FAILURE ANALYSIS - THEORY AND PRACTICE - ECF7

# EFFECT OF REDUCTIONS IN MAXIMUM CYCLIC LOAD ON FATIGUE CRACK PROPAGATION

H. Taylor*, G. Jolley**

## INTRODUCTION

This note examines the delays produced due to reductions in maximum cyclic load and introduces a definition of the delay in terms of the load reduction ratio. The evaluation of delay has been discussed by various investigators in terms of crack length and number of cycles. Obianyor (1) defined the delay in terms of the number of elapsed cycles over a fixed increment of crack growth $(a)^*$ from the point were the change in stress occurred. Others have defined the delay in terms of a resumption in what may be considered as the normal crack growth rate (2). This gives delay as an affected crack length or number of delay cycles to the resumption of the baseline crack growth rate just prior to the change in load conditions. For conditions of constant cyclic load the point at which the behaviour returns to normal is difficult to determine as the nominal stress-intensity increases with increasing crack length. When the cyclic load is reduced an initial reduction is seen in the crack growth rate. The rate will subsequently increase until the conditions of normally increasing growth rate occur, associated with the unretarded behaviour.

## THEORY

The use of the ratio of the maximum stress intensity factors to correlate the delay periods in terms of $N^*$ has been found by some workers (3, 4) to be the main parameter controlling the delay. Crack closure could be expected to account for this type of behaviour, as changes in maximum stress intensity would have a direct influence on the range of the effective stress intensity factor. The delay introduced due to a reduction in the affected crack growth increment or the number of delay cycles. Considering crack tip closure to relate to the maximum stress intensity at the point just prior to the reduction in cyclic stress intensity, the crack growth rate may now be affected until the closure previously determined is removed, subsequent crack growth would then continue unaffected. This condition might be expected to occur when the plastic deformations are of the

* National Nuclear Corporation, Risley, U.K.
** University of Salford, U.K.

same order as the maximum of those previously encountered. At this point the plastic zone formed at the crack tip would hold apart the previously closed crack faces. As the plastic zone size is directly related to K then the retarded behaviour would extend to the point where the maximum stress intensity value equals that just prior to the reduction in block load. Under conditions of normally increasing stress intensity each cycle would cause plastic deformations larger than those from previous cycles. This would alleviate any residual level of closure and would effectively limit closure to the cyclic crack tip.

## RESULTS

Examination of Figure 1 shows a typical plot of the crack growth rate versus crack length, found from experimental data (5). As expected, no point can be found which represents a clear boundary between retarded and unretarded behaviour. Figure 2 shows a plot of the rate of change in crack growth rate versus crack length, showing two distinct regions. These represent regions of (a) reducing and minimum change in crack growth rate and (b) steadily increasing growth rate behaviour. Therefore we could define the extent of the retarded crack growth behaviour as being from the point of reduction in the block load to the return to a steadily increasing rate of change of crack growth. A comparison of the number of delay cycles determined by this method, and those found by use of a fixed increment of crack growth ($a^*$) of 0.5 mm is given in Figure 3. This shows that for lower step-down ratios the difference in delay cycles between the two methods is insignificant, while at higher ratios the difference could become more pronounced, as determination of $a^*$ is more difficult as the changes in crack growth rate become imperceptible. Figure 3 also shows that as the step-down ratio is reduced, a threshold level is reached below which crack arrest occurs, as this lower level is approached the amount of scatter increases. Suresh (6,7,8) studied crack growth behaviour at near threshold stress intensities and concluded that in the presence of crack closure caused by plasticity, surface morphology or oxide formation can cause significant enhancements to the closure mechanism. This type of behaviour could easily explain the scatter found at lower step-down ratios, caused by changes in the relative humidity or crack kinking and branching. Figure 4 shows $a^*$, as defined previously, versus the crack length when K2MAX = K1MAX and shows a good correspondence between the two parameters.

## CONCLUSIONS

1. The ratio of the maximum cyclic stress-intensities is related to the extent of retardation.
2. Below a threshold step-down ratio complete crack arrest occurs.
3. A crack closure model describes steady state load reduction behaviour.

## REFERENCES

1. Obianyor, D.E. et Miller, K.J., J. Strain Anal. 13, 52, 1978.
2. Chanani, G.R., ASTM STP 631, 365, 1977.
3. Jones B.F., Int. J. Fatigue, 6, 75, 1984.
4. Druce, S.G. et al, Eng. Frac. Mech., 11, 385, 1979.
5. Taylor, H., Ph. D. Thesis, Salford, 1986.
6. Suresh, S., Eng. Frac. Mech., 18, 577, 1983.
7. Ritchie, R.O. et Suresh, S., Met. Trans. 13A, 937, 1982.
8. Suresh, S., Met. Trans., 16A, 249, 1985.

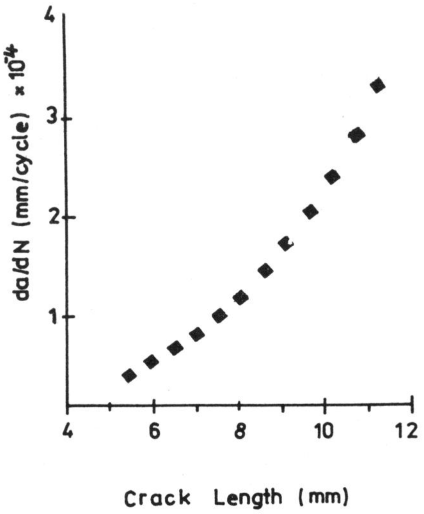

Fig. 1 Crack growth rate versus crack depth.

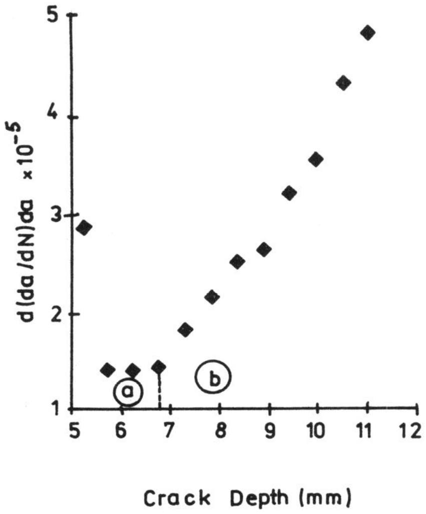

Fig. 2 Difference in crack growth rate versus crack depth.

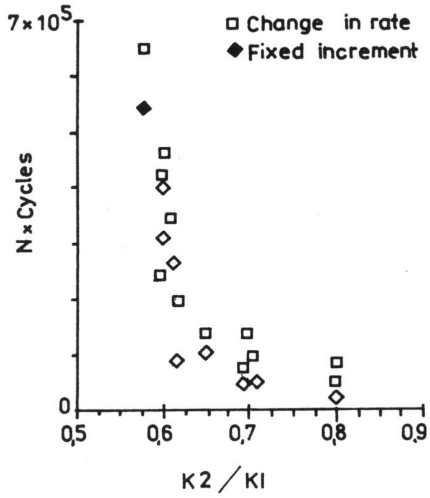

Fig. 3 Delay cycles versus step down ratio.

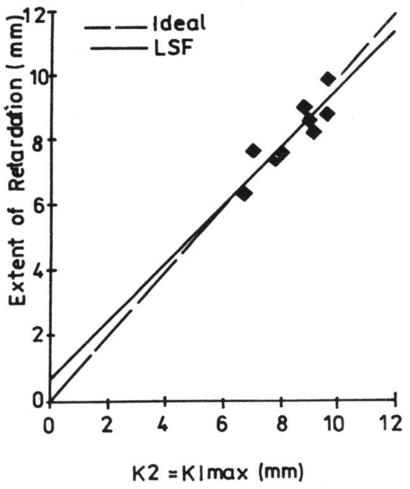

Fig. 4 Correlation between a* and point were K2=Kl.