Determination of Stress Intensity Factor for a crack in thin plate under Mode-I loading using Finite Element Analysis

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ABSTRACT:
The failure of cracked components is governed by the stresses in the vicinity of the crack tip. The stress intensity factors depend on the geometry of the component and on loading condition. This study is on central cracked plate of a finite length. Basically stress Intensity factor is calculated analytically means by LEFM and computationally. ANSYSTM 14.5 is used as a computational tool. For different values of uniform pressure, stress intensity factor is calculated and then compared with analytical results and good agreement is noted between both approaches. This work is to find the optimal pre-cracked length, in order to eliminate the effect of the SIF and the Fracture toughness.

Keywords: — Stress Intensity Factor (SIF), ANSYS, Linear Elastic Fracture Mechanics (LEFM), Crack tip, Optimal Pre-cracked Length

I. INTRODUCTION
Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture. Structural design concepts traditionally use a strength-of-material approach for designing a component. This approach does not anticipate the elevated stress levels due to the existence of cracks. The presence of such stresses can lead to catastrophic failure of the structure. In modern materials science, fracture mechanics is an important tool in improving the Mechanical performance of mechanical components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity, to the microscopic crystallographic defects found in real materials in order to predict the macroscopic mechanical failure of bodies. Fractography is widely used with fracture mechanics to understand the causes of failures and also verify the theoretical failure predictions with real life failures. The prediction of crack growth is at the heart of the damage tolerance discipline. The goal of fracture mechanics is to determine what conditions will create and drive a crack. By understanding the phenomena of fracture engineers can competently design against this particular mode of failure.

A. FAILURE MODES OF FRACTURE
Consider a cracked plate to distinguish several manners in which a force can be applied on the plate which might enable the crack to propagate. Irwin proposed a classification corresponding to the three situations represented in Fig. 1. Accordingly, three distinct modes are considered: mode I, mode II and mode III.

In the mode I or opening mode, the body or structure is loaded by tensile forces such that the crack surfaces are pulled apart in the y direction. The deformed surfaces are symmetric with respect to the planes perpendicular to the y-axis and the z-axis.

In the mode II or sliding mode, the body or structure is loaded by shear forces parallel to the crack surfaces which slide over each other in the x-direction. The deformed surfaces are symmetric with respect to the plane perpendicular to the z-axis and skew symmetric with respect to the plane perpendicular to the y-axis.
Finally, in the mode III or tearing mode, the body or structure is loaded by shear forces parallel to the crack front and the crack surfaces slide over each other in the z-direction. The deformed surfaces are skew-symmetric with respect to the plane perpendicular to the z-axis and the y-axis.

B. MATHEMATICAL CALCULATION OF STRESS INTENSITY FACTORS (SIF)

A sample under plane stress conditions, which typically occurs in thin plates, has a highly variable $K_c$ value whereas, a thick sample under plane strain conditions, has a constant value for $K_c$. Part of Irwin’s revisions of Griffith’s equations was to rewrite the strain energy density in terms of stress because a value for stress is much easier to obtain than a value for strain energy. The resulting equation is:

$$K_c = \beta \sigma_f \sqrt{\pi a}$$

It has unit MPa $\sqrt{m}$, where $\beta$ is a geometry factor, $\sigma_f$ is the stress at failure and unit is MPa, and $a$ is the crack length. Values for $\beta$ have been determined from equations empirically fitted to the results of numerous fracture tests of varying geometry conducted under constant loading conditions. The equations for different geometries can be found in fracture handbooks. The stress intensity experienced by a material is dependent on the loading conditions and crack geometry.

II. LITERATURE REVIEW

In recent years, considerable efforts have been made for the development of analytical as well as numerical models for the better estimation of crack propagation and fatigue life. The ultimate goal for the researchers who are working in the mechanical design field is to develop structures with high reliability and crack resistant.

Gustavo V. Guinea, Jaime Planas and Manuel Elices developed some considerations related to the influence of element size, element shape, and mesh arrangement on numerical values of $K_I$ obtained by the displacement method. Mxolisi L. Mbandzezi and Raymond B. Mabuza demonstrated the Effect of Variations of Crack geometry on the Stress Concentration Factor in a Thin Plate This study includes a preliminary effort which investigates the effect of variations of crack geometry on the stress concentration factor on a simple thin plate subjected to a constant, uniform, Uni-axial tensile load [6]. M.H. Gozin, M. and AghaieKhafri studied plasticity induced crack closure (PICC) concept. A three dimensional (3D) finite element method (FEM) were used to study the effect of compressive residual stress field on the fatigue crack growth from a hole [2]. A. Boulenouar, N. Benseddiq, and M. Mazari illustrate a research on a numerical modeling of crack propagation under mixed mode loading conditions. This work is based on the implementation of the Displacement Extrapolation Method (DEM) and the strain energy density theory in a finite element code. At each crack increment length, the kinking angle is evaluated as a function of stress intensity factors (SIFs) [3]. De Xiea and Sherrill B. Biggers developed an interface element to solve 2D progressive crack growth problems under mixed-mode loading. The interface element is developed to calculate the strain energy release rates based on the virtual crack closure technique (VCCT) in conjunction with finite element analysis (FEA) [8]. A.B. de Morais developed cohesive zone model for mode I delamination in composite beams. The model is an extension of a beam on elastic foundation analysis similar to the one that led to the well-known corrected beam theory data reduction scheme. In particular, it is demonstrated that the shear foundation considered in most formulations can actually be discarded, thereby allowing a much simpler model implementation [7]. Crack free materials do not exist, cracks are everywhere, and they initiate and propagate from the locations of stress and strain concentration. The stress intensity factor gives a measure of the intensity of the stress field in the crack tip region. For a through-thickness crack with straight front in a centre-cracked plate of finite thickness, few authors worked to obtain the stress distribution close to the crack front.

III. PROBLEM SPECIFICATION

Cracks often develop in the corners of a structural member due to high stress concentration factor in those areas. If one can calculate the rate of crack growth, an engineer can schedule inspection accordingly and repair or replace the part before failure happens. Moreover, being able to predict the path of a crack helps a designer to incorporate adequate geometric tolerance in structural design to increase the part life. Finite Element analysis of a thin plate with a central crack is done. ANSYS™ Release 14.5 is used to determine the stress intensity factor for a plate. In this analysis, finite square plate in tension with a central crack is considered. Material is assumed to be linear elastic and isotropic in nature. Width of specimen is 0.2 m and crack length is 0.02m.
IV. OBJECTIVES

In recent years, the finite element method applied to fracture mechanics has been well developed. There are several studies that have sought to build up the calculation technique and provide a possible and efficient way to construct the FEA model for finite cracked bodies. The objectives for this FEA are listed below:

To determine Stress Intensity Factors for central crack in thin plate for Variable loading conditions.
To calculate Stress intensity Factor Analytically by LEFM.

A. Material Properties

For doing the FEA of a plate to determine a stress intensity factor two materials are considered. Materials are steel and aluminium. The material properties for steel and aluminium are described in table 1 [9].

<table>
<thead>
<tr>
<th>MATERIAL PROPERTY</th>
<th>STEEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Modules</td>
<td>210 GPa</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>0.3</td>
</tr>
</tbody>
</table>

B. Plane 183 Element Descriptions

Finite Element Analysis requires nodes and elements to discretize the given domain into smaller parts. For this FEA here we consider Plane 183 as suitable element. The various features of Plane 183 are described in the below text.

PLANE183 is a higher order 2-D, 8-node or 6-node element. PLANE183 has quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced by various CAD/CAM systems).

C. Meshing

Meshing contains nodes and elements. For this FEA no. of elements should be maximum at the crack region with respect to non-crack region. Total no. of elements is 87 and total no. of nodes is 276. The following Fig. 3 contains nodes and elements for the plate. [10].
D. Loading and Boundary Conditions

For this analysis, we consider a pressure of 100 MPa is applied in vertical direction and symmetry is applied at the vertical and horizontal direction as required for quarter symmetry model. The following Fig. 4 contains the one-fourth geometry of the plate including loading and boundary conditions also [10].

![Figure 3. Loading and Boundary Conditions for a crack in thin plate](image)

V. RESULTS AND DISCUSSION

Variation of stress intensity factor $K_I$ can be seen in Table II Here both values of Stress intensity factor $K_I$ (i.e., analytical and computational) are compared. The Specific Fracture Toughness (steel) = 50 MPa.$\sqrt{\text{m}}$ is obtained for the load 280 N. In Fig. 5 graphs can be seen between both the approaches [11].

“Table 2. For Variable Loading Conditions”

<table>
<thead>
<tr>
<th>LOADS</th>
<th>$K_I$(ANALYTICAL)</th>
<th>$K_I$(DEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4.43</td>
<td>4.51</td>
</tr>
<tr>
<td>50</td>
<td>8.86</td>
<td>9.02</td>
</tr>
<tr>
<td>75</td>
<td>13.29</td>
<td>13.53</td>
</tr>
<tr>
<td>100</td>
<td>17.72</td>
<td>18.04</td>
</tr>
<tr>
<td>125</td>
<td>22.15</td>
<td>22.56</td>
</tr>
<tr>
<td>150</td>
<td>26.58</td>
<td>27.07</td>
</tr>
<tr>
<td>175</td>
<td>31.01</td>
<td>31.58</td>
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<tr>
<td>200</td>
<td>35.44</td>
<td>36.09</td>
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<tr>
<td>225</td>
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</tr>
<tr>
<td>250</td>
<td>44.31</td>
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<tr>
<td>275</td>
<td>48.74</td>
<td>49.63</td>
</tr>
<tr>
<td>300</td>
<td>53.17</td>
<td>54.14</td>
</tr>
<tr>
<td>350</td>
<td>62.03</td>
<td>63.17</td>
</tr>
<tr>
<td>400</td>
<td>70.89</td>
<td>72.19</td>
</tr>
</tbody>
</table>

![Graph showing variation of stress intensity factor $K_I$](image)
V CONCLUSION

In this project work the ANSYS 14.5 used as a computational tool for the analysis of static fracture mechanics problem. By the use of ANSYS 14.5, K estimated under different loading conditions. In this work as the load increases the stress intensity factor increases simultaneously by the analytical and computational method.

ACKNOWLEDGMENT

I have taken efforts in this paper. However, it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

I am highly indebted to Prof. Ramdas B. Patthe, for their guidance and constant supervision as well as for providing necessary information regarding the paper. Also I wish to express my sincere thanks to Principal PLITMS Buldana Dr P. M Jawandhiya, and Head of Department Mechanical Engineering Prof. K. R. Sontakke for providing valuable guidance.

REFERENCES