INFLUENCE OF TEMPERATURE ON FATIGUE MICROCRACKS KINETICS IN A TITANIUM ALLOY

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A significant detrimental effect of increasing temperature on the fatigue behaviour of a titanium alloy Ti 6246 has been observed between 20°C and 500°C in air in the low cycle fatigue range (10^2-10^5 cycles). Crack initiation and microcrack propagation were determined by performing interrupted tests under constant or variable stress amplitudes. The detrimental effect of temperature and environment is discussed by taking into account mechanical properties variations as a function of temperature. A high increase of the fatigue life was observed for stress amplitudes below 70% of the yield stress which corresponds to a delay in crack initiation. The increase of temperature on small crack growth rates produces a slight acceleration in terms of $\Delta K/E$. For an equivalent level of plasticity, the resistance to crack initiation is observed to be higher at 300°C.

INTRODUCTION

High temperature resistant titanium alloys have been developed to provide for turbo engine development requirements. These materials are commonly used for manufacturing turbine blades or compressor disks. In these components, in service temperatures can reach 500°C and starts-stops sequences of the engine induce fatigue sollicitations. This phenomenon may initiate cracks which propagation could lead the components to failure.

The objective of this work was to determine the influence of temperature, in the range 20°C - 500°C, on the low cycle fatigue behaviour of an $\alpha+\beta$ titanium alloy Ti 6246 (6Al-2Sn-4Zr-6Mo). Crack initiation and propagation stages were especially studied by performing interrupted fatigue tests.

MATERIAL AND EXPERIMENTAL CONDITIONS

The chemical composition of the Ti 6246 is indicated in table 1.

TABLE 1- Chemical composition of Ti 6246

Element	Al	Sn	Zr	Mo	C	O	Fe	H	Si	Cu
%(wgt	5,68	1,98	3,96	6,25	0,01	<0,15	0,05	<0,015	0,04	<0,01

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The thermomechanical treatment applied on the Ti 6246 is: a "Hot Die" type forge at 950°C, a first solution treatment at 930°C during 2 hours with water-quenching, a second solution treatment at 900°C for 1 hour with air cooling and finally an annealing at 595°C during 8 hours with air cooling.

This material is an (α+β) alloy with an α lamellar Widmanstätten type microstructure (lamellae length varying from 1 to 50µm) in a β transformed matrix hardened by fine secondary α lamellae (less than 1µm in length). The microstructure morphology obtained by optical microscopy is illustrated in figure 1.

The mechanical characteristics for each temperature are summarized in table 2.

TABLE 2- Mechanical properties of Ti 6246

Ti 6246	20°C	300°C	425°C	500°C
E (GPa)	125,4	112,5	105,5	103
σ_y (MPa)	993	716	717	680
σ_m (MPa)	1140	980	930	900
A (%)	10,1	10,9	13,7	10,5

E-modulus was determined by a resonance dynamical method (1).

A plateau is observed between 300°C and 425°C for the yield stress evolution which can be explained by dynamic strain ageing due to solute atoms and dislocation interactions (2).

Fatigue tests were performed on smooth cylindrical specimens having a gauge length and diameter of 13 mm and 4,4 mm respectively. After polishing, tests were conducted under stress controlled push-pull mode ($R\sigma$ = -1) on an electromechanical machine with a frequency of 0,15Hz and a triangular wave form.

RESULTS AND DISCUSSION

The Wöhler curves (stress amplitude versus the number of cycles to failure Nf) were established in air for three temperature levels (20°C, 300°C and 500°C). They are illustrated in figure 2 where the arrows indicate a non-failure of the specimen. So, a detrimental effect of the temperature is observed which is especially marked between room temperature and 300°C. To analyse the fatigue behaviour of the Ti 6246 at each temperature, crack initiation and crack growth were studied via regularly interrupted fatigue tests. At each interruption the specimen surface was observed by S.E.M. in order to identify microcrack initiation sites and microcrack length. By following the same microcrack at different stages of the fatigue life, da/dN-ΔK curves were established for different stress levels and temperatures. ΔK is calculated as $\Delta K=1{,}32\sigma\sqrt{a}$ with the crack depth a=0,45l where σ is the half of the stress amplitude and l the surface crack length.

Figure 3 describes the evolution of surface cracks at 20°C for two stress levels : 750MPa and 680MPa. It appears that, whatever the stress level is, the same propagation behaviour is obtained. In each case, the crack growth rate curves concerned microcracks that propagated from an initial surface length of the order of the microstructure size (less or around 50µm). For the tests conducted under 680MPa, the cracks were initiated at 730MPa after 10000 cycles and then propagated at 680MPa until the specimen failure which occurred after 17000 additional cycles.

The characterization of the state of damage at different stages of cycling revealed that the increase in fatigue life ($N>10^5$ cycles) reached at low stress levels (approximately 70% σ_y for the three temperatures), is clearly related to a delay in microcrack initiation. It must be noted that no cracks were observed on the specimens stopped before failure above 10^5 cycles. In contrast, a small crack initiated at higher stress levels, will always provide failure rapidly when the specimen is recycled at a level of $0{,}7\sigma_y$ at which crack initiation is difficult to achieve.

Concerning the effect of temperature on crack growth, figure 4 compares the microcrack propagation rates for each level of temperature in terms of da/dN versus $\Delta K/E$ (lines indicate the maximal crack growth rate). It appears that the propagation stage is slightly different according to the temperature level, 300°C and 500°C showing faster propagation rates than 20°C. Therefore, the detrimental effect of temperature on small crack growth rates is not corrected by taking into account the variation of the Young's modulus as it has been observed for the intrinsic behaviour in vacuum (3). This would suggest a significant effect of the environment (oxygen, water vapour) on small crack growth. However, the variation of the mechanical properties with temperature also explains the differences in the S-N curves of figure 2. This can be rationalized by plotting the results in terms of (σ/σ_y)-Nf (figure 5). Thus, the main differences are rationalized. However, a higher resistance is then observed at 300°C especially at high stress levels. This is also supported by figure 6 in which the number of cycles to initiate a small crack of 50µm in surface length at low stress levels is plotted against σ/σ_y. Ni was estimated from Nf experimental values considering that Nf=Ni+Np where Np, the number of cycles to propagate the crack from 50µm to failure, was calculated by integrating the propagation law $da/dN=C(\Delta K/E)^m$ corresponding to the lines in figure 4. For an equivalent level of plasticity estimated in terms of σ/σ_y, there is a higher resistance to crack initiation at 300°C compared to 20°C and 500°C. However, the initiation sites are always the α/β interfaces whatever the temperature and the stress levels are.

CONCLUSION

A detrimental effect of temperature in the range 20°C-500°C is observed in air on the fatigue resistance of the Ti 6246. This phenomenon can be mainly related to the drop of mechanical properties. For an equivalent amount of microplasticity, an influence of temperature on the initiation life times is observed with a higher resistance at 300°C. Concerning the crack growth rates, a decrease on the resistance is observed between room temperature and 300°C. High increase on the fatigue life at 70% of σ_y is essentially due to a delay in crack initiation.

On-going fatigue experiments under vacuum will provide information required for the understanding of the temperature and environmental effects which interact in air.

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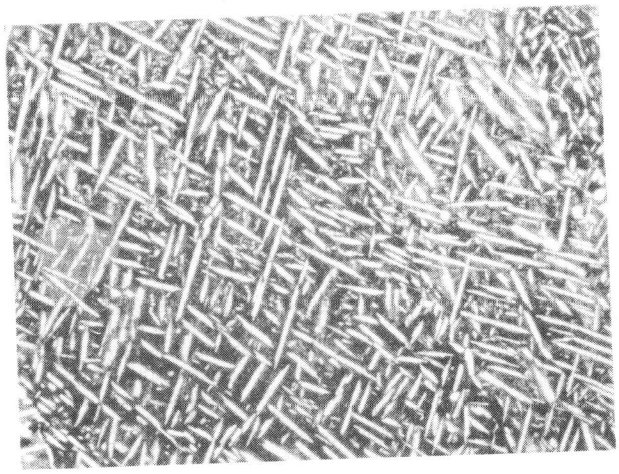

20μm

Figure 1 Microstructure of Ti 6246 - Lamellae α in a β matrix

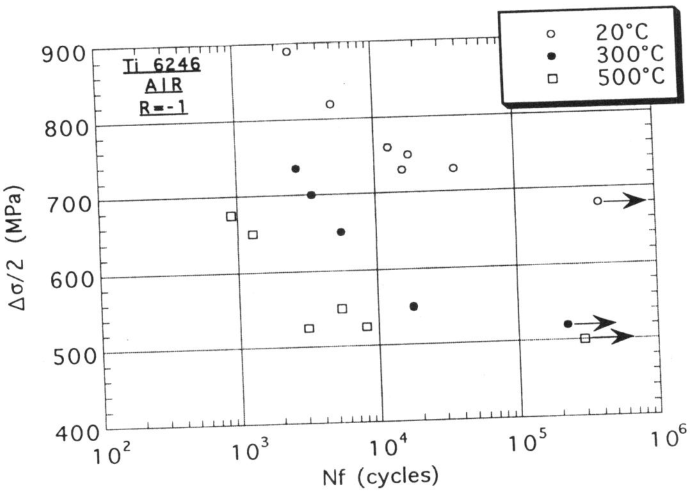

Figure 2 S-N curves between 20°C and 500°C of Ti 6246 in air

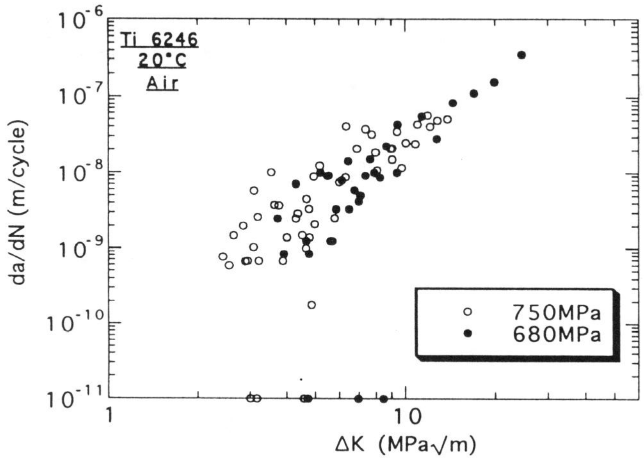

Figure 3 Microcrack propagations at 20°C in air

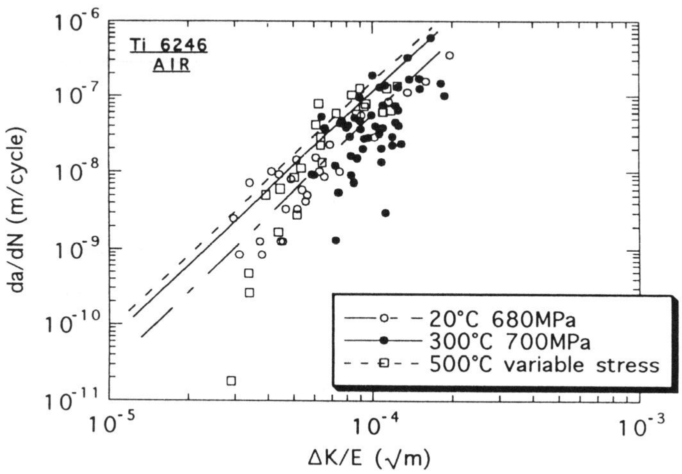

Figure 4 Microcrack propagations at 20°C, 300°C and 500°C in air

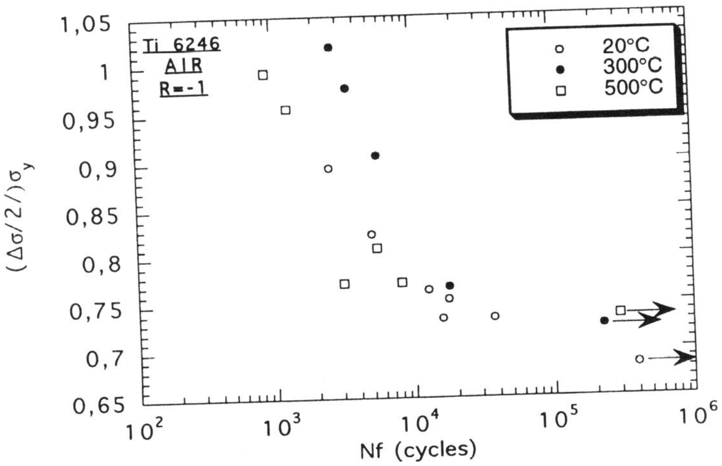

Figure 5 Wöhler curves rationalized by the yield stress

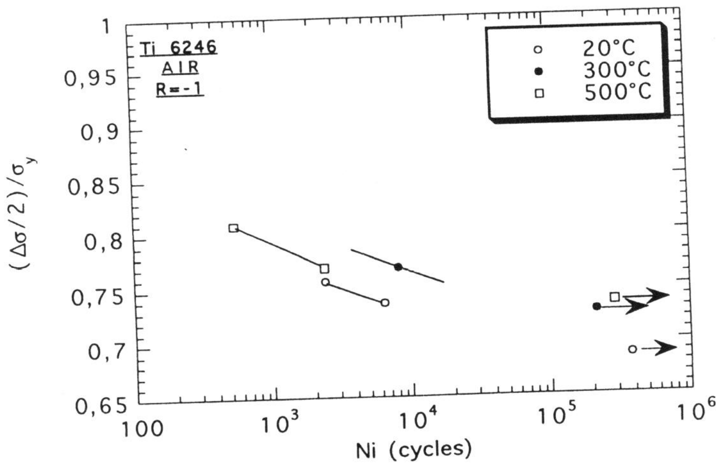

Figure 6 Part of initiation for each temperature