THE EFFECT OF FREQUENCY CHANGES ON FATIGUE CRACK GROWTH IN 7178-T6 ALUMINUM ALLOY

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INTRODUCTION

Environmental effects during fatigue crack growth are often studied by carrying out tests at different frequencies. The reason for this is that the lower the frequency, the greater must be the environmental influence. To the authors' knowledge, however, the measurement of growth rates has been done only at fixed frequencies (see, for instance, the data reviewed in [1 - 4]), although a more accurate study of frequency effects on fatigue crack growth rates would be to carry out tests involving frequency changes on the same specimen. In this paper we report on such a series of tests, carried out on a 7178-T6 aluminum alloy, and show the effect that such changes have on fatigue crack growth rates.

EXPERIMENTAL

Centre cracked test pieces (11.2 cm long x 3.2 cm wide) were cut from extruded sections (thickness, B, 0.18 and 0.29 cm), which were part of the upper wing construction of a C-130 aircraft.

Testing was carried out on a modified Haigh fatigue machine originally set up by Bradshaw and Wheeler [5, 6]. Full details of the testing procedure are given in these references, consequently only brief details are given here.

Crack depths (up to $\sim$ 1.2 cm final depth) were measured by a travelling microscope, and the loads were monitored using a load cell linked to a resistance bridge and oscilloscope. Stress intensity (K) values were calculated from the equation

$$K = \alpha\sigma\sqrt{\pi a} \tag{1}$$

where

α is the Koiter correction factor [7] for a central crack in a finite width sheet,

σ is the stress, and

a the half crack depth for the central cracked test piece.

The alternating gross stressing used by Bradshaw and Wheeler [5, 6] was again used (i.e., $\pm$ 24.8 MPa), which when used at mean stress values of 30.3, 46.1, 74.4 and 116.9 MPa gave R values of 0.1, 0.3, 0.5 and 0.65 respectively.

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Two frequencies were applied to the fatigue machine: 1 and 100 Hz. The wave form during the 100 Hz cycling was sinusoidal, while that during 1 Hz cycling was between sinusoidal and triangular (due to the nature of the switched d.c. supply [6]); we assume therefore that wave form is approximately constant. The procedure during testing was to initiate the crack at 100 Hz, and periodically change the frequency to 1 Hz. This was accomplished by stopping the machine, switching the machine to the d.c. supply, and then recommencing cycling. Changeover from 1 to 100 Hz and 100 to 1 Hz was usually accomplished within 30 seconds. Laboratory conditions were: 293K and 50% relative humidity.

Tensile properties and chemical analyses for the two thickness sections studied are given in Tables 1 and 2. Very little difference exists between the two materials, hence they can be considered as identical except for thickness.

RESULTS

Crack depth versus cycles for the alloy tested in the sequence 100, 1, 100, 1 Hz is shown in Figure 1. When the frequency was first decreased from 100 to 1 Hz the growth rate increased immediately (A, Figure 1), as would be expected if there was a greater environmental influence at the lower frequency. However, when the frequency was returned to 100 Hz, growth rate decreased for a short period (B, Figure 1) before it again increased. This effect was shown more strikingly when the growth rates were plotted against ΔK (= $K_{max} - K_{min}$) (Figure 2). Further testing showed that the phenomenon is favoured by low stress intensities and low R values, and was observed to the same extent in the two thicknesses studied. These observations would all suggest that the phenomenon is environmentally induced.

No clear differences between fatigue crack growth at 1 and 100 Hz were evident on examination of fracture surfaces at high magnification, but at low magnification the overall surface topography for the two frequencies was quite distinct. In particular, at 100 Hz the crack front was nearly linear (Figure 3a), but at 1 Hz it was much more irregular, and hence longer. (Figure 3b). (The test pieces shown were prepared by stopping the fatigue test and then pulling the test pieces to fracture).

DISCUSSION

The significant observation to emerge from this investigation is that for a given wave form, a change in length of a crack front, induced in this case by a change in frequency, is of considerable importance in determining the subsequent crack growth rate.

This has not been considered in most of the work carried out on fatigue crack growth, although recent evidence on aluminum alloys has indicated that the phenomenon can be very significant on a macroscopic scale [8]. The present work indicates that this can also be true on a microscopic scale. Moreover, there is no reason to believe that the event need be unique to aluminum alloys.

If the crack front lengths for the current test pieces are considered, it can be seen that the length at 1 Hz is about 20% longer than at 100 Hz (cf. lengths in Figures 3a and 3b). This increased crack front length at

the resumption of 100 Hz cycling, which is over and above that found normally for this frequency cycling, leads, at equivalent crack growth rates (e.g., E → D, Figure 2), to an effective decrease in ΔK of $\sim 30\%$. Thus it is clear that the usual form for the stress intensity (equation (1)) must be modified to take account of this geometric effect. It is suggested that this modification can be made by the addition of a factor l_o/l to equation (1), i.e.,

$$K = \alpha\sigma\sqrt{\pi a}\,\frac{l_o}{l} \qquad (2)$$

where

l_o is the length of a crack front *characteristic* of the frequency of testing (in the present case it is approximately linear at 100 Hz and $\approx B$), and

l is the length of a *non-characteristic* crack front.

For the crack depth at 100 Hz, before 1 Hz cycling is introduced, l and l_o are synonymous, the ratio l_o/l is unity and equation (2) reduces to equation (1). But for the crack front length after 1 Hz cycling, $l \sim 1.2\,l_o$, the ratio l_o/l is ~ 0.8 and K (and ΔK) are reduced accordingly. It must be noted, however, that this crack front length modification of the stress intensity at the crack tip is effective only until the normal crack front shape is re-established after a number of cycles; the growth rate will then continue to increase as in a constant frequency cycling test.

The effect shown in Figure 1 is very similar to that recorded by Miller et al [9], which in their work was induced by interrupting the fatigue test overnight. No fractographic examination was reported, but some modification by stress corrosion/corrosion may have occurred overnight, thereby increasing l, and hence producing the slower growth rates observed the following day. These authors suggested that such non-steady state crack growth should be excluded from results presentation and, in addition, that data from the start of testing should also be treated with caution. Based on the current observations, it is suggested that slower crack growth rates should be observed near a starter notch, because a crack front length produced by initiation from such a notch (probably on different levels) will be longer than that for a crack which has grown to a depth deep enough to have divorced itself from the effect of the notch geometry.

Thus any circumstance which results in a change in l, and hence of effective ΔK, must be considered very carefully when explaining trends in fatigue crack growth data. Whilst the results need not necessarily be eliminated from the data presentation (as suggested by Miller et al [9]) if the effect is real, the reasons for the divergencies should be appreciated.

Finally, it should be noted that in programmed or random loading testing, different load levels are applied at different frequencies. A single low frequency application of load would not be expected to have any measurable effect on crack front length, although the same cannot be assumed for a series of low frequency load applications. Such a possibility should therefore be considered in interpreting results from these types of tests, particularly in low cycle fatigue.

CONCLUSIONS

1. For sinusoidal fatigue stressing a temporary decrease in crack growth rate was observed in 7178-T6 aluminum alloy cycled at 100 Hz, following a period of low frequency (1 Hz) cycling.

2. The decrease was caused by a temporary reduction in the effective stress intensity, due to an increase in crack front length produced by low frequency cycling.

3. The effect was eliminated once the crack front regained the length characteristic of that for continuous high frequency cycling.

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Table 1   Chemical Analyses of 7178-T6 Aluminum Alloy

	Zn	Mg	Cu	Fe	Si	Cr	Mn	Ti wt%
Stringer (0.18 cm thick)	7.01	2.57	1.84	0.26	0.12	0.21	0.03	0.04
Skin (0.29 cm thick)	6.61	2.52	1.95	0.26	0.11	0.18	0.04	0.04

Table 2   Tensile Properties of 7178-T6 Aluminum Alloy

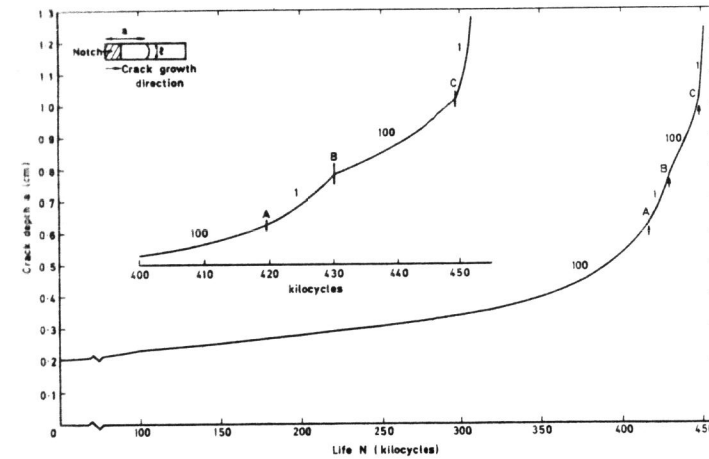|	0.2% Proof Stress MPa	Tensile Strength MPa	E GPa	Elong %	R of A %
Stringer	610	652	71	10	11
Skin	612	660	72	.10	6

Figure 1   Crack Depth (a) versus Cycles (N) for 7178-T6 Aluminum Alloy at R = 0.1; B = 0.18 cm. Figures Indicate Frequency of Cycling. Region of Frequency Changes is Shown in Greater Detail in Inset
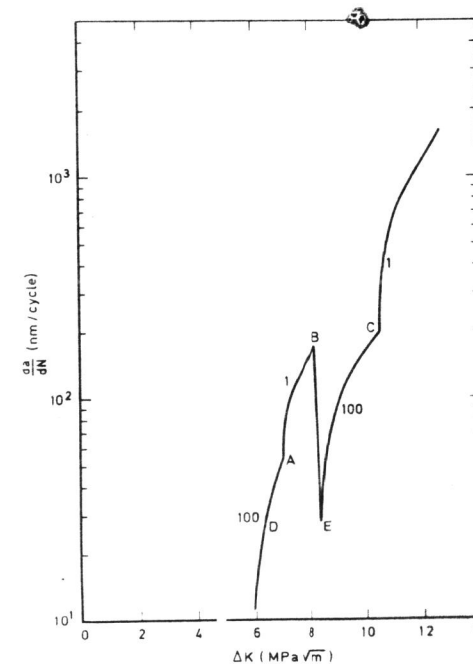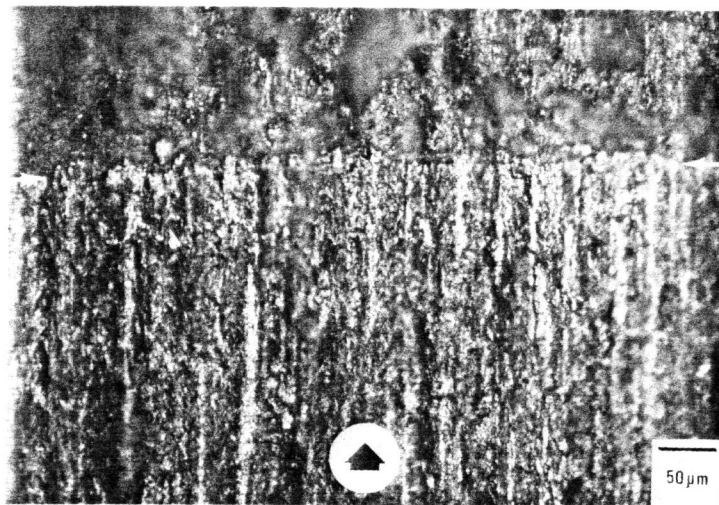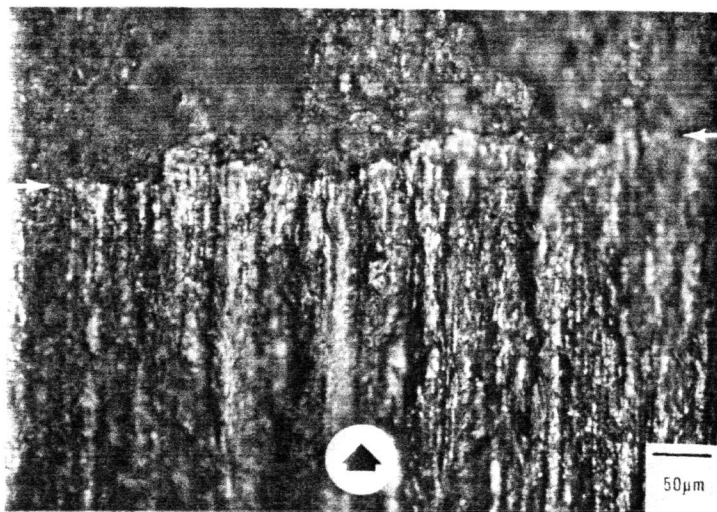

Figure 2   Rate of Fatigue Crack Growth for 7178-T6 Aluminum Alloy Cycled at 100 and 1 Hz; B = 0.18 cm. Data from Figure 1. Figures Indicate Frequency of Cycling

(a)

(b)

Figure 3 Micrographs Illustrating the Surface Topography of 7178-T6
Aluminum Alloy Cycled at 100 Hz (a) and 1 Hz (b); B = 0.18 cm.
Of Particular Interest are the Different Shapes to the Crack
Front in (a) and (b), Shown by Arrows. Stressing Conditions
Similar to Those Shown at B in Figures 1 and 2. Large Arrow
Shows Crack Growth Direction