A STUDY ON CHEVRON-NOTCHED SHORT ROD AND SHORT BAR FRACTURE TOUGHNESS SPECIMENS

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INTRODUCTION

Recently L.M. Barker[1,2] proposed a new type of fracture toughness specimen—chevron-notched short rod specimen (Fig. 1(a)) for plane strain fracture toughness K_{1c} test. This specimen has some advantages over the standard ones, such as: fatigue precracking and crack length measurement are not needed, the specimen is smaller and easier to prepare. Later on, the chevron notch was introduced into short bar specimen[3] (Fig. 1(b)), three point bend specimen[4,5] and four point bend specimen[6]. This paper discusses the criterion for stable crack extension in chevron-notched short rod specimen, suggestions on choice of desirable loading manner and specimen

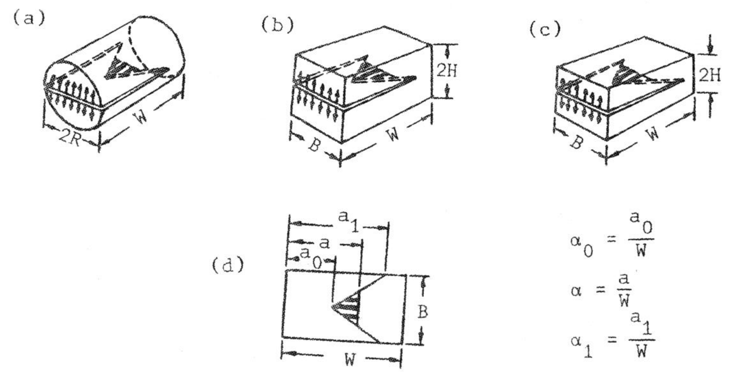

Fig.1 Chevron-notched specimens (a) short rod; (b) short bar (square); (c) short bar (rectangular); (d) chevron notch plane section.

parameters are presented, formulas of critical SIF coefficient are obtained through curve fitting and tested results of K_{1c} for three metallic materials using short rod and short bar specimens are given.

CRITERION OF STABLE CRACK EXTENSION FOR CHEVRON-NOTCHED SPECIMEN

In ehevron-notched specimen, crack is formed under test loading, particularly for brittle materials, because of its initial stable crack extension. The present authors[7] proved that under controlled load condition, the criterion of stable crack extension for chevron-notched specimen is:

$$\frac{dY^*}{d\alpha} < 0 \qquad (1)$$

where Y^* is the SIF coefficient of chevron-notched specimen, α is the dimensionless crack length (Fig. 1(d)). Under controlled displacement, the criterion is

$$\frac{dY^*}{d\alpha} < \frac{2Y^{*3}}{EBC} \times \frac{\alpha-\alpha_0}{\alpha_1-\alpha_0} \qquad (2)$$

where E is Young's modulus, B is the specimen thickness, C is the specimen compliance, α_0, α_1 are dimensionless initial and surface crack (notch) length respectively. Formulas (1) and (2), differ only in the right hand side. Since the right hand side of (2) is positive, the specimen will be more stable in testing under controlled displacement codition than under controlled load condition.

Using an approximate assumption [3] Y^* can be estimeted by

$$Y^* = Y \left[\frac{\alpha_1-\alpha_0}{\alpha-\alpha_0}\right]^{\frac{1}{2}} \qquad (3)$$

where Y is the SIF coefficient of a corresponding straight-through cracked specimen, Y for the short bar is also given in [3], but Y for short rod is lacking. Suppose the short rod is cut into several slices longitudinally, every slice can be regarded as a short bar. If the SIF is assumed to be constant along the crack front in the original short rod, and let the sum of the load shared by each slice shares be equal to the sum of the applied load, Y for the short rod can be determined, Y^* for short rod can be calculated by (3), the results are plotted in Fig. 2 and Fig. 3.

It can be seen from Fig. 2 and Fig. 3 that as α varies from α_0 to a

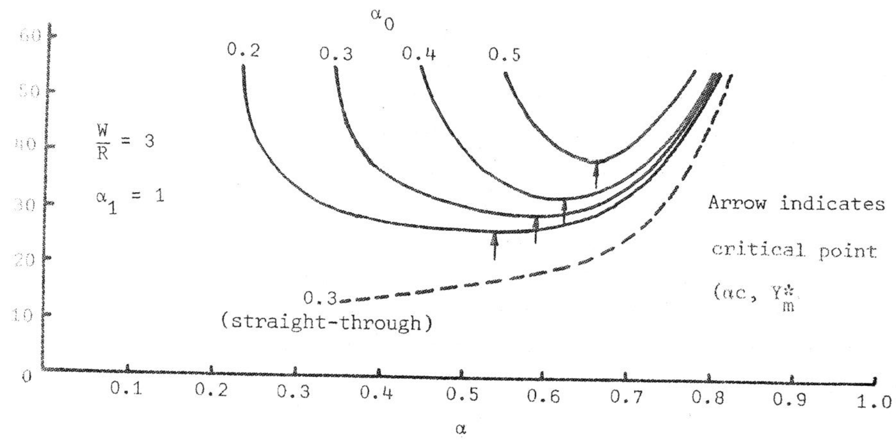

Fig. 2 Calculated SIF coefficient Y^* for chevron-notched short rod specimens of $\frac{W}{R} = 3$, $\alpha_1 = 1$ and different values of α_0.

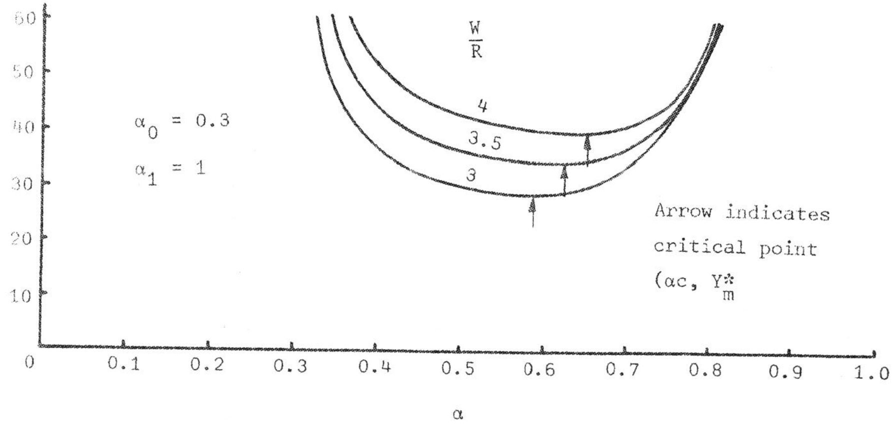

Fig. 3 Calculated SIF coefficient Y^* for chevron-notched short rod specimens of $\alpha_0=0.3$, $\alpha_1=1$ and different values of $\frac{W}{R}$.

ritical dimensionless crack length α_c, $\frac{dY^*}{d\alpha} < 0$; at $\alpha = \alpha_c$, $\frac{dY^*}{d\alpha} = 0$, and after that, $\frac{dY^*}{d\alpha} > 0$. From formulas (1) and (2) it is obvious that under controlled load condition the crack growth remains stable up to α_c, while under controlled displacement condition the stable crack growth can extend still further. Such a Y^*-α plot with a descending-flat-ascending trend is a characteristic feature of chevron-notched specimen. For comparison, the Y-α plot, for straight-through cracked short rod which is monotonically ascending is drawn in Fig. 2 in dotted line.

Since catastrophic failure still occurred occasionally for chevron-notched specimen[7,4], some positive measures should be taken to reduce the possibility of such failure. Based on our experience, the greater the value of $\Delta\alpha(\Delta\alpha=\alpha_c-\alpha_0)$, the more stable will the specimen be during the test. Fig. 2 and Fig. 3 show that smaller α_0 or larger $\frac{W}{R}$ corresponds to greater $\Delta\alpha$ and flatter Y^*-α curve, such conditions are desirable for specimen stability.

CALCULATION OF CRITICAL (MINIMUM) SIF COEFFICIENT Y^*_m

Substitute Eq.(3) into the equation of critical condition $\frac{dY^*}{d\alpha} = 0$, we obtain:

$$\frac{dY}{d\alpha} - \frac{1}{2}\cdot\frac{1}{\alpha-\alpha_0}\cdot Y = 0 \qquad (4)$$

The critical crack length α_c is the root of Eq.(4). Substitute α_c for α in Eq.(3) we get the critical (minimum) SIF coefficient Y^*_m for chevron-notched specimen. A program for computing α_c and Y^*_m was prepared.

In order to simplify the calculation, formulas for calculating Y^*_m of short rod and short bar are obtained by data fitting.

For short rod specimens in the range of $3 \leqq \frac{W}{R} \leqq 4$ and $0.2 \leqq \alpha_0 \leqq 0.5$, Y^*_m is expressed as:

$$Y^*_m = \left\{7.575 + 4.748\frac{W}{R} + 0.625\left(\frac{W}{R}\right)^2 + \left[-66.728 + 13.236\frac{W}{R} + 0.55\left(\frac{W}{R}\right)^2\right]\alpha_0 + \left[216.365 - 53.459\frac{W}{R} + 3.542\left(\frac{W}{R}\right)^2\right]\alpha_0^2\right\}\left[\frac{\alpha_1-\alpha_0}{1-\alpha_0}\right]^{\frac{1}{2}} \qquad (5)$$

For short bar specimens in the range of $3 \leqq \frac{W}{R} \leqq 4.6$ and $0.2 \leqq \alpha_0 \leqq 0.5$, Y^*_m is expressed as

$$Y^*_m = \left\{11.304 + 2.121\frac{W}{H} + 0.664\left(\frac{W}{H}\right)^2 + \left[-80.428 + 17.533\frac{W}{H} - 0.336\left(\frac{W}{H}\right)^2\right]\alpha_0 + \left[255.713 - 63.641\frac{W}{H} + 4.695\left(\frac{W}{H}\right)^2\right]\alpha_0^2\right\}\left[\frac{\alpha_1-\alpha_0}{1-\alpha_0}\right]^{\frac{1}{2}} \qquad (6)$$

We extend the range of $\frac{W}{H}$ up to 4.6 intead of 4 so that this formula can be used for some short bar specimens with rectangular cross section (Fig. 1(c))

Barker[8] performed a delicate experiment on his short rod specimen (α_1=0.992, $\frac{W}{R}$=2.948, α_0=0.343) and obtained Y^*_m=29.6. Calculation by our formula (5), and by computer gives values of Y^*_m=29.5 and Y^*_m=29.6, respectively. Both agree well with Barker's result.

EXPERIMENTAL RESULTS AND CONCLUSION

We carried out experimental work with eight metallic materials, the details of these experiments are described in another paper. Only some test results of three materials are quoted here to support the usefulness of short rod and short bar specimens.

Formulas (5) and (6) are used to calculate Y^*_m of three types of tested specimens (Fig. 1,a,b,c) K_{1c} is calculated by the following formula:

$$K_{1c} = \frac{P_{max}}{B\sqrt{W}}\,Y^*_m \qquad (7)$$

where P_{max} is the maximum load applied.

One of the tested steel is 60Si2MnA. Five pieces of compact tension specimens were first tested according to ASTM E399-78 standard, then, the two fractured halves of one original CT specimen were used to prepare a short rod and a short bar specimen respectively, they were then tested accordingly. Comparison of tested values of K_{1c} is shown in Fig. 4, where the small black dot is the value from short rod specimen, the small square is the value from short bar specimen, pairs of points are linked by a vertical lines to denote that they are taken from the same CT specimen, the corresponding value from CT specimen is determined from the intersection point of the vertical line and the 45 degree inclined line which are not shown for clearness.

One of the tested aluminum alloys is LC4CZ. One piece of three point bend specimen was first tested according to ASTM E399-78 standard, then, its two fractured halves were used to prepare eight short rod specimens. They were then tested accordingly. The tested values of K_{1c} is shown in Fig.5, where the small black dot is the value from short rod specimen, the horizontal line is the vlaue from three point bend specimen.

Fig.4 and Fig.5 show that the agreement between the tested K_{1c} from standard and chevron-notched specimens is good, the difference is generally less than 10%.

Another aluminum alloy LY11CZ was tested with chevron-notched specimens in different size and configurations as shown in Fig.6, where the

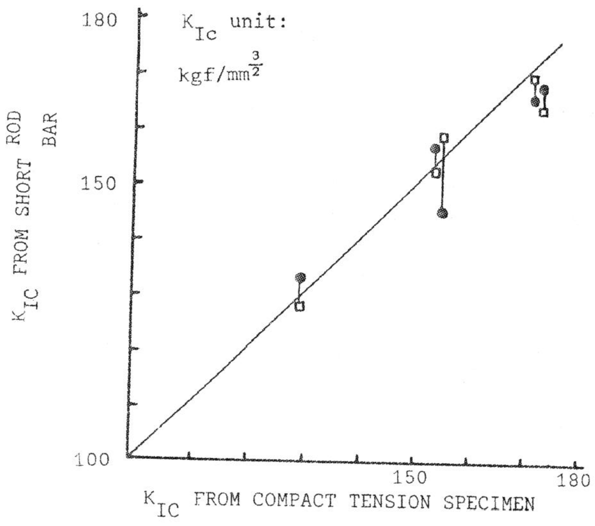

Fig.4 Comparison of tested values of K_{1c} from compact tension specimen and short rod, short bar specimen for steel 60Si2MnA.

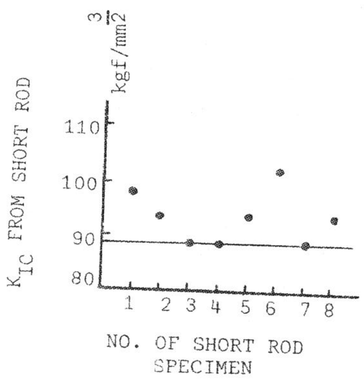

Fig.5 Comparison of tested values of K_{1c} from three point bend specimen and short rod specimens for aluminum alloy LC4CZ

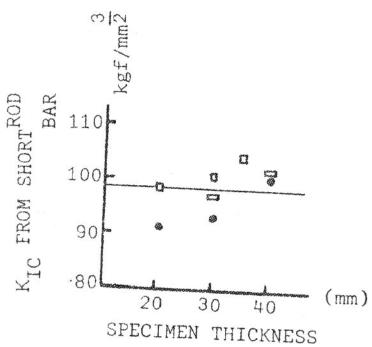

Fig.6 Tested values of K_{1c} from short rod and short bar specimens in different size and configuration for aluminum alloy LY11CZ

small rectangle is the value from short bar specimen with rectangular cross section, other marks are the same as mentioned above. The size effect is not notable, the K_{1c} values do not change much as specimen size is increased, No obvious effect of specimen configuration is observed.

The excellent experimental results provide a convincing evidence to support chevron-notched specimens to be used as convenient specimens to test fracture toughness K_{1c} for metallic materials with limited plasticity.

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