HIGH TEMPERATURE FATIGUE CRACK GROWTH BEHAVIOUR OF THE UDIMET 720 Li ALLOY.

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The fatigue crack growth behaviour of the Udimet 720 Li alloy has been studied at temperatures up to 700°C in air and in vacuum. The influence of wave shape, the maximum value and the R-ratio of the applied load on crack propagation have been analysed. These results permit to describe the main operative damaging mechanisms and to evaluate and separate the contributions of oxidation and creep in enhancing fatigue crack propagation rate. In fact, in vacuum no significant frequency effects are observed, on the other hand in laboratory air tests the da/dN vs ΔK curves are strongly time dependent showing that oxidation effect dominates over creep. The effect of temperature on fatigue crack propagation has been found negligible in the high frequency tests, where the damage mechanism is mainly cycle dependent, but becomes important in the hold time and constant load creep crack growth tests.

INTRODUCTION

The demand of increasing efficiency of aero-engines turbine discs led to a higher temperatures and stresses service. Fatigue is the life limiting factor in designing turbine engine discs and fatigue failure of high temperature components is often closely related to the growth of cracks, from stress concentration regions due to thermal gradients or to pre-existing flaws, under the action of cyclic loads.

The effect is more remarkable when cyclic loads are applied at low frequency or are combined with a static load and an oxidising environment is present. As a consequence of the temperature and the stress gradients increase, creep and oxidation mechanisms at crack tip, in addition to fatigue, becomes important factors in controlling component life (1). It is thus necessary to investigate the resistance to high temperature crack growth in such complex loading conditions in order to evaluate allowable flaw size and to improve residual life prediction methods. In this work crack propagation behaviour of the Udimet 720 Li alloy has been evaluated in condition of pure fatigue, pure creep and in combined condition of creep-fatigue loading. Moreover the environmental effect has been analysed performing tests in air and in vacuum. The experimental results will be useful in validating models to

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describe material behaviour and permit to describe the main operative damaging mechanisms and, when air and vacuum results are compared in evaluating and separating the contributions of oxidation and creep in enhancing fatigue crack propagation rate.

MATERIAL AND EXPERIMENTAL PROCEDURES

The material studied in the present investigation is the nickel-base superalloy Udimet 720 Li. The high strength, the good hot corrosion resistance and particularly the excellent workability made this alloy very interesting for turbine disk applications (2).

The material was supplied by Thyssen Umformtechnik, Remscheid, (D) in form of a forging to disk size obtained isothermally at 1080°C and strain rate of 0.01 $s^{-1}$and subsequently heat treated 4 h /1110°C/oil quench + 24 h/650°C/air quench + 16 h/760°C/air quench. Due to the high forging temperatures a molybdenum alloy was used as die material. The resulting microstructure consisted of rather uniform grain size, ASTM 9 to 10 with uniform gamma prime distribution. This fine grained microstructure appears suitable for a defect tolerant disk design. The chemical composition of the material is shown in Tab. 1.

TABLE 1 – Chemical composition (wt %) of the Udimet 720 LI alloy.

	Al	Co	Cr	Mo	Ti	W	Zr	Fe	Ni
Wt (%)	2.5	14.7	16	3.0	5.0	1.25	0.4	0.5	Ba

Creep crack growth tests were conducted at 700°C in air on a levered load creep frame. Heating was provided by a three zone resistance furnace

Fatigue crack propagation rate (FCPR) tests were carried out on a closed loop servo controlled hydraulic testing machine , in load control with the R ratio normally kept equal to 0.1 at the temperature of 700°C. A radio frequency unit was used to heat the specimen with a temperature control of ±3°C. The fatigue tests were performed in laboratory air and in vacuum ($pO_2 \cong 10^{-3}$ Pa) environment.

The influence of wave shape of the applied load has been analysed adding an hold time period, of 1 and 120 seconds, at maximum load to the triangular wave. A slow loading and/or unloading of 30 seconds has been employed in the wave shape with 1 second hold time. Hereinafter the different load wave shapes will be designed by four numbers indicating the time, in seconds, spent in the four stages of the wave. For instance 30-1-1-1 means 30 seconds loading, plus 1 second hold at maximum load, plus 1 second unloading and 1 second hold at minimum load. The effect of the value of the maximum load in the experimental tests has also been analysed.

Corner crack specimens (CC) were used in the present investigation. The test specimens, machined from the disk forging, had a square gauge cross section of 7 x 7 mm^2 with a 0.2 mm deep starter notch. The crack length was monitored by the electric potential drop technique and the crack growth rates were calculated by the secant method.

EXPERIMENTAL RESULTS AND DISCUSSION

The influence of maximum load on FCPR at 700°C is shown in Fig. 1a in the case of the 1-1-1-1 and in Fig. 1b in the case of 1-120-1-1 wave shape, respectively. In the Paris region no maximum load influence appears for the 1-1-1-1 wave shape indicating that linear elastic fracture mechanics (LEFM) conditions are respected while for the 1-120-1-1 wave shape FCPR is no longer a unique function of ΔK when the maximum load values exceed 26 kN, indicating a failure, in this condition, of the K based description. Hence all the reported testing at 700°C, with the exception of the two tests in Fig. 1, has been performed within the LEFM frame.

The influence of R-ratio on FCPR in the 0.1 to 0.8 range at 700°C, with the wave shape of the 1-1-1-1 type, is shown in Fig. 2. The increase of R values mainly shifts the FCPR curves to the left. As a result an increase of the fatigue crack propagation rate and a decrease of the ΔK threshold appear. This effect is rather systematic at R-ratio values larger than 0.4, and could be attributed to creep phenomena contributing to da/dN at high R values due to the higher average load involved.

In Fig. 3 the effect of the wave shape of the applied load on FCPR curves in air and in vacuum environment are compared. Open points, that represent curves obtained from tests conducted in vacuum, show a clear frequency effect only for the longest hold time at maximum load, meaning that creep mechanism becomes relevant only at this extreme condition. The solid point FCPR curves, that represent laboratory air data, are much more time dependent, with FCPR at the lowest values in the high frequency 0.1-0-0.1-0 test, that corresponds to a triangular wave at the frequency of 5 Hz, while the highest propagation rate is shown by the 1-120-1-1 wave. This behaviour , associated with the vacuum data, clearly shows that, in this temperatures range, environment effects dominate over creep in enhancing fatigue damage. An intermediate FCPR is measured in the 1 second hold time tests, either in the 1-1-1-1 or in the 30-1-1-1 waves, indicating that, for this material, oxidation mechanisms at crack tip are more damaging during the hold period at maximum load, also at the relatively low value of 1 second, than during the loading part of the cycle.

The influence of temperature in the 650 – 700°C range is reported in Fig. 4 for the 0.1-0-0.1-0, 1-1-1-1, 1-120-1-1 and for the constant load creep tests. The temperature effect has been found negligible in the highest frequency tests (5 Hz), Fig.4a, where the damage mechanism involved is mainly cycle dependent. The effect of temperature appears if a hold time at maximum load is added to the fatigue cycle, as shown in Fig. 4b for the 1s dwell and becomes more important increasing the dwell up to 120 s, Fig. 4c, where the 50°C temperature increase causes a FCPR increase of more than an order of magnitude. A similar temperature effect is found in the creep crack growth tests, as shown in Fig. 4d.

CONCLUSIONS

The fatigue crack propagation rate of the Udimet 720 Li forging to disk size has been measured at the temperature of 700°C with different load wave shape, in air and in vacuum. Vacuum FCPR is practically insensible to wave shape with the exception of a very severe condition of the cycle with 120 s hold time. In air FCPR strongly depends on hold time at maximum load but is insensible to a slowly increasing of the load.

Increasing R-ratio value FCPR increases and the ΔK threshold decreases indicating a creep contribution to fatigue crack propagation at the highest R values.

The influence of temperature in the 650 – 700°C range depends on the wave shape of the applied load. No effect has been found at the highest test frequency, but FCPR increases significantly with temperature when a hold time is added to the fatigue cycle and in the constant load creep crack growth test.

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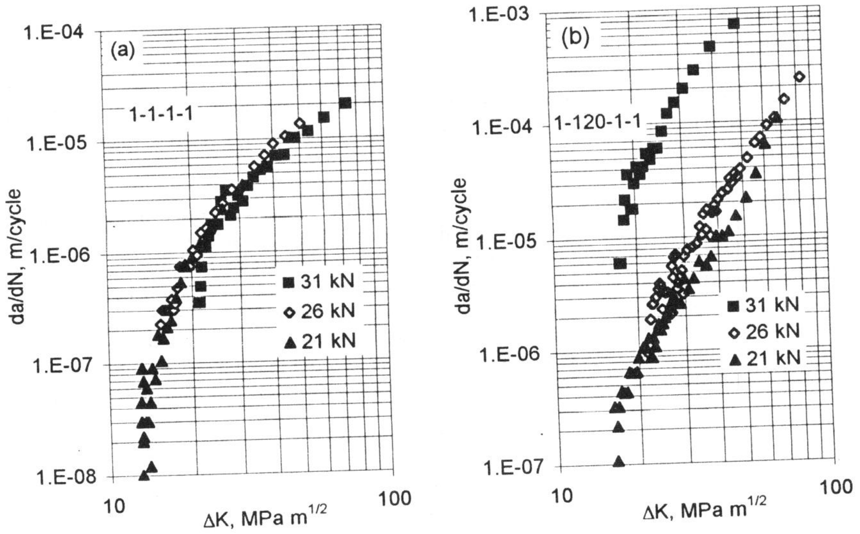

Figure 1 Influence of maximum load on FCPR with 1-1-1-1 (a) and 1-120-1-1 (b) wave shape.

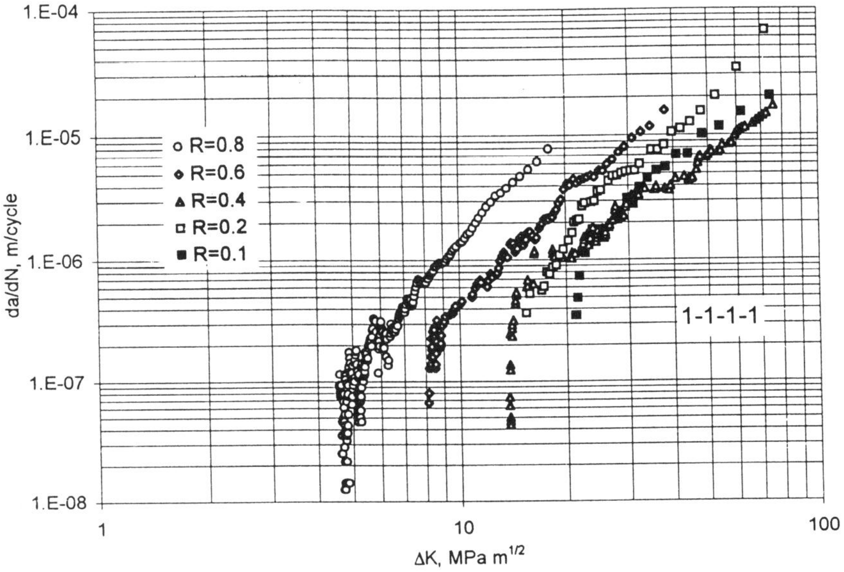

Figure 2 Influence of R-ratio on FCPR

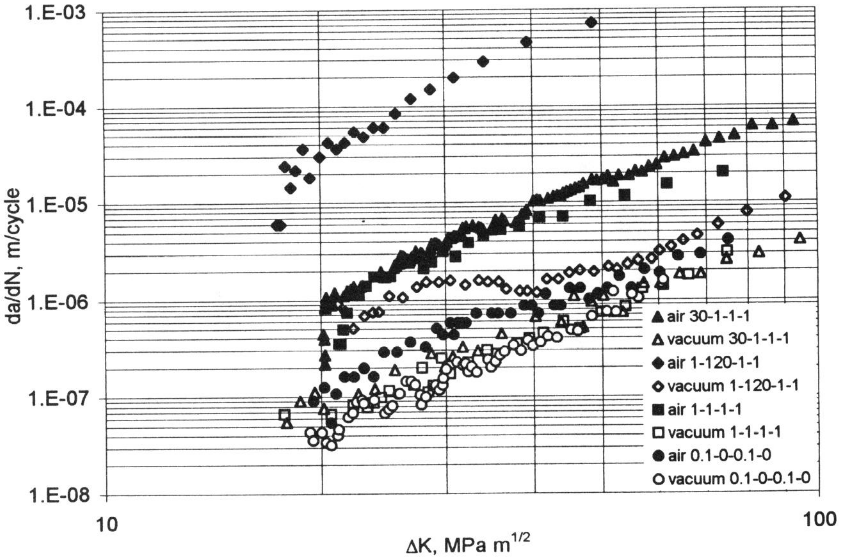

Figure 3 Influence of wave shape and environment on FCPR.

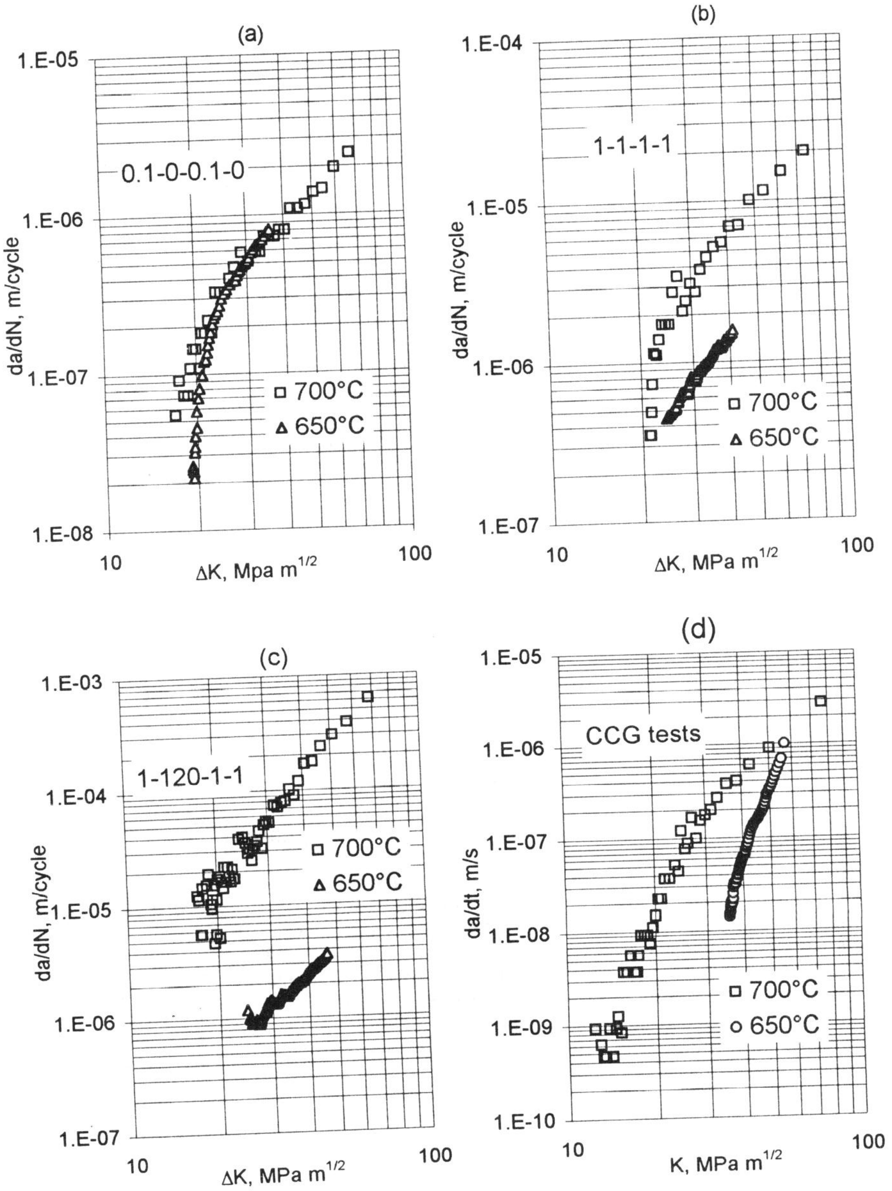

Figure 4 Influence of temperature on FCPR with different wave shape (a, b, c) and on constant load creep crack growth rate (d).