MEASUREMENT OF ΔK_{Th} VALUES OF CRACKS NUCLEATING IN SMOOTH SURFACES, USING AN ACPD METHOD

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ABSTRACT

The suitability of using an AC potential drop technique for measuring very small growth rates has been investigated. Values of ΔK_{Th} for short cracks initiating in smooth surfaces have been obtained for different R-ratios. These are compared with the corresponding values for long cracks. The effect of crack length on threshold values has also been observed.

KEYWORDS

AC potential drop; fatigue initiation; threshold stress intensity factors; short cracks; crack growth rates; inclusions.

INTRODUCTION

Very little attention has been devoted to the study of fatigue crack initiation from metallurgical discontinuities as opposed to artificial notches (Yokobori, 1976). It has already been shown that a high frequency AC potential drop method can be used in an unconventional way to detect and measure fatigue cracks initiating from smooth surfaces (Jutla, 1983; 1984). It was considered that since the technique is capable of detecting very small fatigue cracks (of the order of 10μm), it might be applicable to the measurement of growth rates in the threshold region. Although the actual growth of small cracks is a very complex process involving interactions of many effects (Lankford, 1980), it should be noted that the threshold measurements made by the authors are of an exploratory nature, based on incremental observations of crack length.

MATERIAL

The material used was a carbon-manganese mining steel, hardened from 900°C and tempered at 600°C. The chemical composition and some of the mechanical properties are given in Table 1. This steel is typical of that used for haulage and winding gear in the British mines, as described in BS2772: 1977.

TABLE 1 Chemical Composition and Mechanical Properties of the Material Used

Element	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	B
Wt.%	0.13	0.34	1.43	0.01	0.017	0.12	0.09	0.06	<0.01	0.05	<0.005

Yield Stress (MPa)	510
Ultimate Tensile Stress (MPa)	584
Vickers Hardness (30 Kg.)	203

EXPERIMENTAL PROCEDURE AND RESULTS

The type of specimen used in this investigation is shown in Fig.1. A high

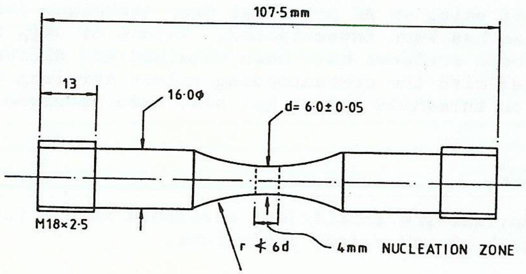
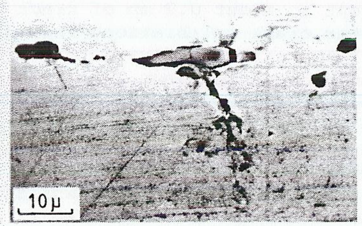


Fig. 1. "Hour-glass" type push-pull fatigue specimen.

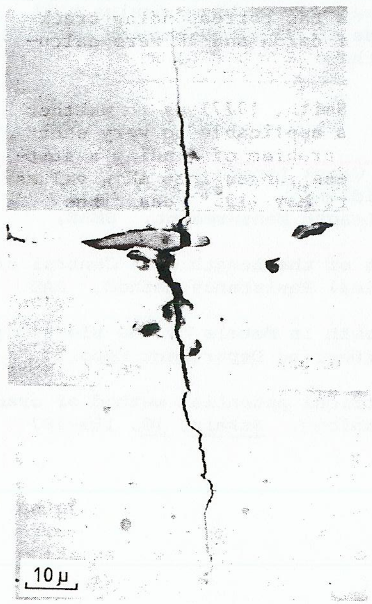
frequency (8 KHz) alternating current was passed through the specimen by a Testwell "CPD2" ACPD crack measurement unit. By placing a set of probes across the central 6mm band, the potential drop was measured across the nucleation zone. Details of measuring the PD in this way are well described elsewhere (Jutla, 1983; 1984). The potential drop was continuously monitored on a time-base chart recorder.

At an R-ratio (= $\sigma_{min}/\sigma_{max}$) of 0.1, a specimen was fatigued until a PD of 8μV had occurred and the test was stopped. The central surface of the specimen was then subjected to a thorough examination in the scanning electron microscope. Figure 2 shows nucleation occurring from a duplex (MnS and Al_2O_3) type inclusion; this was the only nucleation site in the specimen. The specimen was then replaced in the fatigue machine in the same position and orientation, and subjected to a new set of reduced loads, in accordance with the size of the crack present as discussed below. Growth was again monitored using the AC potential drop equipment. Figure 2 shows some of the successive crack advances which were photographed, and Fig. 3, shows the PD/crack length calibration curve.

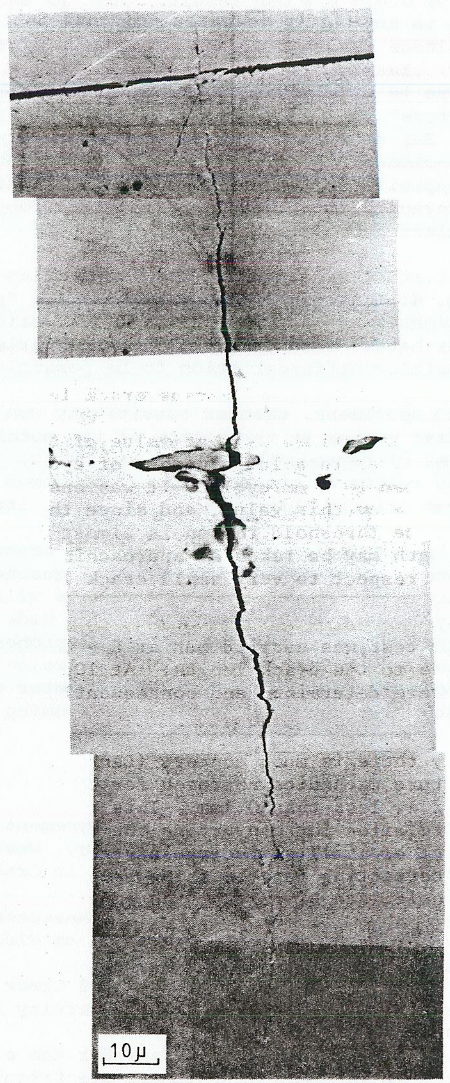


(i) N = 1.6 x 10^5

(ii) N = 3.4 x 10^5



(iii) N = 9.7 x 10^5



(iv) N = 1.3 x 10^6

Fig. 2. Crack growth from a duplex inclusion

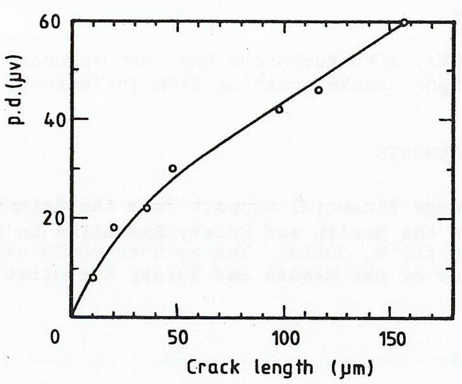


Fig. 3. Pd versus crack length calibration curve

Threshold was defined as that value of ΔK below which no appreciable crack growth occurred in a large number of cycles, i.e. so that the growth rate was less than 10^{-7} mm/cycle. It was ensured that all the growth rates were kept well below this value, and since the gradient of the da/dN versus ΔK curve in the threshold region is almost infinity, the value of ΔK for each crack length may be taken as approaching ΔK_{Th}. In this way the variation of ΔK_{Th} with respect to very small crack lengths was observed in a single specimen.

A further test was carried out at R = 0.25, using just the calibration curve as a guide to the crack length. At 10μV intervals the corresponding crack lengths were determined and consequently values of da/dN and ΔK were calculated.

Currently there is much concern (Lankford, 1980; Smith, 1977) as to whether the fracture mechanics approach for long cracks is applicable to very short cracks, i.e. less than 0.1mm. This presented the problem of finding a suitable correlation for converting the threshold stress ranges into ΔK_{Th} values for growth of small semi-circular cracks. However, May (1968) describes that by correcting for the shape factor the following relationship may be used to calculate ΔK for surface embedded flaws;

$$\Delta K = \Delta\sigma \sqrt{\frac{1.2\pi a}{2.2}}$$

This equation was therefore adopted for ΔK calculations.

Table 2 shows ΔK_{Th} values for R = 0.1 calculated using the crack length determined from the scanning electron micrographs presented in Fig. 2. Table 3 shows ΔK_{Th} values for R = 0.25 calculated using the PD/crack length calibration curve. The variations of ΔK_{Th} and $\Delta\sigma_{Th}$ with crack length are given in Fig. 4.

DISCUSSION

The growth behaviour of the fatigue crack near the threshold is known to be dependent on the crack length. Many researchers (Frost, 1963; 1964; Usami and Shida, 1979) have reported that the threshold range of stress intensity factor, ΔK_{Th}, decreases with decreasing crack length. A more detailed study carried out on a high strength steel by Kitagawa and Takahashi (1976) indicated that the ΔK_{Th} value decreased when the crack length was shorter than about 0.13mm and the threshold value of the stress, $\Delta\sigma_{Th}$, approached the fatigue limit of the smooth specimen for extremely short cracks. Smith (1977) expanding on the work of Kitagawa and Takahashi showed that the minimum crack size at which linear elastic fracture mechanics controlled the threshold behaviour was related to a subgrain slip-band.

TABLE 2 ΔK_{Th} values for R = 0.1 calculated using the crack lengths determined from the scanning electron micrographs

Average crack length, a x 10^{-3}mm	da/dN mm/cycle x 10^{-8}	$\Delta\sigma_{Th}$ MPam$^{\frac{1}{2}}$	ΔK_{Th} MPam$^{\frac{1}{2}}$
11.25	7.03	462	2.03
20.5	5.139	466	2.771
36.5	6.08	456	3.62
48.5	3.82	453	4.15
98.0	12.8	431	5.61
116	3.9	396	5.6
157	7.67	375	6.2

TABLE 3 ΔK_{Th} values for R = 0.25 calculated using the PD/crack length calibration curve

Potential difference, V, x 10^{-4}	Crack length a, x10^{-3} mm	da/dN mm/cycle x 10^{-8}	$\Delta\sigma_{Th}$ MPam$^{\frac{1}{2}}$	ΔK_{Th} MPam$^{\frac{1}{2}}$
0.10	12	3.26	438	2.0
0.20	25	2.40	434	2.05
0.30	56	4.54	430	3.15
0.40	90	7.90	408	3.12
0.50	124	5.20	396	3.03
0.60	158	6.22	371	2.84

The present results, Fig.4, show that the threshold stress range, $\Delta\sigma_{Th}$, approaches the fatigue limit for cracks shorter than 60μm. Figure 4 also indicates that ΔK_{Th} rapidly decreases below about 60 - 100μm.

Although two points are not sufficient to establish the variation of ΔK_{Th} with the R-ratio, it is, however, seen that the present values (taken at a = 100μm) are comparable with the values obtained by Blacktop (1981) and

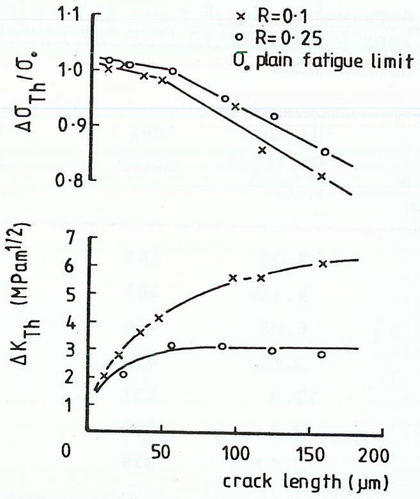


Fig. 4. Variation of ΔK_{Th} and $\Delta\sigma_{Th}$ with crack length for cracks growing from alumina inclusions.

Cadman (1981) for long cracks in the same material, Fig. 5. It is also seen that threshold values for short cracks are noticeably lower than the corresponding values for long cracks.

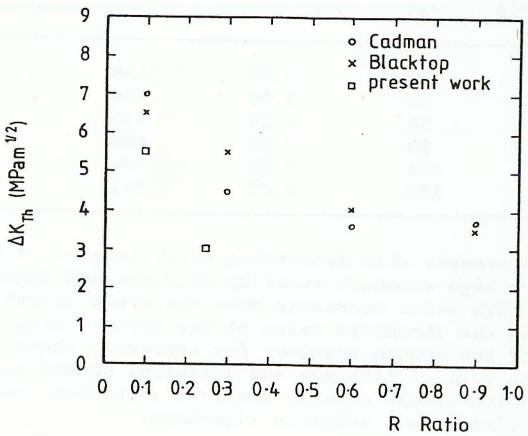


Fig. 5. Comparison of ΔK_{Th} values for long cracks and short cracks. Cadman and Blacktop results represent ΔK_{Th} values for long cracks.

CONCLUSION

A high frequency (8KHz) ACPD technique has been successfuly used to measure ΔK_{Th} values for fatigue cracks starting from inclusions.

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