FATIGUE CRACK PROPAGATION BEHAVIOUR OF A LAMELLAR Ti-Al ALLOY

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In the present study, the fatigue crack growth behaviour of a quaternary TiAl based alloy has been investigated. The influence of microstructure has been analysed by considering two different microstructures: a nearly fully γ microstructure and a nearly fully lamellar one. Crack closure effects have been taken into account in this analysis. Thus the influence of temperature on the intrinsic fatigue behaviour (i.e. without any closure or environmental effect) has been examined. In addition, the fatigue resistance has been shown to be strongly lessened in ambient air and this effect has been related to the presence of moisture.

INTRODUCTION

In recent years, ordered intermetallic compounds have received considerable interest as candidate materials for structural applications in extreme conditions (high temperatures, hostile environments) to replace the conventional alloys currently used [1]. They are expected to fill the gap between superalloys and ceramics, not only with respect to the service temperature range, but also with respect to the specific properties. Indeed, in addition to their low density, they exhibit attractive properties such as very good oxidation and corrosion resistance, excellent modulus retention and quite reasonable strength at elevated temperatures. Among all the categories of intermetallic alloys which have monopolised attention, the TiAl based alloys are the most promising ones from an industrial processing point of view. However, the major concern for practical use of these compounds is their low room temperature ductility and fracture resistance. Moreover, their Fatigue Crack Propagation (FCP) resistance is ill-known although their damage tolerance assessment might be of very high interest.

In the present study the influence of different intrinsic and extrinsic parameters on FCP behaviour of a γ based alloy is examined. Thus, the role

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of the intrinsic parameter that is microstructure is analysed in an inert environment by tests getting free of the influence of extrinsic parameters as crack closure effects. The effect of temperature is then evaluated in the same conditions. Finally, the environmental influence is investigated by comparing effective crack growth data obtained in different environment.

EXPERIMENTAL PROCEDURE

The material investigated in this study is a quaternary alloy of nominal composition Ti-48Al-2Mn-2Nb. Table 1 gives its chemical composition. The material was provided as a slice of an ingot produced in a large-scale plasma furnace by the IRC (Interdisciplinary Research Centre) in Birmingham. Further details are available elsewhere[2]. The microstructure is nearly fully lamellar, consisting of coarse alternating γ and α_2 plates grains with a grain size of approximately 300-400 µm. The preferential orientation of these plates is perpendicular to the longitudinal axis of the lamellar grains. The colonies elongation is longitudinal in the centre part of the ingot and becomes progressively radial for grains near the edge.

TABLE 1- Chemical composition (at %)

Ti	Al	Mn	Nb	O
47.92	47.96	2.02	1.93	0.17

In order to investigate the role of microstructure, another quaternary alloy Ti-48Al-2Cr-2Nb provided by the CEA/CEREM/CE2M/LETRAM was also considered. The microstructure of this material consisted of γ grains of about 150 µm [3].

Fatigue crack growth experiments were carried out using CT type specimens (W=22mm, B=5mm) taken with different orientations within the ingot [2]. The conventional notch was prolonged by short slit (≈ 0.05 mm) performed by electrodischarge machine. The FCP tests at room temperature were carried out on a servohydraulic machine in an environmental cell permitting tests in vacuum or in controlled atmosphere. These tests were conducted at 35 Hz in tension-tension loading with a constant load ratio R=0.1. The crack length was optically determined on the polished side of the specimens by means of a travelling microscope. Crack closure measurements were performed at test frequency according to the unloading compliance method using a back face gauge. Additional fatigue tests were conducted in vacuum at 700°C at the IRC in Birmingham on a servohydraulic machine operating at 10Hz. In that case, the growth of fatigue cracks was monitored by the use of a direct current potential difference technique. Since crack closure measurements were not possible at this temperature, several test methods were used to evaluate the crack closure effects: constant-load-ratio crack propagation (with R=0.1, R=0.5 and R=0.7) and constant-Kmax increasing load ratio crack growth control.

RESULTS AND DISCUSSION

As a consequence of the prominent role of crack closure highlighted elsewhere [4], the intrinsic behaviour and the influence of environment at room temperature on FCP of the investigated material are presented in the following sections with the crack growth rates plotted with respect to ΔK_{eff}. In addition, for the sake of clarity, all the results exhibited here have been collected from the same lamellar plates orientation specimens (notch B specimens). Anyway, it should be reminded that the effective resistance curves have been shown to be similar whatever the lamellae orientation [5].

Microstructural influence on the intrinsic behaviour

The influence of microstructure on the intrinsic behaviour at room temperature is presented in figure 1. The salient feature of this figure is the difference in the Paris law exponent for the two materials. The fully γ microstructure is much more sensitive to the applied ΔK_{eff} values: the threshold is extremely close to the final rupture regime, suggesting that the whole range could be influenced by a quasi-static failure mode. The lamellar microstructure offers a higher resistance which might result from different toughening mechanisms such as microcracking and interlamellar decohesion [6]. Finally, as the Paris law exponents exhibited in the FCP rates curves by such compounds are very high, the threshold value might be the most relevant parameter for a damage tolerance assessment. From this point of view, it is worth noticing that the two microstructures are very close.

In the following sections, only data pertaining to the lamellar microstructure FCP behaviour will be presented.

Elevated temperature behaviour

FCP rates curves in vacuum at 700°C are presented in figure 2. It is first important to note that the curves obtained at R=0.7 and R=0.5 are nearly similar for crack growth rates up to 10^{-8} m/cycle, leading to the conclusion that for such high load ratio, the crack closure effect is reduced. This opinion is reinforced by the results from constant-Kmax tests. Indeed, the FCP rates obtained from these tests when R=0.1, R=0.5 or R=0.7 are in very good agreement with the respective constant-R curves. Although further work is necessary to clearly evaluate the magnitude of crack closure effect at low growth rates, these observations suggest that the FCP data obtained at constant load ratio with R=0.7 can be considered as effective data. Anyway, to the authors knowledge, no other effective data from tests performed in vacuum at high temperature are available in the literature. Therefore, the comparison of the FCP results at 700°C and at room temperature in vacuum as presented in figure 3 makes sense. The FCP rates are plotted versus $\Delta K_{eff}/E$ in order to take into account the

Young modulus retention at elevated temperature. The knowledge of the influence of temperature on the intrinsic behaviour is essential when one aims to evaluate and compare the role of environment at ambient and elevated temperature. The present results seem to denote a slightly deleterious effect of temperature on the intrinsic resistance. Future work at higher temperature will aim to elucidate this point.

Environmental influence at room temperature

The effect of the environment at room temperature on the FCP rates of the Ti-48Al-2Mn-2Nb alloy is shown in figure 4. Two types of tests in vacuum were performed: tests in high vacuum of better than 5.10^{-4} Pa and tests under low vacuum of roughly 2.5 Pa. Also included for comparison purpose in figure 4 are fatigue crack growth rates data obtained in air and in O_2 atmosphere.

The FCP of the conventional engineering alloys has been shown to be strongly influenced by a moist environment. Besides, many intermetallics are assumed to be highly sensitive to the presence of moisture in the test environment. In the case of aluminides, the sequential embrittling process would be as follows [7]: surface reaction between water vapour and aluminium, hydrogen release and subsequent embrittlement. However for titanium aluminides, titanium might be reactive as well [7]. As a consequence, FCP in titanium aluminides is logically expected to be significantly enhanced in air compared to vacuum. This is actually observed in figure 4 where the crack growth rates in air are approximately two orders of magnitude faster than those obtained in high vacuum at low ΔK_{eff}. Meanwhile, as ΔK_{eff} increases, the crack propagation rates in air and under vacuum tend to become similar. This phenomenon may be explained by the competition between two mechanisms during the crack advance process: the intrinsic fatigue crack growth mechanism and the environmental mechanism. Thus, at high $\Delta Keff$, the environmentally-assisted mechanism is kinetically unable to cope with the high crack growth rates and environmental influence vanishes. The influence of water vapour content is confirmed by the crack growth rates in low vacuum where the moisture is more important than in high vacuum and less important than in air: the fatigue resistance is then intermediate.

Finally, in order to get an insight on the possible competitive adsorption process on rupture surfaces between water vapour and oxygen, fatigue tests were conducted in oxygen. The water vapour content in this atmosphere and in low vacuum were roughly the same (15 ppm H_2O). It is noteworthy that the two corresponding curves are similar, suggesting the presence of oxygen does not deeply affect the water vapour adsorption process. It is therefore legitimate to infer the water vapour adsorption is not strongly hampered by oxygen in ambient air.

CONCLUSION

1. The lamellar alloy has been shown to offer an improved intrinsic fatigue resistance compared to the fully γ alloy behaviour except in the slow growth rate regime where the difference is not so sharp.
2. A slight deleterious influence of temperature on the intrinsic behaviour has been observed at 700°C with respect to room temperature.
3. The fatigue resistance has been proved to be severely lessened by water vapour. Details of the embrittling mechanisms need however to be clarified.

ACKNOWLEDGEMENTS

The authors would like to thank Pr P. Bowen for providing the material and for his fruitful suggestions. Appreciation is also extended to Dr A. Dowson for chemical analysis. The help of Miss B. Bittar in testings is gratefully acknowledged.

SYMBOLS USED

E = Young modulus

ΔK = stress intensity factor amplitude

ΔK_{eff} = effective stress intensity factor amplitude

Kmax = maximum stress intensity factor

R = load ratio

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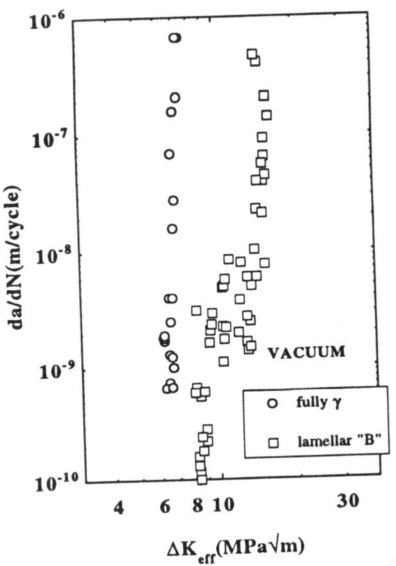

Figure 1 Microstructural influence in vacuum

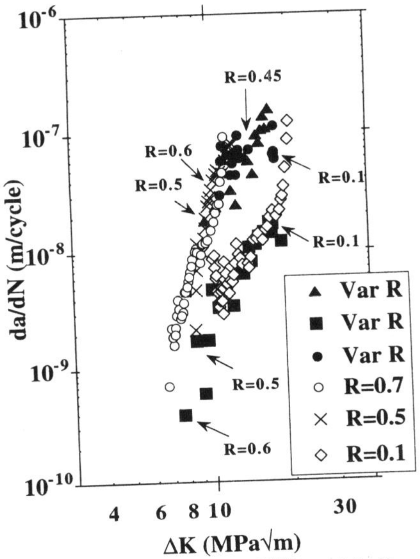

Figure 2 Constant R and variable R testing results at 700°C in vacuum

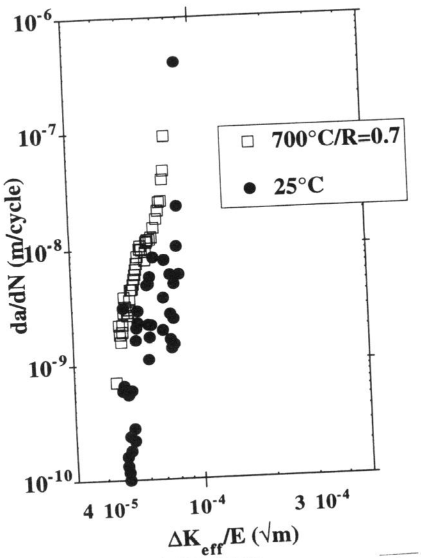

Figure 3 Influence of temperature in vacuum

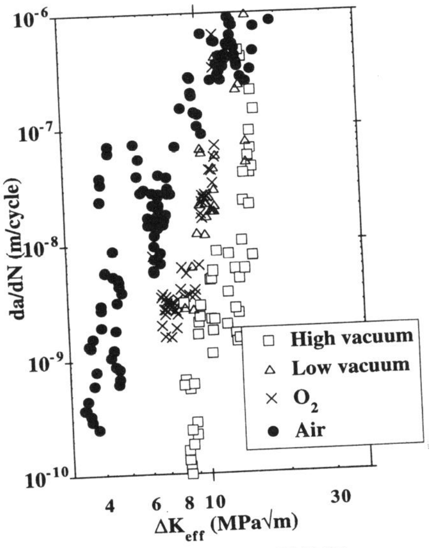

Figure 4 Environmental influence at room temperature