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METHODS OF EXPERIMENTAL DETERMINATION OF STRESS-INTENSITY FACTORS OF SIMPLIFIED GEOMETRIES OF STRUCTURAL PARTS

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INTRODUCTION

When a material with a crack is loaded, the stress intensity factor K characterises and describes the stress field in the vicinity of the crack tip. In fracture mechanics one defines a critical stress intensity factor as a material property which indicates the beginning of a fast or brittle fracture under conditions of purely elastic deformation.

Knowledge of the critical stress intensity factor which is readily determined from a simple test performed on standardized fracture mechanic specimens, permits evaluation of critical stresses at given crack lengths or critical crack lengths at given stresses in structural parts using the well known formula

$$K_{IC} = G_c\sqrt{a} \cdot Y\left(\frac{a}{W}\right) \qquad (1)$$

$Y(\frac{a}{W})$ represents a factor which depends on the geometric form and on the crack length of a loaded body.

Application of this formula on structural parts or on arbitrary specimen geometries by calculating exact values of fracture stresses at given crack lengths or crack configurations requires knowledge of the factor $Y(\frac{a}{W})$.

PROBLEM

The problem with which we are concerned here is the determination of the fracture stress of a specimen geometry shown in Figure 1. This shows a sheet of thickness B with a hole of diameter D in the middle. Two through thickness cracks are fabricated at the rim of the hole opposite to each other and perpendicular to the stress direction. The length of the manufactured cracks are b (b_1, b_2).

If we want to calculate the fracture stress by means of fracture mechanics concepts, the stress intensity factor must be calculated, which depends on the factor $Y(\frac{a}{W})$.

In the following, two ways will be discussed in which to determine experimentally those factors $Y(\frac{2a}{W})$, which may be regarded as a function of the crack-length including the geometrie correction. For experimental procedures and measurements the specimen dimensions may be reduced to smaller dimensions as far as a satisfactory measurement accuracy is given. If the proportions of the specimen dimensions other than thickness are kept constant,

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the value of $Y(\frac{2a}{W})$ for a given value of $\frac{2a}{W}$ will be the same regardless of the size of the specimen, its thickness or the material from which it is made.

COMPLIANCE METHOD

The one method of determining values of $Y(\frac{2a}{W})$ is based on energetic considerations and compliance measurements as described below [1].

To determine quantities of elastic deformation energy of a body with a definite crack length a it is necessary to measure the load P and the deflection v in the line of loading. Then the area under the load-deflection curve corresponds to the elastic deformation energy. By measuring specimens of the same size but with different crack lengths a curve can be established shown in Figure 2 (Eichkurve). The term

$$X\left(\frac{2a}{W}\right) = \frac{E \cdot B \cdot \nu}{P}$$

represents the reciprocal spring constant related to the Youngs modulus E and to the specimen thickness B and is solely dependent on the crack length a or on the dimensionless crack length $\frac{2a}{W}$ respectively, where W is the width of the specimen. In our consideration the crack length is given as $2a = D + 2b$.

The deformation energy can be written as

$$U = \frac{P \cdot \nu}{2} = \frac{P^2}{2} \cdot \frac{X\left(\frac{2a}{W}\right)}{E \cdot B} \qquad (2)$$

Referring to the literature [2], the energy release rate G is defined as

$$G = -\frac{1}{B}\frac{du}{da} = \frac{k^2}{E} \qquad (3)$$

and can be considered as the variation of potential energy with the crack length.

From equations (1) and (2) one can derive the stress intensity factor which is obtained as

$$K = \frac{P}{B \quad 2W} \sqrt{\frac{dX\left(\frac{2a}{W}\right)}{d\left(\frac{2a}{W}\right)}} = \frac{P}{B\sqrt{2W}} \cdot Y\left(\frac{2a}{W}\right) \qquad (4)$$

Consequently it can be seen that the correction function $Y(\frac{2a}{W})$ is obtained by differentiating the curve shown in Figure 2. To establish such a curve, the measurements have to be extremely accurate especially when using small specimens.

CRACK GROWTH TECHNIQUE

This method is based on fatigue crack growth measurements and is recommended for cases when the compliance technique cannot be applied [3],[4],[5]. Moreover, it represents a supplement to the complaince technique. During crack propagation in a material the crack growth rate is considered to be dependent solely on the stress intensity factor if material properties and test conditions are held constant. The crack growth rate can be written as

$$\frac{da}{dN} = \dot{a}^* \left(\frac{\Delta K}{K^*}\right)^n \qquad (5)$$

where $\dot{a}^*$, K^* are constants containing material properties. The use of this expression implies that once the relation between fatigue crack growth rate

$$\frac{da}{dN}$$

and the cyclic range of the stress intensity factor ΔK has been established from tests on standardized specimens an observed crack growth rate can be translated into a stress intensity factor. To establish a socalled "calibration curve" Figure 3 which describes the dependency of crack growth rate

$$\frac{da}{dN} \text{ on } \Delta K,$$

standardized specimens, i.e., Compact-Tension-Specimen, are used of which the geometric correction function $Y(\frac{a}{W})$ is known.

Therefore, K can readily be calculated from the relation

$$\Delta K = \Delta\sigma\sqrt{a} \cdot Y\left(\frac{a}{W}\right) \qquad (6)$$

if the crack length a and the range of the applied cyclic load expressed as Δσ can be measured. The crack growth rate

$$\frac{da}{dN}$$

can be measured by the change of crack length with the number of load cycles N. All data obtained from measurements are plotted in a diagram with logarithmic scale and form approximately a straight line, which may be regarded as calibration curve or as the graphical representation of equation (5). Such a reference dependence is then needed to ascribe the stress intensity factor K to a measured value of crack growth rate in an arbitrary structure. By defining the quantities Δσ and a for a given value of K the geometric correction factor $Y(\frac{a}{W})$ can be calculated using equation (6).

TEST PROCEDURE

To establish the $\frac{da}{dN}$ vs. ΔK relation, crack growth measurements were performed with Compact Tension Specimen of 40 mm thickness. The material from which the specimens were made was ASTM A508 Cl.2 steel. To determine the crack growth the method based on compliance measurements was applied. The measured ratio of load to deflection gives the crack length, so that the crack length can easily be taken from the reference curve of Figure 4. This reference curve was established by loading purely elastically samples of different crack lengths. The tests were carried out on a closed loop hydraulic test machine at constant cycling load. The minimum load was set at 10% of the maximum load. Crack growth measurements using model specimens of the above mentioned form, were performed under the same conditions as used with the CT-Specimens. As there is no calibration curve for determining the crack length by compliance measurements, crack growth data had to be obtained stepwise under different loading rates.

By examination of the specimen after fracture the lines, formed by different loading rates of ΔK-values, can be observed on the fracture surface. Thus it is possible to measure the different fatigue crack lengths or the crack growth rates, which were then transferred into ΔK-values by using the

$$\frac{da}{dN} - \Delta K$$

relation, (Figure 3) as described above. On consideration of equation (5) the factors $Y(\frac{a}{W})$ were calculated.

RESULTS

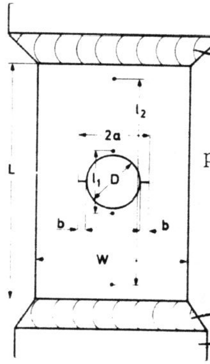
The results of these measurements are shown in Figure 5. The factors Y, which were obtained by compliance measurement procedure and crack growth procedure, are plotted versus the crack length and form a scatter band. The average values form a curve, which can be regarded as the correction function Y. Also Figure 5 shows the correction-function of the Center Cracked Specimen taken from the literature. One can see that there is little difference between the two curves. This means that the investigated specimen can be regarded as a center cracked specimen without taking account of the hole in the middle. Therefore the correction function is apparently independent of the hole diameter, within the used specimens.

In a tensile test performed on a 60MN test machine the measured nominal fracture stress was in one sample 394 N/mm^2 and in the other sample 374 N/mm^2. This corresponds approximately to a critical K value K_c = 8000 N $mm^{-3/2}$.

The fracture stress corresponding to the net section was in one sample 563 N/mm^2 and in the other sample 534 N/mm^2 which is the yield stress of the material investigated.

REFERENCES

1. SRAWLEY, J. E. and JONES, M. H., NASA TN D-2396.
2. SRAWLEY, J. E. and BROWN, W. F., ASTM STP No. 381.
3. SOMMER, E. and RATWANI, M., Materialprüfung 15 Nr. 11, 1973.
4. JAMES, L. A. and ANDERSON, W. E., Eng. Fract. Mech. 1 Nr. 3, 1969.
5. BROEKHOVEN, J. J. G., Rep. MMPP-84, Delft University of Techn., December 1973.



Specimen No.	W	B	D	2a	L	l_1	l_2
1,3	500	120	150	185/181	~850	200	800
2	300	70	100	141	~350	160	-
Model Specimen	100	30	34	-	200	50	-

Figure 1 Specimen dimensions in mm.

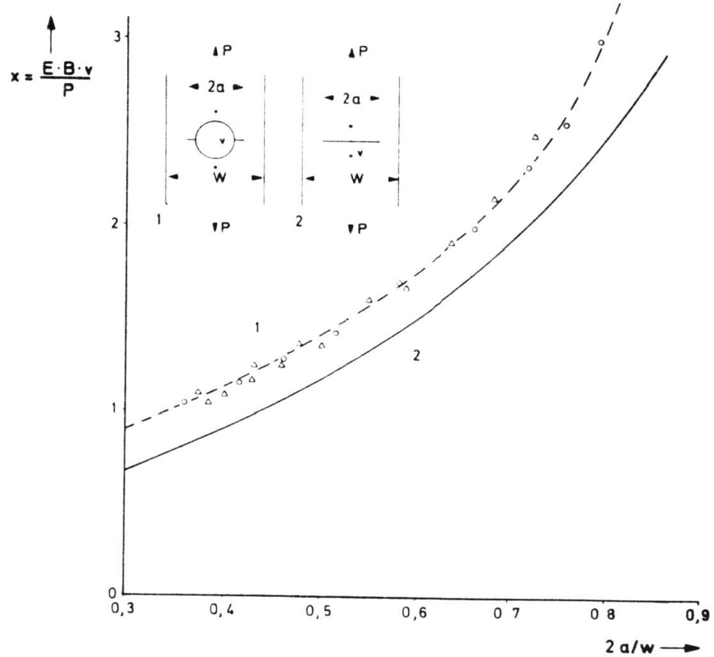


Figure 2 Compliance for the (1) Plate with two symmetrical cracks originating at a hole. (2) Center Cracked Tension specimen.

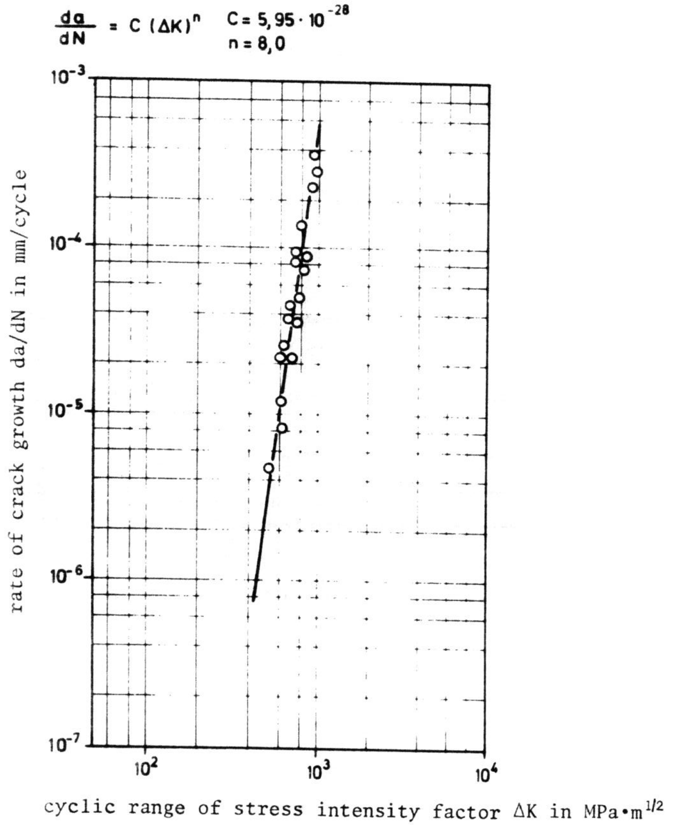


Figure 3 Laboratory crack growth rate data for the steel A 508 C12

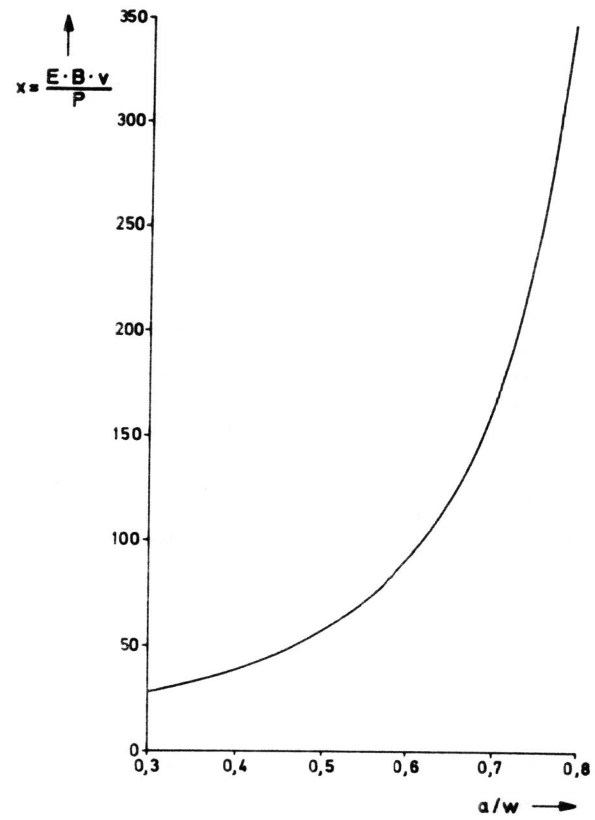


Figure 4 Compliance for the Compact Tension specimen

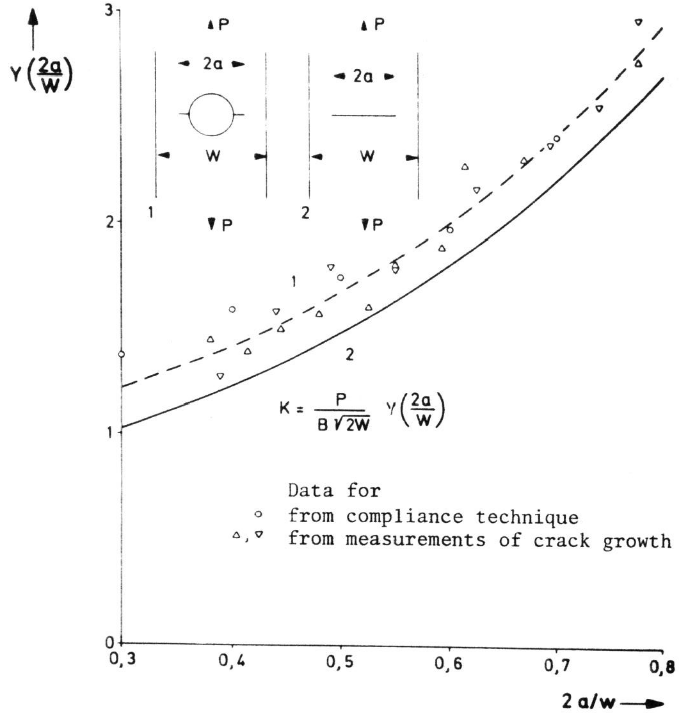


Figure 5 Stress intensity factors for a plate with two symmetrical cracks originating at a hole (1) and for the Center Cracked Tension specimen (2).