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3D Crack Analysis with Finite Element Method using ANSYS Software on Steel Plate

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Abstract – ***In the paper, a three dimensional plate in tension with a central crack is considered. Crack propagation behavior is a major issue in a variety of industries. Aerospace structures, gas turbine engines, pressure vessels and pipelines are obvious examples where failure could lead to catastrophic consequences and loss of life. Generally available fracture mechanics techniques such as the crack opening displacement (COD) method for LEFM, crack tip opening displacement (CTOD) method for EPFM, and the J-Integral method and their implementation are used to find the crack propagation. In this work, we used ANSYS to find the cracks behavior and its propagation. The plate is made of steel having some material properties. The analysis used to find the propagation of cracks involve the prediction of the Stress Intensity Factor (SIF) and topology and meshing in relation to three dimensional cracks using Finite Element Method (FEM) with ANSYS software. The results are shown in appropriate form i.e. Stress Concentration Factor (SCF).***

Keywords: **Crack opening Displacement (COD), Stress Concentration Factor (SCF), linear elastic fracture mechanics (LFEM) and Finite element method (FEM), Stress Intensity Factor.**

I. INTRODUCTION

Crack propagation behavior is a major issue in many of industries. Aerospace structures, gas turbine engines, pressure vessels and pipelines are obvious examples where failure could lead to catastrophic consequences and loss of life. For example, grounding of a fleet of aircraft because of cracks found in a turbine blade of the engine, or shutting down of a pipeline have huge implications.

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. While producing durable, reliable and safe structures are the goals of every aerospace component manufacturer, there are technical challenges that are not easy to be solved. Given limited engine design space, engineers strive to optimize bracket geometry to produce high efficient and high performance engines that will operate at minimum weight and cost. Engineers often look to shave materials from bracket and design the thinnest possible brackets. Benefits from this approach include reduced weight, and smaller probability of encountering brittleness inducing micro structural defects. The mere presence of a crack does not condemn a component or structure to be unsafe and hence unreliable. Whether under cyclic or sustained loading, it is necessary to know how long an initial crack of a certain size would take to grow to a critical size at which the component or structure would become unsafe and fails. Also by knowing how a crack evolves and its rate of propagation, one should be able to estimate the residual service life of a component under normal service loading conditions.

II. LINEAR ELASTIC FRACTURE MECHANICS FOR CRACK

Linear Elastic Fracture Mechanics (LEFM) is a methodology that allows predicting, study and measure fracture toughness. Fracture toughness characterizes the resistance of a material to cracking, and it depends on a variety of factors such as temperature, environment, loading rate etc. Out of the three crack opening modes, the one that is analyzed is Mode I, which is typically more critical from the design standpoint (lower fracture toughness with respect to the Mode II and Mode III fracture toughness [1].

$$K_t = F.\ S.\sqrt{\pi a} \qquad (1)$$

Equation 1 shows the Mode I stress intensity factor, which characterizes the behavior of the material when a crack of length 2a is present in it. F is a factor that depends on the geometry of the specimen and the crack itself, S is the nominal stress. When the stress intensity factor reaches a critical value, the crack grows.

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It is possible to express the stress at a distance r ahead of a crack in terms of $K_I/\sqrt{r}$ .As r → 0, the stress should theoretically be infinite, but this is not possible in nature. The material will yield, so there will be a plastic zone at the crack tip. The size of this plastic zone depends on whether, for example, the specimen is subject to a plane strain or a plane stress case. If the specimen has dimensions x, y, z, plane strain corresponds to the case $\varepsilon_z = 0$ (for example, a beam with width z where there is no deformation in the width direction) and plane stress to the case $\sigma_z = 0$ (for example, a (x,y) plate where there is no perpendicular loading). In a plane stress problem, the plastic region is found to be larger. However, the plastic region could be even larger than in the case of plane stress if the material has yielded in a great part of the specimen.

Linear elastic fracture mechanics (LEFM) is used when the plastic zone ahead of the crack is much smaller than the dimensions of the crack or of the specimen. When this is no longer the case (for example, in a cracked specimen with 80% yielding present), one has to use Elastic Plastic Fracture Mechanics (EPFM), which is not based on the concepts of stress intensity factors and fracture toughness, but on other more complicated concepts (crack tip opening displacement, J-integral). K_I is the Mode I, plane strain fracture toughness. It is best to use this parameter because this is a material constant.

Stress Intensity Factor, K, is used in fracture mechanics to more accurately predict the stress state (stress intensity) near the tip of a crack caused by a remote load or residual stresses [4]. When this stress state becomes critical a small crack grows (extends) and the material fails. The load at which this failure occurs is referred to as the fracture strength. The experimental fracture strength of solid materials is 10 to 1000 times below the theoretical strength values, where tiny internal and external surface cracks create higher stresses near these cracks, hence lowering the theoretical value of strength. The original, "as fabricated" cracks were very small and hard to see with naked eyes, hardly a solution based on what we understand today. Unlike "stress concentration", Stress Intensity, K, as the name implies, is a parameter that amplifies the magnitude of the applied stress that includes the geometrical parameter Y (load type). These load types are categorized as Mode-I, -II, or -III. The Mode-I stress intensity factor, K_I is the most often used engineering design parameter in bridges, buildings, aircraft, or even bells. Typically for most materials if a crack can be seen it is very close to the critical stress state predicted by the "Stress Intensity Factor".

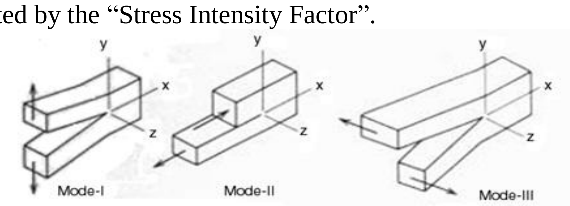

Fig. 1 Basic modes of loading involving different crack surface displacements.

Generally there are three modes to describe different crack surface displacement in Fig.1 Mode I is opening or tensile mode where the crack surfaces move directly apart. Mode II is sliding or in-plane shear mode where the crack surfaces slide over one another in a direction perpendicular to the leading edge of the crack. Mode III is tearing and antiplane shear mode where the crack surfaces move relative to one another and parallel to the leading edge of the crack. Mode I is the most common load type encountered in engineering design and will be explained here in more detail.

The value of the stress intensity factor, K, is a function of the applied stress, the size and the position of the crack as well as the geometry of the solid piece where the cracks are detected, Fig. 2. The tensile stress in X and Y directions, and the shear stress in the X-Y plane can calculated in terms of K and position can be written as:

Mode-I

$$\sigma_y = \frac{K}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$
$$\sigma_x = \frac{K}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$
$$\tau_{xy} = \frac{K}{\sqrt{2\pi r}}\left(\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2}\right)$$

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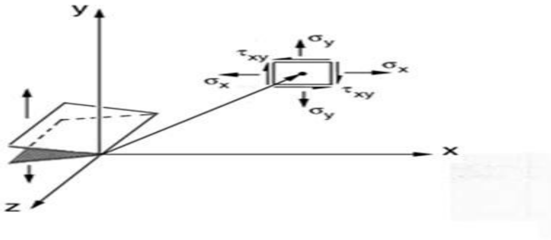

Mode-I

Fig. 2 Distribution of stresses in vicinity of crack tip

The stress concentration factor can also be found:

$$K_I = C\sqrt{\pi a},$$

Where

$$C = (1 - 0.1\eta^2 + 0.92\eta^4)\sqrt{1/\cos \pi\eta}$$

And $\eta = \frac{a}{b}$

III. PROBLEM FORMULATION

The problem is formulated for three dimensional analyses. For finding Stress Intensity Factor (SIF) parameter of the three dimensional crack problem (shown in fig. 3) ANSYS 13.0 is used as a tool of the solution.

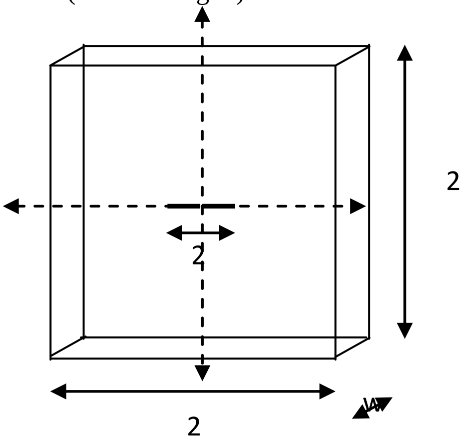

Fig. 3

Fig. 3 shows the three dimensional rectangular section with *b = 0.2 m*, central surface crack *a = 0.02m* subjected to constant pressure of *100 MPa* on y-axis. It is assumed that the three dimensional structure is made up of steel with Young's modulus as *200 GPa* .

Due to symmetry of the three dimensional crack analyses, the structure is divided in to four symmetrical parts dividing in the *xy plane* as shown in Fig 4.

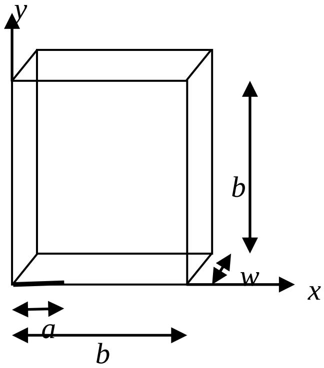

Fig. 4: One Fourth of the *3D-*

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IV. CONCLUSION

The main work presented here is to find analyze the crack intensity factor for the three dimensional structure. This is done with the help of the ANSYS Software, where the 3- dimensional analysis is done in the plane stress with thickness used in meshing process. Stress concentration factor (SFC) is obtained at crack tip of the crack with the Software.

The stress concentration factors obtain from the ANSYS 26.308. From the equations the stress concentration factor is found as 26.464, which is close to the result find from the ANSYS software. The difference between the theoretical and ANSYS value is as follows:

$$\epsilon = \frac{K_I^{Theoratical} - K_I^{ANSYS}}{K_I^{atheoratical}} \times 100 = \frac{26.464 - 26.308}{26.464}$$
$$= 0.59\%$$

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