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Short-crack modelling of the effect of corrosion pits on the fatigue limit of a 12% Cr steel

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EPRI organised an international research project [1], where ultrasonic testing was used to determine the fatigue limit of plain specimens of 12% Cr steel at $R > 0$ with artificially produced, sub-mm size corrosion pits. Moreover, the plain fatigue limit of uncorroded specimens was determined at $R > 0$, and fatigue-crack-growth testing, including the threshold, was carried out at R-values ranging from -1 to 0.9. This comprehensive set of fatigue data constitutes an ideal basis for investigating the capability of a variety of methods to predict the fatigue limit of pitted specimens.

A pre-pitting procedure was used to produce single, nearly spheroidal corrosion pits as shown in Fig. 1. The semi-width-to-depth ratio r/d was typically around 0.5. It was therefore decided to model two extremes: a semi-spherical pit with $r/d = 1$ and a cylindrical "pit" with $r/d = 0$. To simplify the analysis, the fatigue behaviour of the semi-spherical surface pit was approximated by that of a spherical *pore* in a wide body.

Consider an annular crack of depth a at the equator of a spherical pore. For a shallow crack, $a \ll a^*$, the asymptotic stress intensity factor is given by

$$\Delta K = 1.12 K_t \Delta S \sqrt{\pi a},\ \ K_t = \{\nu = 0.3\} = 2.05, \tag{1}$$

for a deep crack, $a \gg a^*$, by

$$\Delta K = (2/\pi)\Delta S \sqrt{\pi(a + r)}. \tag{2}$$

Interpolation between the two asymptotes, in good agreement with a numerical solution presented by Murakami [2], is accomplished through

$$\Delta K = (2/\pi)\Delta S \sqrt{\pi(a + \theta r)}, \quad 0 \le \theta < 1, \tag{3}$$

where the interpolation function θ is defined as

$$\theta = 1 - \mathrm{e}^{-a/a^*}, \quad a^* = r/(k^2 - 1), \quad k = 1.12 K_t/(2/\pi). \tag{4}$$

The driving force for fatigue-crack growth is assumed to be given by an "equivalent" stress-intensity range, ΔK_{eq}, based on original ideas by El Haddad and Härkegård as recently described by Zambrano and Härkegård [3]. Formally, ΔK_{eq} is obtained by adding to the physical crack depth, a, a suitably chosen "intrinsic" crack depth, a_0. Thus, for a shallow annular crack, $a \ll a^*$, the asymptotic ΔK_{eq} is

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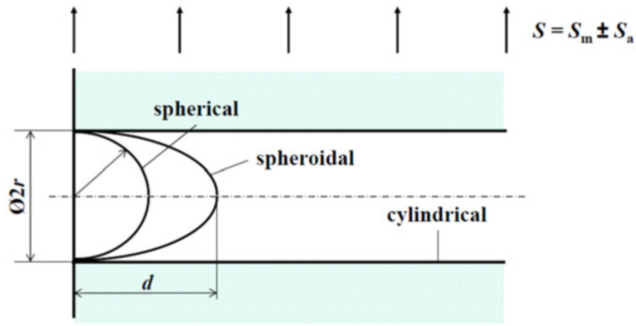

Figure 1. Idealised geometry of corrosion pit in member subjected to a uniaxial stress cycle.

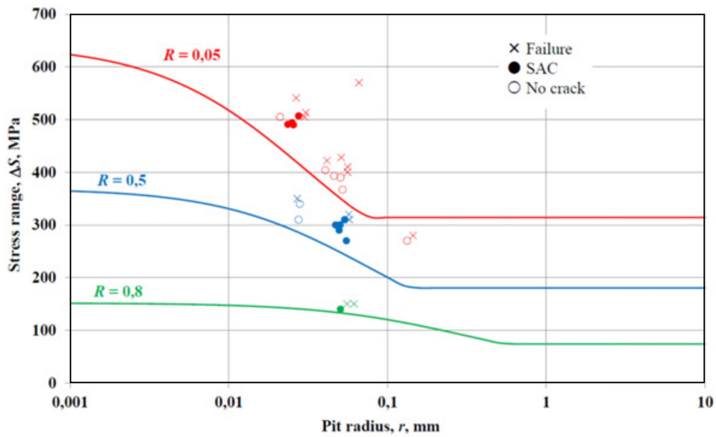

Figure 2. Predicted fatigue limit and fatigue test data for plain specimens with single corrosion pits.

given by

$$\Delta K_{eq} = 1.12 K_t \Delta S \sqrt{\pi (a + a_{0s})}, \quad a_{0s} = (1/\pi)(\Delta K_{th}/1.12 \Delta\sigma_A)^2, \tag{5}$$

for a deep crack, $a \gg a^*$, by

$$\Delta K_{eq} = (2/\pi)\Delta S \sqrt{\pi(a + r + a_{0d})}, \quad a_{0d} = (1/\pi)(\Delta K_{th}/(2/\pi)\Delta\sigma_A)^2. \tag{6}$$

Interpolation between the two asymptotes is obtained by

$$\Delta K_{eq} = (2/\pi)\Delta S \sqrt{\pi \left[a + \theta r + \theta a_{0d} + (1-\theta) K_t^2 a_{0s}\right]}. \tag{7}$$

By adjusting ΔS so that $\Delta K_{eq,min} = \Delta K_{th}(R)$, the model predicts the fatigue limit of a specimen with a single corrosion pit. Fig. 2 shows the predicted fatigue limit, ΔS, vs. the (semi-spherical) pit radius, r, for three different stress ratios. In the same diagram have been plotted data from ultrasonic fatigue testing [1]. Three categories of data points have been identified: "failure" from a few 100 000 cycles and upwards, and "no crack" or a (short) "self-arrested crack" (SAC) observed after more than 10^9 cycles. With the exception of an odd data point at $r > 0.1$mm, predictions are conservative. Clearly, the predictions for a cylindrical "pit" ($r/d = 0$) would fall below those for the semi-spherical pit. Investigations of the predictive capability of other criteria such as those due to Smith and Miller [4] and Murakami [5] are ongoing.

References

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