EFFECT OF STRESS LEVEL ON FATIGUE CRACK DELAY BEHAVIOUR

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INTRODUCTION

In recent years there have been numerous studies investigating the interaction effects on fatigue crack propagation due to simple overload type of loading sequences (e.g. [1 – 4]). There is generally a significant reduction in the growth rate following the application of the overload. There may be an initial slight increase in the growth rate but overall there is a net delay in the number of cycles. The number of delay cycles generally increases with increasing ratio of the overload level to the maximum fatigue loading level. Alcos, et al, [4] observed that an underload following the overload decreases the amount of delay. The load sequence he used (and also used in this study) is shown in Figure 1. Alcos defined the following parameters in terms of the applied stress intensity levels shown in Figure 1:

\[
\begin{align*}
Q_{OL} &= \frac{K_{OL}}{K_{MAX}} \\
R_{OL} &= \frac{K_{OL}}{K_{MIN}} \\
R_{M} &= R_{OL} \\
R_{M} &= R_{MIN} \\
R_{M} &= R_{MAX}
\end{align*}
\]

(1)

Using these parameters he generated two test matrices to investigate the effect of each parameter on the delay behaviour. For these matrices

Matrix A:  
\[
R_{M} = 0.22 \\
Q_{OL} = 1.6, 1.8, 2.2 \\
R_{M} = -1.0, -0.5, 0.01, 0.22, 0.3
\]

Matrix B:  
\[
Q_{OL} = 1.8 \\
R_{M} = 0.11, 0.22, 0.30 \\
R_{M} = -1.0, -0.5, 0.01, 0.22, 0.3
\]

where tests were run for each combination of parameters. For all of the tests, \( K_{OL} \) was 50.6 MPa-m². Specifying \( K_{OL} \) plus \( Q_{OL} \), \( R_{MG} \) and \( R_{M} \) completely specifies the load levels. Alcos observed that the parameters \( R_{MG} \) and \( Q_{OL} \) had a significant effect on the delay but there was little or no effect due to \( R_{M} \).

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This study was undertaken to investigate the effect of keeping each of the parameters, \( R_\infty \), \( R_y \), and \( R_{OL} \) constant and varying the stress intensity levels. The test matrix selected consisted of:

\[
\begin{align*}
    & R_{OL} = 1.8 \\
    & R_y = 0.22 \\
    & R_\infty = -1.00, -0.5, 0.01, 0.22 \\
    & K_{OL} = 11.0, 16.5, 22.0, 27.5, 36.0 \text{ MPa} \cdot \text{m}^{1/2}
\end{align*}
\]

This test matrix is shown in Figure 2, where the results from Allos's study were used for the last row of tests. The specimens were from the same lot as those used by Allos and the same test method was followed. Comparing results down each column of the matrix isolates the effect of increasing load level.

**EXPERIMENTAL PROCEDURE**

The specimens tested in this study were centre crack panels, 559 by 152 x 2.54 mm thick. The material was 2024-T3 aluminum alloy loaded parallel to the direction of rolling. Crack length was measured with a 100x microscope mounted on a measuring traverse. For recording the data, the microscope was advanced a specified increment and the number of cycles required to grow the crack that distance was recorded. The fatigue cycling was at 20 Hz with the overload/underload applied at 0.02 Hz. Once an overload was applied the fatigue cycling was not interrupted until the test was terminated. The fatigue cycling was run under quasi-constant stress intensity levels by shedding the load to maintain \( K \) within three percent of the desired value. Lightweight aluminum compression guides lined with felt were used to support the specimen when a compressive underload was applied. A dessicant was enclosed in plastic sheet around the centre of the specimen to assure the same environmental conditions. These procedures were identical to those used by Allos which permits direct comparison of the test results.

**RESULTS**

The crack length versus number of cycles were plotted for each of the tests and are presented in matrix form in Figure 3. The number of delay cycles, \( N_\infty \), and the overload affected zone, \( z_{OL} \), were determined for each test and are presented along with the loading parameters in Table 1. Sufficient data were recorded to permit determining the growth rate through the overload affected region. The minimum growth rate that occurred following the overload is also listed in Table 1.

As can be seen in Figure 3 there is a significant effect due to \( R_\infty \) on the delay behaviour. This is the same as observed by Allos. The influence of the loading level is better visualized by examining the number of delay cycles, \( N_\infty \), versus \( K_{OL} \) as shown in Figure 4. The results for constant values of \( R_\infty \) are shown in this figure, i.e., each column of the test matrix. Decreasing \( K_{OL} \) below 22 \text{ MPa} \cdot \text{m}^{1/2} \) caused a marked increase in the number of delay cycles. Increasing the level of \( K_{OL} \) above this same level also caused an increase in the number of delay cycles for positive values of \( R_\infty \).

**REFERENCES**

Table 1: Loading Parameters and Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>K_{OL}</th>
<th>R_{OL}</th>
<th>N_0</th>
<th>N_{OL}</th>
<th>da/dN</th>
<th>Min/mm/cycle</th>
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<tbody>
<tr>
<td>10</td>
<td>11.0</td>
<td>-1.0</td>
<td>66,800</td>
<td>0.95</td>
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<tr>
<td>1</td>
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<td>-0.5</td>
<td>91,300</td>
<td>0.12</td>
<td>2.02x10^-7</td>
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</tr>
<tr>
<td>2</td>
<td>11.0</td>
<td>0.01</td>
<td>arrest</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
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<td>-1.0</td>
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<tr>
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</tr>
<tr>
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<td>0.01</td>
<td>arrest</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>128,250</td>
<td>0.16</td>
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</tr>
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<td>6</td>
<td>27.5</td>
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<tr>
<td>10*</td>
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<td>2.48</td>
<td>1.24x10^-4</td>
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<tr>
<td>17*</td>
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<tr>
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<td>19*</td>
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<td>0.22</td>
<td>107,650</td>
<td>3.99</td>
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</tr>
</tbody>
</table>

*From Allon's Original Data

\[ k = 0.22, \sigma_{OL} = 1.8 \]

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Figure 1: Overload/Underload Sequence

Figure 2: Test Matrix Illustrating Stress Intensity Levels for Each Test
Figure 3 Crack Length versus Number of Cycles Following Overload/Underload Sequence

Figure 4 Number of Delay Cycles versus $K_{OL}$ for each $R_{\infty}$ Level