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Assessment of equivalent initial flaw size estimation methods in fatigue life prediction using compact tension specimen tests

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ABSTRACT

To assess the efficiency of the Equivalent Initial Flaw Size (EIFS) concept in the life estimation of mechanical components, a novel approach is outlined in this paper. For this purpose, experimental tests are conducted on the compact tension specimens made of 4340 steel and the number of cycles required for the crack to grow from the end of the notch up to the fracture of the specimen is counted. In fact, the fatigue cycling for the pre-crack initiation is a part of cycle count procedure and it is assumed that an initial micro-crack exists at the end of the notch, which grows due to fatigue loading, the length of which is estimated using the EIFS method. Three methods of back extrapolation, Kitagawa–Takahashi diagram, and time to crack initiation are used in order to estimate EIFS and their results are compared. For estimating EIFS by Kitagawa–Takahashi diagram, the threshold value of the stress intensity factor (ΔK_{th}) is required. In this paper, ΔK_{th} is estimated by both K-increasing and K-decreasing methods. The experimental results show that the value of ΔK_{th} estimated by the K-increasing method is lower than that estimated by K-decreasing method. It is observed that the estimated EIFS by back extrapolation method and TTCI method is dependent on the loading amplitude, while the estimated EIFS by Kitagawa–Takahashi diagram is identical for all loading amplitudes and it can be considered as the material property. The predicted life based on the Kitagawa–Takahashi method is in relatively good agreement with the experimental results. However, the TTCI method does not have sufficient accuracy especially in low amplitude fatigue.

1. Introduction

Fracture mechanics based life prediction is an applicable method in industry especially in aerospace industries. It has been a research topic of many international organizations such as AGARD, ASTM, NASA, and CAE from 1992 up to present [1]. In this concept, it is always assumed that an initial crack (similar to the crack which forms and initiates from voids) exists in the specimen. Of course, this assumption is not far away from reality for many industrial components which experience defects during their manufacturing processes.

The numbers of cycles are usually determined according to the available fatigue models, such as the Paris model (1).

$$N_f = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m} \tag{1}$$

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Nomenclature

a	crack length
a_c	critical crack length
a_f	final crack length
a_i	initial crack length
B	specimen thickness
C	coefficient of Paris equation
E	Young's modulus
K	stress intensity factor
K_{IC}	fracture toughness
K_{max}/K_{min}	maximum/minimum stress intensity factor
m	exponent of Paris equation
N	number of cycles
N_e	experimental measured life
N_f	predicted life
P	load
P_{max}/P_{min}	maximum/minimum load
V	crack mouth opening displacement
W	specimen width
da/dN	fatigue crack growth rate
$g_s(a)$	small crack growth curve
$g_L(a)$	large crack growth curve
ΔK	cyclic stress intensity factor
ΔK_{th}	threshold value of cyclic stress intensity factor
ΔP	load amplitude
ΔP_f	load limit corresponding to fatigue limit
$\Delta\sigma_f$	fatigue limit
EIFS	equivalent initial flaw size
IFS	actual initial flaw size

In this relation, the upper limit of the integral can be calculated according to fracture toughness of the material. However, calculation of the initial crack length (a_i) is one of the problems of this method. The initial crack length can be measured by NonDestructive Tests (NDTs). However, the initial flaw size (IFS) can be below the current detection capability of the NDT technique. If the NDT detection limit is chosen as the initial flaw size, it will result in a very conservative design [2]. In addition, the behavior of a small crack growth is complicated and is dependent on the microstructures of the material. The crack growth behavior of small and large crack growth rate curves have been compared in Fig. 1. It is useful to distinguish between small cracks and short cracks. For a small crack, all of its dimensions are similar to or smaller than the dimension of greatest microstructural significance, such as the average crystal grain size or the average reinforcement particle spacing. However, a short crack has a dimension that is large compared with the microstructure. The behavior of a small crack can be profoundly affected by the microstructure. For example, while the crack is within a single crystal grain in a metal, the growth rate is much higher than expected from the usual da/dN versus ΔK curve, as illustrated by Fig. 1. Upon encountering a grain bound-

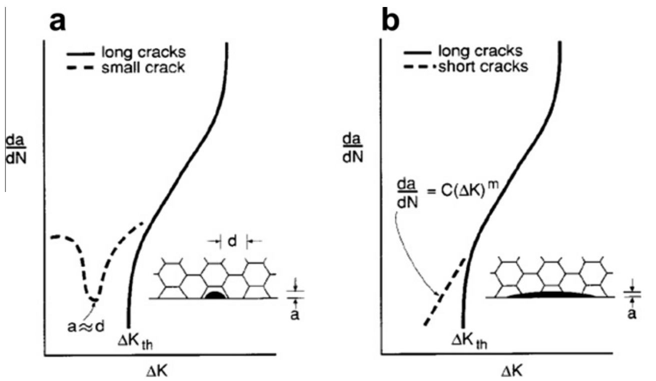

Fig. 1. Comparison between (a) small and (b) large crack growth rate curves [2].