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. Alzos, 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. Alzos defined the following parameters in terms of the applied stress intensity levels shown in Figure 1:

$$Q_{OL} = \frac{K_{OL}}{K_{MAX}} \qquad R_M = \frac{K_{MIN}}{K_{OL}}$$
$$R_{UO} = \frac{K_{UL}}{K_{OL}} \qquad R_F = \frac{K_{MIN}}{K_{MAX}} \tag{1}$$

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

Matrix A: $R_M = 0.22$

$Q_{OL} = 1.6, 1.8, 2.2$

$R_{UO} = -1.0, -0.5, 0.01, 0.22, 0.3$

Matrix B: $Q_{OL} = 1.8$

$R_M = 0.11, 0.22, 0.30$

$R_{UO} = -1.0, -0.5, 0.01, 0.22, 0.3$

where tests were run for each combination of parameters. For all of the tests, K_{OL} was 36.6 MPa·m$^{3/2}$. Specifying K_{OL} plus Q_{OL}, R_{UO} and R_M completely specifies the load levels. Alzos observed that the parameters R_{UO} 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_{UO}, R_M and Q_{OL} constant and varying the stress intensity levels. The test matrix selected consisted of

$$Q_{OL} = 1.8$$

$$R_M = 0.22$$

$$R_{UO} = -1.00, -0.5, 0.01, 0.22$$

$$K_{OL} = 11.0, 16.5, 22.0, 27.5, 36.6 \text{ MPa}\cdot\text{m}^{3/2}$$

This test matrix is shown in Figure 2, where the results from Alzos's study were used for the last row of tests. The specimens were from the same lot as those used by Alzos 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 per cent 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 insure the same environmental conditions. These procedures were identical to those used by Alzos 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_D, 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_{UO} on the delay behaviour. This is the same as observed by Alzos. The influence of the loading level is better visualized by examining the number of delay cycles, N_D, versus K_{OL} as shown in Figure 4. The results for constant values of R_{UO} are shown in this figure, i.e., each column of the test matrix. Decreasing K_{OL} below 22 MPa·m$^{3/2}$ 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_{UO}.

For $K_{OL} = 22$ MPa·m$^{3/2}$

$$\frac{1}{2\pi}\left(\frac{K_{OL}}{\sigma_y}\right)^2 = 0.50 \text{ mm} \qquad (2)$$

which is 1/5 of the specimen thickness, nearly sufficient for plane strain conditions. From Figure 4 it is apparent that the delay behaviour is different under plane strain conditions.

CONCLUSIONS

For each column of the test matrix, the ratios of each of the load levels were held constant and the loading level scaled for each. This permits a direct comparison of the effect of the magnitude of the loading. In the plane strain region decreasing the overload level causes a significant increase in the number of delay cycles.

REFERENCES

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Table 1 Loading Parameters and Test Results

Test No.	K_{OL} MPa·m$^{3/2}$	R_{UO}	N_D	Z_{OL} mm	$\left\|\frac{da}{dN}\right\|_{Min}$ mm/cycle
10	11.0	-1.0	66,800	0.05	1.50×10^{-7}
1	11.0	-0.5	91,300	0.12	2.02×10^{-7}
2	11.0	0.01	arrest	-	-
7	16.5	-1.0	39,850	0.33	3.43×10^{-5}
8	16.5	-0.5	52,820	0.39	2.51×10^{-5}
9	16.5	0.01	52,630	0.46	1.63×10^{-5}
15	16.5	0.22	128,250	0.16	2.27×10^{-6}
3	22.0	-1.0	10,400	0.25	1.31×10^{-4}
4	22.0	-0.5	18,875	0.24	7.49×10^{-6}
5	22.0	0.01	31,150	0.21	1.78×10^{-6}
14	22.0	0.22	77,750	0.69	6.40×10^{-6}
11	27.5	-1.0	16,450	0.92	2.35×10^{-5}
12	27.5	-0.5	22,880	0.80	1.37×10^{-5}
6	27.5	0.01	34,300	1.02	8.71×10^{-6}
13	27.5	0.22	75,200	1.41	2.19×10^{-6}
16*	36.6	-1.0	13,540	2.48	1.24×10^{-4}
17*	36.6	-0.5	17,700	3.32	1.08×10^{-4}
18*	36.6	0.01	47,680	4.53	2.52×10^{-5}
19*	36.6	0.22	107,650	3.99	1.99×10^{-6}

*From Alzos' Original Data

$R_m = 0.22$, $Q_{OL} = 1.8$

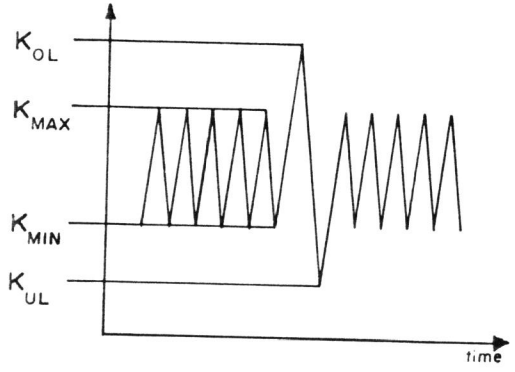

Figure 1 Overload/Underload Sequence

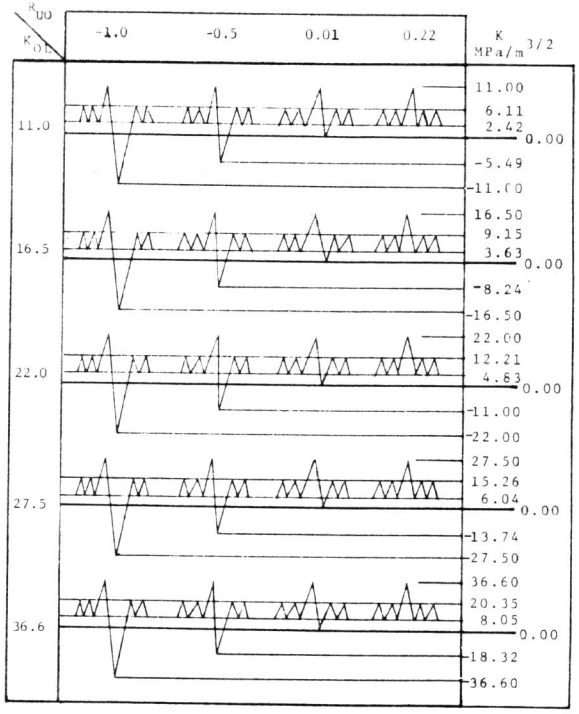

Figure 2 Test Matrix Illustrating Stress Intensity Levels for Each Test

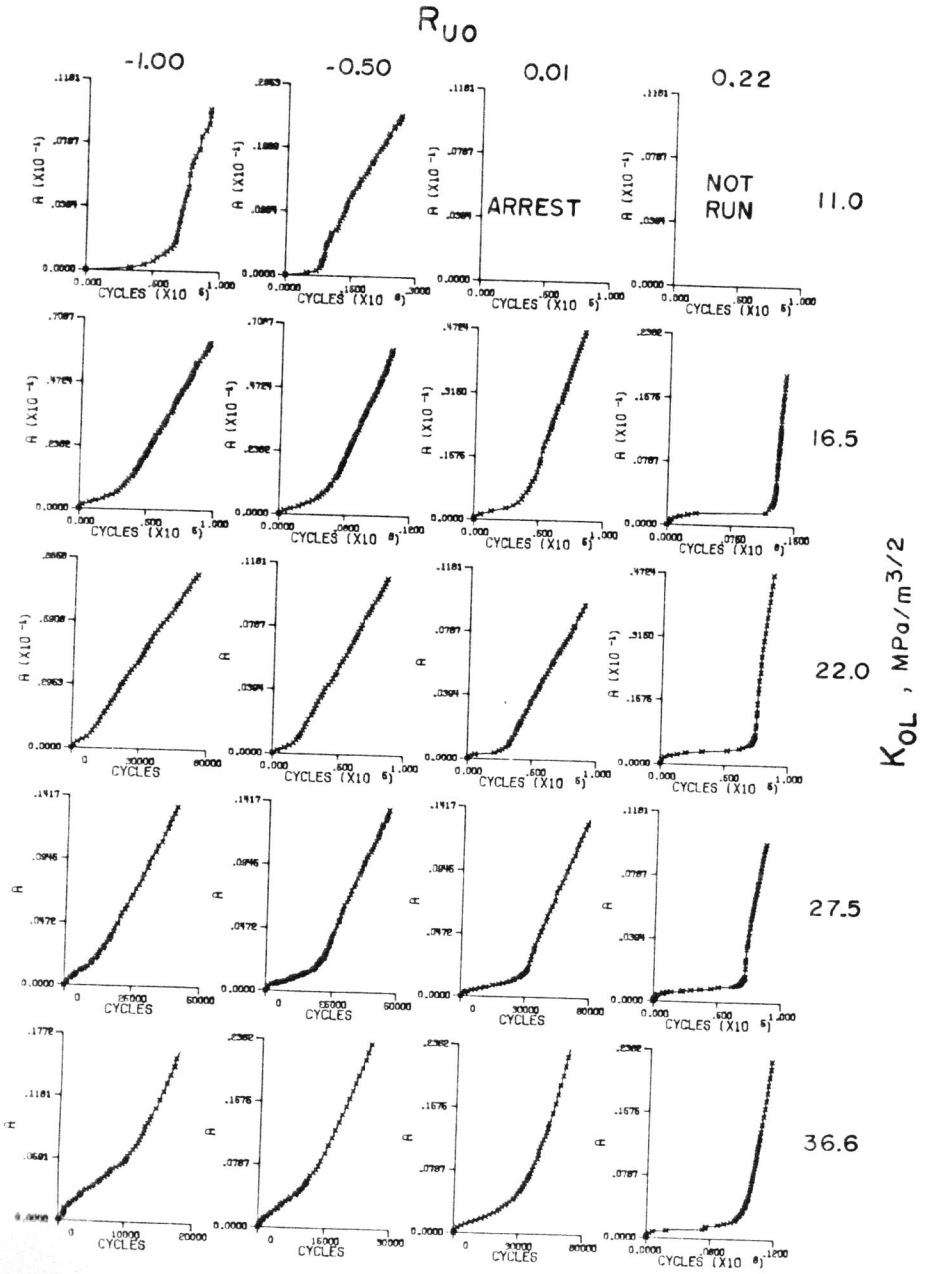

Figure 3 Crack Length versus Number of Cycles Following Overload/Underload Sequence

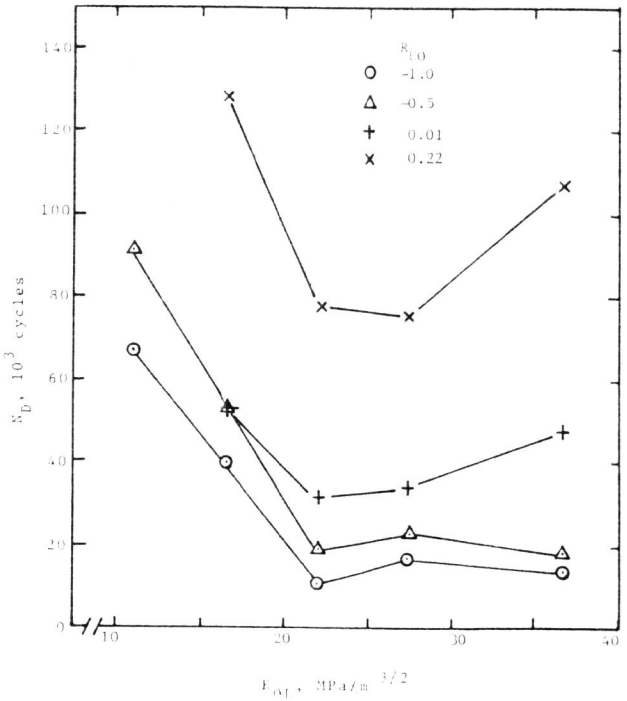

Figure 4 Number of Delay Cycles versus K_{OL} for each R_{UO} Level