# A New Method for Fracture Toughness ($K_{Ic}$) - Determination

Gunter Feddern and Eckard Macherauch
Institut für Werkstoffkunde I Universität Karlsruhe, Germany

## Abstract

A new experimental method for fracture toughness ($K_{Ic}$) determination is presented. It is based on the measurement of the elastic energy which is absorbed by a precracked specimen up to onset of unstable fracture. This method can be applied as long as the relation between the applied load and the specimen deflection is linear. With regard to instrumentation equipment necessary, simplicity of evaluation, and scatter of results it is more advantageous than the commonly used ASTM method.

## 1. Commonly Used Way of $K_{Ic}$-Testing

For $K_{Ic}$-testing standardized test methods have been developed (1), basing on the equation of the stress intensity factor

$$K = \sigma_n \cdot Y \cdot \sqrt{a} \qquad (1)$$

$\sigma_n$ is the nominal stress, $a$ the crack length, and Y the K-calibration function which for a given specimen type depends on the crack length only. Data for $a$ and $\sigma_n$ have to be determined under the condition of plane strain (2). Fig. 1 shows a series of practical specimen types: the well known 3-Point-Bend Specimen (top), the CT-specimen (bottom left) and a recently designed new specimen with a round contoured geometry. The latter specimen type - called RCT-specimen (Round Compact Tension) - is of particular advantage if specimen fabrication from round bars is necessary. The K-calibration function Y of the RCT-specimen (fig. 1 right) has been determined by two different ways (3).

## 2. Relation between Elastic Work of Bending A and Stress Intensity Factor K

For a given specimen type the explicit knowledge of the relation $K = K(A)$ is necessary for a K-determination based on the measurement of the elastic work of bending.

The elastic work of bending comprises two parts:

- the part of the stress field due to the load: $A_L$
- the part of the stress field due to the crack: $A_C$

The sum of both parts must be equal to the work done by the applied load P. Therefore we obtain

$$A = A_C + A_L = \frac{1}{2} \cdot P \cdot f \qquad (2)$$

where f is the deflection of the specimen produced by P. It has been shown (3, 4) that the parts $A_L$ and $A_C$ can easily be calculated from the Y-function. The relation between K and A is

$$K = Z \cdot \sqrt{E \cdot \frac{A}{V} \cdot a} \qquad (3)$$

where E is Young's modulus of the specimen material, V the specimen volume, and Z for a given specimen type a function depending on the crack length only. Z is (corresponding to Y in equ. (1)) also a K-calibration function. Fig. 2 shows the dependance Z (a/W) for 3-Point-Bend specimens (left) and CT- resp. RCT-specimens (right).

## 3. A New Method for K-Determination

The results presented in fig. 2 offer a possibility for a new, simple method of K-determination. For all specimen types considered Z (a/W) varies only slightly over a wide range of a/W. Therefore, Z can be put constant with an absolute error ≤ 3 % within a certain range of a/W. Thus a simple formula is obtained:

$$K = Z^* \sqrt{E \cdot \frac{A}{V} \cdot a} \qquad (4)$$

Values of the constant Z* and the corresponding ranges of validity of equ. (4) can be taken from table 1.

| Specimen type | L/W | Z* | Range (a/W) |
|---|---|---|---|
| 3-Point Bend Specimen | 4<br>6<br>8 | 5,24<br>6,36<br>6,84 | $0{,}3 \leq a/W \leq 0{,}6$<br>$0{,}2 \leq a/W \leq 0{,}5$<br>$0{,}15 \leq a/W \leq 0{,}5$ |
| Compact Tension Specimen | 1,0<br>1,1<br>1,2 | 3,04<br>3,28<br>3,58 | $0{,}4 \leq a/W \leq 0{,}7$<br>$0{,}4 \leq a/W \leq 0{,}7$<br>$0{,}45 \leq a/W \leq 0{,}65$ |
| RCT-Specimen | RCT | 3,29 | $0{,}4 \leq a/W \leq 0{,}7$ |

Table 1: Values of Z* and range of validity for several specimen types

## 4. Comparison of $K_{Ic}$-Results Obtained by the New Method and the ASTM-Procedure

Comparative tests have been performed with an aluminium alloy (AlZnMgCu 0,5 , $\sigma_B = 46$ kp/mm$^2$) which meets the requirement for a linear elastic behaviour up to fracture onset. At the same time, load, crack opening displacement and deflection were recorded so that $K_{Ic}$ could be determined from equ. (1) and equ. (4). Fig. 3 shows the frequencies of results from a series of 36 CT-specimens (L/W = 1,2). $K_{Ic}$-values calculated from equ. (4) evidently scatter less than those obtained from equ. (1).

This may be due to the fact that normally the crack front is not a straight line but more or less curved. In this case an exact determination of the crack length is not possible and can only be done approximatively. This error influences the result by the crack length a and the calibration function Y resp. Z. The Y-function, however, shows a strong dependance from a/W whereas the Z-function is nearly independant on a/W at least within the range given in table 1. Thus the application of equ. (4) leads to a mean standard deviation ± 4 % compared to ± 4,7 % obtained by the ASTM procedure.

References:

1 W.F. Brown: Tentative Method of Test for Plane Strain Fracture Toughness of Metallic Materials. ASTM STP 463 (1970)

2 W.F. Brown; J.E. Srawley: Plane Strain Crack Toughness Testing of High Strength Metallic Materials. ASTM STP 410 (1967)

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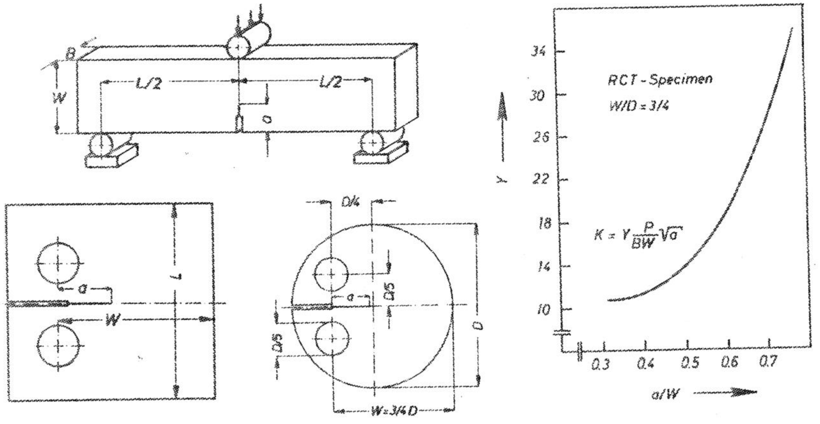

Fig. 1: Specimen types for fracture toughness testing

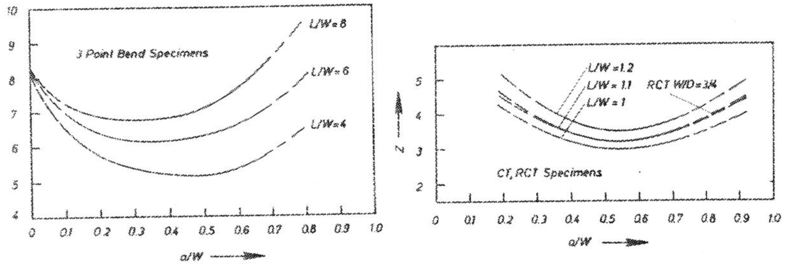

Fig. 2: Values of Z (a/W) for several specimen types

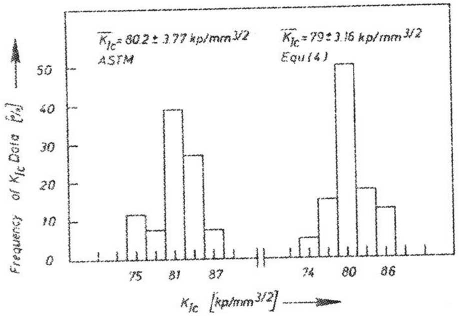

Fig. 3: Comparison of scatter of $K_{Ic}$ - data