INITIATION OF SHORT CRACKS AT NOTCHES BY FATIGUE

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INTRODUCTION

The initiation of fatigue cracks at notches of different root radii (ρ) but constant depth was studied by Jack and Price[1] in 1970. Based on standard LEFM formulae, they treated the notches as sharp cracks to enable an estimate of the effect of the notch root to be made in terms of the stress intensity range, ΔK. Jack and Price found a linear relation between log N_i, the number of cycles to crack initiation, and log $(\Delta K/\rho^{\frac{1}{2}})$. Their data also supported calculations indicating that a notch having a root radius less than 0.25 mm could be considered equivalent to a sharp crack.

The findings of Jack and Price were confirmed by two, independent, studies[2,3]. However in one of these, Barsom and McNicol[3], working on a high-strength steel, found a different linear relationship between log N_i and log $(\Delta K/\rho^{\frac{1}{2}})$ for each value of root radius, ρ, considered. These plots collectively appeared to converge on a limiting value of $(\Delta K/\rho^{\frac{1}{2}})$, which Barsom and McNicol termed the initiation threshold, below which cracks would not be initiated.

Barsom and McNicol related empirically the static yield stress (σ_y) of their material to the initiation threshold

$$(\Delta K/\rho^{\frac{1}{2}})_{threshold} = 0.6\ \sigma_y \qquad \ldots\ldots 1$$

This formula was revised, first by Rolfe and Barsom[4], to

$$(\Delta K/\rho^{\frac{1}{2}})_{threshold} \simeq 9.5\ (\sigma_y)^{2/3} \qquad \ldots\ldots 2$$

and again by Barsom[5] to

$$(\Delta K/\rho^{\frac{1}{2}})_{threshold} \simeq 26\ (\sigma_y)^{\frac{1}{2}} \qquad \ldots\ldots 3$$

Kim et al[6] confirmed Barsom's final relationship[5] and their data showed that little difference resulted from replacing the monotonic yield stress by the cyclic yield stress.

The work to be described re-examines the Barsom approach to a fatigue crack initiation threshold, but using a quenched and tempered steel of lower yield strength than hitherto.

EXPERIMENTAL PROCEDURE

A 0.15%C 1.5%Mn constructional steel, quenched and tempered to a tensile strength of 450 MWm^{-2} and a yield strength of 350 MNm^{-2}, was studied. Specimens 12.5 mm thick x 25 mm wide x 110 mm long were machined from hot-rolled plate and heat-treated. A transverse notch of depth 10 mm and root radius either 10, 5, 2, 1 or 0.5 mm was cut after heat-treatment: The notch root was polished to a 5 µm finish. Fatigue tests in three-point bend at R = 0.1 and 100 Hz were made on an Amsler Vibrophore. Crack initiation was taken to be the point at which a crack was first observed at the notch root when viewing the side of the specimen through a telescope.

RESULTS AND DISCUSSION

The test data is presented in the form log N_i V log $(\Delta K/\rho^{\frac{1}{2}})$ in Fig. 1 and it is apparent that a relation of the form first found by Jack and Price does not appear to be reasonable in this instance. However if

Barsom's most recent expression (eq. 3) is used to provide a threshold value for $(\Delta K/\rho^{\frac{1}{2}})$ then this is close to the initiation level found experimentally and is also in the region where individual lines constructed for each root radius would be expected to converge, again supporting the work of Barsom.

The results can also be analysed in a different manner, using the model of Smith and Miller[7] which allows the calculation of stress intensities at small cracks sited at the base of notches. Their expression, rearranged,

$$\ell = \frac{1}{\pi}\left(\frac{\Delta K}{[1 + 7.69\sqrt{(D/\rho)}]^{\frac{1}{2}}\Delta\sigma}\right)^2 \quad ..... \; 4$$

where ℓ = crack length

D = notch depth

$\Delta\sigma$ = the applied alternating stress across the notch

ρ = notch radius

allows an estimate to be made of the size of defect that must be produced by initiation processes before fatigue crack growth under fracture mechanics control can occur. For this, a particular value of ΔK needs to be used, namely, that of the threshold stress intensity for fatigue crack growth ΔK_{th}. Fortunately, a suitable measurement of ΔK_{th} ($\approx$7MN $m^{-3/2}$) for this material was available[8] which made it possible to calculate the crack sizes necessary for growth, appropriate to the specimen geometries and loading conditions used experimentally. These crack sizes were then related to the relevant initiation lives, log N_i, as shown in Fig. 2. A well-delineated trend is followed by all the data for the range of notch root radii considered. It appears that if a crack longer than 1 mm has to be formed by the initiation processes, then initiation is inhibited and the specimen will not fail by fatigue. This philosophy can be followed for all notches and loading situations to which the Smith-Miller model is applicable.

CONCLUSIONS

A study of crack initiation at notches under fatigue loading of a quenched and tempered, low-carbon, alloy steel has added support to the findings of Barsom and, in particular, his expression

$$(\Delta K/\rho^{\frac{1}{2}}) \simeq 26(\sigma_y)^{\frac{1}{2}}$$

Furthermore, the Smith-Miller model for the estimation of stress-intensities in these circumstances can be linked with crack-growth threshold data. In this way an estimate can be made of the upper limit to crack-size required to be formed by initiation processes in order to inhibit failure by fatigue.

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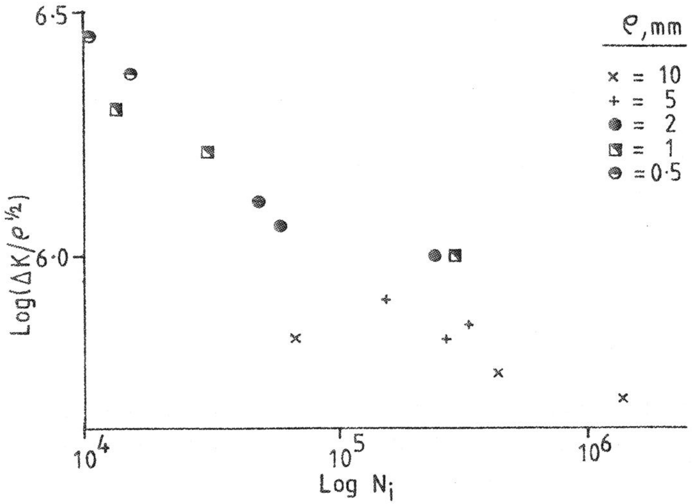

Fig.1. Initiation Life (N_i) v. Notch Stress Intensity Parameter ($\Delta K/\rho^{\frac{1}{2}}$)

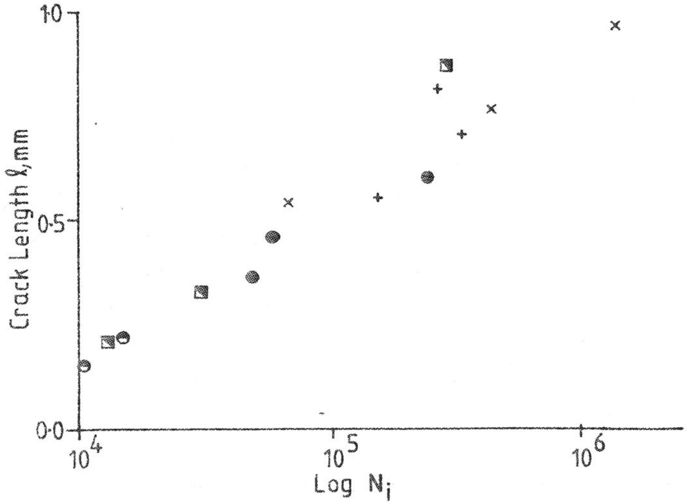

Fig.2. Initiation Life (N_i) versus Crack Length (ℓ)