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INVESTIGATION OF MIXED MODE I/II FRACTURE PROPERTIES OF SE(B) SPECIMENS OF ALUMINUM ALLOYS SUBJECTED TO ASSYMENTRIC THREE-POINT BENDING

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Abstract

This work is on investigating the mixed mode fracture behavior of bend specimens with single edge cracks. The materials chosen are Aluminum 5083 and 7075 grades. The principle of this test method is based on loading at an inclined line from the crack tip so that the crack is made to grow in a Mixed-mode I/II.

Unloading compliance technique is used to determine mixed mode J-resistance curves for SE (B) fracture specimens. Laboratory testing of 5083 and 7075 grade aluminum alloys at room temperature using SE(B) specimens with eccentric loads provide the load–displacement data needed to estimate the mixed mode crack growth resistance curve for the material. The results presented here produce a representative set of fracture toughness for mixed mode SE(B). The specimen is modeled in ANSYS 10.0. The results obtained from Finite Element Analysis are compared with that of the experimental results.

Keywords: Mixed mode, Stress intensity factor, Shear mode, Fracture toughness

Introduction

Over the past many years, considerable research work is devoted to fracture mechanics under the principle of mode I(opening mode). But in many practical situations, loading is applied in the direction inclined to the crack faces, giving rise to mixed-mode fracture. Hence, one needs to characterize the crack under mixed-mode loading.

Conventional testing programs [1-8] to measure fracture toughness routinely employ three-point bend, SE(B), or compact, C(T), specimens in pure mode I. But, very little work has been done in mixed mode category, like Kamat and Hirth [6].

The problem of characterizing the mixed-mode I/III fracture toughness of the two dimensional plate problem with an initial precrack is unique and have not been addressed earlier. Here, the experiment is done by keeping the load inclined at an angle to the crack face is unique. Although the specimen in this study has simple geometry and loading, the orientation of the load gives rise to mixed-mode I/III deformation on the crack lips that is tensile mode and shear mode.

Experimentation

Analytical efforts to support the development of laboratory measurements for fracture toughness resistance data have focused primarily on the load displacement data based upon testing of a single specimen. Implementation of the method essentially follows from determining the instantaneous value of the specimen compliance at partial unloading during the measurement of the load vs. displacement curve as illustrated in Fig. 1; here, the specimen response is defined in terms of load–load-line displacement (LLD) data or load-crack mouth opening displacement (CMOD). The technique then enables accurate estimations of K and critical stress intensity factor, K_{Ic} at several locations on the load–displacement records from which the SIF, K can be developed.

Before deriving the quantities and parameters needed to determine the crack growth resistance curves for the SE (B) specimens, this section first provides an overview of the nature of the procedure.

For the SE(B) specimen, parameter K_i is evaluated at the current load, P_i, as

$$K_{(i)} = \left[\frac{P_i S}{B W^{\frac{3}{2}}} \right] f\left(a_i / W\right)$$

where $f\left(a_i / W\right)$ defines a nondimensional stress intensity factor dependent upon specimen geometry, crack size and loading condition (pin-loaded vs. clamped ends). For the SE(B) specimens analyzed here, ASTM E1820 [9] provides analytical expressions for the nondimensional stress intensity factors $f\left(a_i / W\right)$.

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A_{pl}	plastic area under the load vs. LLD or load vs. CMOD
a	crack length
Δa	crack extension
a_0	initial crack length
a/W	crack length to width ratio
B	specimen thickness
B_N	net specimen thickness
b	remaining ligament
b_0	initial remaining ligament
C	specimen compliance
CMOD	crack mouth opening displacement
C(T)	compact specimen
E	longitudinal elastic modulus
$E = E(1-\nu^2)$	longitudinal elastic modulus in-plane strain
$f(a_i/W)$	nondimensional stress intensity factor
K_I	stress intensity factor
K_{Ic}	critical stress intensity factor or fracture toughness
LLD	load-line displacement
M	nondimensional deformation limit
P	applied load
SE(B)	single-edge notch specimen under bending
SIF	Stress Intensity Factor
W	specimen width
σ_Y	effective yield stress (mean value between yield stress and
ν	Poisson's ratio
e	eccentricity, mm

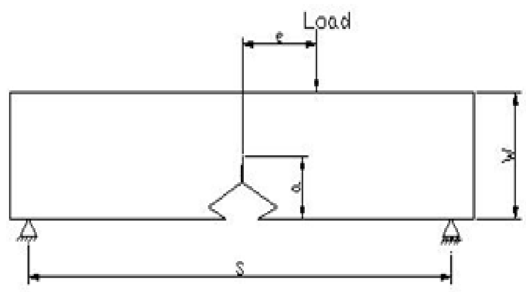
Mixed mode fracture testing on SE(B) specimens

In the present research the three-point bend specimen with an inclined loading is introduced and investigated for the study of mixed-mode crack growth. A similar type of specimen is analyzed by Sha and Yang [11].

The symmetrical three-point bend cracked specimen has been used extensively in fracture-mechanics studies for studying mode I fracture properties. It is one of the standard specimens used in the ASTM codes for determining the fracture toughness K_{Ic}. The mixed-mode bend specimen (where the load is inclined to the crack face), has not been studied as much as much as the symmetrical case i.e. a centre loaded specimen in the literature.

The specimen taken for this case was of dimensions 114.2 x 25.4 x 12.7 mm and all specimens were notched for mounting clip gauge. The specimen drawing is shown in fig. 1. Then all the specimens were precracked for a/W=0.5.

Fig. 1. SE(B) specimen with mixed mode loading



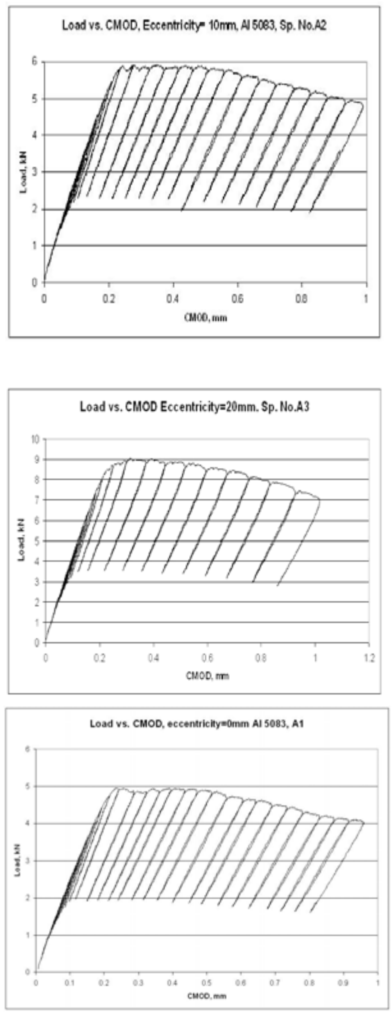
The purpose of this paper is to determine the critical stress intensity factor K_c under mixed mode. After precracking, the specimens were tested under inclined load as shown in fig.1. The load displacement plot of a sample specimen is shown in fig.2b. The sizes are span between the supports, S=100 mm, width, W=25.4 mm, thickness, B=12.54 mm and the precracked a/W ratio is kept at 0.5 for all specimens. The load eccentricity is set at e = 0, 10, 20, 30 and 45 mm. When the eccentricity e=0, the case is pure mode I.

The K_c tests are carried out on the specimens by loading unloading cycles to get a load-displacement plot as shown in fig. 2.

Results and Discussion

The load-displacement records of all the experiments are shown below. Now the critical stress intensity factors (K_{Ic} or K_{IIc}) can be readily determined from the ASTM E1820 guidelines[9]. First, the critical or peak loads are evaluated as per the ASTM E399 [10]. The estimated K_{Ic} values are listed in the table.

Fig 2. Load vs displacement plot of Al 5083 for different load eccentricity distances(e=0, 10, 20, 30, 40 mm for the specimen numbers A1, A2, A3, A4, A5 respectively)



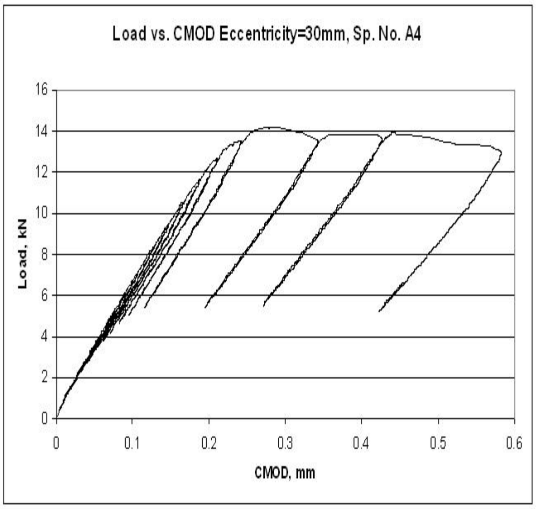
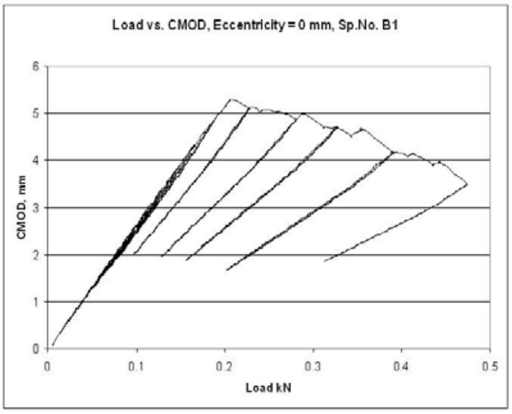
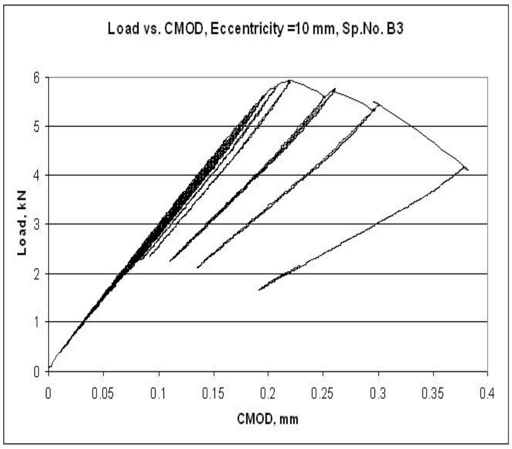
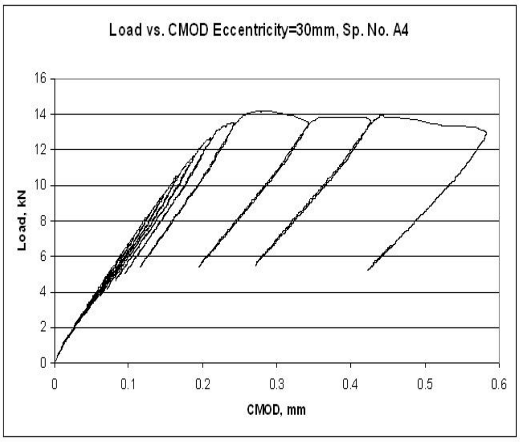
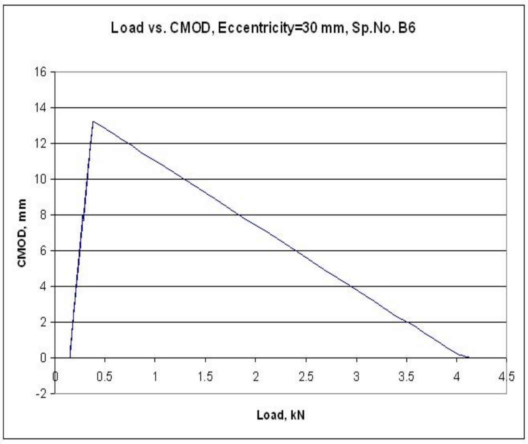


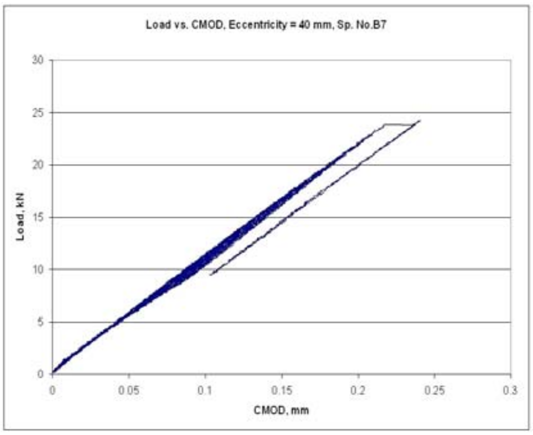
Fig 3. Load vs CMOD plot of Al 7075 for different load eccentricity distances(e=0, 10, 20, 30, 40 mm for the specimen numbers B1, B3, B4, B6, B7 respectively)











The stress intensity factor and fracture toughness can be evaluated from the formula The fracture toughness as stipulated by ASTM E 1820 [9] for different load eccentricity values are given below.

Fig. 4. Fracture toughness K_{Ic} vs eccentricity of Al 5083

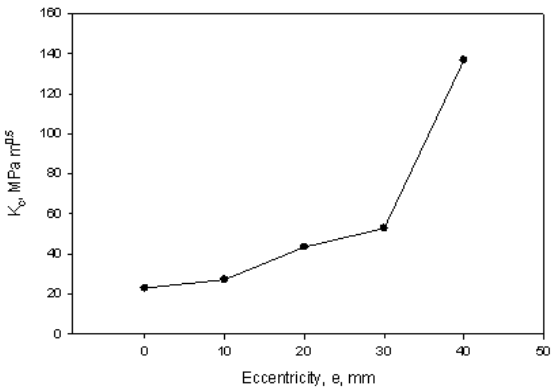
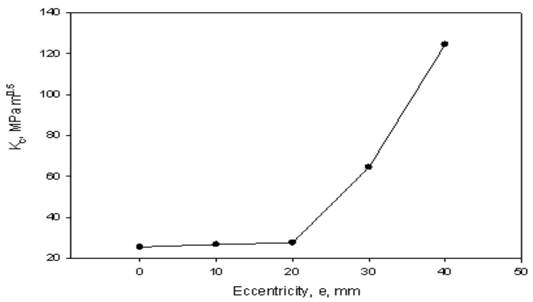


Fig. 5. Fracture toughness K_{Ic} vs eccentricity of Al 7075



Finite element analysis

Finite element analyses (FEA) of the specimens were performed in order to determine the J-integral for different loading conditions, geometries, and material properties. The FEA results are compared to the J-integral determination using the experiments as explained above. 2D finite element models of the SE (B) specimens were constructed using isoparametric 8 noded elements (PLANE 82) using the commercial finite element program ANSYS 10.0.

The specimen is modeled as a plane stress element with the thickness input. The model is meshed with quadratic elements. The area near the crack tip is fine-meshed with the element size in the order of 2-3 microns. The meshed model is shown in fig. 7. The two zoomed views are shown in the inner figures. The total number of nodes and elements are 29613 and 9742 respectively. The inner most mesh has an element edge length in the order of 3e-3mm.

Fig. 6. Comparison of Load vs Stress intensity factor of Experimental and Numerical data

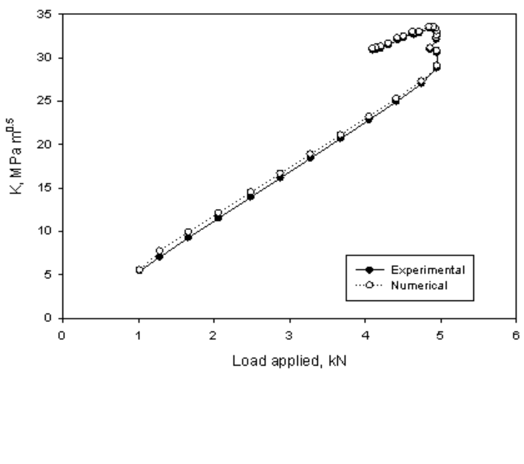
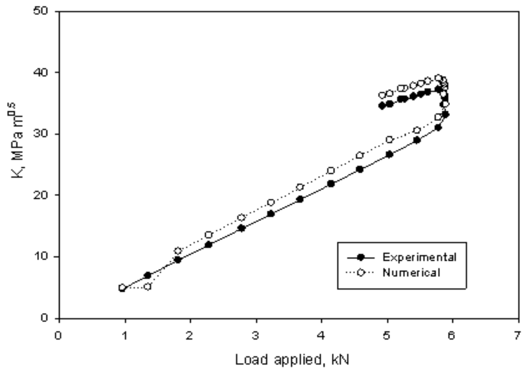


Fig. 7. Comparison of Load vs Stress intensity factor of Experimental and Numerical data



Conclusion

The following are the conclusions made in this research work.

1. The mixed mode fracture toughness of the Al 5083 material increases as the load eccentricity increases. But the toughness of Al 7075 is almost a constant upto the eccentricity e=20mm, and after that the toughness increases with eccentricity.
2. The mixed mode stress intensity factor obtained numerically has good agreement with the experimental results for both the materials (Al 5083 and Al 7075).
3. The maximum load withstood by Al 7075 is more than Al 5083 though the former behaves relatively brittle in the plastic region when compared to the latter.

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