Low Cycle Fatigue Behaviour of Smooth and Notched Specimens

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1. Introduction

One of the important problems that should be cleared up in low cycle fatigue design is to what extent the theoretical stress concentration factor K_t due to structural discontinuity, weld defect and the like would be allowed from a viewpoint of reduction of low cycle fatigue strength. Fatigue strength reduction factor K_f in low cycle fatigue has been investigated by Manson et al., Iida, Krempl, Kawamoto et al., Udoguchi et al., Hickerson et al., Sakabe et al., Watanabe et al., Ohuchida et al., Liebrich, Saal and others. The results of these investigations, however, are divided into two groups: the one concludes by giving the relation $K_f \leq K_t$ and the other leads the relation $K_f > K_t$.

For the purpose of obtaining a basis for definite interpretation of K_f in low cycle fatigue, strain- and load-controlled fatigue tests were carried out for smooth and notched specimens of the same material, and possibly defined K_f values were discussed in connection with the "A"-factor in USAS Code B31.7.

2. Material Tested and Testing Method

Smooth and grooved cylinder specimens with the geomtry and dimensions shown in Fig. 1 were machined out of 70 mm thick mild steel plate.

Cyclic characteristics of surface strain at the notch root were measured by strain gauges of 0.2 mm gauge length which were applied longitudinally with the transverse center line of the gauge located at the minimum cross section of the specimen. By appling alternating axial load, both smooth and notched specimens were tested by two methods: (1) diametral natural strain controlled and (2) axial load controlled conditions. All fatigue tests were performed with reversed strain or stress cycling of triangular wave shape at the cycling rate ranged from 2 through 12 cpm. Loading was started with tension phase.

3. Results

One-eighths of cylinder body was divided into about 350 elements with nodal points of about 200, and elasto-plastic strain distribution in the minimum cross section of a specimen was calculated by FEM. Good agreement was found between calculated and measured longitudinal total strain amplitudes at a notch root as illustrated in Fig. 3, in which the abscissa stands for the controlled value in the diametral strain controlled test.

In Fig. 4 the equivalent strain amplitude $\epsilon_{eq,a}$ is plotted against visible crack initiation life N_c , that is defined as number of cycles to initiation of a surface crack 0.2 to 0.5 mm in length. The $\epsilon_{eq,a}$ was calculated, with the assumption of constant volume in plastic deformation, by substituting measured value of axial total strain amplitute and controlled value of diametral total strain amplitude. It is observed in Fig. 4 that the N_c value may by approximately same if the $\epsilon_{eq,a}$ would be equal for any K_t value. This observation may lead to a conclusion that K_f is, in principle, nearly equal to plastic strain concentration factor K_ϵ. Plotting K_f and K_ϵ against nominal stress amplitude revealed good agreement between these values.

Definitions of K_f that were previously proposed by Iida and Kremple are summarized in Table 1 (cf. Fig. 2). In Figs. 5 to 9 the K_f for any K_t value are plotted as a function of nominal stress amplitude in load controlled test or in stable stage of diametral strain controlled test. Excluding cases of Figs. 7 and 9, K_f is larger than K_t.

The A-factor in the USAS B31-7 (1969) was calculated and plotted in Fig. 10. Large discrepancy between the present results and the given value by B31-7 may provide discussion basis about the K_e-factor in ASME Boiler and Pressure Vessel Code Sec. III (1971).

4. Conclusions

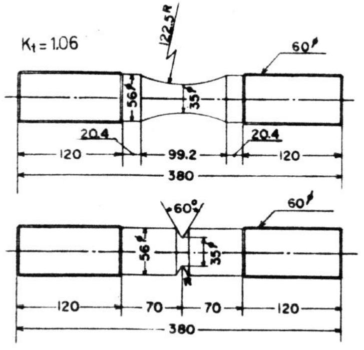
(1) A visible surface crack 0.2 to 0.5 mm long will initiate at the notch root of a grooved cylinder specimen with any shape factor at an approximately same number of cycles, if the same equivalent strain at the notch root would be applied as the measure of evaluating strain amplitude.

(2) Fatigue strength reduction factor that is derived from strain cycling tests on smooth and notched specimen would be approximately equal to the dynamic plastic strain concentration factor.

Table 1 Definitions of Fatigue Strength Reduction Factor

Method	Controlled Value	Use of Dynamic Stress Versus Strain Curve of Smooth Specimen	Definition
Iida's	$\epsilon(S)$ $\epsilon(N)$	No Use	$\epsilon(S)/\epsilon(N)$
Krempl's Ia	$\epsilon(S)$ $S(N)$	$S(N) \longrightarrow \epsilon^*(N)$	$\epsilon(S)/\epsilon^*(N)$
Krempl's Ib	$\epsilon(S)$ $S(N)$	$\epsilon(S) \longrightarrow S^*(S)$	$S^*(S)/S(N)$
Krempl's II	$\epsilon(S)$ $S(N)$	No Use	$E\cdot\epsilon(S)/S(N)$
Stress Amp.	$S(S)$ $S(N)$	No Use	$S(S)/S(N)$

Note: $\epsilon^*(N)$ and $S^*(S)$ are figured on a S-ϵ curve as a corresponding value to $S(N)$ and $\epsilon(S)$ respectively.



Notch Radius R (mm)	1.05	2.80	4.90
K_t	3.49	2.49	2.01

Fig. 1 Details of Specimens

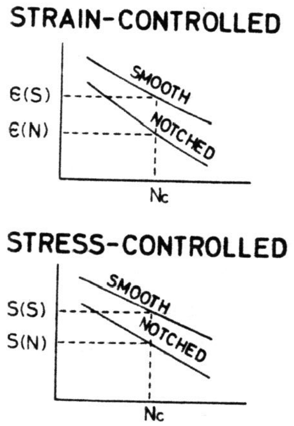


Fig. 2 Controlled Values in Table 2

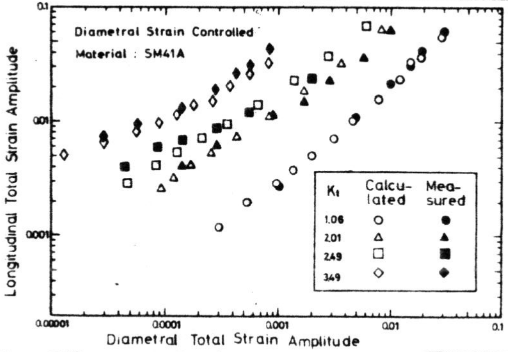


Fig. 3 Comparison of Measured and Calculated Longitudinal Strain Amplitudes

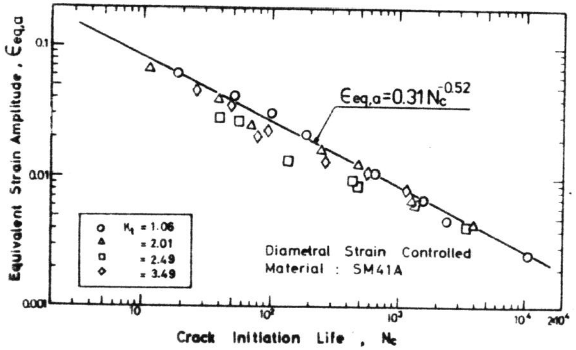


Fig. 4 Equivalent Strain Amplitude vs. N_C

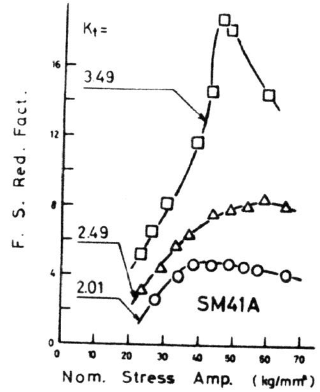


Fig. 5 K_f by Iida's Method

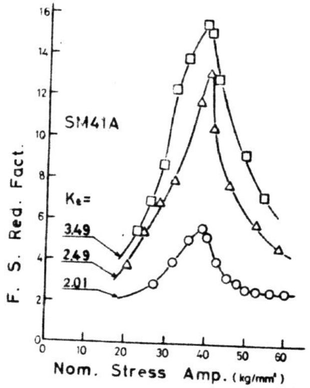


Fig. 6 K_f by Krempl's Ia Method

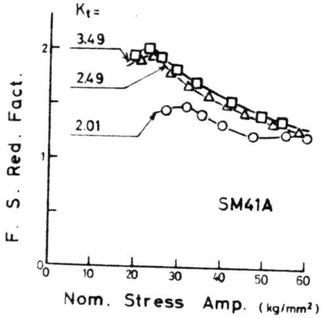


Fig. 7 K_f by Krempl's Ib Method

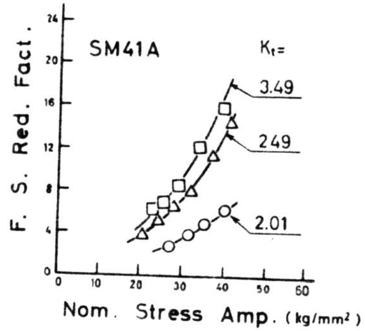


Fig. 8 K_f by Krempl's II Method

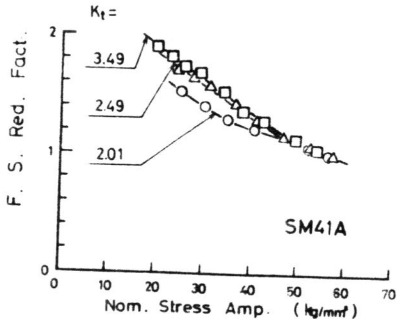


Fig. 9 K_f by Stress Amplitude Ratio

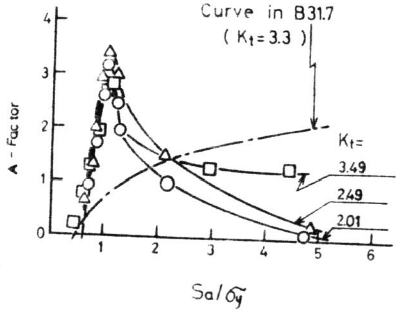


Fig. 10 "A"-factor vs. Modified Stress Amplitude