EFFECT OF ENVIRONMENT ON THE PROPAGATION BEHAVIOUR OF LONG AND SHORT CRACKS IN A TA6V ALLOY

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An experimental study of the propagation of bidimensional through cracks grown at low rates in ambient air and in vacuum is presented. The role of crack closure is studied through the removal of crack wakes. The existence of a so called short crack effect is only observed on specimens pregrown at threshold in air. Results are discussed on the basis of microfractographic observations.

INTRODUCTION

Few researches have been carried out on the influence of environment on the fatigue propagation of short cracks apart from those specific ally related to the so called corrosive environments [1]. Previous studies on 7075 Aluminium alloys [2,3] and a construction steel [4] have shown that the initial growth of short cracks occurs at a much lower stress intensity range (ΔK) in an active environment (ambient air or nitrogen containing traces of water vapour) than in vacuum. However, GERDES et al [5] have shown that there is no significant difference in the initial stress level in air and in vacuum for small surface cracks initiated in a Ti-8.6 Al alloy.

Moreover, crack closure is known to play a dominant role in influencing near threshold growth rates [6,7]. Through the removal of material from the wake of long crack arrested at threshold, several authors [3,4,8-10] have studied the location and the origin of crack closure. It has been concluded that the behaviour of short and long bidimensional cracks can be rationalized in terms of the effective stress intensity factor range for Al alloys and steels.

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To get more information on the fatigue behaviour of Ti-Alloys, the growth of long cracks and of physically short bidimensional cracks has been studied on a TA6V alloy. This paper presents the preliminary results obtained on the influence of the crack wake on the propagation of fatigue cracks in specimens tested in ambient air and in high vacuum.

EXPERIMENTAL DETAILS

The material used for this investigation was a forged Ti-6Al-4V alloy (wt % 6.27 Al, 3.86 V, 0.12 Fe, 0.18 O_2). After forging the alloy was heat treated at 955°C for 1 h 30 and water quenched, followed by 2 h at 700°C and air cooling.

Fatigue crack propagation tests were carried out under ambient air and high vacuum (<5.10^{-4}Pa) on CT specimens 5 or 12 mm thick and 24 mm wide, at a test frequency of 35 Hz and a load ratio R = 0.1. Crack advance was optically monitored and crack closure was detected by mean of the compliance technique with a back face strain gauge. A long crack was first obtained at $a/w \simeq 0.5$ using a load shedding procedure down to threshold or at constant ΔK. Then the plastic wake of the crack was progressively removed by spark erosion to obtain a crack length about 0.1 mm. Then the bidimensional short through cracks were propagated at increasing ΔK.

RESULTS AND DISCUSSION

Near threshold propagation of long cracks

The relationship between the propagation rate da/dN and the nominal (ΔK) and the effective (ΔK_{eff}) stress intensity factor ranges are plotted in figure 1 for tests performed in ambient air at R = 0.1 and 35 Hz on the Ti 6Al-4V alloy. Decreasing the specimen thickness from 12 to 5.5 mm (Fig.1) lowers the nominal threshold range but does not affect the effective threshold range (ΔK_{eff})th. Consequently the thinner specimen correspond to a lower K_{op} level, which will be verified further (Fig. 3).

In figure 2 are compared experimental data for 5.5 thick specimens tested in air and in high vacuum. A strong detrimental influence of the ambient environment on the resistance to crack propagation at low rates can be observed. The effective data confirm that the ΔK_{eff} concept cannot account for the influence of environment [7].

Consequently, the crack growth mechanism in moist ambient air (about 50 % R.H.) must be different from the intrinsic mechanism governing crack propagation in vacuum. Similar behaviours have previously been observed on Al alloys and steels [11-13], for which materials an embrittling effect of water vapour adsorbed at the crack tip has been proposed [11-13]. A similar mechanism could be suggested for Ti alloys.

Crack closure location

To analyse the location of crack closure, the crack wake was progressively removed and K_{op} measurements were performed at each step of this procedure.

The evolution of K_{op} versus the remaining crack length Δa is plotted in figure 3 for cracks pregrown at threshold ambient air on 5.5 mm and 12 mm thick specimens. The lowering of K_{op} at decreasing Δa is more pronounced on the thinner specimen. At $\Delta a \simeq 0.1$ mm no closure was detected on the 5.5 mm thick specimen while a substantial remaining closure effect was measured with the thicker specimen. The length along which the decrease in K_{op} was observed, i.e. where crack closure is localised, is about 1.5 mm for the thinner specimen thickness and 0.7 mm for the thicker one.

A complementary test on a 12 mm thick specimen was performed at a constant ΔK of 7.5 MPa$\sqrt{m}$ corresponding to a constant growth rate about 3.10^{-9} m/cycle. Removing the crack wake did not affect K_{op} except for the last measurement at $\Delta a \simeq 0.1$ mm (Fig. 4).

The same measurements were made on cracks pregrown at threshold in vacuum. The results are also presented in figure 4. It can be seen that, as in air, K_{op} is lower for the smaller thickness but it is independant of Δa. Similar observations have been made on a construction steel type E460 [4].

As a consequence of these observations, it appears that the short crack effect (defined as the decrease in K_{op} with Δa) depends upon the embrittling effect of environment for cracks pregrown near threshold in air. However, for the crack pregrown at a constant rate of 3.10^{-9} m/cycle, K_{op} is, as in vacuum, independant of Δa, which suggests that this embrittling effect in air occurs only at ultra low rates. But an environmental influence is also observed at rates higher than 10^{-9} m/cycle (fig. 2). This suggest the existence of two distinct regimes in environmentally assisted crack growth. Similar behaviours have been observed on Al alloys and steels [7,11].

Short crack propagation

The short cracks here obtained on 5.5 mm specimens were propagated at increasing ΔK. In vacuum, there was no difference between long and short cracks, which was consistent with the independance of K_{op} upon Δa. The relations da/dN vs ΔK and ΔK_{eff} are plotted in figure 5 for the long and short cracks in air. Initially, the short crack grew for about 0.3 mm at ultra low rates (about 3 to 6.10^{-11} m/cycle) without any detectable closure. There after, there was an abrupt acceleration of the crack rate and crack closure was detected ; and then progressively, a behaviour similar to the one of a long crack was reached for a crack length about 1 mm.

The effective data confirm the existence of a typical near threshold mechanism without closure which is different from the mechanism governing the propagation above 2.10^{-10} m/cycle. The microfractographic aspects of the fracture surfaces (Fig. 6a,b,c) show that, compared to vacuum, the facies in air appear more brittle with crystallographic facets corresponding to α grains and lamellae. This crystallographic aspect is more developped at ultra low rates. On going experiments will hopefully give new information which may permit a deeper analysis of these crack growth mechanisms.

CONCLUSION

The main conclusions of the present study on short cracks obtained artificially from long cracks in a TA6V alloy are :

1) The following conditions are required to obtain a short crack effect :
- a pregrown long crack near threshold in air ;
- removal of crack wake.

2) Under such condition a propagation regime typical of ultra low rates, without detectable closure, is observed for short cracks grown in ambient air.

3) No short crack effect is observed in other studied conditions, i.e. :
- short cracks obtained from long crack pregrown in air at a constant rate of 3×10^{-9} m/cycle ($\Delta K = 7.5$ MPa$\sqrt{m}$) ;
- short cracks in vacuum.

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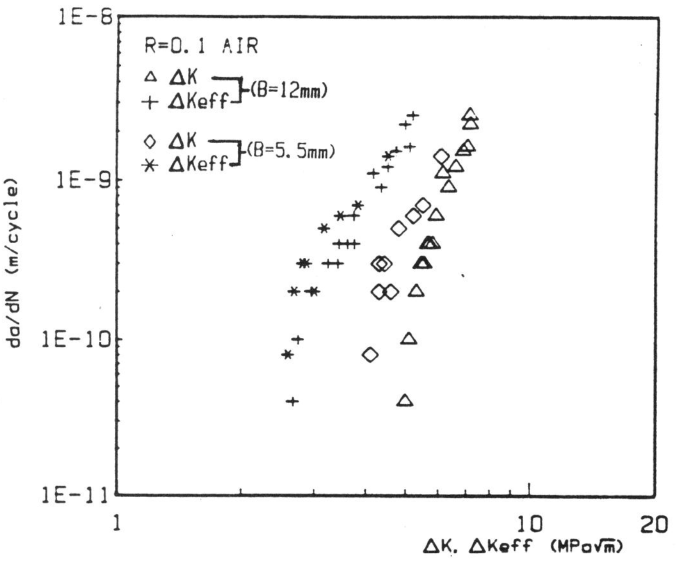

Figure 1 - Influence of specimen thickness on near threshold crack growth in ambient air.

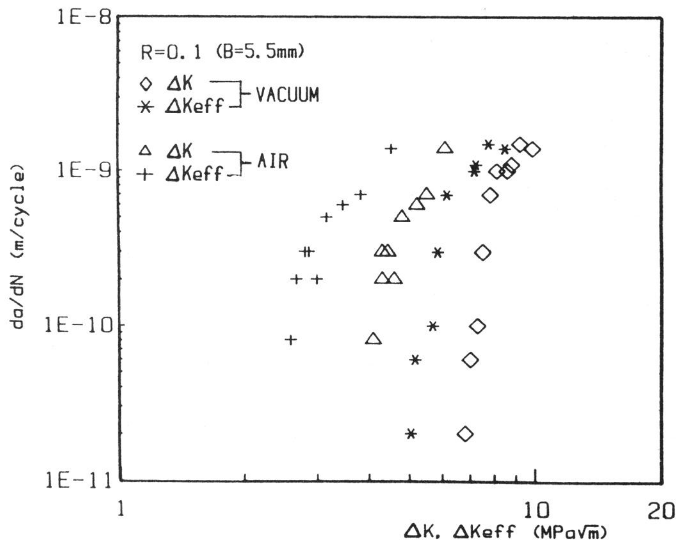

Figure 2 - Near threshold propagation in ambient air compared to high vacuum.

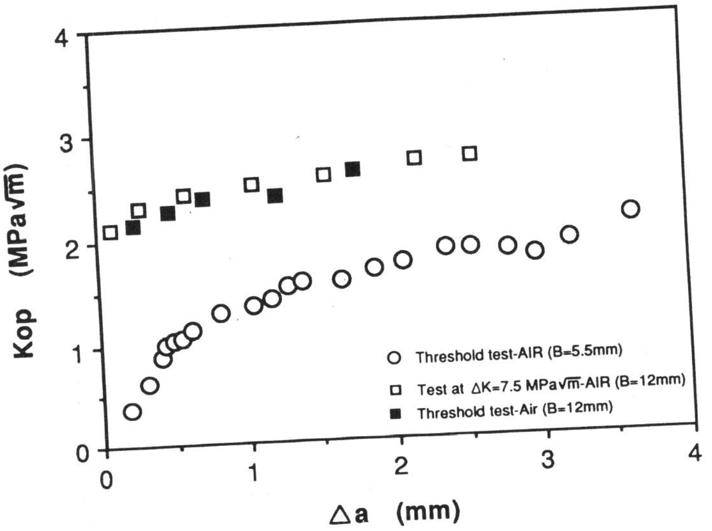

Figure 3 - Crack opening stress intensity factor K_{op} versus the remaining crack length Δa at different steps of crack wake removing procedure.

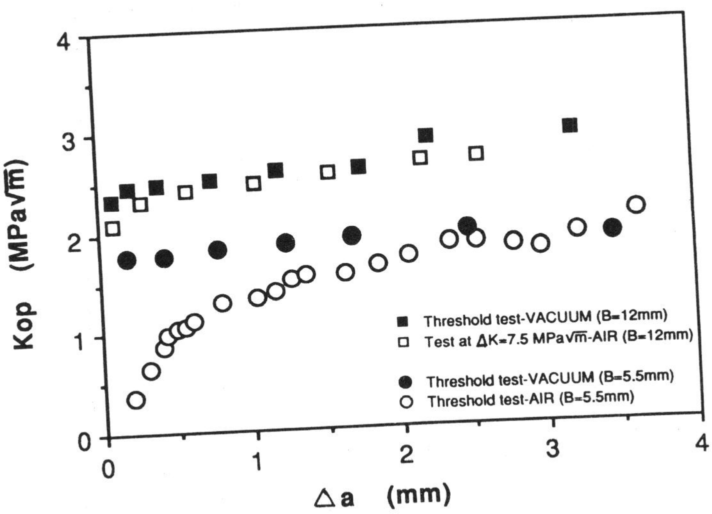

Figure 4 - Crack opening stress intensity factor K_{op} versus Δa : influence of environment.

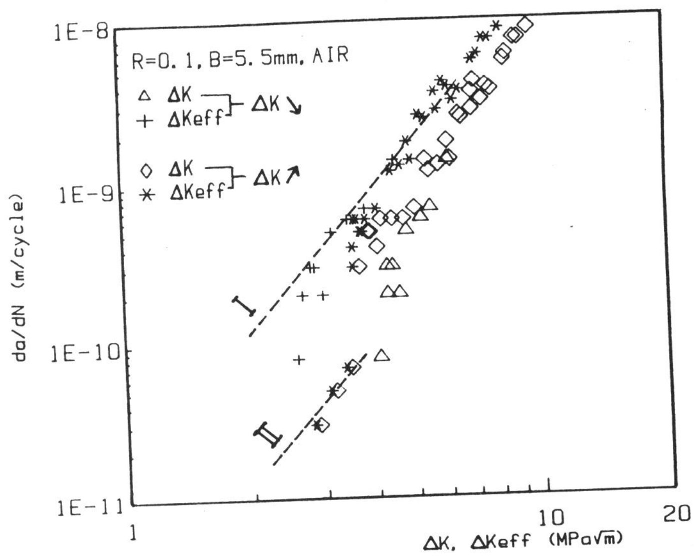

Figure 5 - Short through crack propagation in ambient air (initial length ≃ 0.1 mm) with two distinct regimes (I and II).

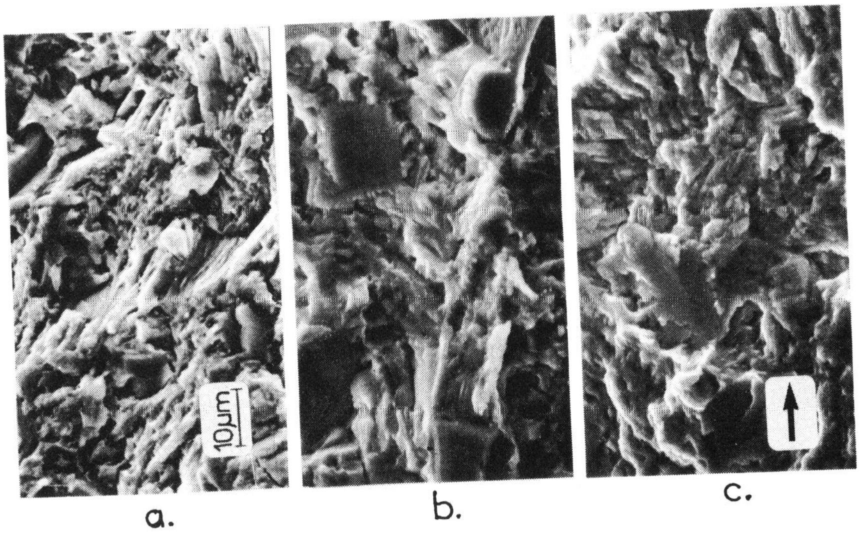

Figure 6 - SEM micrographs near threshold conditions : long (a) and short (b) cracks in air compared to vacuum (c).