FACTORS INFLUENCING CREEP-FATIGUE CRACK PROPAGATION IN P/M ASTROLOY AT 650°C AND 750°C

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A study of the environmental and mechanical effects on crack growth rate during creep-fatigue tests in different PM superalloys was conducted in air and in a high vacuum at 650°C and 750°C. Up to 650°C, it is well established that the environment plays a predominant role in the acceleration of fatigue crack growth, oxidation being the main factor at the origin of time-dependent effects. At 750°C holding time effects are still higher. Complex mechanical and environmental interactions have been revealed at 750°C temperature at which the da/dN-ΔK relationship obtained in air appears to be highly dependent on the initial ΔK values applied at the beginning of the creep-fatigue test.

INTRODUCTION

The development of high temperature resistant nickel base alloys for turbine discs necessitates a better understanding of creep-fatigue-environment interactions which govern their durability. Up to 650°C, it is well established that the environment plays a predominant role in the acceleration of fatigue crack growth, oxidation being the main factor at the origin of time-dependent effects. Moreover, microstructure effects observed in air are also associated with oxidation influence since they disappear when the creep-fatigue experiments are performed in vacuum. In contrast, creep-fatigue behaviour at higher temperatures still remains poorly documented.

This report provides some results on the effects on crack growth inducted by environment and tests conditions established on different PM Ni-base alloys cycled in air and in vacuum at 650°C and 750°C.

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EXPERIMENTAL PROCEDURES

The compositions of the different alloys used are shown in table 1. Some physical dimensions, including grain and γ' precipitate size, are summarised in table 2.

TABLE 1 - Nominal composition of Ni-base superalloys.

Alloys	Ni	Co	Cr	Al	Ti	Mo	Hf	C	B	Zr
N18	bal.	15,30	11,32	4,23	4,30	6,36	0,44	0,018	0,017	0,054
ATGP3	bal.	16,42	14,69	3,86	3,46	5,01	-	0,030	0,021	0,032
NP1	bal.	16,30	14,48	4,34	3,65	4,95	-	0,018	0,011	0,047

TABLE 2 - Alloys and microstructural features.

Alloys	grain size (µm)	grain boundary morphology
Astroloy ATGP3 'reference'	30	smooth
N18 fine-grained	12	smooth
N18 coarse-grained	60	smooth
NP1 fine-grained	20-30	smooth
NP1 ' SGB'	45-65	serrated

Crack propagation tests in creep-fatigue were conducted at 650°C and 750°C in a high vacuum using KTr samples with a 10 sec–t_m–10 sec trapezoidal cycle, dwell-time t_m varying between 0 and 1000 seconds; a load ratio of 0,05 was used. Moreover, for comparison, some results obtained in air at the ONERA and previously published by Loyer-Danflou et al (1) are also reported here. In both environments the crack length was determined from potential drop measurements.

RESULTS AND DISCUSSION

Mechanical, environmental and microstructural effects at 650°C

At 650°C, mechanical variables fall essentially on the effect of hold time at peak load. The main question to be solved is the relative contribution of creep and oxidation in time dependent damage. Figure 1 gives results obtained in vacuum for ATGP3 'reference' with a hold time of 0 and 300 sec. FCGR increases weakly with dwell-time at this temperature.

Concerning environmental effects, experiments conducted on fine grained N18 and ATGP3 'reference' show that oxidation produces a strong acceleration of crack propagation rates, especially for low ΔK values, associated with a marked modification of the fracture mode which is essentially transgranular in vacuum and becomes clearly intergranular in air (figure 2).

Figure 3 shows the results obtained for N18 fine-grained and ATGP3 'reference' which are different in nominal composition and microstructural dimensions (γ ' precipitates and grain morphology). In vacuum, FCGR still remains weakly influenced by microstructural variations.

Concurrently, as shown by Hochstetter et al (2), Lautridou (3) and Bernede (4), results obtained in air for the same alloys under identical loading revealed that time dependent damage processes are predominant and that the FCGR behaviour is strongly dependent on the microstructure.

Mechanical, environmental and microstructural effects at 750°C

To dissociate parts of creep and oxidation activation which have a competitive influence in time damage processes at very high temperature, mechanical effects at 750°C were investigated in vacuum. Figure 4 shows results observed for creep-fatigue experiments on crack growth on Astroloy. At this temperature, creep processes become predominant giving a strong influence of the load holding time. Concurrently experiments describing the effect of the load ratio reveal that Kmax rather than ΔK seems to control crack growth in this case.

At 750°C the effect of environment is more complex (1); for ATGP3 'reference' the da/dN-ΔK relationship in air can be represented by two different curves according to the initial ΔK conditions:

- when test in air is started at 21 MPa√m the crack growth rate is about 100 times higher in air than in vacuum.

- when test in air is started at low ΔK values (13 MPa√m) high initial crack growth rates are also observed but da/dN decreases, reaching values identical to that obtained in vacuum (figure 5). However, the crack path is intergranular with no significant changes between the two test conditions. We have shown that this atypical behaviour, also observed with all other alloys presented here, seems to be tied in with an overaging treatment obtained during the decrease of the crack growth rate at the beginning of the low initial ΔK experience. The exact modification of microstructure, only efficient in air tested materials, remains to be determined. This behaviour was allowed by the crack clamp during the first stage of the experiment conducted at low ΔK. Indeed, holding the material in a furnace at 750°C in vacuum for a period equivalent to the time required to reach in air the pseudo-vacuum curve in low initial ΔK conditions also permits to obtain the pseudo-vacuum behaviour in air creep-fatigue tests started at high initial ΔK values (figure 5).

Concerning microstructure effects, figure 6 gives results obtained for the different N18 and NP1 alloys in vacuum. These results show that, without environmental effects, the increase of the grain size affects weakly the FCGR. That means that the high influence of grain size observed in air at 750°C is still mainly related to oxidation effects. In contrast the grain boundary morphology is an important intrinsic parameter controlling FCGR at 750°C. SGB strongly improve crack growth resistance under creep-fatigue at 750°C. This effect is explained by modification of the propagation modes witch are clearly intergranular for materials with smooth boundaries and become mixed intergranular-transgranular with serrated structures.

CONCLUSION

At 650°C, environment plays a predominant role in acceleration of fatigue crack growth, oxidation being the main factor at the origin of time-dependent effects and of the transition from transgranular to intergranular crack propagation mode. In vacuum FCGR seems to be weakly influenced by an additive dwell time or by a modification of alloy's microstructure.

At 750°C the environmental effects are still stronger but, with some particular test procedures, oxidation embrittlement can be suppressed. The sensitivity of crack growth rates to hold times in vacuum and constant intergranular fracture surfaces shows that creep damage becomes predominant at this temperature. For a given alloy only grain boundary morphology seems to have a strong influence on FCGR in vacuum while in air all microstucture parameters and specially grain size are influential.

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ABBREVIATIONS USED

SGB = Serrated Grain Boundary

FCGR = Fatigue Crack Growth Rate

REFERENCE

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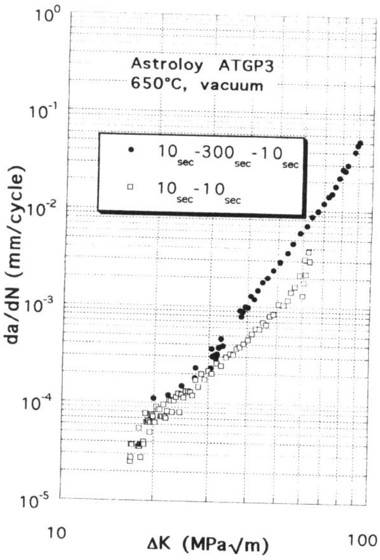

Figure 1 Influence of holding time on FCGR at 650°C

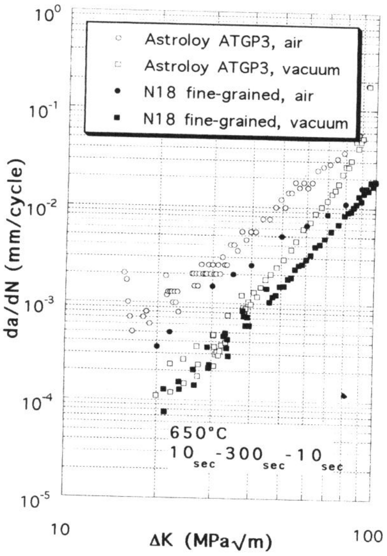

Figure 2 Influence of the microstructure on FCGR at 650°C

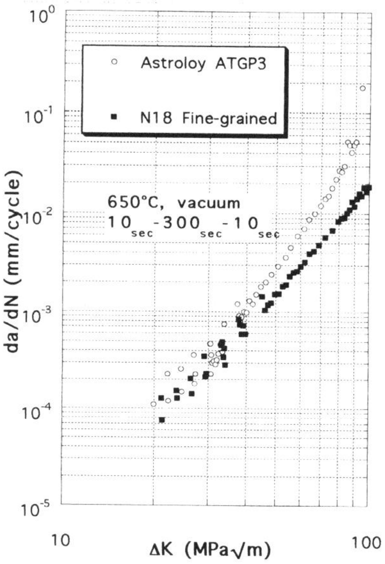

Figure 3 Influence of environment on FCGR at 650°C

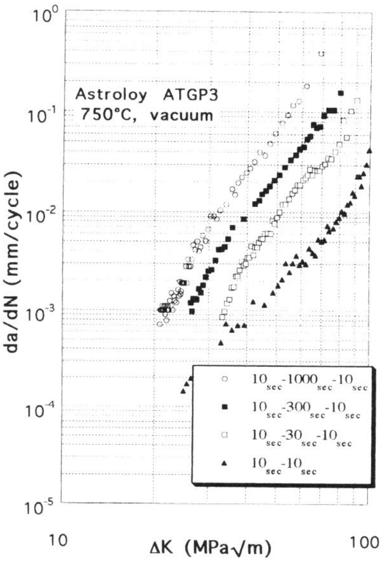

Figure 4 Influence of holding time on FCGR at 750°C

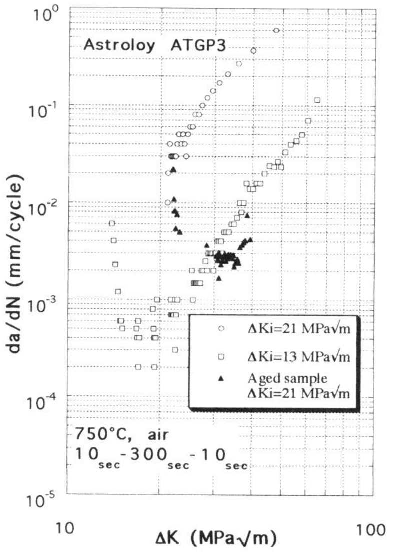

Figure 5 Influence of the microstructure on FCGR at 750°C

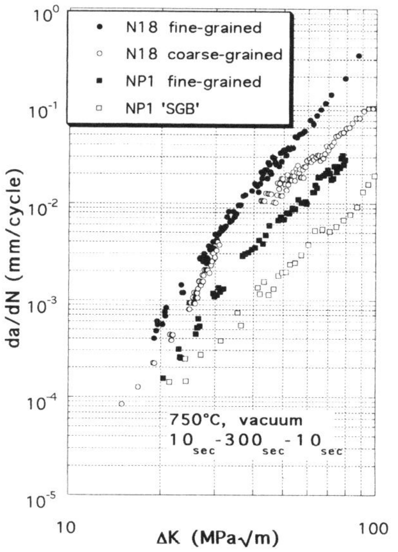

Figure 6 Influence of environment on FCGR at 750°C