MEASUREMENT OF $\Delta K_{th}$ 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 $\Delta K_{th}$ for short cracks initiating in smooth surfaces have been obtained for different F-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 10$\mu$m), 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

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Ni</th>
<th>Cr</th>
<th>MnO</th>
<th>V</th>
<th>Cu</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. %</td>
<td>0.13</td>
<td>0.34</td>
<td>1.43</td>
<td>0.01</td>
<td>0.017</td>
<td>0.12</td>
<td>0.09</td>
<td>&lt;0.01</td>
<td>0.05</td>
<td>&lt;0.005</td>
<td></td>
</tr>
</tbody>
</table>

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 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 6μm 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.

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

At an R-ratio (= c_{min}/c_{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 Al2O3) 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.

Fig. 2. Crack growth from a duplex inclusion

(i) N = 1.6 x 10^5
(ii) N = 3.4 x 10^5
(iii) N = 9.7 x 10^5
Threshold was defined as that value of $\Delta K$ 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 $\Delta K$ curve in the threshold region is almost infinity, the value of $\Delta K$ for each crack length may be taken as approaching $\Delta K_{th}$. In this way the variation of $\Delta K_{th}$ 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 $\Delta K$ 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 $\Delta K_{th}$ 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 $\Delta K$ for surface embedded flaws:

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

This equation was therefore adopted for $\Delta K$ calculations.

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

### Table 2

<table>
<thead>
<tr>
<th>Average crack length, $a$ x 10^-3 mm</th>
<th>$da/dN$ mm/cycle x 10^-8</th>
<th>$\delta \sigma_{th}$ MPa</th>
<th>$\Delta K_{th}$ MPa^-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.25</td>
<td>7.03</td>
<td>462</td>
<td>2.03</td>
</tr>
<tr>
<td>20.5</td>
<td>5.139</td>
<td>466</td>
<td>2.771</td>
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<tr>
<td>36.5</td>
<td>6.08</td>
<td>456</td>
<td>3.62</td>
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<tr>
<td>48.5</td>
<td>3.82</td>
<td>453</td>
<td>4.15</td>
</tr>
<tr>
<td>98.0</td>
<td>12.8</td>
<td>431</td>
<td>5.61</td>
</tr>
<tr>
<td>116</td>
<td>3.9</td>
<td>396</td>
<td>5.6</td>
</tr>
<tr>
<td>157</td>
<td>7.67</td>
<td>375</td>
<td>6.2</td>
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### Table 3

<table>
<thead>
<tr>
<th>Potential difference, $a$ x 10^-3 mm</th>
<th>$da/dN$ mm/cycle x 10^-8</th>
<th>$\delta \sigma_{th}$ MPa</th>
<th>$\Delta K_{th}$ MPa^-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>12</td>
<td>3.26</td>
<td>438</td>
</tr>
<tr>
<td>0.20</td>
<td>25</td>
<td>2.40</td>
<td>434</td>
</tr>
<tr>
<td>0.30</td>
<td>56</td>
<td>4.54</td>
<td>430</td>
</tr>
<tr>
<td>0.40</td>
<td>90</td>
<td>7.90</td>
<td>408</td>
</tr>
<tr>
<td>0.50</td>
<td>124</td>
<td>5.20</td>
<td>396</td>
</tr>
<tr>
<td>0.60</td>
<td>158</td>
<td>6.22</td>
<td>371</td>
</tr>
</tbody>
</table>

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 $\Delta K_{th}$ rapidly decreases below about 60 - 100µm.

Although two points are not sufficient to establish the variation of $\Delta K_{th}$ 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...
CONCLUSION

A high frequency (8kHz) AGFD technique has been successfully used to measure $\Delta K_{\text{th}}$ values for fatigue cracks starting from inclusions.

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REFERENCES