THE EFFECT OF CRACK NUCLEATION ON PRE-LOADING IN STRESS CORROSION CRACKING OF HIGH STRENGTH STEEL

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ABSTRACT

The effect of pre-loading on crack initiation was investigated by using AISI 4340 steel.
The main results were summarized as follows:
(1) Without pre-loading of notched specimens, the life to crack nucleation at the notch root was found to be determined by the quotient of the stress intensity factor divided by the square root of notch tip radius.
(2) Stress corrosion cracks were formed from the notch on three different planes: the original notch plane and two inclined plates to the notch. The crack plane changed depending on environments, notch-root radii and stress levels.

INTRODUCTION

Load variation will induce the residual stress field near the tips of a notch or a crack and subsequent cracking will be affected by residual stress (1-4).

In the present paper, a method to evaluate the load variation was proposed on the basis of residual stress calculations near a notch or a crack tip.

EXPERIMENTAL PROCEDURE

The material used was AISI 4340 steel (wt%: 0.39C, 0.27Si, 0.77Mn 0.019P, 0.014S, 0.13Cu, 1.77Ni, 0.83Cr, and 0.17Mo). The yield strength is 1530 MPa. The specimen is of compact tension type (5-7). The radius of the notch tip, ρ, was 0.25, 0.5, 1.25 mm

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and the thickness, B, was 5.5 mm.

The stress intensity factor (SIF) value, K, was calculated from the load for blunt notches. It is SIF for blunt notches ρ =0. The corrosive environment were in distilled water, 3.5 % NaCl and 0.1 N H_2SO_4 solution.

RESULTS AND DISCUSSION

Stress corrosion cracks were formed from the notch on three different planes: the original notch plane and two inclined planes to the notch. The direction of crack in original notch plane was observed with distilled water and 3.5 % NaCl solution. In the case of 0.1 N H_2SO_4 solution, crack was observed into three directions. The crack plane changed depending on environments, ρ value and stress levels.

Figure 1 shows the relation between K_1 and crack nuc'eation time, t_n for specimens with and without pre-load. The t_n is increased with increasing value of K_2 when compared with $K_2 = 0$ at a same K_1.

The maximum stress and hydrostatic pressure at the notch root are given by

$$\sigma_{max} = 2K / (\pi \rho)^{1/2} \qquad \text{Eqn. (1)}$$

Thus, the stress field can be characterized by σ_{max} and ρ.

The stress distribution inside the plastic zone ω ($\omega \leq 3.18\rho$) is obtained from the slip line solution as (8).

$$\sigma_y = \sigma_Y \left[1 + \ln(1 + x/\rho)\right] \qquad \text{Eqn. (2)}$$

$$\sigma_x = \sigma_Y \ln(1 + x/\rho)] \qquad \text{Eqn. (3)}$$

The normal stress and hydrostatic stress take the maximum value at $x = \omega$, and the magnitude of the maximum stress σ_y is given by

$$\sigma_y = \sigma_Y \left[1 + \ln(1 + \omega/\rho)\right] \qquad \text{Eqn. (4)}$$

This is an approximate solution because σ_x and σ_z are not continuous at the elastic-plastic boundary.

Compressive residual stresses are built up near the notch root of the specimen subjected to pre-overloading. Thus, the real maximum stress ρ_{eff} at the notch bottom under K_1 is given as

$$\sigma_{eff} = \sigma_{1max} + \sigma_r \qquad \text{Eqn. (5)}$$

Where σ_{1max} is determined by substituting K_1 into Eqn. 1 and σ_r is the residual stress. The residual stress σ_r is determined as the maximum stress σ_y at K_2 minus the maximum stress due to unloading.

$$\sigma_r = \sigma_y - \sigma_{2max} \qquad \text{Eqn. (6)}$$

where σ_{2max} is determined from Eqn. 1 by use of K_2. The results shown in Fig. 1 are replotted in Fig. 2 as the relation between σ_{eff} thus calculated. It is found that crack nucleation life was determined by σ_{eff} and was expressed as three straight lines depending on environment.

SYMBOLS USED

K_1	=	Stress intensity factor in second applied (MPa $\sqrt{m}$)
K_2	=	Stress intensity factor in first applied (MPa $\sqrt{m}$)
ρ	=	Notch tip radius (mm)
σ_{max}	=	Maximum stress (MPa)
σ_{1max}	=	Maximum stress in second applied (MPa)
σ_{2max}	=	Maximum stress in first applied (MPa)
σ_r	=	Residual stress (MPa)

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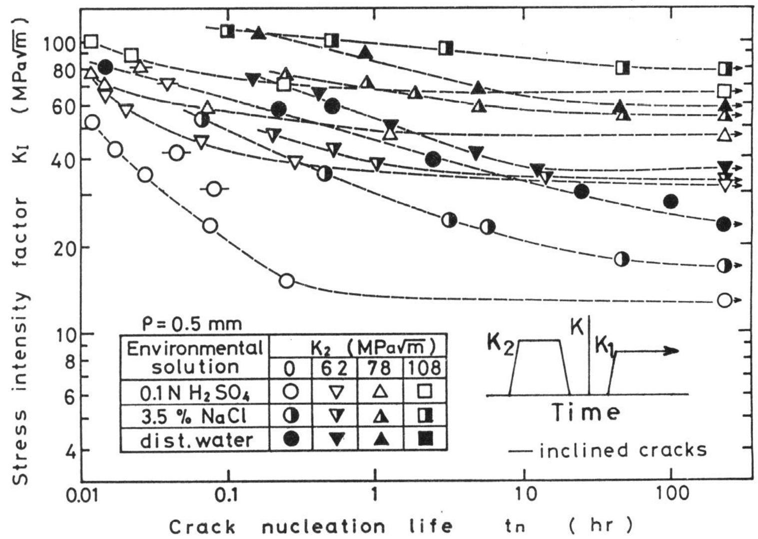

Fig. 1 Relation between stress intensity factor and crack nucleation life.

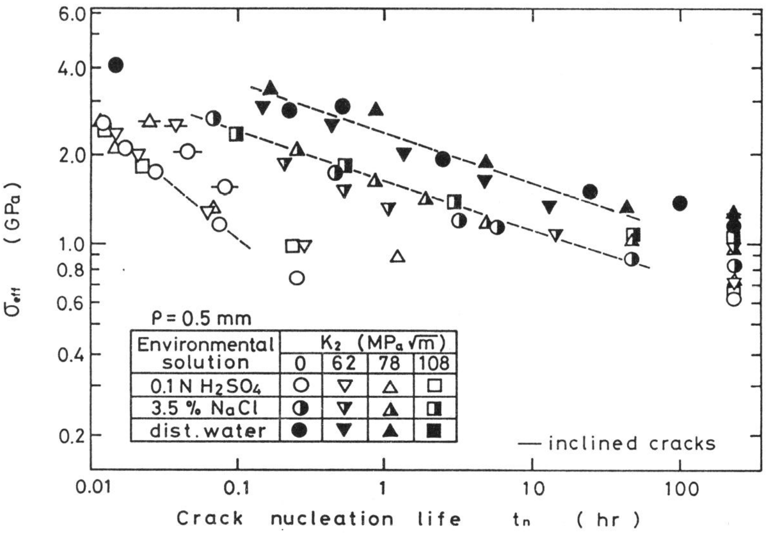

Fig. 2 Relation between σ_{eff} and crack nucreation life.