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Computational Fracture Mechanics Analysis of Cold Rolled Mild Steel by CTOD Technique

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ABSTRACT

Recent research experimental studies indicated that the load-drop technique. Which can serve as a valid fracture criterion for predicting elastic plastic fracture for Cold rolled steel sheets. Which is in predominantly plane stress conditions. The purpose of this project is to examine the validity of a J -integral as a fracture parameter and the J –CTOD (CTOD-crack tip opening displacement)and generating probabilistic model for CRMS. A full 2-D finite element model was formulated to verify the critical load, critical CTOD and plastic-zone size. Linear Elastic Fracture Mechanics (LEFM) is valid as long as non-linear material behavior is confined to a small region surrounding the crack tip. In many situations, it is virtually impossible to characterize fracture behavior with LEFM; hence an alternate model is Elastic-Plastic Fracture Mechanics (EPFM).

In this paper a new method is presented to determine the crack-tip opening displacement (CTOD) for the center cracked plate with uniaxial uniform tension (CT) load by a using FEA analysis for elastic plastic fracture mechanics of cold rolled mild steel. The experimental test has been performed on cold rolled mild steel to find out the mechanical properties .This properties has been take for FEA analysis using ABAQUS. Meshing of FEA model is done in such a way that non Linear Elastic Plastic Fracture Mechanics model formulation converges to the solution.

Keywords— CTOD, FEA analysis, Linear Elastic Plastic Fracture Mechanics,CT Specimen.

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I. INTRODUCTION

Large structures made of thin sheet material can have large critical crack lengths. As a result, failure of these structures is frequently related to the development of large amounts of stable crack extension, which takes place under large scale yielding conditions. In such cases the application of the K-concept and the J-integral concept provides very limited results. For many materials stable crack propagation in thin wall structures takes place under plane stress conditions and its fracture surface shows a transition from normal fracture to slant fracture. Assessments of engineering structures with defects require convenient fracture parameters which quantify the damage processes occurring at the crack-tip.It is well known the concept of the J-integral and CTOD (crack-tip opening displacement) have been developed separately, and that they are widely used as important elastic–plastic fracture parameters in structural integrity assessments.

Several researchers have made attempts for the determination of the CTOD. Among them, Dug dale proposed a model which is widely used to estimate the values of CTOD. Liu [1] and his co-workers have suggested some guidelines to assess fracture criteria for thin and tough plates of structural materials. Further D M Kulkarni [2] et al 2004 has found the experimental technique for fracture criteria of sheet metals and he has examined the effect of the variation of thickness of such steel sheets on their fracture

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criteria.A new approach is suggested in his research for determining fracture criterion of thin sheets using load drop technique, which assists in detecting the physical event of crack initiation.

Beremin[3,4]proposed a model in which initiation of cleavage fracture could be characterized by local stress.This model has been widely used as cleavage fracture model. The present model incorporates micro-crack nucleation and propagation in a volume element and applies the weakest link mechanism to the volume elements in a process zone. The model was validated by the CTOD tests of a structural steel. That is the model can predict the distribution of fracture initiation points.

As well as that ofcritical CTOD values. This research has been carried out to find out to find out crack tip opening displacement (CTOD) of cold rolled mild steel by using FEA analysis on commercial software. The good agreement between theoretical and experimental values has been found on a CT specimen.

II. BACKGROUND

Linear elastic fracture mechanics (LEFM) is valid only as long as nonlinear material deformation is confined to a small region surrounding the crack tip. In many materials, it is virtually impossible to characterize the fracture behavior with LEFM, and an alternative fracture mechanics model is required.

Elastic-plastic fracture mechanics applies to materials that exhibit time-independent, nonlinear behavior (i.e., plastic deformation). Two elastic-plastic parameters are introduced in this chapter: the crack-tip-opening displacement (CTOD) and the J contour integral. Both parameters describe crack-tip conditions in elastic-plastic materials, and each can be used as a fracture criterion. Critical values of CTOD or J give nearly size-independent measures of fracture toughness, even for relatively large amounts of crack-tip plasticity. There are limits to the applicability of J and CTOD, but these limits are much less restrictive than the validity requirements of LEFM.

A. Crack Tip Opening Displacement

The Crack Tip Opening Displacement or CTOD Test measures the resistance of a material to the propagation of a crack. CTOD is used on materials that can show some plastic deformation before failure occurs causing the tip to stretch open. Accurate measurement of this displacement is one of the essentials of the test.There are a number of alternative definitions of CTOD. The two most common definitions, which are illustrated in Figure, are the displacement at the original crack tip and the 90° intercept.Most laboratory measurements of CTOD have been made on edge-cracked specimens loaded in three-point bending.

The CTOD fracture parameter provides a relatively simple method by extending the fracture mechanics concepts from the plane-strain linear elastic fracture behaviour to the elastic–plastic fracture behaviour. So the CTOD criterion is used as a vital engineering tool, the critical value of which dc has been applied extensively to predict the onset of crack initiation. Hence it is important to determine the value of CTOD δ which is compared to δc to assess the safety state of cracked component in practice.

Early experiments used a flat paddle-shaped gage that was inserted into the crack,as the crack opened, the paddle gage rotated, and an electronic signal was sent to an x -y plotter. This method was inaccurate, however, because it was difficult to reach the crack tip with the paddle gage. Today, the displacement V at the crack mouth is measured, and the CTOD is inferred by assuming the specimen halves are rigid and rotate about a hinge point shown in Fig 1.We can estimate CTOD from a similar trianglesconstruction.

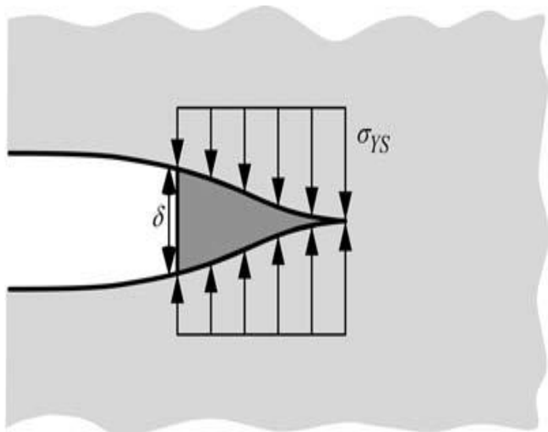

Fig. 1 Crack Stress Distribution

B. Material

The specimens were taken for analysis is Cold rolled mid steel which is being heavily used in industry. The young’s modulus of cold rolled mild steel is 155 GPa and nominal tensile strength of material is 250 MPa. Composition of material is as shown in Table I.

TABLE I

COMPOSITION OF MATERIAL

Chemical constituents	C%	Mn%	P%	S%	Al%
	0.1	0.6	0.03	0.035	.01

C. Tensile test

To analyse the model in the Elastic plastic fracture mechanics (EPFM) it is necessary to find plastic strains hence tensile test was carried out for Cold rolled mild steel. Following are the results of tensile test.

TABLE II

PROPERTIES OF CRMS

Properties	Young's Modules (MPA)	Elongation
	155 GPa	30

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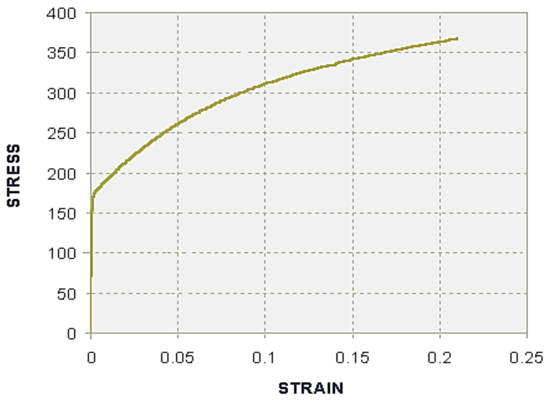

Fig.2 Stress v/s strain graph for CRMS.

III. FEA FORMULATION

The CTOD test specimens were modelled by Two-dimensional elastic-plastic finite element (FE) analysis, using Abaqus 6.10. Because of the symmetry, 1/2 of the specimen was modelled. Crack tip of the fatigue crack was modelled by 5μm radius semicircle. Minimum element size was 0.1 mm.

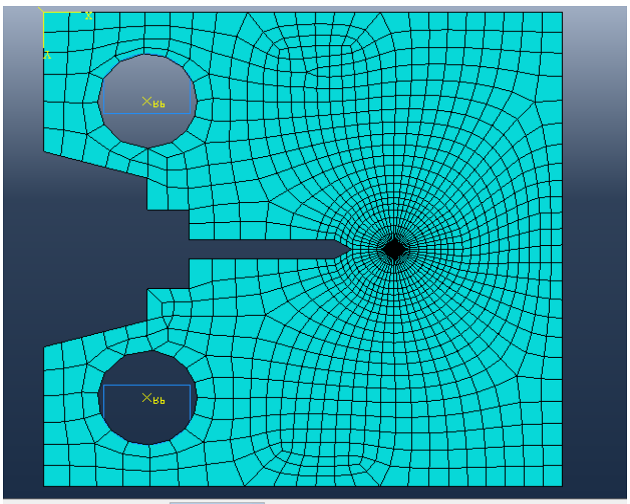
Fig 3 Mesh model of CT Specimen

The element was defined by using 20 nodes having 2 degrees of freedom per node and translations in x, y directions as shown in fig. Meshing was graded from fine at the crack tip to coarse at the solid boundary. The most important region ina fracture model is the region around the edge of the crack. Element size that ranges from 0.035% to 0.060% of the absolute crack length is considered around the crack tip. A triangular wedge-shaped element is formed by collapsing the top plane of a Quad element along the surface diagonal. The elements with multiple nodes are arranged along different radial lines around the crack tip. These elements arequadratic in behaviour. The mid nodes of the elements in the first radial line are placed at the quarter positions to produce the appropriate 1/γ singularity as the limit of the plasticity is approached

The elastic-plastic process requires continuous assessment of stress and plastic strain at all points of the structure, as the applied load increases. Hence the load is applied in a sequence of relatively small increments, and within each step a check on stress and equilibrium is made. As loading starts, the program starts to iterate the stress above the yield stress to consider the plastic effects. The whole nonlinear curve is considered to consist of a number of straight lines, each being designated as a load step.

IV. RESULTS AND DISCUSSION

A. FEA Results

FEA analysis gives the results of J –integral for different 3 no of contours .The average J integral for a particular time steps is calculated. J-integral has been calculated for different contours along the stress intensity over cracked specimen. CTOD of the CT specimen of Cold rolled specimen has been calculated from the relationship from J-integral.

The values of CTOD for a three contours have been tabulated. The average value of CTOD has been taken after 1 second step of analysis. The distribution of Von-Misses stress is shown in fig 4,which illustrates stress intensity is higher near the crack tip and plastic zone is easily detected.

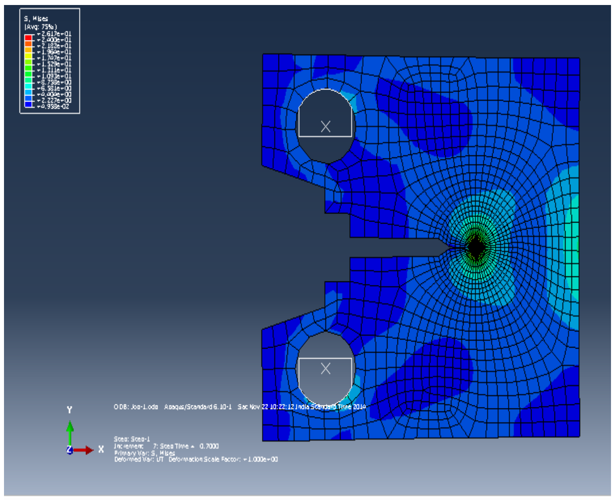
Fig 4 Distribution of Von-Misses Stress in a CT Specimen

The Graph shows the CTOD of a single contour over I second time interval step and for 1 mm travel of pins in up-word direction. The Last value is taken as CTOD of material.

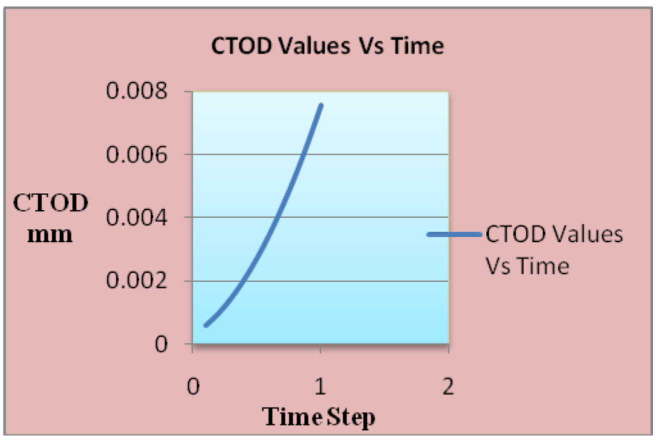

Fig.5CTOD Versus Time step

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B. Experimental Results

Experimental analysis is done on Cold Rolled Mild Steel.Following are the results obtained from experiment.

TABLE III

EXPERIMENTAL RESULTES

EXPERIMENTAL RESULTES		
Sr No	**Rp**	**CTOD**
1	0.002055	0.5
2	0.005681	0.89
3	0.012797	1.37
4	0.025036	1.78
5	0.044514	1.38

From FEA and Experimental results we can compare the results.

TABLE IV

COMPARISION OF FEA AND EXPERIMENTAL RESULTES

Method	**FEA**	**Experimental**
Sr No	**CTOD**	**CTOD**
1	1.273	1.3
2	1.2	1.25
3	1.459087	1.37
4	1.6	1.78
5	1.7	1.9

V. CONCLUSION

The paper focuses on the estimation method of CTOD. The 2-D elastic–plastic finite element analysis is employed to quantify the CTOD for a centre cracked plate subjected to uniaxial tension stress for cold rolled mild steel. CTOD Values shows good agreement with experimental values that has been predicted in literature. The future analysis has to be carried out to predict the probabilistic model for CRMS.

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