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Mixed Mode Characterisation of Fracture Toughness

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ABSTRACT

The applications of fracture mechanics have traditionally concentrated on crack growth problems under an opening or mode I mechanism. However, many service failures occur from growth of cracks subjected to mixed mode loadings. This paper reviews the various criteria and parameters proposed in the literature for predictions of mixed mode crack growth directions. The physical basis and limitations for each criterion are briefly reviewed.

Keywords : Mixed-Mode Fracture, ASTM, E1820, CTOD

I. INTRODUCTION

In actual practice, all components and structures will have crack irrespective of the material they are made of. The discontinuity or defect may be manmade such as a notch, a hole, a re-entrant corner etc., or it may already exist within a component due to manufacturing defects like slag inclusion, welding procedure, etc. In all these cases, the designer wants to know about the possibility of the crack to grow further before allowing them to continue in their service. It is here we seek the aid of what is called Fracture Mechanics that plays an important role in designing the components and structures and evaluating their life. It also helps in finding the upper limit of the load applied on a component for which the dimensions, location and orientation of the crack and loads are given.

II. METHODS AND MATERIAL

A. Literature Review

Gdoutos and Zacharapoulos (1987) have made a combined theoretical and experimental study of crack growth in a plate subjected to unsymmetrical three-point bending. They have determined opening mode $K_{\surd}$ and sliding mode K_{II}, stress intensity factors describing the local stress field around the crack tip by a finite-element computer program. They have analyzed the crack growth by the maximum circumferential stress and the minimum strain energy density criteria. They stated that the experimental results were in accordance with the theoretical predictions.

Kamat and Hirth (1996a) have evaluated the mixed mode I/II fracture toughnesses of two .They have used a modified compact tension type specimen and have tested in mixed-mode pattern. They have stated that these curves indicated trends with increasing Mode II loading since the Mode II/Mode I loading ratio increases as increases. They have also shown that the total fracture toughness under mixed mode I/II loading.

Sha and Yang (1988) have proposed weight function technique to calculate mixed mode stress intensity factors of the three-point bend specimen under test conditions of either loading or support eccentricity. They have detailed the effect of eccentricity on K_I and K_{II} values for three-point bend specimens. They have also proposed a method of obtaining the required stress-intensity factors of asymmetric crack geometry under the constraint conditions.

ASTM 1820-99a Standard Test Method for Measurement of Fracture Toughness method covers procedures and guidelines for the determination of fracture toughness of metallic materials using the following parameters: K, J, and CTOD (δ). Toughness can be measured in the R-curve format or as a point

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value. The fracture toughness determined in accordance with this test method is for the opening mode (Mode I) of loading.

E 399 – 90 (Reapproved 1997) Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials. This standard is issued under the fixed designation E 399; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision.

B. Mixed Mode

Mixed-mode fracture is a case where two or more modes are combined so as to produce a different effect on the behaviour of the material. Though, the majority of fracture mechanics studies on the toughness of engineering materials have been performed under tensile loading, recently the research on mixed-mode has gained insight. Mode I fracture is the most occurring one and many researchers have worked on it. However, random cracks are also developed and they may lead to failure in different orientation other than those.

This type of cracks must be studied with the insights gained from the literature available on mixed-mode. Though number of studies is available on situations where Mode I and Mode II type fractures are acting together, there is ambiguity in the explanation of the effect of Mode II and III on combined mode or mixed-mode. The effect of mode I decrease with increasing the crack distance to interface. It has been investigated and quantified fracture toughness in Mode I and Mode III loading conditions, and they have demonstrated that fracture toughness in Mode I is highly dependent on the mode-mixity.

Moreover, addition of Mode III to the system does not affect the critical fracture criterion. Under shear force, cracks tend to propagate in Mode I, Mode II and Mode III configuration as shown in figure 1. There were many attempts to apply fracture mechanics concepts to study mixed-mode failure and crack propagation by many researchers.

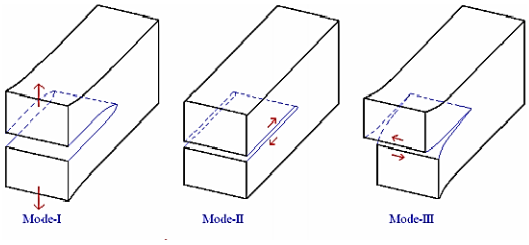


Figure 1

C. Importance of Mixed-Mode Fracture

The power of fracture mechanics really lies in the fact that local crack tip phenomena can be characterized by relatively easily measured parameters, e.g. crack length and nominal global stress (calculated in the absence of the crack), together with finite geometry correction factors. Use of fracture mechanics in engineering critical assessment of defects has been codified in documents like British Standards (BS PD 6493, 1991) and American standards ASTM E399 (2005) and ASTM E1820(2001).

The fracture mechanics approach allows us to design and select materials while taking the presence of flaws into consideration. There are three variables to be considered while designing a component in fracture mechanics point of view: the elastic property of the material, the stress that the material must withstand, and the size of the flaw.

III. EXPERIMENTAL PROCEDURE AND RESULTS

In the present research the three-point bend specimen with asymmetrical crack is introduced and investigated for the study of mixed-mode crack growth. The symmetrical three-point bend cracked specimen has been used extensively in fracture-mechanics studies. It is one of the standard specimens used in the ASTM codes for determining the fracture toughness. The mixed-mode bend specimen has not been studied as much as the symmetrical case i.e. a centre loaded specimen in the literature. The specimen taken for this case was of dimensions 200 x 25 x 12 mm. The specimen drawing is shown in Figure 2. Then all the specimens were precracked for a/W=0.5. Then all the specimens were loaded with varying eccentricity. The list of specimens with loading conditions is given in Table 1

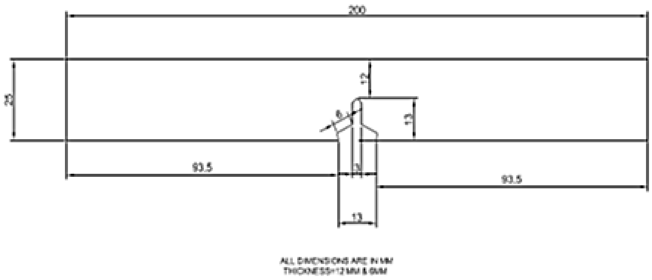
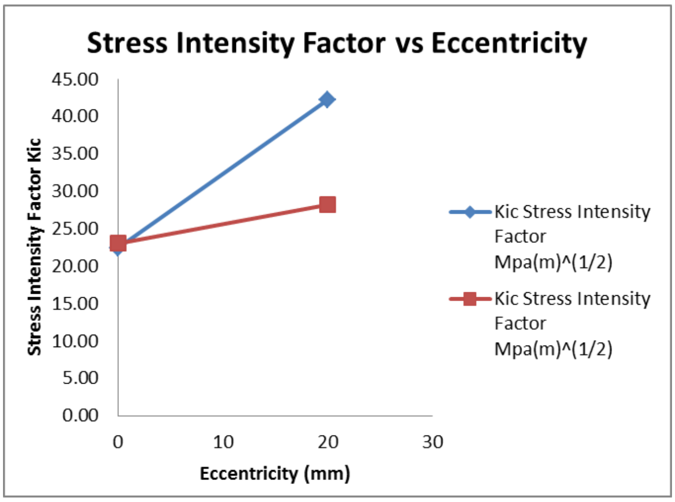


Figure 2

Table 1			
Specimen No.	**Eccentricity (mm)**	**Load (KN)**	**SIF K_{Ic} MPa√m**
Al 6101			
1	0	4.16	22.42
2	20	7.83	42.20
Al 6351			
1	0	4.27	23.01
2	20	5.23	28.19

The graph shows Critical stress intensity factor values versus eccentricity distance



IV. CONCLUSION

This paper focuses on analysing new methods of characterizing mode-mixity using bend specimens. The work involves determination of mixed-mode fracture toughness and other related parameters experimentally using bend specimens of Aluminium alloys. The mixed-mode (I/II) stress field arises in bend specimens when they are subjected to loads at a distance from the crack location. They are tested like a usual mode I testing using unloading compliance method and the exact crack length was determined using an effective modulus technique. The Aluminium alloys 6101 and 6351 are characterized in mode I/II. The fracture toughness is found to increase with the eccentricity and mainly related to the resistance to bending. Such an increase in fracture toughness in Aluminium 6101 alloy is steep against eccentricity in loading, while the increase in fracture toughness in Aluminium 6351 was marginal.

V. REFERENCES

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