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Determination of Stress Intensity Factor for a Plate Having Square Hole with Inclined Crack using Numerical Method

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Abstract: The objective of this work is to develop a new material model to simulate the fracture behavior of structural plate with hole. Plates are subjected to different types of loading like tension, compression, bending or any combination of these. These different types of loading situation may initiate and propagate a crack. The issue of crack detection and fracture has gained wide spread industrial interest. Crack or damage affects the industrial economic growth. Generally crack in a structural element may occur due environmental defects and during manufacturing of the plates. A finite element based two dimensional crack propagation simulator software ANSYS is used for the analysis. Finite element analysis was employed to simulate the fracture behavior of the plate with inclined crack. The stress intensity factor is an important parameter for estimating the residual life in cracked structures. To determine the mixed-mode stress intensity factors quarter-point (Q-P) singular finite elements are employed. Crack growth depends on the initial crack length, material properties and dimensions, loading conditions etc. So Load versus crack length increase and load versus potential energy are calibrated.

Key words: stress intensity factor, mixed-mode, quarter-point and singular elements.

INTRODUCTION

Aluminium, the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently as the end of the 19th century. Aluminium played the role of an automotive material of increasing engineering. In recent times aluminium materials are used for aerospace applications and fracture failure been identified. Surface and corner cracks are encountered in engineering structures and in aerospace applications at locations where high stresses or material imperfections exist. Sometimes, surface or corner cracks can also be observed in a component even before its service life begins.

Fracture is the separation, or fragmentation, of a solid body into two or more parts under the action of stress.

PROBLEM FORMULATION

A plate with hole is analyzed to find the stress concentrations around holes, normally causes failure and have a great practical importance. The analysis of holes are imperative because the holes are used in engineering components such as bolts, rivets etc. and the stresses and deformation which occur near them at given load are analyzed. Due to the increase in stress above the maximum yield stress around the vicinity of the hole, crack starts to initiate, as the load crosses the threshold value the crack starts to propagate and structure will fail. To predict this crack better study is required "Determination of Stress Intensity Factor for a plate having square hole with inclined crack using numerical method". And predict the direction of crack with different material properties and loading condition.

OBJECTIVE

- Preparation of 2D geometric model using Ansys package.
- Calculating the stress, displacement, and strain energy of the geometric model by applying boundary conditions.
- At constant angle and constant load, increase the crack length and find the stress, displacement, energy release rate and stress intensity factor.
- By applying varying load at different angles of the crack find the stress, strain energy, displacement, energy release rate and stress intensity factor.
- By using different materials, find the material behavior at different loads, crack length.

GEOMETRIC MODEL

Figure 3.2 shows the geometric model. The rectangular plate of height 25mm and width 27.75mm.

The square hole inside the plate is of 6.25mm, initial crack length a_1 is 1.5625mm and crack length a_2 is 4.6097mm.

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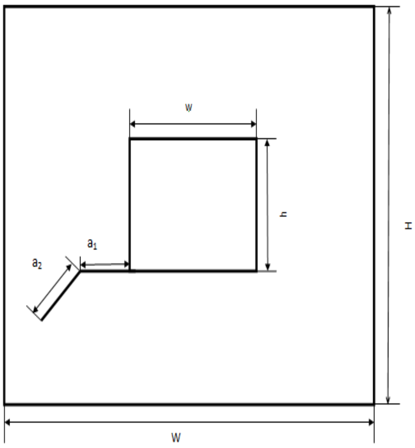

Figure 3.2 Geometric Model

MESHING

In finite element model two lines are highlighted which is shows the crack length. Horizontal crack length denoted by a_1 and inclined crack length denote by a_2.Inclined crack length made angle to the Y axis is 40° as shown in geometrical model.

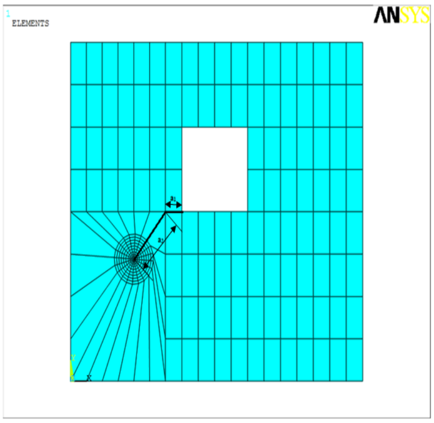

Figure3.3 Geometric Model

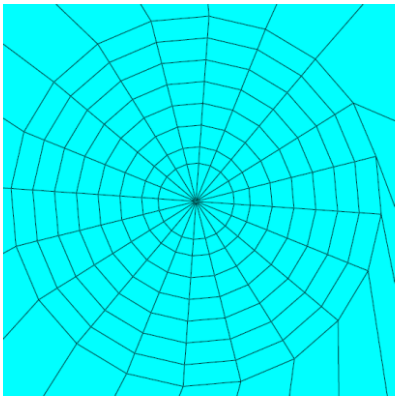
Figure 3.4 Enlarged view of crack tip

3.2.8 Two conditions are used for the analysis of the plate.

- Uniaxial load
- Biaxial load

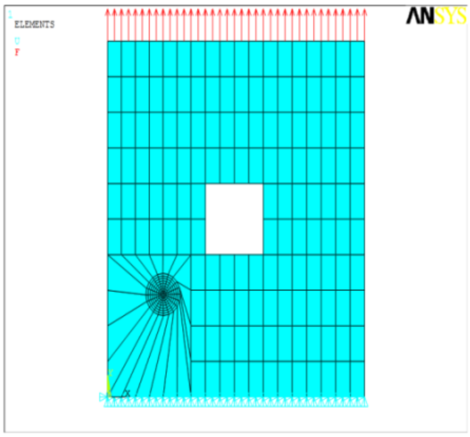

Figure shows the geometric model of uni axial load condition

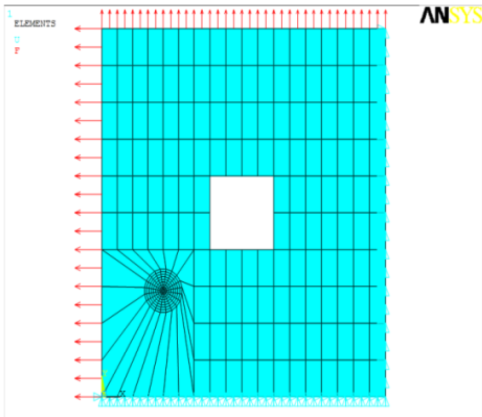

Figure shows the geometric model of biaxial load condition

RESULTS AND DISCUSSION

By varying the crack angle and with different load condition the stress and energy release rate has been determined. We have considered two materials, mild steel and aluminium in this analysis. The material properties are shown in table 4.1.

Table: 4.1 Properties of the materials.

Properties	**Aluminum**	**Mild Steel**
Elastic Modulus	70-79 GPa	210GPa
Poisson's Ratio	0.33	0.28
Density	2600-2800 kg/m^3	7850 kg/m^3

CALCULATE THE STRESS NEAR THE CRACK TIP AT VARIOUS ANGLE WITH CONSTANT CRACK AND LOAD.

4.1.1 Aluminium with uniaxial loading.

The values of crack tip stress, displacement, and strain energy for the boundary conditions shown in figure 4.1 are tabulated in the Table 4.2.

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Table 4.2 Variation of strain energy and displacement with varying crack angle

Crack length a_1 (10^{-2})	**Crack length a_2 (10^{-2})**	**Angle θ**	**Crack tip stress N/m^2**	**Strain energy (∅) J**	**Displacement (Δ) mm**
1.5625	4.6097	30	363.31	1.565	0.27779
1.5625	4.6097	35	376.38	1.564	0.27756
1.5625	4.6097	40	387.06	1.563	0.27753

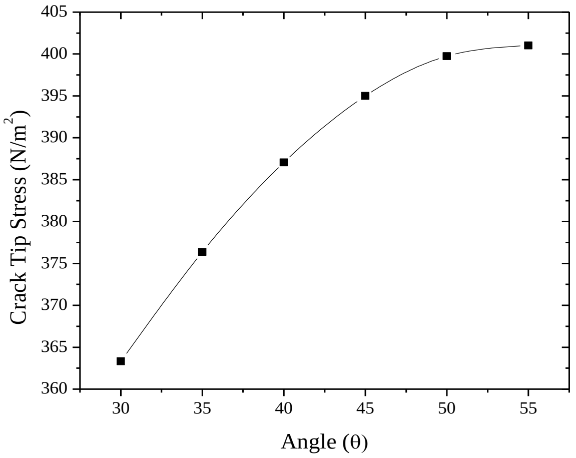


Figure 4.2 Angle v/s Crack tip stress.

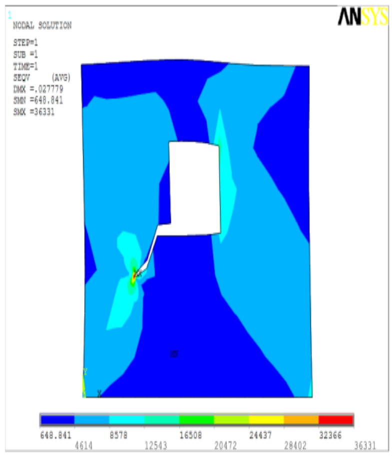


Figure 4.5 Von-mises stress plot for 30^0 crack angle.

Figure 4.5 shows the Von-mises stress plot for 30^0 and 55^0 crack angles. It can be observed from the figure that the maximum stress of 363.31N/m^{2}and 401.03N/m^2 was found at the crack tip for 30^0 and 55^0 crack angles respectively. At the crack tip maximum stress is shown which is indicated by red colour and blue colour indicates stress is minimum or less at that region.

CALCULATE THE STRESS NEAR THE CRACK TIP AT VARIOUS ANGLE WITH CONSTANT CRACK AND LOAD.

4.2.1 Mild steel with uniaxial loading.

By keeping the crack length and load as constant and increasing the crack angle for the plate with square hole, the variation in stress and strain were tabulated in table 4.3.

Table 4.3.Variation of strain energy and displacement with varying crack angle

Crack length a_1 (10^{-2})	**Crack length a_2(10^{-2})**	**Angle θ**	**Crack tip stress N/m^2**	**Strain energy (∅)J**	**Displacement (Δ) mm**
1.5625	4.6097	30	374.32	5.432	0.0964
1.5625	4.6097	35	385.34	5.427	0.09632
1.5625	4.6097	40	394.15	5.425	0.00963

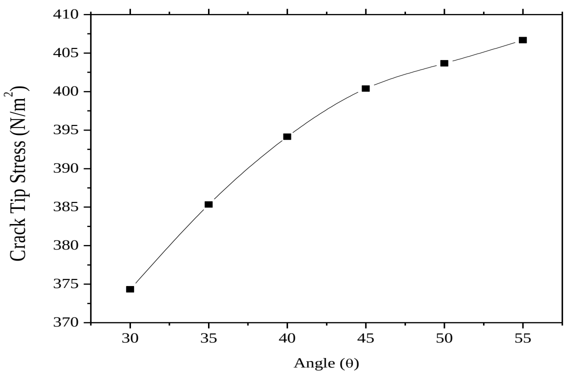
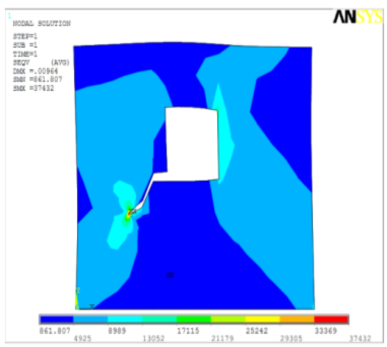


Figure 4.8 Angle v/s crack tip stress

Figure 4.8 shows the variation of crack tip stress with varying crack angle. It can be observed from the figure 4.8 that at a crack angle of 30^0 a minimum crack tip stress of 374.32 N/m^2 was present and varied linearly till the crack angle of 55^0 with a maximum crack tip stress of 406.67 N/m^2.



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Above figure shows the Von-mises stress plot for 35^0 and 45^0 crack angles. It can be observed from the figure that the maximum stress of 374.32 N/m^2 and 406.67 N/m^2 was found at the crack tip for 30^0 and 55^0 crack angles respectively. At the crack tip maximum stress is shown which is indicated by red colour and blue colour indicates stress is minimum or less at that region.

STRESS INTENSITY FACTOR FOR A CRACK LENGTH UNDER VARIOUS BIAXIAL LOADS.

4.5.1 Aluminium with biaxial load

Table: 4.13 The stress intensity factor for varying load.

Load N	**Potential energy at Crack length 4.6097 (∏) J**	**Potential energy at Crack length 4.950 (∏) J**	**Change in potential energy (d∏) J**	**Energy release rate (*G*) Jm²**	**Stress intensity factor (k) MPa√m**
σ_1-4000, σ_2-2500	4.82	4.97	-0.15	44.03	1.85
σ_1-5000, σ_2-3000	7.35	7.56	-0.21	61.65	2.20
σ_1-7500, σ_2-5000	17.76	18.27	-0.51	149.73	3.42

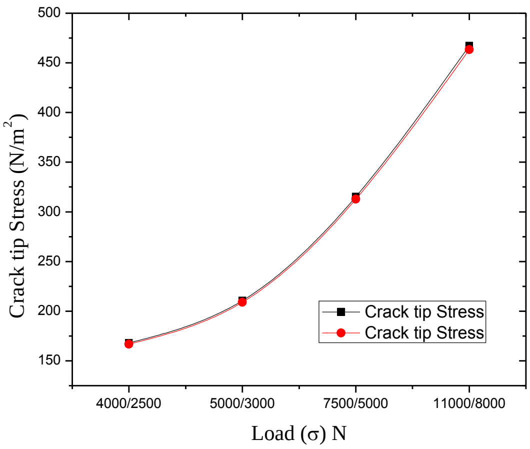

Figure 4.27 Load v/s crack Tip Stress.

Figure 4.27 shows the comparison of the variation of the crack tip stress 166.80N/m^2 for crack lengths of 4.6097 cm at a load of σ_1-4000N, σ_2-2500N and 168.04 N/m^2 for crack lengths of 4.9503 cm at a load of σ_1-4000N, σ_2-2500N and increase linearly till the crack length of 4.6097cm and 4.9503 cm at a load of σ_1-4000N, σ_2-2500N.

STRESS INTENSITY FACTOR FOR A CRACK LENGTH UNDER VARIOUS BIAXIAL LOADS.

Mild steel with bi axial load condition

Figure 4.31 shows the comparison of the variation of the crack tip stress for crack lengths of 4.6097 cm and 4.9503 cm respectively.

Table: 4.13 The stress intensity factor for varying load.

Load N	**Potential energy at Crack length 4.6097 (∏) J**	**Potential energy at Crack length 4.6097 (∏) J**	**Change in potential energy (d∏) J**	**Energy release rate (*G*) Jm²**	**Stress intensity factor (k) MPa√m**
σ_x-4000, σ_2-2500	1.79	1.84	-5	14.67	1.82
σ_1-5000, σ_2-3000	2.73	2.81	-8	23.48	2.31
σ_1-7500, σ_2-5000	6.62	6.80	-18	52.84	3.46

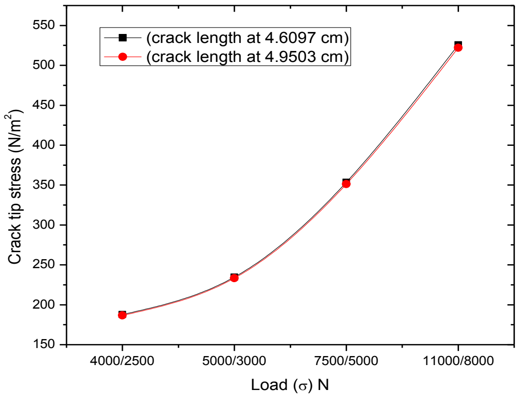

Figure 4.31 Load v/s crack Tip Stress

CONCLUSION

5.1 CONCLUSION BASED ON ANALYTICAL STUDY:

Mixed-mode stress intensity factor solutions were presented for inclined cracks in finite thickness plates under uniform tensile loading conditions. As the numerical solution tool, ANSYS -11 was used, different crack lengths, crack angles and different load conditions were considered and plate was analyzed.

- With the variation of load results in increases of the crack tip stress, potential energy, energy release rate and stress intensity factor.

- The variation in strain energy with the change in crack angle was shown. It was observed that the strain energy had a decremented slope for 30^0, 35^0 and 40^0 angle of crack while incremental slope for 45^0,50^0 and 55^0 angle of crack.
- The variation in displacement with the change in crack angle was shown. It was observed that the strain energy had decremented slope from 30^0 ,35^0 and 40^0 angle of crack while incremental slope for 45^0 ,50^0 and 55^0 angle of crack.
- In the polar plot the stress was maximum at an angle of 120^0 to 180^0 and the crack will grow in the direction where the stress is maximum.
- For the biaxial load for the different material with increase in crack length the crack tip stress, strain, displacement and potential energy increase.

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