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AN APPROACH TO PREDICTION FOR NATURALLY SHORT FATIGUE CRACK GROWTH BEHAVIOURS

W.Z.Jiang and B.Q.Xu
Beijing University of Aeronautics and Astronautics
Beijing, P.R.China

Abstract

A reasonable method for predicting naturally short fatigue crack growth(NSFCG) behaviours was proposed, good predictions relating to the actural experimental was achieved. This provided a better prospect in ultilizing NSFCG behaviours to damage tolarate design and life estimation of components.

1. Introduction

Considered that the process of fatigue damage of most engineering components in service conditions is acturally a process of NSFCG, which involved the crack growth under conditions of greatly diminished shielding effect[1], so the growth rates for short crack are found to be greater than those for long crack at the same apparent driving force[2]. Furthermore the rapid NSFCG rates are also confirmed at applied stress intensity levels well below the low R-ratio long crack threshold value. Consequentely, it is very impotant that the component design and life calculation based on damage tolerent design concepts must take the NSFCG behaviours[3] into consideration.

In this paper, a mothed for the prediction of NSFCG curves based on a reasonable inference was proposed, and its prediction ability was quite good.

2. Inference

It was suggested that the closure effect might play an important role in crack growth especially near the threshold regime. As Navarro's equation[4] was ultilized to describe the NSFCG process and it is pointed to be in the first grain, the threshold condition might be shown as

$$K_{th,int} = Y\sigma_{fl}(\pi D/2)^{1/2} \qquad (1)$$

in which a short crack growth is of almost no shielding effect, where $K_{th,int}$ is the intrisic threshold, σ_{fl} is the fatigue limit, D is the average grain size, Y is the geometrical factor of stress intensity of short crack concerned.

On the other hand, in constant K_{max} decreasing-ΔK test the growth rate of long crack would finally reach an effective threshold $\Delta K_{th,int}$, and in regime near the $\Delta K_{th,int}$ the crack propagated also in the same situation of almost no shielding effect as mentioned above.

Therefore, considered that the $K_{th,int}$ might be equivalent the $\Delta K_{th,eff}$ and in the regime near the $\Delta K_{th,eff}$ of long crack growth curves there is surely a point in which the data equivalent to data of the velley point on the lower limit curve of NSFCG(at this time the initially short crack tip reaches approximately to the first grain boundary) at a certain applied stress.

Thus, a method for predicting NSFCG behaviours proceeded on the following way:

1. Take data(da/dN,ΔK_{eff}) from a point near the $\Delta K_{th,eff}$ located on the curve obtained in constant K_{max} decreasing-ΔK test, and take it equivalent to the data(dc/dN,$\overline{K}$) of a velley point on the lower limit NSFCG curve at a certain applied stress, in which

$$\Delta K = Y\sigma(\pi D/2)^{1/2} \qquad (2)$$

The corresponding applied stress level driving NSFCG consequentely can be given from equ.(2).

2. With the applied stress level given above, the ultimate tensile strength σ_u, the intrisic threshold $K_{th,int}$ (=$\Delta K_{th,eff}$) and the stress intensity $\overline{K}$, the critical demensionless crack size parameter n_c associated the minimal dc/dN at the velley point on lower limit curve in Navarro's equation can be calculated as

$$n_c = \cos\left[\frac{\pi}{2}\frac{\sigma}{\sigma_u}\left(1 - \frac{\Delta K_{th,int}}{\overline{K}}\sqrt{n_c}\right)\right] \qquad (3)$$

3. At the same time, suppose the velley point rate dc/dN equivalent to the long crack growth rate da/dN selected and take c=D/2, then the factor f interprected as the fraction of dislocations on the slip band which participate in process of crack extension can be calculated by

$$f = da/dN \Big/ \left[\frac{2(1-\nu)}{G}\sigma c\,\frac{\sqrt{1-n_c^2}}{n_c}\right] \qquad (4)$$

where G is the shear modulus, υ is Poisson's ratio.

4. If data of three or more points are selected from the regime near the effective threshold and a least squares fit are performed, a relevant function between σ and f and a family of NSFCG curves σ-dc/dN-c can be predicted.

3. Verification

Test material and its properties

300M steel was used as a test material, its chamical compositions(wt%): 0.39C, 0.91Cr, 1.12Ni, 0.63Mn, 0.4 Mo, 0.07N, 1.61Si. Heat treatment: austenitize 870℃, two tempers 300℃, prior austenite grain size D=0.025mm. Mechaical properties: σ_u 2015MPa, $\sigma_{0.2}$ 1727MPa, δ_5 12.5%, ψ 52.9%, σ_{-1} 853MPa, ΔK_{th} 5.35MPa$\sqrt{m}$ (R=0.1).

Constant K_{max} decreasing-ΔK test

Fig.1 displays the results of constant Kmax decreasing-ΔK test with Kmax=22.2MPa(m) and 11.1MPa(m) . Since two curves all approach to the effective threshold($\Delta K_{th,eff}$ = 3.07MPa$\sqrt{m}$), the regime near $\Delta K_{th,eff}$ of two curves are close to each other, it provide convenience in taking data from these regimes.

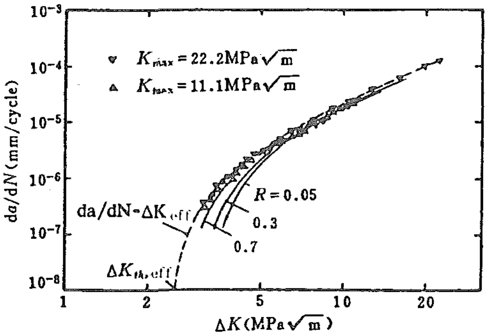

Fig.1 Long fatigue crack growth behaviours of 300M steel

Predicting NSFCG behaviours

Three sets of pairs(da/dN,ΔK_{eff})were taken from data of

Table 1. Experimental and predicted parameters

selected long crack growth data		predicted corresponding NSFCG parameters		
da/dN (m/cycle)	ΔK_{eff} (MPa$\sqrt{m}$)	σ (MPa)	n_c	f
$3.39{*}10^{-11}$	3.26	904.7	0.9991	0.0341
$1.00{*}10^{-10}$	3.45	957.5	0.9965	0.0481
$2.15{*}10^{-10}$	3.62	1004.6	0.9962	0.0678

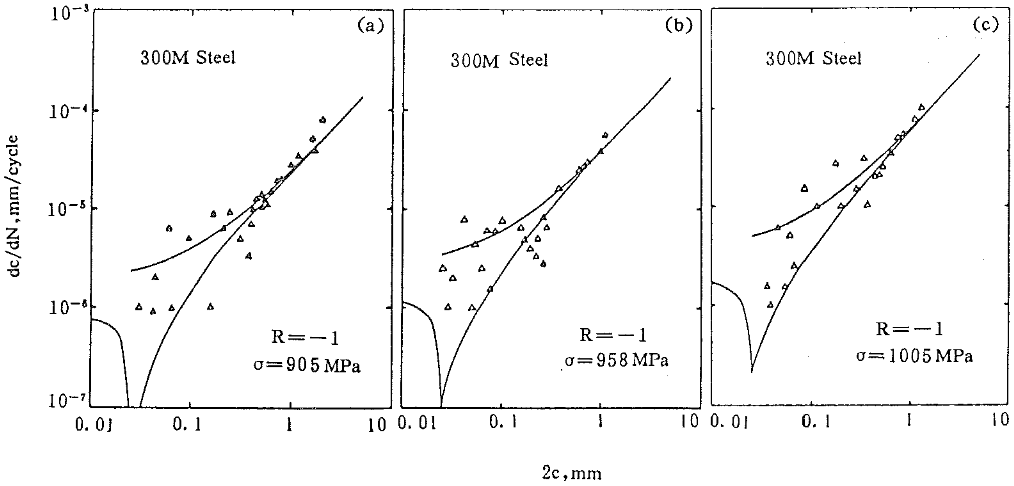

Fig.2 Comparison of experimental NSFCG data of 300M steel with predicted upper and lower limit curves

near $\Delta K_{th.eff}$ growth curve in constant K_{max} decreasing-ΔK test, corresponding NSFCG parameters calculated were listed in Table 1 and a power law expression such as

$$f = 1.4921\ 10^{-21}\ \sigma^{6.5467} \qquad (5)$$

which represented a good relation between values of f and σ shown in Table 1.

Comparison between experimental and calculated results

Three sets of NSFCG test proceeded on stresses listed in Table 1, all experimental data(dc/dN,2c) were shown in Fig.2a,b,c respectively. The upper and lower limit curves derived by calculated parameters were shown in corresponding figures as well, in which the values of geometrical factor Y determined by surface crack size parameter t/R and t/c (Fig.3) on the cylinder specimen[5], where t/c was taken as 0.8 approximately which agreed with the fractograph analysis, and curves predicted involved most of experimental data obviously. For further verifing the prediction ability of this method a series of experimental life N_{exp} compared with corresponding predicted life N_{pre} were shown in Fig.4. the scatter factor covered most experimental data were equal to 1.3 lower than the usual value of 2 or more, so the prediction ability was improved evidently.

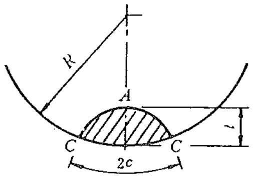

Fig.3 Surface crack size parameters of smooth cylinder specimen

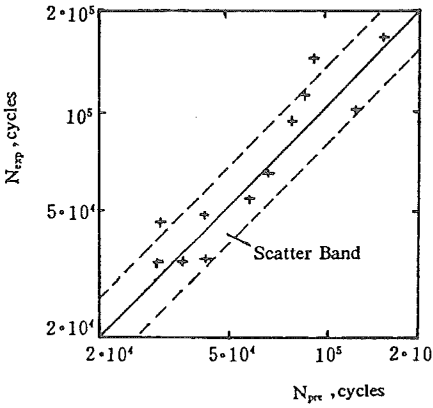

Fig.4 comparison of experimental life with predicted life of 300M steel

4. Conclusion

It was supposed that the long crack growth behaviours near effective threshold in constant K_{max} decreasing-ΔK test can be equivalent to the behaviours of naturally short fatigue crack which approach to the first grain boundary at a certain applied stress. As this was introduced in NSFCG equation developed by A.Navarro, the closure effect was considered and the NSFCG behaviours itselves were predicted also, so the procedure described above provides a good prospect in ultilizing NSFCG behaviours to damage tolarate design and life estimation of engineering structures and components.

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