SMALL CRACKS AND MULTIPLE CRACKS PROBLEMS IN FATIGUE

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ABSTRACT

To clarify the relationship and rolls of small cracks problem and multiple cracks problem in fatigue, various types of small crack problems are characterized and compared; including a small crack started from a single small notch, small cracks started from smooth surfaces at higher stress levels or at high temperature and small cracks started from randomly distributed small notches in corrosion fatigue. Some use of small cracks concept and data are demonstrated.

SIGNIFICANCE OF THE PROBLEMS AT PRESENT

1. Significance of Small Cracks Problems in Fatigue

The expression "SMALL CRACKS" in the title of the present paper means a small crack or cracks on the surface of materials with crack-length of, e.g., several micron to several hundreds micron or one milimeter for structural steels. These cracks often show different behavior from larger cracks.

"Small crack" problems have recently been a matter of great concern in the fields of fatigue and fracture mechanics(FM). Their significance at the present time is understood as follows;

(a) FM as an engineering methodology for material-testing has been almost completed. One of the next problems is to find the way how to apply the

FM to evaluation of the NATURAL CRACKS in structures. Limitation of the application of conventional FM to small crack and modification of FM are important.

(b) In the recent NON-DESTRUCTIVE INSPECTION, it is required to detect and measure fairly small cracks, quantitatively evaluate them and identify harmful cracks.

(c) Most of structure design depend on the strength or life data of smooth specimens with no cracks. For introduction of FM to the DESIGN, it is becoming most important for FM to evaluate or predict the strength or fracture time of the materials or structures with no large pre-crack. One of the keys to this problem is to follow the behavior of small cracks.

(d) All of (a),(b),(c) above depend on the UNDERSTANDING of a fatigue fracture process, in most part of which small cracks can be observed.

2. Significance of multiple Cracks Problems

(a) At welds, parts exposed to corrosion, parts with defects , notch-roots and locally highly stressed parts numerous cracks in a group can be sometimes found Unified evaluation of these multiple cracks is required in the recent NDE.

(b) The sizes, locations & initiation time of these cracks are random variables. Measurements, records and analysis of these multiple cracks need two-dimensional image processing, statistical simulation, and other recent computor techniques.

(c) Small cracks are very often multiple cracks distributed over material surfaces at high density (e.g., several hundreds cracks in square milimeter area, in some cases. See Fig. 1)[1], because highly stressed area is usually broader than the cracks' sizes. Therefore, SMALL CRACKS PROBLEMS can not fully be discussed without MULTIPLE CRACKS PROBLEMS. The propagation rates of these cracks can be affected by their coalescence.

In the present paper, MULTIPLE CRACKS PROBLEMS will be discussed as a part of SMALL CRACKS PROBLEMS.

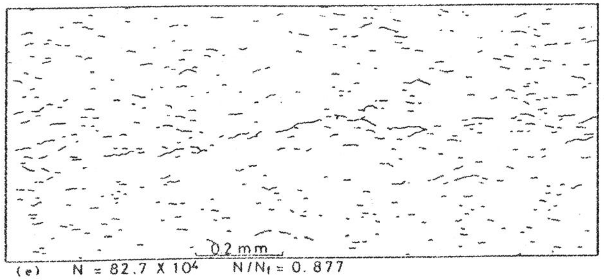


Fig. 1. Numerous micro-fatigue-cracks distributed on the smooth surface of a specimen (SUS 304, Axial loads, $R = 0.1$, 538°C, 400cpm, $\sigma_{max} = 38.98 kg/mm^2$) [1]

GENERAL CHARACTERISTICS OF SMALL FATIGUE CRACKS

Summarizing the many data given by many separate papers (mostly by the authors'), general or common features of so-called "small cracks"or "a small crack" in fatigue are arranged as the follows;

(i) Mostly a small crack is a surface crack. The surface crack grows two-dimensionally and has many freedoms of crack behavior, which needs additional criteria relating to crack surface shapes. And also measurements of crack depth or the crack surface shape and three dimensional analysis of FM parameters (K,J,etc.) are required.

(ii) In most fatigue tests for "small cracks", the stress level of $\Delta\sigma$ or σ_{max} was higher, compared with convensional FM fatigue tests using center-cracked specimens; that is, the stress level higher than the fatigue limit of unnotched smooth specimens of the material or at least the stress level somewhat lower than the fatigue limit; which suggested in Fig. 2[2][3].

Above the stress level, the hysteresis loops on cyclic stress-strain records can continue to swell.Then the fatigue growth rate of a small surface crack becomes higher than regular crack growth rate ($da/dN = C(\Delta K)^m$) and follows parameters including total strain range $\Delta\varepsilon_t$ better than stress range $\Delta\sigma$, e.g., $\Delta K_{\varepsilon t}(= \Delta\varepsilon_t\sqrt{\pi a})$,remarkably in lower R (stress ratio) ranges.

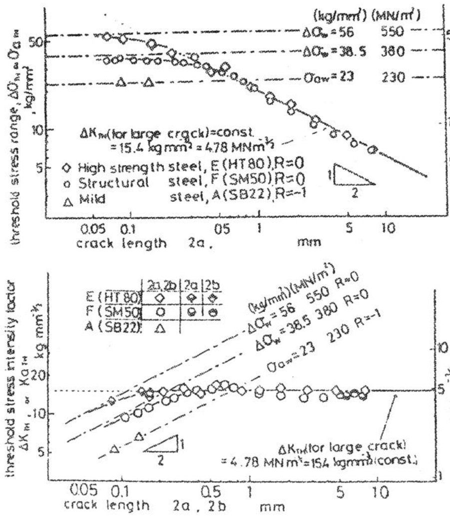
For ductile steels and in higher R ranges, the peak of the stresses σ_{max}, at the stress level stated above, can often exceed the yield stress; which possibly affects (a) variation of the shape of a surface-crack and (b) its crack closure, and increases the density of crack initiation on the surface, which induces extension of cracks assisted by their coalescence.

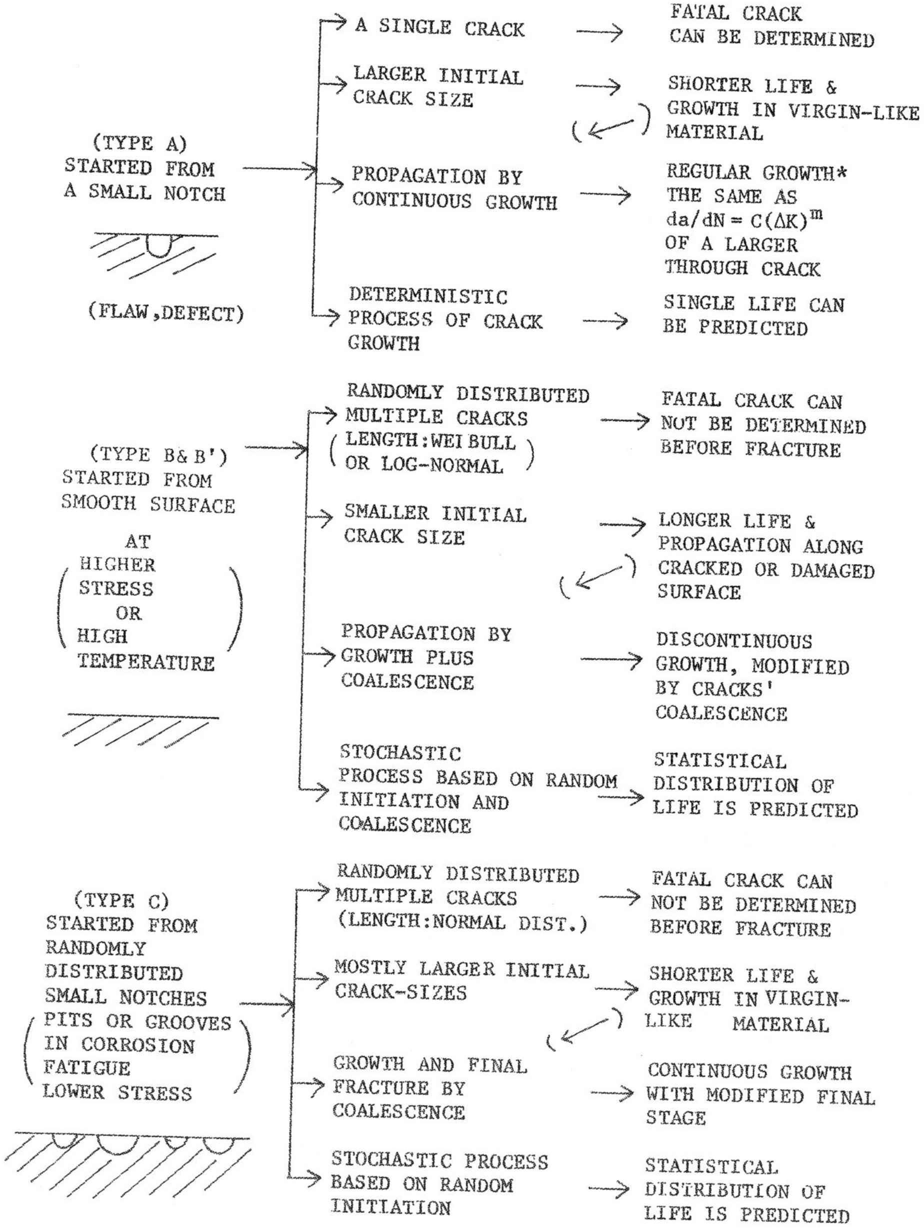
(iii) Due to the small sizes of cracks, it becomes easier that crack extension is affected by the coalescence and initiation of cracks. Also due to the smallness, cracks can exist surrounded by local plastically deformed area.

Fig. 2 Threshold conditions for stable fatigue crack growth of a surface crack against the crack length [2]

(a)

(b)





* NOTE: WHEN $\Delta\varepsilon$ OR $\Delta K/\sigma_{ys}$ IS HIGH, da/dN DEPENDS ON ΔK_{ε}, ΔJ, ETC.

Fig.3 TYPES OF "SMALL CRACK" PROBLEMS IN FATIGUE

CLASSIFICATION OF "SMALL CRACK" PROBLEMS

Examining many data including recent ones, SMALL CRACK problems are classified into Types A, B (&B') and C, as shown in Fig. 3.

In Type A, one surface fatigue crack, started from a small notch,e.g., 50μ in diameter, grows into the virgin-like material, and can follow the same crack growth law as a larger crack. For a crack on a thicker plate loaded at R≅0 and $\sigma_{max} < \sigma_{ys}$ (yield stress), its growth law follows the law $da/dN = C(\Delta K)^m$.

In Type B, in a high-stressed area many cracks are prepared to initiate simultaneously, and then some of the cracks grow through the crack-prepared or cracked surface.

In Type B', the case of small cracks high temperature, their behavior is almost the same as B, except for the extraordinarily high density of cracks, several ten thousands cracks in 1 cm^2 area.

In Type C, many cracks initiate successively from small corrosion fatigue pits distributed on the surface randomly in their sizes and locations. In this type, a stochastic process is composed of a group of crack-growth-processes which are independent from each other and have different initiation times and different initial sizes of the small cracks. The process terminates by coalescence of the cracks.

The Type B(&B') is controlled by the competition between the crack initiation rate and the crack growth rate; which probably depends on stress and strain conditions. The Type C is controlled by the competition between the pit growth rate and the crack growth rate.

CHARACTERISTIC CRACK GROWTH BEHAVIOR IN EACH TYPE

(i) Type A. The da/dN seems generally to follow regular crack growth laws for a large through crack. Crack depth and length follow $da/dN = C(\Delta K)^m$ within the cyclic stress-strain range with sufficient narrow hysteresis loops[3]. In the stress- strain range correspond to hysteresis-loops with increased widths, C' in $da/dN = C'(\Delta\sigma\sqrt{\pi a})^{m'}$ depends on the stress level and type of loads, and the surface length follows $da/dN = C_\varepsilon(\Delta\varepsilon_t\sqrt{\pi a})^{m_\varepsilon}$, etc.[2] The ΔK_{TH} varies with crack sizes as shown in Fig. 2[3].

(ii) Types B & B'. The typical N-a diagram for extension of a fatal crack line (a group of firstly connected multiple cracks) includes steps. The diagram is composed of (a) jumping extension by coalescence, (b) temporarily accelerated and decelerated growth just before and after the jumping extension, and (c) regularly continuous growth [4][5]. The parts of the N-a diagram corresponding to(c)showed the same properties as the one shown in Type A[5]. The process including (a) or (a) + (c) can be calculated by using various stochastic process models [6][7][8].

(iii) Type C. The growth rate of surface length of each crack in some corrosion fatigue tests followed $da/dN = C''(\Delta\sigma\sqrt{\pi a})^2$ and the C″ gave normal distribution[7].

(iv) In Types B' & C, from difficulties in experimental techniques, it has not been assured that the crack growth rate generally depends on ΔK. The growth behavior of surface lengths of each cracks, the maximum length, the mean length and ditribution functions of crack-lengths have been formulated [1][7].

USAGE OF SMALL CRACKS' CONCEPT AND DATA

Usage of the concept and data of "small multiple cracks" or "a small crack" is now being developed for various purposes, e.g.,(a) measurements of the progress of fatigue damage or determination of the residual fatigue life[7][See,Appendix 1][7], (b) determination of P-S-N curves, probability of failure at any N (number of load cycles), two dimensional fracture pattern, etc., of unnotched smooth-surface-material by using small cracks data [9]. [See, Appendix 2][9] and NDE of welds and notches[8].

CONCLUSION

(1) Small crack problem will be better understood, if it is combined with multiple cracks problem.

(2) It will be useful for the analysis of the fatigue process if it is understood that the small crack problems can be classified into 3 or 4 types.

(3) Further developements of small-multiple cracks concept make it easier to combine usual fatigue and FM, and to introduce FM to design.

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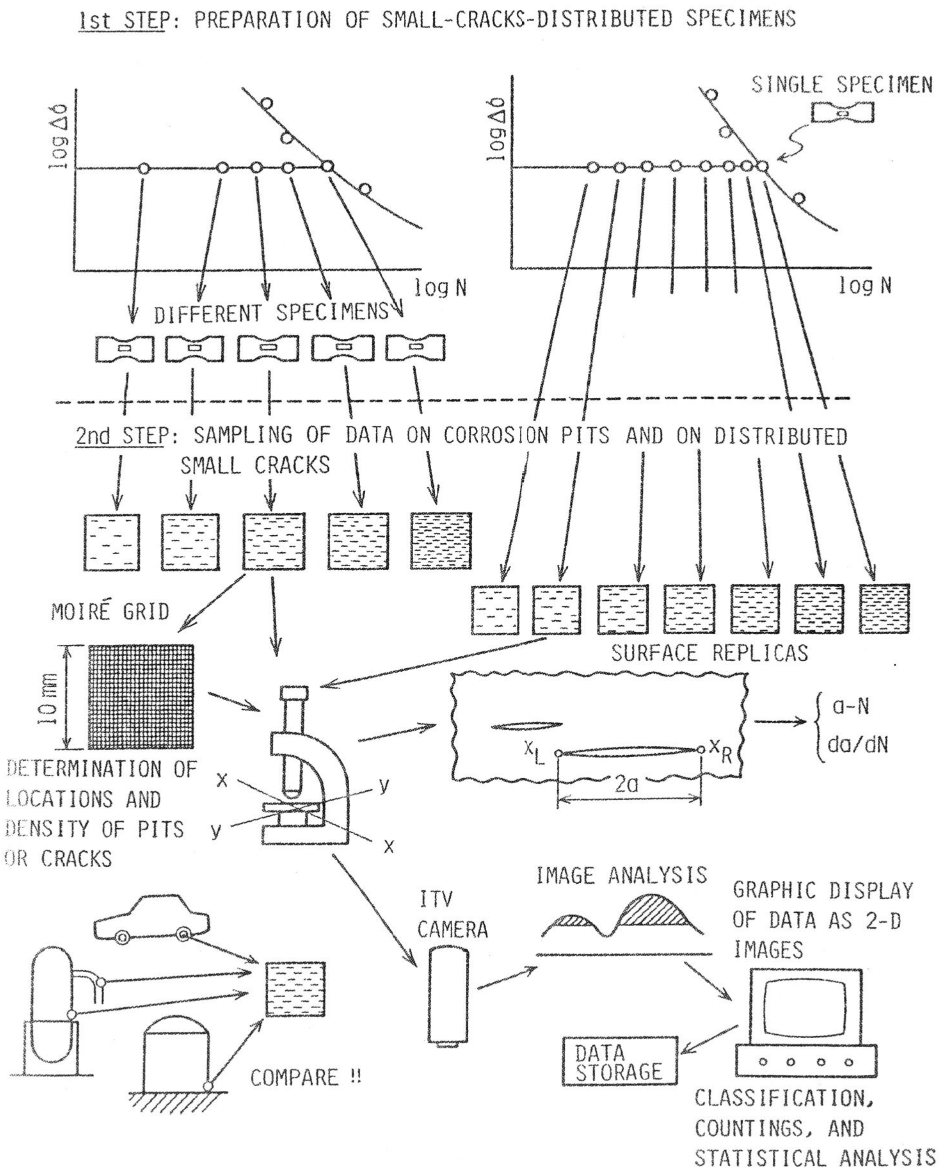
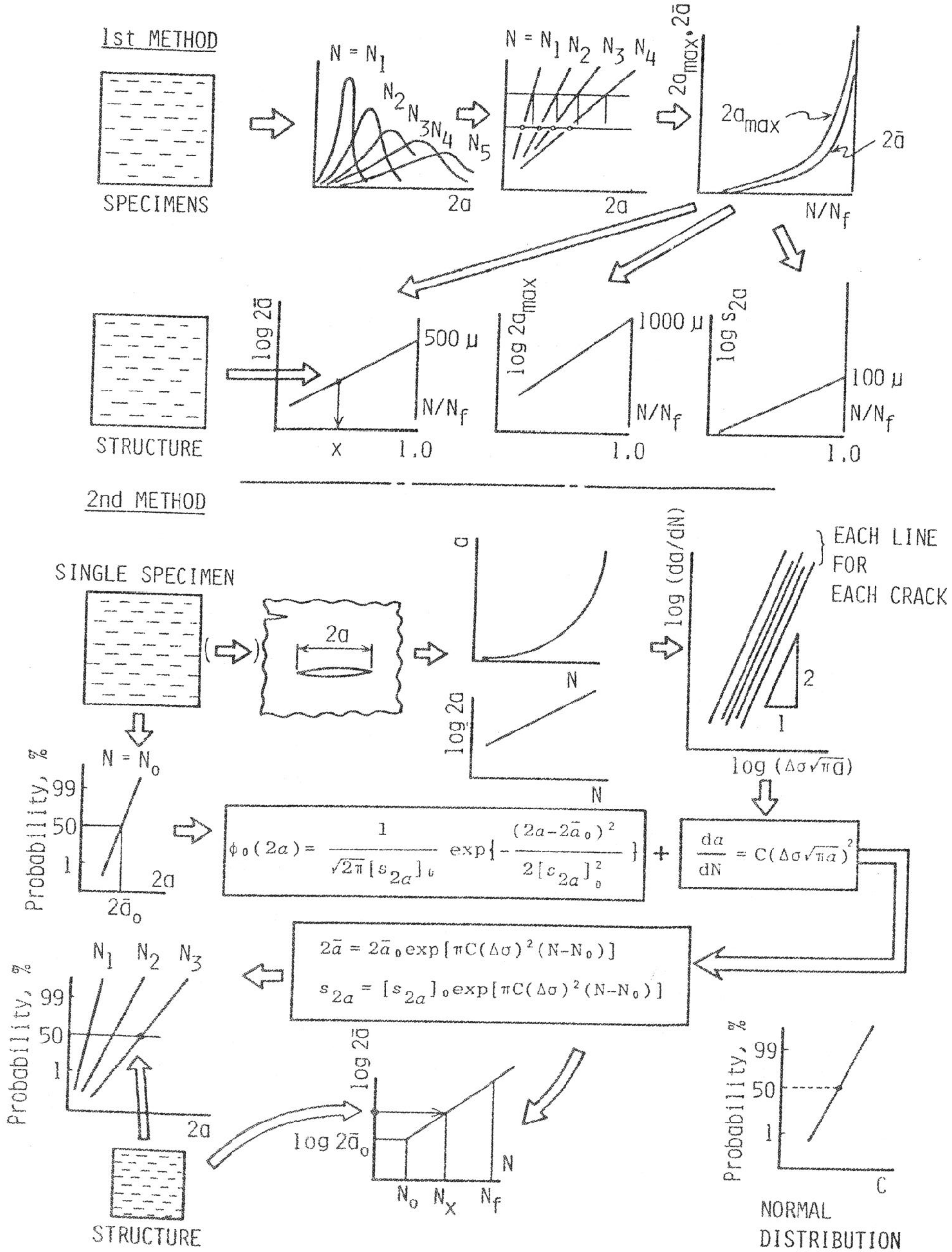
Appendix 1(a)[7] Schematic representation of the procedures of the proposed method.



Appendix 1(b)[7] Schematic representation of the procedures of the proposed method



Appendix 2[9] Simulation of Growth of Randomly Distributed Fatigue Cracks Accompanied by Coalescence