of Finite Element Analysis

Hold Values Length of the Plate: 200mm Width of the Plate: 80mm Thickness of the Plate: 5mm Minor Axis of Elliptical Hole: 20mm Material of the Plate: Mild Steel - IS2062		
Trial No.	Major Axis in mm	a/w Ratio
1	22	0.275
2	24	0.300
3	26	0.325
4	28	0.350
5	30	0.375
6	32	0.400
7	34	0.425
8	36	0.450
9	38	0.475
10	40	0.500
11	42	0.525

III. RESULTS AND DISCUSSIONS

Von mises stress is one of the most appropriate parameters in engineering materials which is used to predict theyielding. In this context, the induced Von mises stress in the plate with elliptical hole has been extracted fromfinite element analysis. in this section, the influence of cut out geometry in the plate was analysed with respect toVon mises stress, further a regression prediction model was established to understand the relationship betweena/w ratio and Von mises stress.

A. Von mises Stress

Figure 2 shows a sample finite element analysis model for a/w of 0.400. Von mises stress was recovered from theanalysis and recorded as shown in the Table 2 for Mild Steel – IS2062.

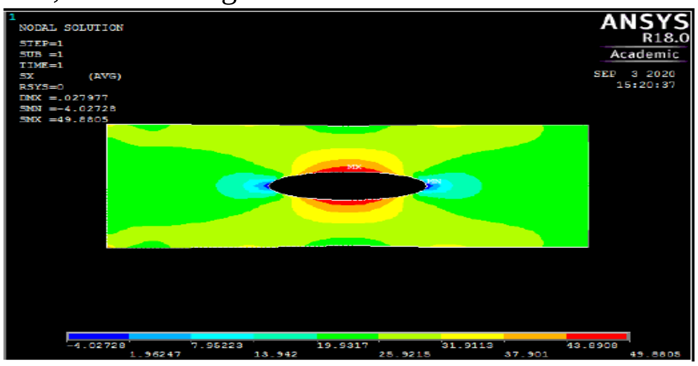

Fig. 2: Finite Element Analysis Model of the Plate.

TABLE 2: Von mises Stress for Mild Steel – IS2062 Material from Finite Element Analysis

Sl.No.	**a/w Ratio**	**Von mises Stress (MPa)**
1	0.275	54.771
2	0.300	53.264
3	0.325	52.009
4	0.350	50.979
5	0.375	50.112
6	0.400	49.376
7	0.425	48.747
8	0.450	48.204
9	0.475	47.734
10	0.500	47.323

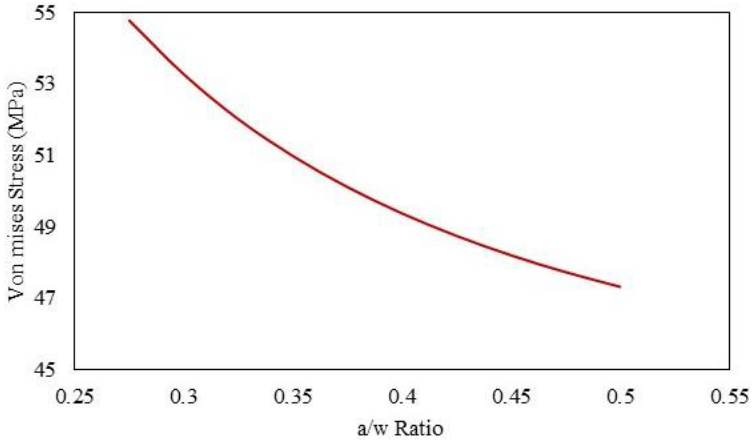

Fig. 3: Influence of a/w ratio on Von mises stress.

Figure 3 shows the correlation between a/w ratio and Von mises stress. It was seen that the Von mises stress tooka hit as the a/w ratio shot up. This observation may be due to reduced intensity of internal resistance offered bythe material. The increase in a/w ratio decreases the amount of material, as a consequence, the plate losesmolecules, which decrease the bonding strength and hence initiates the presence of less internal resistance. Wecan also assume these holes as partially yielded circular holes. This also can serve to be another reason as to whythe Von mises stress decreases as the area of the elliptical hole decreases. We can see that there is not a significantdecrease in the Von Mises Stress, because the Nominal Cross-Sectional Area remains constant throughout all thetrials which is a product of minor and major axes.

Figure 4 shows the plot of normalized values of the area of the elliptical hole and Von mises stress is plotted withrespect to the number of trials. The relation between these two parameters signifies similar trends of reduction inVon mises stress with increase in elliptical hole size. From Figure 4, it is observed that the optimum value of a/wratio and Von mises stress is 0.375 and 50.112 MPa respectively.

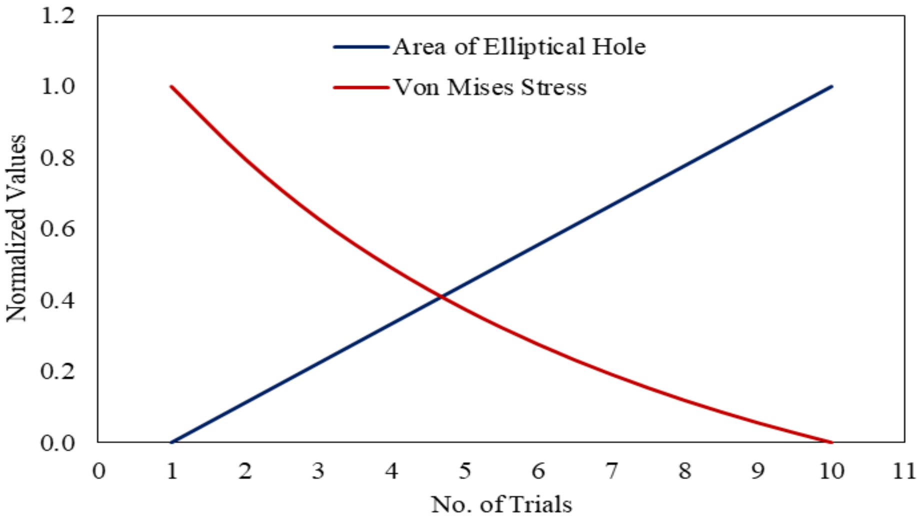

Fig. 4: Correlation between Area of Elliptical Hole and Von Mises Stress.

B. Regression Prediction Model

Regression prediction model was developed to establish the relationship between a dependent variable (von misesstress) and the independent variable (a/w ratio). Equation (1) is generated through the regression process. Table 3shows the Von mises stress from finite element analysis and Regression prediction model.

$\sigma v = -300.82r3 + 454.\ .05r3 - 245.67r + 94.237$ (1)

Where, $\sigma v = VonmisesstressinMPa$; r = a/w ratio.

TABLE 3: Comparison between Finite Element Analysis Values and Regression Prediction Model Values.

Sl. No.	a/w Ratio	Von mises Stress (MPa)		Percentage error
		From Finite Element Analysis	From Regression Prediction Model	
1	0.275	54.771	54.759	0.02
2	0.300	53.264	53.278	-0.03
3	0.325	52.009	52.027	-0.03
4	0.350	50.979	50.976	0.01
5	0.375	50.112	50.098	0.03
6	0.400	49.376	49.365	0.02
7	0.425	48.747	48.747	0.00
8	0.450	48.204	48.218	-0.03
9	0.475	47.734	47.749	-0.03
10	0.500	47.323	47.312	0.02

It is observed that the variation between the values of Von mises stress from finite element analysis and regressionprediction model is negligible and the regression equation (1) may be used to predict the Von mises stress valuesfor a predefined range of a/w ratio.

IV. CONCLUSION

Finite element analysis was performed for a Mild Steel (IS2062) plate with an elliptical hole of varying major axisdimensions. The Von Mises Stress has been chosen as a parameter of importance as we are in the pursuit of materials with high yield criterion and this analysis aims to provide designers with appropriate data to make an informed decision as to which a/w ratio should be selected. The Von mises stress was extracted for each a/w ratioand discussed in detail with respect to change in elliptical hole size. The investigation reveals that the Von misesstress decreases with increase in area of the elliptical hole in the plate. The less material leads to weaker bondingand lower internal resistance offered by the material could be one of the concerns for the inverse relation betweenVon mises stress and elliptical hole size. The relation between the elliptical hole area and Von mises stressprovides an opportunity to select the optimum value of a/w ratio. This investigation leads to understanding thatlightening holes used in the Spar of an Airplane wing are subjected to high loads and we must make sure that thematerials used do not fail easily when the lightening holes are cut out. Equation (1) i.e. the regression predictionmodel, gives ample opportunity to the designer, to select an appropriate a/w ratio to maintain safe Von misesstress for a plate with a central elliptical hole.

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