FREQUENCY EFFECTS AND SLANT FATIGUE CRACK GROWTH

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INTRODUCTION

Earlier experiments on Al-2024, Edwards et al. (1), Zuidema and Blaauw (2), have shown that under constant ΔK loading shearlips on fatigue crack surfaces will develop when ΔKeff Elber (3) exceeds about 6 MPa$\sqrt{m}$. Under constant ΔK loading the shearlip width ts tends to approach an equilibrium value tseq. Assuming that the rate of growth dts/da is proportional to the difference between the steady state value tseq and the actual value ts it was shown that

$$ts = tseq(1 - \exp(-c(a - a0)))\ \text{mm} \qquad (1)$$

fits the experimental data very well (figure 1). It was concluded that tseq and c are functions of ΔKeff. When applied to constant stress amplitude loading it was shown that the formulae of c and tseq could accurately predict the development of shearlip width ts. An important discovery was that at constant ΔK loading the crack growth rate da/dN decreased as the shearlip width increased. At a ΔKeff of about 10 MPa$\sqrt{m}$ a reduction in velocity of a factor 2 to 3 was found. Vogelesang and Schijve (4) demonstrated that the shearlip width is not just determined by mechanical parameters. Environmental conditions play an equally important role. To investigate the relations between crack growth rate, shearlip width and test frequency in air, we performed constant ΔK tests on 6 mm plates of Al-2024-T351 at different frequencies.

EXPERIMENTAL PROCEDURE AND RESULTS

Nine constant ΔK tests at different frequencies were performed on 6 mm thick centre cracked plate specimens. The specimen width was 100 mm. The tests were performed in lab air at a temperature of 20 ± 0.5°C. The relative humidity was 35%. We applied $\Delta K = 18$ MPa$\sqrt{m}$ and $R = 0.1$. With an x-y digital measuring table and a microscope we were able to determine the shearlip width ts as a function of the crack length a. We did this for four quadrants after the specimen was fatigued and broken. The four results were fitted by equation 1, leading to the best fit values of tseq and c for each frequency. During the test the crack growth rate da/dN was determined using a potential drop technique. A typical form of da/dN versus crack length a is shown in figure 2. A data reduction technique was used for this figure. For all frequencies we measured the rate da/dN for ts = 0, da/dN(tens), at the beginning of the constant ΔK test and the da/dN found after 10 mm of crack growth, da/dN (10). Using equation 1 we calculated the shearlip width at this crack length.

In figure 3 da/dN(tens) and da/dN (10) are plotted against the

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frequency. The tensile crack velocity seems to be independent of the frequency whereas da/dN (10) is not. Also ts at this crack length appeared to be frequency dependent. We plotted this ts value against Δ(da/dN) = da/dN(tens) - da/dN (10). The best fit formula found was:

$$ts = 1.63(\Delta(\frac{da}{dN}))^{0.266} \text{ mm} \quad da/dN \text{ in units } (*10\text{-}4 \text{ mm/c}) \qquad (2)$$

The results thusfar indicate that for the given material-environment combination the frequency influence on crack growth rate can be associated with shearlip development, i.e. when no shearlips are present no frequency effect is present (see the table).

To check our findings that tensile mode cracking is frequency independent we performed 3 tests at 0.1, 1 and 10 Hz at ΔKeff = 5 MPa√m in which case the fracture surface was expected to remain tensile (2). The latter was indeed the case. The crack velocities were nearly the same which confirmed our conjecture. To test the usefulness of equation 2 for other thicknesses we performed a constant ΔK test on a 10.3 mm thick plate with again ΔK = 18 and R = 0.1. The frequency used was 17.5 Hz. We measured Δ(da/dN) = 1.85 (*10-4 mm/cycle). Using equation 2 this leads to ts = 1.9 mm. Measuring the shearlip width gives ts = 3.2 mm. The conclusion is that the formula cannot be used for other thicknesses. This is not too strange if the effect of shearlips at different thicknesses is considered. At the same ΔKeff we have almost the same shearlip width for 6 and 10.3 mm thick plate specimens (2). It may be clear that the effect of a special shearlip width will be greater for a thin specimen where the shearlips form a greater part of the total thickness t. Therefore we suspect that the relative shearlip width 2ts/t is a better measure for the decrease in velocity due to shearlip development. We changed equation 2 to (figure 4):

$$2ts/t = 1.63/3 \left\{(da/dN)\right\}^{0.266} \text{ mm} \qquad (3)$$

When we now apply Δ(da/dN) = 1.85(*10-4 mm/cycle) we find ts = 3.2 mm which is a remarkably good result. However, more tests have to be performed, and are in progress, to check equation 3.

CONCLUSIONS

1. The shearlip width ts increases with increasing frequency in air.
2. The velocity da/dN decreases with increasing frequency.
3. The tensile mode velocity da/dN(tens) is frequency independent.

REFERENCES

(1) Edwards, R.A.H., De Jong, E.M. and Zuidema, J., "The fracture mode transition and its effect on crack growth retardation", Proceedings of fatigue 84, edited by C.J. Beevers, University of Birmingham, England, 1984.

(2) Zuidema, J. and Blaauw, H.S., "The effect of shear lips on fatigue crack growth in Al2024 sheet material", Proceedings of the third international conference on fatigue and fatigue thresholds, University of Virginia, Charlottesville, USA, 1987.

(3) Elber, W., "Fatigue crack closure under cyclic tension", ASTM STP 486, 1971.

(4) Vogelesang, L.B. and Schijve, J., Fat. Eng. Mat. Struct., 3, pp. 85-98 (1980).

TABLE

freq. Hz	da/dN(tens) $*10^{-4}$ mm/c	da/dN(10) $*10^{-4}$ mm/c	Δda/dN $*10^{-4}$ mm/c	ts(10) mm	t mm	ΔKeff MPa√m
0.05	8.63	8.36	0.27	1.1	6	9.72
0.1	8.41	7.80	0.61	1.4	6	9.72
0.25	9.41	8.30	1.11	1.8	6	9.72
0.5	8.63	7.42	1.21	1.8	6	9.72
1	8.97	6.75	2.22	2.1	6	9.72
2.5	8.63	5.76	2.87	1.9	6	9.72
5	8.63	5.54	3.09	2.2	6	9.72
10	8.41	4.65	3.76	2.5	6	9.72
17.5	8.75	3.54	5.21	2.4	6	9.72
17.5	9.52	7.67	1.85	3.2	10.3	9.72
0.1	1.20	-	-	-	6	5
1	1.23	-	-	-	6	5
10	1.10	-	-	-	6	5

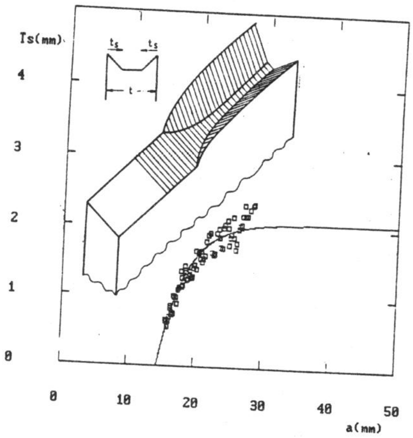

Fig. 1 Shearlip development in a constant ΔK test. freq. = 2.5 Hz.

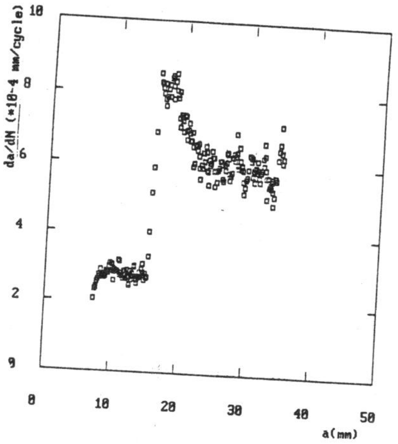

Fig. 2 da/dN versus a for increasing shearlip. freq. = 2.5 Hz.

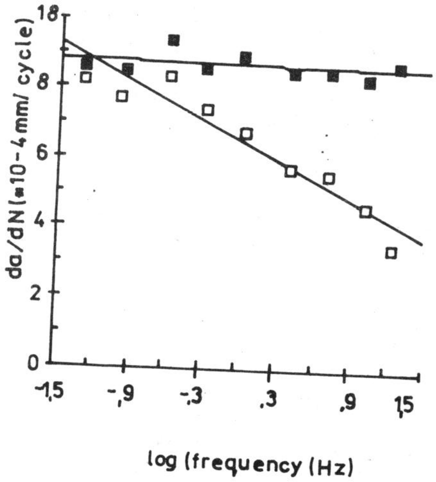

Fig. 3 da/dN(tens) and da/dN(10) versus freq. (Hz). ΔKeff = 9.72 MPa√m.

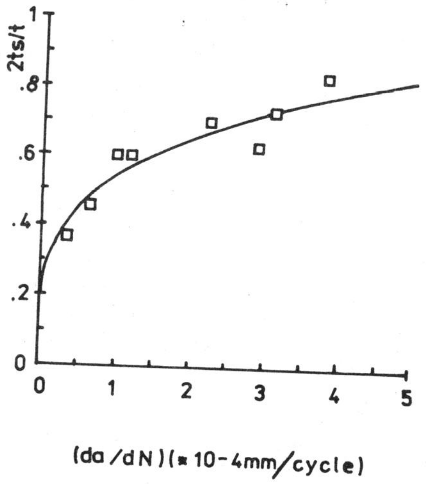

Fig. 4 A generalised curve of 2ts/t versus Δ(da/dN). ΔKeff = 9.72 MPa√m.