Growth of Distributed Cracks Under Fatigue Loading

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1. INTRODUCTION

The data relating the information on distributed flaws (cracks) with the fatigue strength and life of materials have been collected and arranged by many authors(1,2,3). Possibility of the application of fracture mechanics simulation to the analysis of this relation is studied.

2. DEPENDENCY OF GROWTH RATE OF DISTRIBUTED FATIGUE CRACKS ON "K" (STRESS INTENSITY FACTOR)

2.1 POINTS OF STUDIES AND PROCEDURES

Referring to the results of bi-axial loads tests, non-propagating crack tests and K-varying fatigue tests, the applicability of the law of fatigue crack growth for a single crack [$\frac{da}{dN} = C(\Delta K)^m$] to distributed cracks problems has to be examined for the following cases : (a) Bi-axiality of stress distribution different from the case of single crack (b) Steep gradient of stress distribution (c) K_{II} generated by asymmetry (d) Growth of plastic band affected by close free surface (e) Comparatively low yield strength materials (f) Unstability of the whole cross section (g) Curve of growing course of cracks (h) different starting conditions of crack growth at each notch root.

To examine these points, the following selection was made for the tests. (1) Symmetric three cracks (Fig.1) and asymmetric two cracks (Fig.2) with crack-arresters for basic models. (2) Two steels with different yield strength (Table 1) (3) Various arrangements of cracks (Table 2) (4) Two dimensional measurements of crack growth by a travelling microscope and successive intermittent photography.

2.2 CALCULATION OF "K" FOR 2 OR 3 CRACKS IN A FINITE PLATE

K for a finite plate is computed by the energy release method of finite element method at each stage of actual crack growth. In early stage, these results coincided with that by Laurent expansion method for a infinite plate developed by one of the authors(7,8)(Fig.9.a), and the results by the COD method of finite element method, differed extremely from them (Fig.9.a). In the case of overlaped small cracks, the results by Yokobori et al.(5,6) for a infinite plate were referred.

2.3 SOME OF THE RESULTS

(1) A center crack of three cracks grows essentially straight at first (Fig.3). When one of side cracks starts growing after slow-down of the center crack by interference, K_{II} appears and the growing course curves (Fig.3). In the case of two cracks, at first the cracks grow curving slightly outwards and then inwards, being affected by K_{II}, suggested by Yokobori et al.(5)(Fig.4). In both cases, final connection of the cracks is brought by the yielding unstability of the whole cross section due to growth of outer tips of the cracks.

(2) The upper limit properties of $\Delta K \sim \frac{da}{dN}$ diagrams (K_{fc}), indicated by broken lines, are decided by the condition that the peak value of the mean stress in the residual cross section outside the outer tips of the cracks reaches the yield strength of the material ($\sigma_{fc} = \sigma_Y$), for all the cases, one, two and three cracks (e.g.Fig.5)

(3) The lower limit properties (apparent threshold) ,shown by broken lines, are characterized by the abrupt slow-down of $\frac{da}{dN}$ immediately after the start of growth from the notch root, which is governed by the test loads and the notch configuration. Intrinsic threshold intensities, ΔK_{th} of the materials used are $20 \sim 30$ kg/(mm$^{\frac{3}{2}}$)(10).

(4) The data points for the inner tip of the center crack in three-crack-tests fall in the same slant scatter band for single-crack-tests (Fig.6.a). The band is, however, modified by the upper and lower limit properties, as suggested in Forman formula(8). When the fall-down of K by the interference occurs, the data points fall outside the slant band or below the lower limit temporarily.

(5) The data points for the inner tips of the two cracks fall in the same but modified scatter band for single-crack-tests (Fig.7). The crack lengths used for the calculation of $\frac{da_1}{dN}$, $\frac{da_2}{dN}$ and ΔK are the projections onto the extension line of the initial cracks. The modification of K_I regarding K_{II} , suggested by Erdogan & Sih(9) and Yokobori, et al.(5), does not seem to be required in this case, because the K_{II}/K_I ratio is much less than 1.

3. RELATION OF CRACK TIP POSITIONS, K, AND CRACK GROWTH

The following problems will be discussed.

(a) Threshold stress intensity factors of three cracks of equal length (Fig.8 by FEM) and other distributed cracks.

(b) Variation of interference with growth of a center crack of three cracks (Fig.9.a, 9.b, by FEM, Fig.10,9.a, by Laurent expansion). Falling down of K occurs (Fig.11 by FEM).

(c) Variation of the K_{II}/K_I ratio and the effective "K" with growth of two cracks.

(d) Growth of a total effective crack including actual cracks.

(e) Computed crack growth curves compared with test results.

4. STRENGTH AND LIFE OF THE MATERILAS WITH DISTRIBUTED CRACKS

Other results of tests and computation and our concepts will be discussed.

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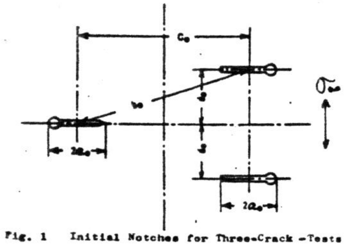

Fig. 1 Initial Notches for Three-Crack -Tests

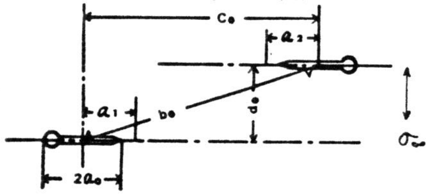

Fig. 2 Initial Notches for Two-Crack - Tests

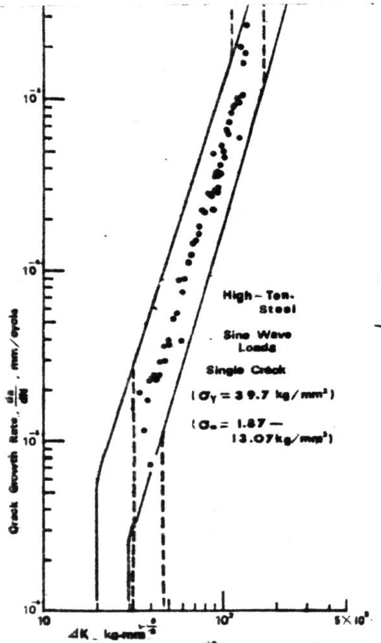

Fig. 5 An Example of $\Delta K - \frac{da}{dN}$ Diagram for Single-Crack-Tests (High-ten. Steel, Sine Wave Loads)

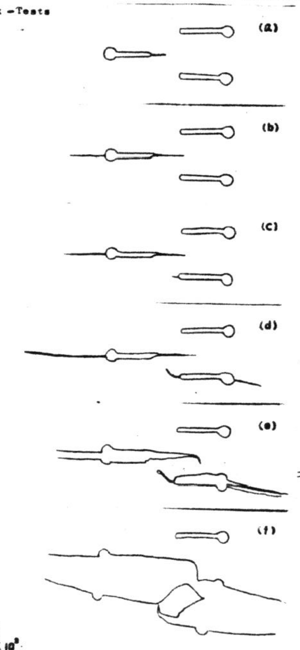

Fig. 3 Fatigue Crack Growth from Three Notches (Series N, High-ten. Steel)

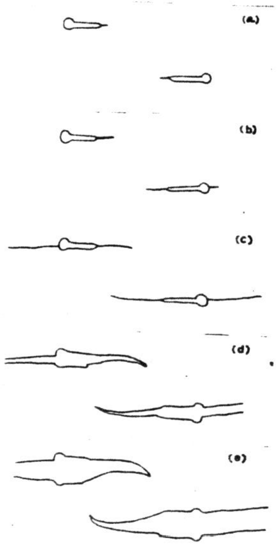

Fig.4 Fatigue Crack Growth from Two Notches (Series N, Mild Steel)

Table 2 Results of Tension Tests

Materials Used for Fatigue Tests	Tensile Strength (kg/mm²)	Yield Strength(0.2%) (kg/mm²)	Elongation %
High-ten. Steel (NAW 50)	51.4	39.7	25.2
Mild Steel (S10C)	33.4	25.0	42.7

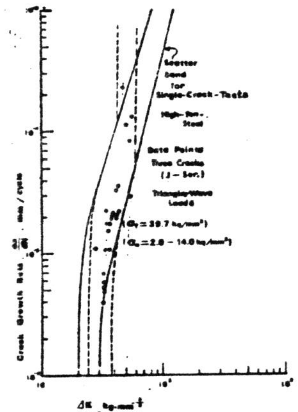

Fig. 6 (a) $\Delta K - \frac{da}{dN}$ Diagrams for Three Crack Tests (High-ten. Steel, Triangular Wave Lo...

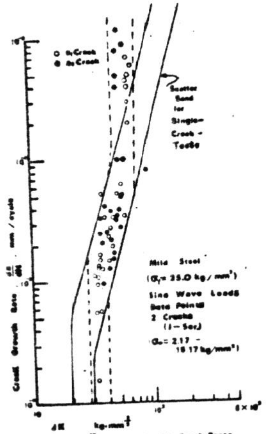

Fig. 7 $\Delta K - \frac{da}{dN}$ Diagram for Two-Crack-Tests (Mild Steel)

Table 1 Dimensions of Initial Notches (*: mm)

Series	$2a_0$*	C_0*	d_0*	C_0/a_0	$2a_0/b_0$
J	4	10	5	2	0.358
L	5	9	3	3	0.527
N	5	9	2	4.5	0.542

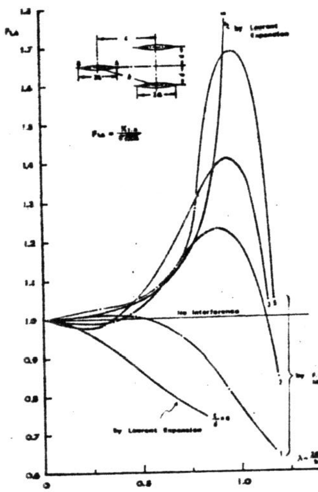

Fig. 8 Correction Factor for K of Three Cracks (at A)

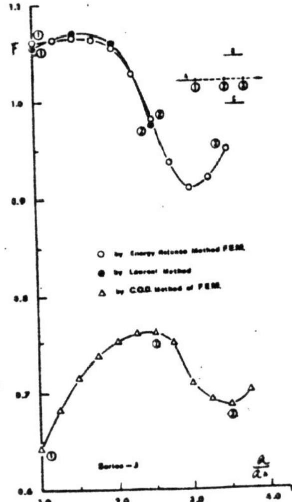

Fig. 9.(a) Variation of K Correction Factor with Growth of Center Crack

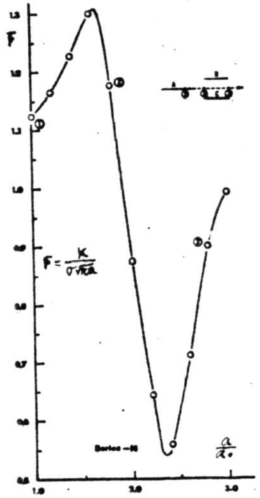

Fig. 9.(b)

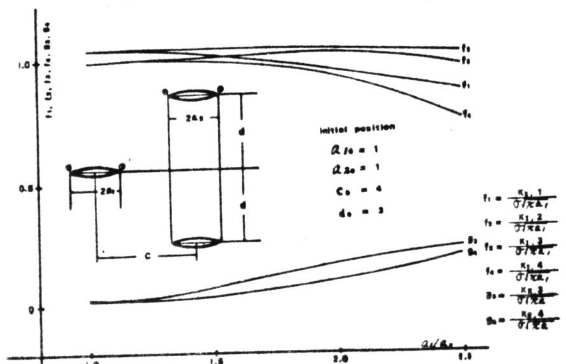

Fig. 10 Variation of K Correction Factor with Growth of Center Crack of Three Cracks Calculated by Laurent Expansion

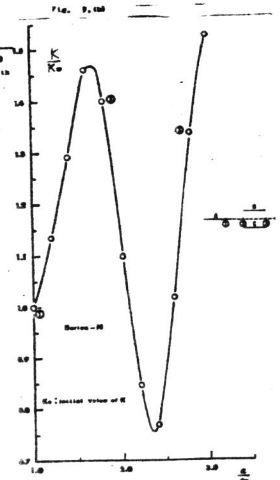

Fig. 11 Variation of K with Growth of Center Crack of Three Cracks