ATMOSPHERIC INFLUENCE ON FATIGUE CRACK PROPAGATION IN Ti6246 ALLOYS AT ELEVATED TEMPERATURE

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The fatigue behaviour of Ti6246 alloy is studied at temperatures ranging from Room Temperature (RT) to 500°C. It is shown that increasing the operating temperature leads to an increased environmental influence and results in a significant degradation of the material resistance specially pronounced at 500°C. Water vapour is identified as the active specie responsible of the corrosion fatigue process involved.

INTRODUCTION

The high strength to weight ratio of Titanium alloys has made them particularly attractive for a variety of structural applications at moderatly elevated temperatures. As there has been an attempt to raise the service temperature of these alloys, the potential for corrosion-fatigue interaction is also increased (1,2).

During the last years, an investigation of the effect of environment on fatigue crack propagation rates on Ti alloys at elevated temperature has been conducted (3-6). Tests were run in laboratory air, high vacuum and under environments with controlled partial pressures of water vapour and oxygen to identify the mechanisms involved in the degradation of the fatigue crack growth resistance respectively due to temperature and gaseous environment. This paper deals with recent works on a Ti6246 alloy carried out at temperatures ranging up to 500°C.

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EXPERIMENTAL PROCEDURE

The Ti alloy, Ti-6%Al-2%Sn-4%Zr-6%Mo (in wt%), used in this investigation was β-forged at 950°C. The specimen was subjected to heat treatment consisting of 930°C for two hours, followed by water quenching, 900°C for one hour and air cooled, held at 595°C for a total aging time of eight hours and air cooled. It displays a Widmanstätten structure (see fig.1) consisting of aligned alpha platelets and basketweave structure contained in large prior beta-grains (200 µm-300 µm). Fatigue crack growth experiments were carried out on compact tension specimens (10 mm thick and 40 mm wide) complying with ASTM recommendations (standard E647, 86). Tests were conducted on a servo-hydraulic machine which can operate at temperatures up to 500°C under sinusoidal load time waveforms and at frequencies varying from 0.1 Hz to 35 Hz. Some additional dwell waveforms (10s-90s-10s and 10s-180s-10s) and a triangular signal (10s-10s) were used. Tests under controlled gaseous atmospheres were performed at 500°C in an environmental chamber with partial gas pressures measured by mean of a mass spectrometer. A recording electrical potential system was used for monitoring crack length. At elevated temperature, crack closure was determined using a capacitive displacement detector or eliminated by performing tests at variable R (constant K_{max}).

EXPERIMENTAL RESULTS AND DISCUSSION

Crack propagation data

The environmental contribution of laboratory air to fatigue growth in Ti6246 has been assessed by a comparison of crack propagation rates in air and high vacuum over a range of temperature from RT to 500°C. Fatigue crack growth results are presented in figure 2 in the conventional da/dN vs ΔK fashion. This diagram shows that when test temperature increases crack propagation resistance decreases because of a coupled effect of environment and temperature. This effect is strongly pronounced in the near threshold range associated with the presence of a plateau phenomenon around 10^{-8} m/cycle and crack growth rates in air can be two orders of magnitude higher than in high vacuum.

To characterize the specific effect of environment, crack growth data including closure correction and after correction for Young modulus, E, are considered as presented in figure 3. The detrimental role of air is also encountered in all the explored rate range in accordance with nominal data but with a more pronounced effect. Very similar effective data at 500°C and 300°C in high vacuum (see fig.3) confirm a temperature effect closely limited to Young modulus variation when operating in high vacuum and suggest a deleterious effect of ambient air specially pronounced at 500°C. An important change of the sensitivity to environment with temperature seems to operate in the range 465°C-500°C. In the following, the environmental effects on fatigue behaviour of Ti6246 at 500°C will be specially discussed.

Influence of test frequency

Three additional tests were performed at 500°C, at frequencies of 3.5 Hz, 0.5 Hz and 0.1 Hz and compared to the effective data obtained at 35 Hz on the figure 4. It is shown that lowering the frequency from 35 Hz to 0.1 Hz induces enhanced propagations. To identify such a synergical effect between a time dependent environmental process and the mechanical loading, some complementary growth rate data have been measured from tests conducted with dwell waveforms (10s-90s-10s and 10s-180s-10s) and a triangular waveform (10s-10s) as shown in figure 4. Growth rates are comparable to those obtained from the sinusoidal loading at 0.5 Hz and 0.1 Hz. These results suggest a saturation of the environmental influence at frequencies lower than 0.5 Hz and support the existence of a corrosion fatigue mechanism instead of a creep fatigue process.

Identification of the active specie

Cracked surfaces examination at 500°C has revealed a more pronounced oxidation than at lower temperatures (3) with typical colorations evolving from yellow to purple corresponding to the different steps of propagation. In all cases, the oxide composition has been identified as TiO_2 (rutile) whatever the coloration, this last one being related to the oxide thickness. Nevertheless, no direct correlation has been established between crack growth rate and oxide thickness.

Water vapour, even in a very low amount has been identified as the active specie responsible of the loss in the fatigue resistance of Ti-6Al-4V alloy at 300°C (6). Following the same assumption tests were carried out at 500°C in atmospheres containing controlled amount of water vapour and oxygen to check out a potential role of water vapour even at such elevated temperature. A first experiment was performed at atmospheric pressure in a pure argon gas containing the same amount of water vapour as in laboratory air (1.3 kPa). The partial pressure of oxygen was 1 Pa, i.e. $2x10^4$ times lower than in air. The crack growth rate data obtained at 35 Hz are plotted in figure 5 and compared to those in ambient air. Crack propagation in humidified argon is also increased like in air with a little more pronounced effect. This result supports a predominant influence of water vapour. The propagation curve obtained at 35 Hz in low vacuum ($P_t = 1.33$ Pa, $P_{H2O} = 1$ Pa) is similar to the reference data in high vacuum, and consequently does not present any environmental effect at such a frequency. But, tests conducted in low vacuum at low frequencies (0.1 or 0.01 Hz) reveal an enhanced propagation similar to that obtained in ambient air and humidified argon at low frequency as shown in figure 6. The partial pressure of water vapour in ambient air is more than 10^4 times higher than in low vacuum, which indicates an effect of water vapour less active in ambient air, or, at least needing much more water vapour to act. These observations suggest a more or less pronounced inhibiting role of oxygen on crack propagation.

This environmentally assisted propagation can be described by a relation in accordance with the initial model proposed by Mc Clintock (7) for a propagation controlled by the ΔCTOD, including a hydrogen assisted propagation : $da/dN = 0{,}5\ \Delta CTOD$

CONCLUSION

This study of fatigue crack propagation tests performed on a Ti6246 alloy from RT to 500°C leads to the following conclusions:

- Effective data compared to intrinsic data support a substantial influence of atmospheric environment specially at 500°C.
- The loss in the fatigue crack propagation resistance of the alloy at 500°C has been related to a corrosion fatigue mechanism induced by water vapour and described by a propagation law controlled by the ΔCTOD.

SYMBOLS USED

R = load ratio

ΔK = stress intensity factor range (MPa√m)

K_{max} = maximum stress intensity factor (MPa√m)

E = Young modulus (MPa)

ΔCTOD = crack tip opening displacement (μm)

P_t = total pressure (Pa)

P_{H2O} = partial pressure of water vapour (Pa)

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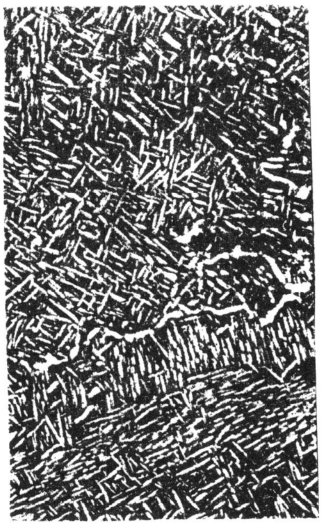

Figure 1 Illustration of Ti6246 alloy (x 300)

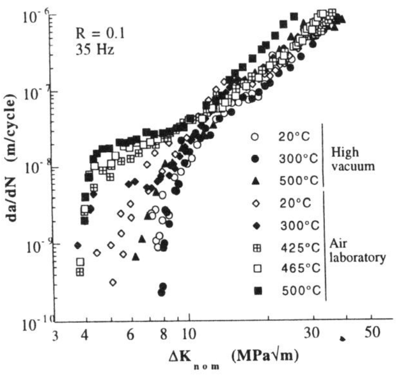

Figure 2 Influence of environment on nominal propagation

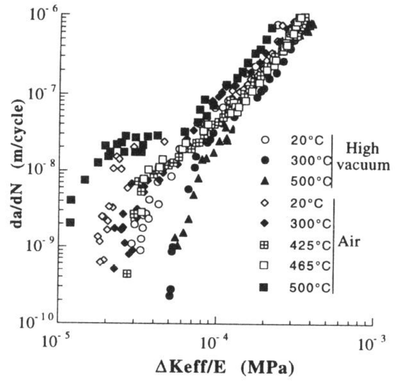

Figure 3 Specific influence of environment

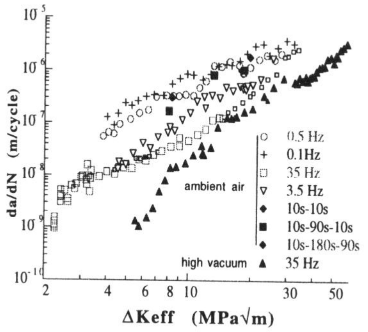

Figure 4 Effect of loading frequency on effective propagation at 500°C

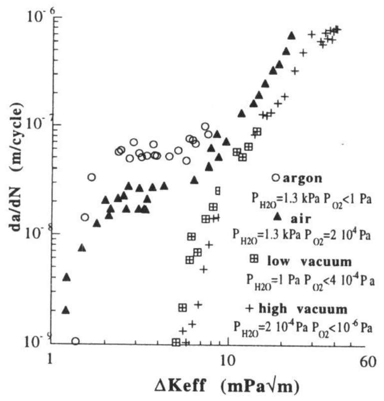

Figure 5 Influence of water vapour on effective propagation at 35 Hz

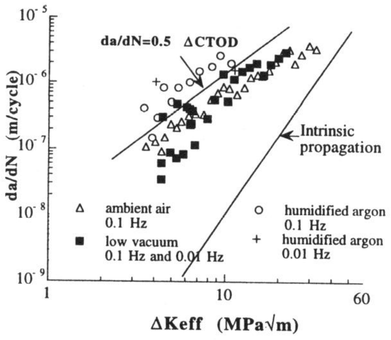

Figure 6 Influence of frequency in air, humidified argon and low vacuum