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I. INTRODUCTION

This note presents fracture toughness data obtained during the development of a fracture testing procedure for use in alloy development programs in the authors' laboratory and includes data on several plastics, an alloy steel, and an aluminum alloy. These results are reported to illustrate the use of dimensionless parameters in measuring fracture toughness. In addition, it is considered desirable to report these results to add additional confirmation to fracture toughness testing procedures and thus aid their more universal acceptance.

II. EXPERIMENTAL

The fracture specimen design chosen for testing is shown in Fig. 1; this specimen was chosen for its small load requirement, economy of material, and the good agreement between fracture data obtained with it and with other fracture specimens.[1] It is recognized that this specimen may not give valid plane strain fracture toughness values for all materials, especially those exhibiting large plastic flow at the crack tip. However, we consider that the specimen is useful for some studies, such as preliminary survey programs and programs involving the investigation of many variables with the reservation that larger specimens may be needed to establish accurate K_{Ic} values for design use or to confirm results obtained with the small specimen.

Fracture toughness was measured with this specimen by the experimental K-calibration method of Irwin and Kies.[2] This approach utilizes a general relation[2] between the strain energy release rate, G, in a specimen containing a crack and the change in elastic compliance as the crack propagates:

$$G = \frac{P^2}{2B}\frac{dc}{da} \qquad (1)$$

Here, P is the applied load, B is the specimen thickness, c is the specimen compliance (extension per unit load) and a is the crack length. This expression can be put in a more useful, dimensionless form in terms of the stress intensity factor, K, by using the relation

$$G = \frac{K^2\left(1 - \nu^2\right)}{E} \qquad (2)$$

for the case of plane strain. Thus,

$$\frac{2K^2\left(1 - \nu^2\right)}{\sigma^2 w} = \frac{d(EcB)}{d\left(\frac{a}{w}\right)} \qquad (3)$$

where w is the specimen width, σ is the applied stress, and ν and E are Poisson's ratio and Young's modulus respectively.

The right hand side of Eq. (3) was obtained experimentally by measuring the compliance of specimens with narrow machined slots of various lengths. Specimens with the loading holes at both the w/2 position (tension) and the w/3 position (tension plus bending) were calibrated. For the w/3 position, specimens were machined from polystyrene and 4340 steel (austenitized at 850°C, 30 minutes; oil quenched; tempered 225°C, 2 + 1-1/2 hours); for the w/2 position, acrylic specimens were prepared. The specimens were loaded in tension in a 5,000 kg Instron testing machine. The extension of the specimen between the loading points was measured with a strain gage extensometer. A dimensionless compliance term, EcB, was plotted as a function of relative slot length and a curve fitted to the results. This curve was differentiated to give the right-hand side of Eq. (3) and the results are shown in Figs. 2 and 3.

In order to check the calibration and testing procedure being used, the fracture toughness of 7075-T6 aluminum alloy was measured and compared to results in the literature (Table I). Additional values of fracture toughness have now been obtained using this procedure during current fracture studies and selected values are shown in Table II. These values of K_{Ic} were obtained either from pop-in type load displacement curves or from flat, abrupt type failures.

III. DISCUSSION

The dimensionless form of Equation (3) suggests that this equation is independent of specimen size and material properties. Experimentally, the results shown in Figures 2 and 3, which include data from the literature, show good agreement for materials with large differences in elastic moduli (steel, aluminum, and plastics). Theoretically, this independence of elastic modulus can be predicted from either the left-hand or right-hand side of Equation (3). Considering the left-hand side, only the stress intensity factor, K, can involve the elastic modulus. However, the stress intensity factor is derived from the stress field and the conditions for the independence of the stress field from the elastic constants has been discussed by Michell.[9] Specifically, Michell considers planar states of stress and shows that the stress field is independent of elastic properties for simply connected bodies. For multiply connected bodies, the stress field is independent of the modulus, but may depend upon Poisson's ratio, depending upon the boundary conditions. Thus, K, and hence the left-hand side of Equation (3) is independent of modulus, but may depend upon Poisson's ratio. Since the variations in Poisson's ratio for most materials is small, this effect is expected to be small, as shown in Figs. 2 and 3.

Alternately, the influence of specimen size and material properties on the right-hand side of Equation (3) can be investigated with dimensional analysis considerations. The quantity (cB) is expected to depend upon a, ν, E, w, and ℓ where ℓ is the specimen length. Accordingly, (cB) is expected to have the form:

$$(cB) = \frac{1}{E}\, f\left(\frac{\ell}{w}, \frac{a}{w}, \nu\right)$$

where $f\left(\frac{\ell}{w}, \frac{a}{w}, \nu\right)$ is an unknown function of the relative specimen dimensions and Poisson's ratio. This expression demonstrates that the right-hand side of Equation (3) is independent of modulus and specimen scale.

This independence of elastic modulus suggests that low modulus materials such as plastics would be useful in establishing calibration curves, since the displacements would be larger and more accurately measurable. This approach has been used by the authors with the acrylic and polystyrene specimens.

ACKNOWLEDGMENTS

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Table I

Comparison of specimen types for K_{Ic} measurements on 7075-T6 aluminum alloy

Specimen	K_{Ic} ksi $(in)^{1/2}$	Reference
1 × 2 SEN, w/3, 1/16 thick	40	this work
1 × 2 SEN, w/2, 1/16 thick	36	this work
1 × 2 SEN, w/2, 1/4 thick	41	8
3 × 12 SEN, w/2, 1/4 thick	38	8
3 × 12 CN	36.7	9
Notched round	38	9

Table II

Plane Strain Fracture Toughness

Material	Specimen	K_{Ic} ksi $(in)^{1/2}$
4340 steel[1]	1 × 2 SEN, 1/16 thick, w/3	75
Polycarbonate[2]	1 × 2 SEN, 1/4 thick, w/3	3.20
Polystyrene[2]	1 × 2 SEN, 1/8 thick, w/3	1.61
Acrylic[2]	1 × 2 SEN, 1/8 thick, w/3	0.99
Vinyl Chloride-Vinyl Acetate[2]	1 × 2 SEN, 1/8 thick, w/3	3.61

1. Austenitized at 850°C, 30 minutes; oil quenched; tempered at 225°C 2 hours; fatigue cracked; tempered at 225°C 1-1/2 hours. Yield strength 200 ksi.
2. Notch sharpened with a razor blade; notch radius less than 0.0005 in. Specimens conditioned at 23°C and 50 percent relative humidity in accordance with Procedure A of ASTM D618.

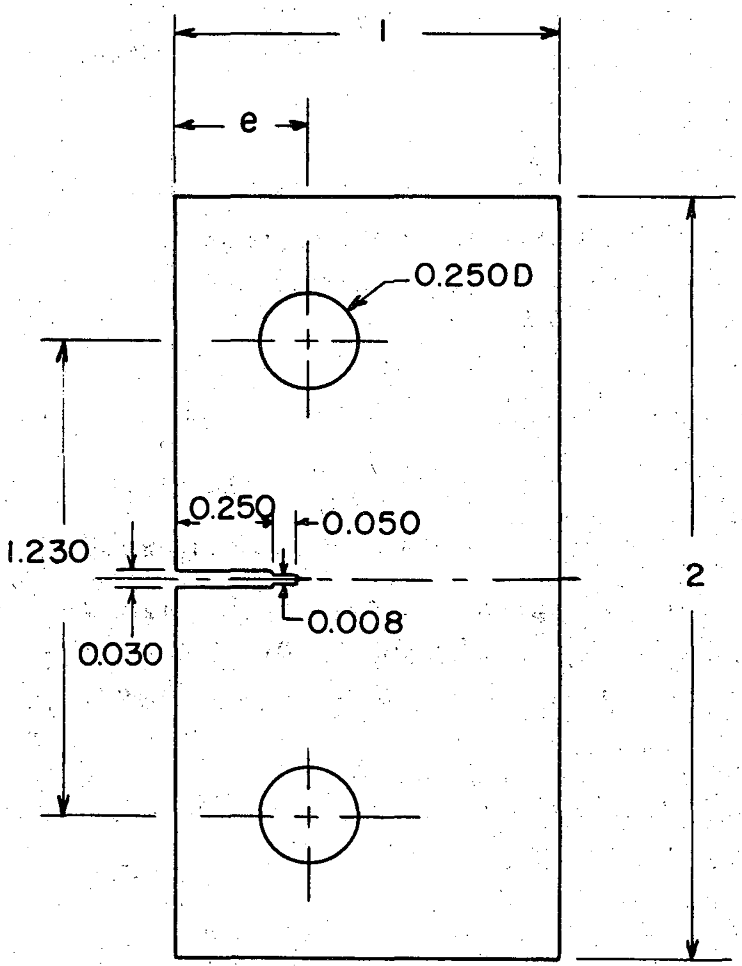

Fig. 1 Dimensions of Single Edge Notch Fracture Specimen.

1. Thickness: 1/16 to 1/4 inch
2. Eccentricity: e = 1/3 or 1/2 inch
3. Crack sharpened by fatigue (metals) or razor blade (plastics). Total crack length approximately 1/3 inch.

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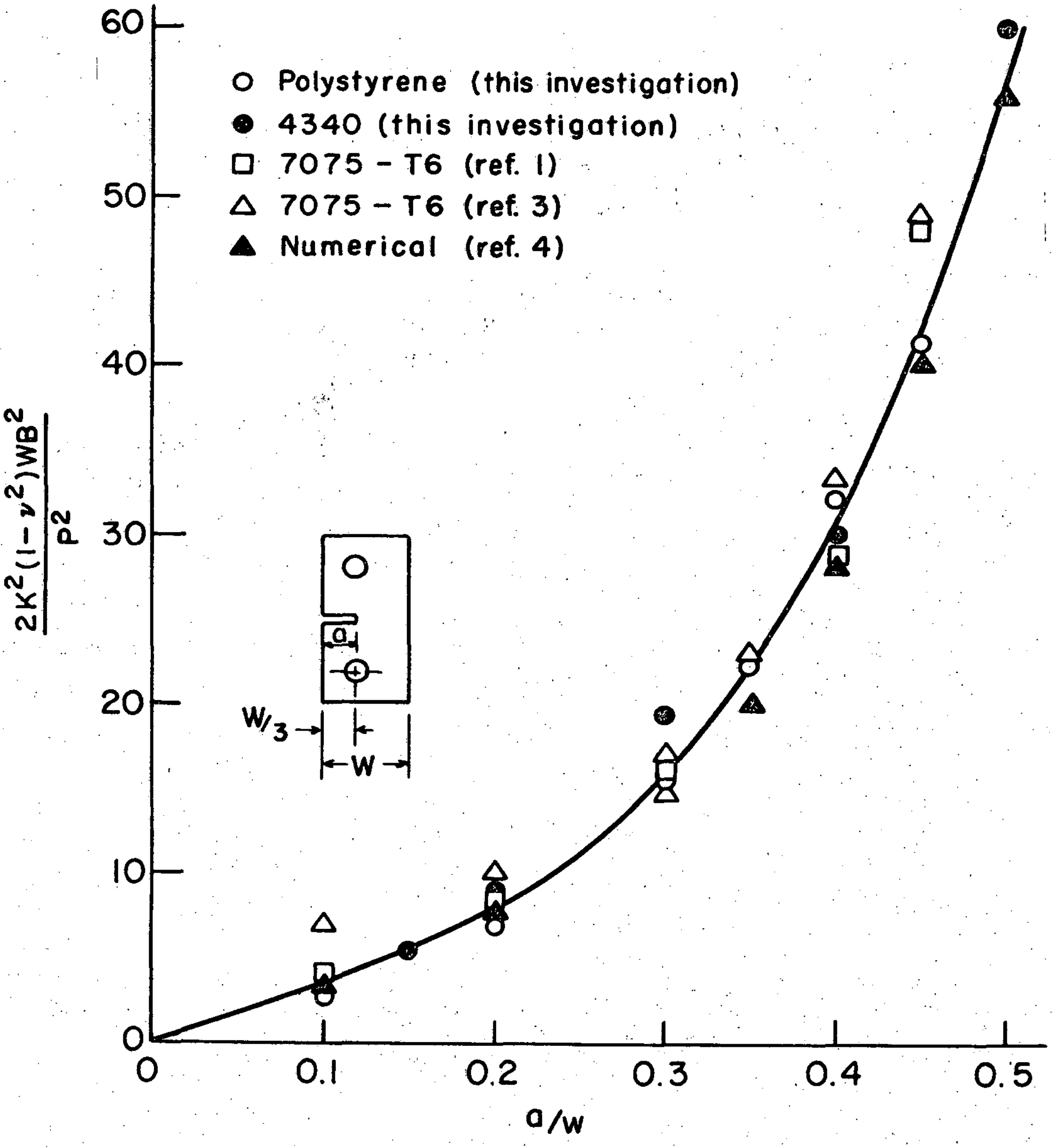

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Fig. 2 Dimensionless Fracture Toughness Parameter for Single Edge Notch Specimens (W/3).

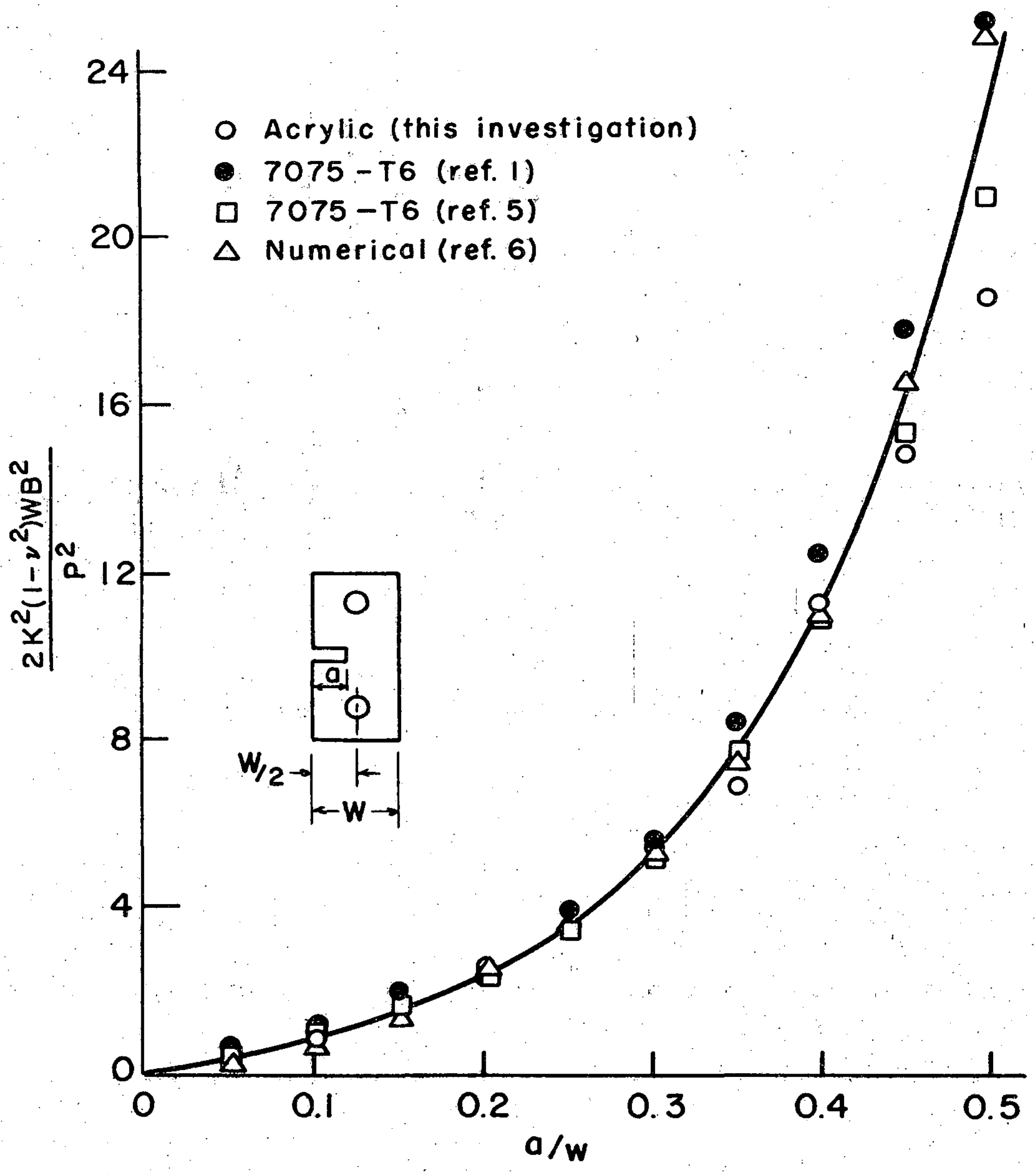

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Fig. 3 Dimensionless Fracture Toughness Parameter for Single Edge Notch Specimens (W/2).