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Experimental and Computational Analysis of Fracture Toughness Parameters & Crack Growth Initiation of Pressure Vessel Material Used in Disc Shaped Compact Tension Specimen

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ABSTRACT

Stress intensity factor (K), J-Integral & Crack tip opening displacement (CTOD) is used in fracture mechanics to more accurately predict the stress state near the tip of a crack caused by an inaccessible load or residual stresses. The present paper describes to evaluate critical stress intensity factor of disc shaped compact specimen DC(T) which have crack/width ratio suggested by ASTM E-399 for pressure vessels materials IS 2062 and SA 516 Gr-70 with different thickness. Simultaneously the experimental results has been examined by numerical simulation of disc shaped compact specimen using ANSYS with Westerguard method to find stress intensity factor for each case. A comparison with an Experimental Vs Computational investigation on disc shape compact tension specimen suggests the validation of both the results.

KEYWORDS : critical stress intensity factor (K) for plane-strain, critical length of crack (a).

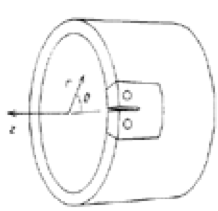
1. INTRODUCTION

There are many components of mechanical machines, industrial process plants and household appliances that fail through overloading improper utilities. Tradition failure criteria cannot adequately explained many structural failures that occur at stress level consider lower than the ultimate strength of the material e.g. bridges, tanks, pipes, weapons, ships, railways and aerospace structures. Some of these failures occur due to deficiency of constructions, but many due to material deficiencies in the form of pre-existing flaws that initiates cracks and thus caused fracture. If the crack reaches the certain size and is subjected to highly strained region which are regarded as potential cause of failure [1].

Fracture mechanics is based on the implicit assumption that there exists a crack in a work component. The crack is artificially prepared in different shapes i.e. a hole, a notch, a slot, a re-entrant corner etc. Use of fracture mechanics analysis and data has explained many service fracture failures with a satisfactory degree of quantitative accuracy. By studying the possibilities for such fractures in advance and effective fracture control plans have been developed [1].

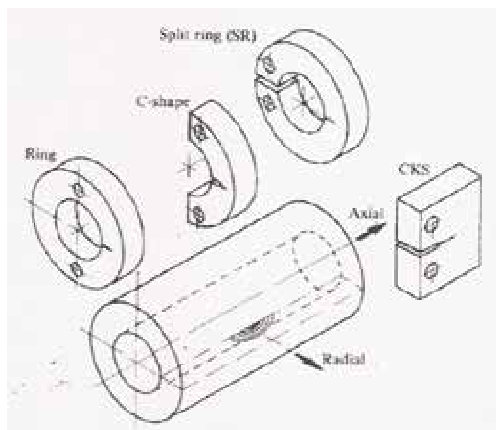
2. LITERATURE REVIEW

Evans et al. [2] described a method of testing cylinder wall material based on the compact tension specimen design.



Some examples of tests on specimens taken from an aluminium alloy cylinder were given. The Fracture of the specimen simulates crack extension along the axis of the cylinder driven, for example, by the hoop stress in a pressure vessel wall in fig.2.1

Webster et al. [3] (2007) investigated the failure of thick walled tubing subjected to internal pressure. Thick-walled tubing is used for variety of applications in the chemical, nuclear and armaments industries where high internal pressure has to be withstood. If this pressure is cyclic, initiation and propagation of cracks by fatigue may take place with the ultimate risk of failure by fast fracture. Usually fatigue crack in thick walled cylinders initiate at the bore and propagate in a radial plane in the manner illustrated in Fig. 2.2



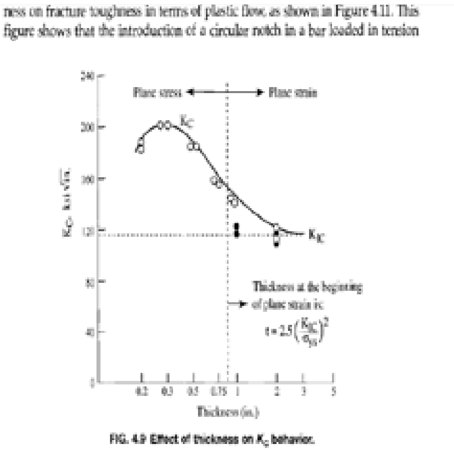
[4] Fig 2.3 Strain gauge positions on C-shaped specimen

The important conclusion of their work was that in the pin-loaded C-shaped specimen the strains on the inner surface are related to crack depth only for very shallow crack depths and the strains on the outer surface directly in front of the crack line, are related to crack depth and may be used as an indicator of crack growth.

3. EXPERIMENTAL METHODOLOGY

Stress intensity factors are a function of load, crack size and geometry. The critical stress-intensity factor, K_c at which unstable crack growth occurs for conditions of static loading at a particular temperature actually depends on specimen thickness or constraint as shown in fig.3.1.

The experiments should be controlled so as to have its loading in plane strain only; that is, the plastic zone size in front of the crack tip is quite small in comparison to the specimen thickness. Then the linear elastic fracture mechanics can be applied to analysis. The entire body of this assumed to be elastically.



3.1 K_{Ic} Test Set-up:

1. Determine critical specimen size dimensions.

$$a = \text{crack depth} \geq 2.5\left(\frac{K_{Ic}}{\sigma_{ys}}\right)^2$$

$$B = \text{specimen thickness} \geq 2.5\left(\frac{K_{Ic}}{\sigma_{ys}}\right)^2$$

$$W = \text{specimen depth} \geq 5.0\left(\frac{K_{Ic}}{\sigma_{ys}}\right)^2$$

2. Select a test specimen:

A variety of fatigue-cracked test specimens can be used to determine the plain-strain fracture toughness (K_{Ic}) of metallic materials as described in ASTM Specification E-399.

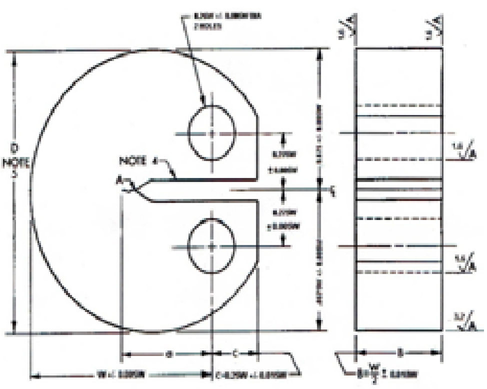


fig 3.2 Disc shaped compact DC[T] specimen

In the experimental work, the disc shaped specimen is selected and total 8 specimens are fabricated having thickness of 12mm, 16mm, 18mm and 20mm respectively of IS-2062 and SA-516 GR-70 materials.

3. Fatigue-crack the test specimen.

A fatigue crack is considered to be the sharpest crack that can be reproduced in the laboratory; the machine notch is extended by fatigue. The initial machined crack length, a, should be 0.45 so that the crack can be extended by fatigue to approximately 0.05W.

3.2 K_{Ic} Test Procedure:

I. The specimen is prepared following several dimensional constrains which are based on the guessed value of K_{1C}. The crack tip is made very sharp with a fatigue growth.

II. The specimen is pulled in a tensile machine to obtain a relation between a load and a crack mouth opening displacement. This relation provides the critical load P_Q.

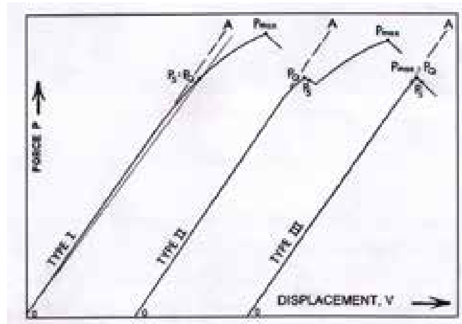


Fig.3.3 Force vs. Load-line Displacement Curve

III. Accounting for the crack length and geometry of specimen the stress intensity factor K_Q corresponding to P_Q is determined using LEFM.

IV. If K_Q satisfies all the constraints on the geometry of the specimen and of, fatigue growth, it becomes K_{1C}. Critical stress intensity factor indicates the upper limit of SIF which can be allowed in the component.

4. Computational analysis of Critical Stress Intensity Factor

In the present study 3D FE analysis of disc shaped compact specimen is carried out to complete the Y component of stress intensity factor solution for SA516 Gr-70 and IS-2062 material. By looking at the symmetry of FE model, conditions only half the component tension specimen was modelled in 3D.

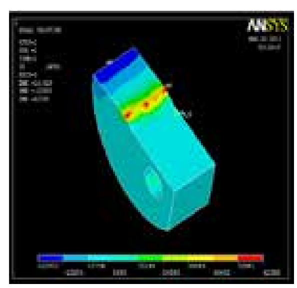


Fig. 4.1 obtained results of FE analysis in plot results window

After getting stress Westergaard method will be employed to find the critical stress intensity factor.

CONCLUSIONS

In this work, critical stress intensity factor has been found experimentally for pressure vessel steel IS2062 and SA516 Gr.70. using disc shaped tension specimen as suggested in ASTM E399. Variation of critical stress intensity factor with thickness of specimen will be studied by compared with the numerical value from the ANSYS. The important points of the present work are summarised as under:

(1) For SA516 Gr-70 material as thickness increases stress intensity factor increases except for 20 mm thickness. The similar thing would found out for IS 2062 material.

(2) For both the materials SA516 Gr-70 and IS-2062, 18mm thickness materials give the lower percentage deviation of critical stress intensity factors.

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