Scientific Journal of Impact Factor (SJIF) : 3.134
ISSN (Print): 2348-6406
ISSN (Online): 2348-4470
International Journal of Advance Engineering and Research Development

REDUCTION OF STRESS INTENSTITY FACTOR FOR A CENTRAL CRACKED PLATE

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Abstract *—Stress intensity factor is used in fracture mechanics to predict the stress state or stress intensity near the tip of a crack caused by a remote load or residual stresses. The stress intensity factor is a single-parameter characterization of the crack tip stress field. For a body with a crack and known boundary conditions, once the stress intensity factor is determined one can predict whether the a crack in the component is likely to grow or not. Reduction of stress intensity factor can prevent crack from propagation. The paper presents the method of reducing stress intensity factor for a finite length plates by introducing auxiliary holes, the analysis is done by using the finite element method. The finite element analysis program used is the ABAQUS® 6.13. It has been found out that the stress intensity factor is reduced by introducing an auxiliary hole in the plate. The result shows that the stress intensity factor is significantly reduced when the auxiliary holes are nearer to the crack. The variation of the stress intensity factor with diameter of the hole is also studied. The result shows that the stress intensity factor is significantly reduced when the diameter of the holes reduces.*

Keywords- *stress intensity factor; finite element method; fracture mechanics; linear elastic fracture mechanics; crack propagation.*

I. INTRODUCTION

1.1. Fracture Mechanics

Fracture mechanics involves a study of the presence of the cracks on overall properties and behaviour of the engineering component. The process of fracture may be initiated at defect locations like micro-cracks, voids, and the cavities at the grain boundaries. These defects can lead to the formation of a crack due to the rupture and disentanglement of molecules, rupture of atomic bonds or dislocation slip [1].

1.2. Classification of Fracture Mechanics

It is classified two types
1. Linear Elastic Fracture Mechanics (LEFM)
2. Elastic Plastic Fracture Mechanics (EPFM)
LEFM is valid only when the inelastic deformation is small compared to the size of the crack, what we called small-scale yielding. If large zones of plastic deformation develop before the crack grows, Elastic Plastic Fracture Mechanics (EPFM) must be used.

1.2.1. Linear Elastic Fracture Mechanics (LEFM)

For any homogeneous and isotropic material, stress surrounding the crack tip is often analyzed assuming linear elastic material behavior. The method of linear elastic fracture mechanics assumes the plastic region near crack tip is much smaller than the dimensions of the crack and the structural member. This is a very important concept, scientists and engineers call it small-scale yielding, for simplifying the stress analysis near crack tip. Assuming the geometry has very small displacement and the material is elastic, homogeneous and isotropic.

1.3. Modes of Fracture

Mode I: Opening Mode
In which the crack faces separates in a direction normal to the plane of the crack. Loading is normal to the crack plane, and tends to open the crack. Mode I is considered the most dangerous loading condition.

Mode II: Sliding Mode
Corresponds to in-plane shear loading and tends to slide one crack face with respect to the other. The stress is parallel to the crack growth direction.

Mode I: Tearing Mode
Corresponds to out-of-plane shear. In which the crack faces are sheared parallel to the crack front.

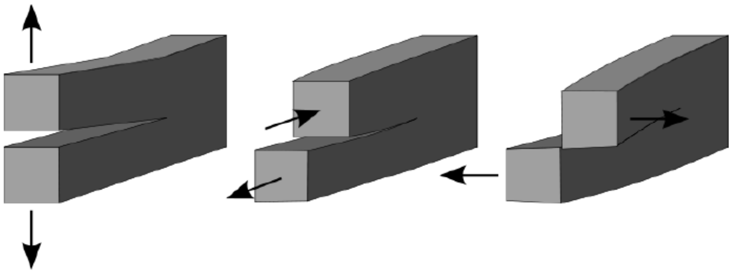

Figure 1 Modes of fracture

1.4. Stress Intensity Factor (SIF), K

When a crack exists in a structure, stress is concentrated at the tip but the stress concentration do not account for the fracture behavior at the tip of a crack. As the radius of the curvature of the crack tip approaches zero the stress level could become infinity, which is not a real property of a loaded structure. As an alternative to describe the structural strength at the crack tip appropriately, the stress-intensity factor, K, is used. It is defined as a measure of the stress field intensity near the tip of an ideal crack in a linear elastic solid when the crack surfaces are displaced in the opening mode (Mode I). The SIF depends on the loading, the crack size, the crack shape, and the geometric boundaries of the specimen. The parameter, K, is related to the nominal stress level (σ) in the structural member and the size of the crack (a). In general, the relation is represented by:

$$k = y\sigma\sqrt{\pi a}$$

Where y is a dimensionless shape factor, depends on the structural member and crack.

1.5. Contour Integral Evaluation method

The stress intensity factors can be calculated from the J-integral with the so called interaction integral method [2]. The J-integral is a contour integral method to calculate the strain energy release rate, the energy dissipated during fracture per unit created fracture surface area [3]. This measure is also important in fracture mechanics since the energy can be related to crack growth. The interaction integral method is an extension of the J-integral, where the J-integral is calculated for pure modes.

1.6. J integral method

This method is implemented in ABAQUS [4], which makes its use simple and direct. The contour integral is defined by the node correspondent to one of the crack tips and the direction perpendicular to the crack. Five contours are used in each analysis (5 elements are defined along the crack).In general ,all but the first and last contour integral provide identical values for K_I.The fifth contour is the one whose results are chosen as the final results. Results for both crack tips are considered. Therefore each analysis (each value of α) provides two values for K_I

II. BENCHMARK PROBLEM

The benchmark problem is solved to determine the stress intensity factor (K) by using both finite element analysis and analytical equations to find the discrepancy of the results. The material analysed is Mild Steel plate of width 0.2 m having a centre crack of length 0.02 m. The material is analysed using ABAQUS assuming it to be in isotropic plane strain condition by meshing using CPS8R: An 8-node biquadratic plane stress quadrilateral, reduced integration. The model is only analysed since the plate is in symmetric geometry. Then the result is validated using analytical equations.

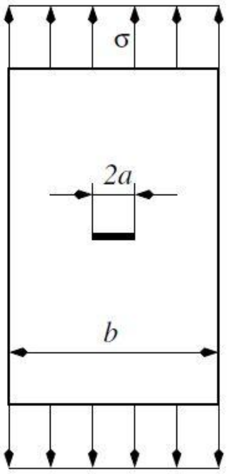

Figure.1 Steel plate with crack

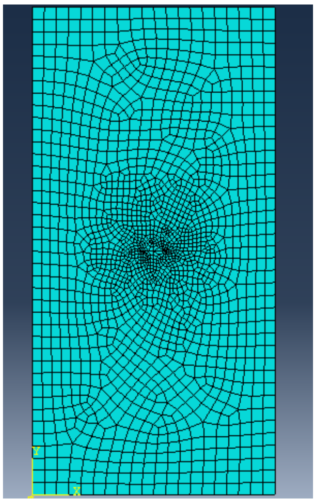

Figure. 2 Meshed model

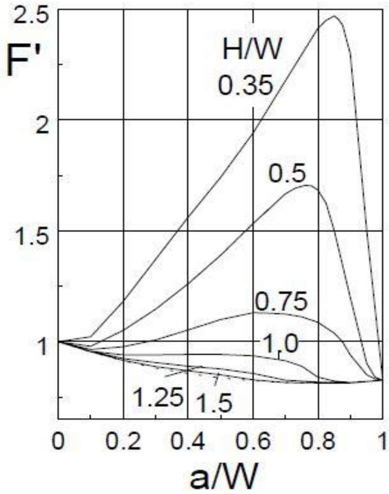

Figure.3 F' vs. a/W

Analytical solution is
Obtained from:

$$K = \sigma F \sqrt{\pi a}$$

$$F = \frac{F'}{\sqrt{(1 - \frac{a}{W})}}$$

Where,

a=half length of the crack
W=half width of the plate
F, F' = function of a, W, H
F' can be obtained from Fig 3.
σ = Pressure applied

The results obtained from FEA and analytical equations are:

From ABAQUS;	K = 26.27
From theoretical equations;	K = 26.53
The discrepancy of two solutions;	= 0.09%

III. PROBLEM SPECIFICATION

Consider a finite rectangular plate in tension with a central crack as shown in figure (4). The dimensions of plate considered for study is tabulated in the table (1). Material is assumed to be linear elastic, with a young's modulus E = 210 GPa and poison's ratio is μ=0.3.
To reduce the stress intensity factor, Consider the same plate subjected to uniaxial tensile stress with central crack and auxiliary holes which forms voids in the plate as shown in figure(5) the finite element mesh and the boundary condition for the plate the is shown in figure(7).

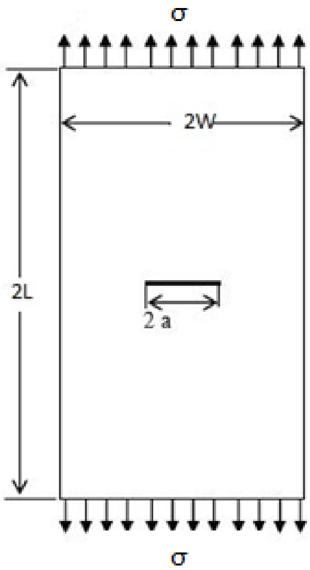

Figure 4. Plate with centre crack

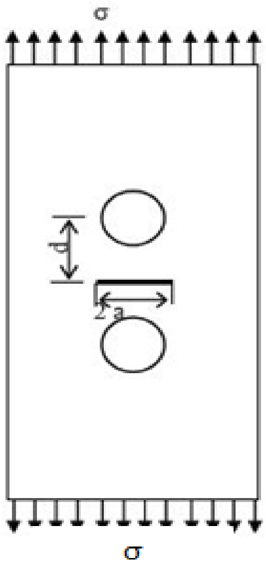

Figure 5. Plate with centre crack and holes

Table 1.plate dimensions

Applied Stress (σ)	200 MPa
PLATE DIMENSION	
Length x Breadth	100mm x 200 mm
Crack length(2a)	30 mm

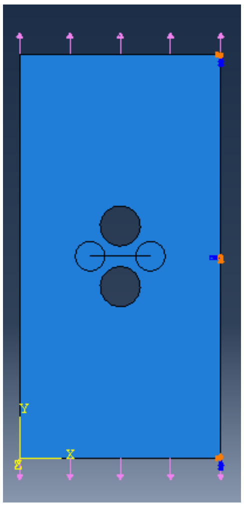

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Figure 6. Geometry and loading for plate

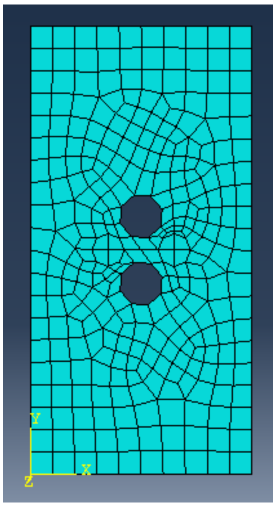

Figure 7. Finite element meshes of plate

The stress distribution in the plate without the holes is shown in the figure(8), the stress distribution I the plate with the holes is shown in the figure(9)

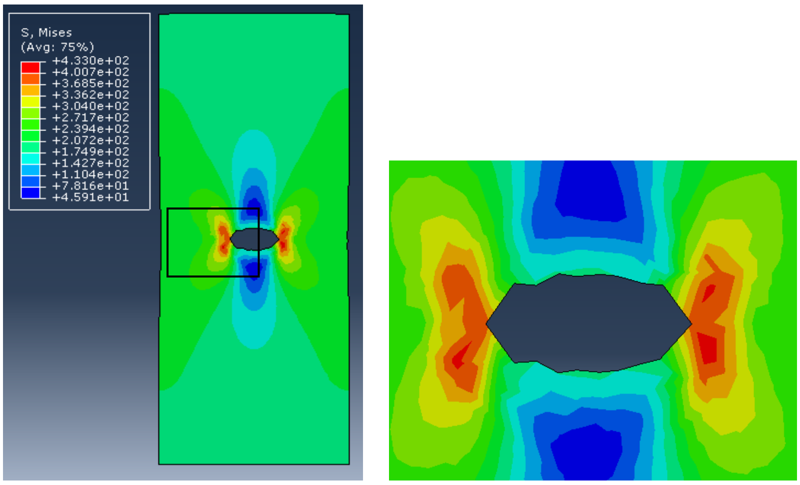

Figure 8. Stresses distribution around the crack

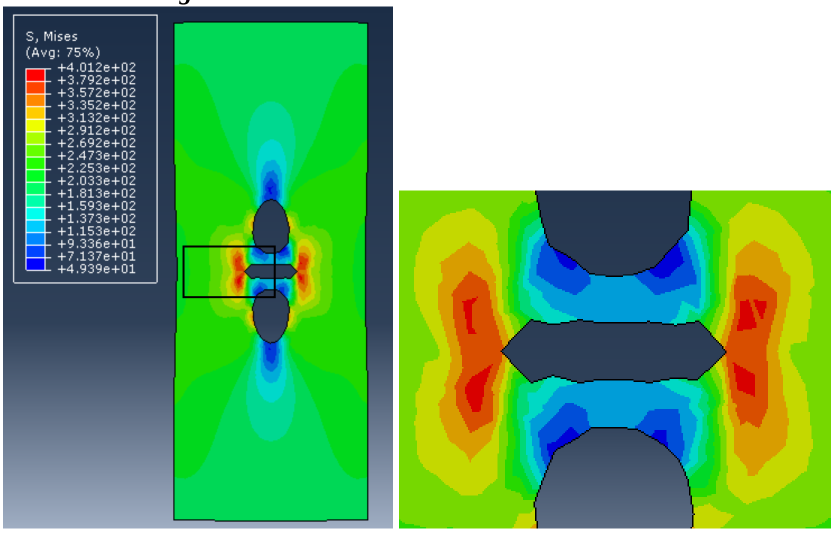

Figure 9. The reduction of stresses around the crack

It can be seen from the stress contours that the stress concentration around the crack is reduced with the introduction of the holes near the crack.

IV. RESULTS AND DISCUSSIONS

4.1. Variation of stress intensity factor with distance of the auxiliary hole from centre crack.

Results are calculated by Modeling and meshing in ABAQUS 10.0 and then stress intensity factor is obtained directly. Figure (15) shows the variation of stress intensity factor with the distance of the auxiliary hole in plate from centre crack.

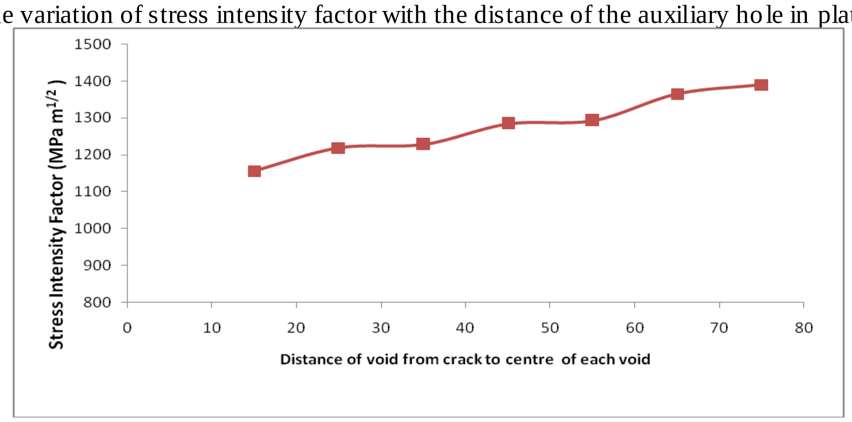

Figure 10. Variation of stress intensity factor with'd'

It can be seen from the graph that with the decrease of the distance of auxiliary holes from the centre crack the stress intensity factor reduces. This means that the stress intensity factor is minimum when the distance of auxiliary holes from the crack is minimum.

4.2. Variation of stress intensity factor with the variation of the radius of the hole

In order to understand the effect of the radius of the holes on the stress intensity factor a study is conducted for the variation of the radius of the hole for the minimum distance of the holes from the crack.

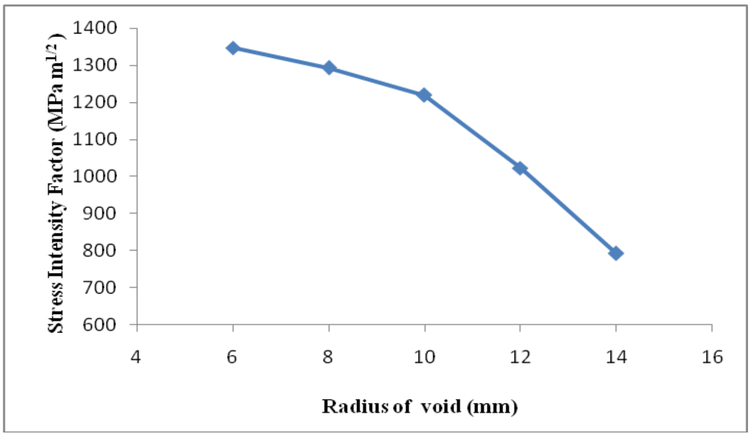

Figure 11. Variation of Stress Intensity Factor with radius of the hole.

It can be seen from the above graph that the stress intensity factor is minimum when the radius of the holes is minimum.

VII. CONCLUSION

The paper presents the method of reducing stress intensity factor for a finite length plates by introducing auxiliary holes, the analysis is done by using finite element analysis program ABAQUS® 6.13. By introducing auxiliary holes in the direction of loading on either side of the crack, the stress intensity factor at the crack tip decreases as the auxiliary holes come nearer the crack. The diameter of the auxiliary hole is also having effect on the stress intensity factor. As the diameter of the auxiliary holes on either side of the crack decreases, the stress intensity factor at the crack tip decreases accordingly. Thus the stress intensity factor can be reduced by introducing auxiliary holes nearer the crack with minimum diameter.

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