INFLUENCE OF GRAIN SIZE ON HIGH TEMPERATURE LOW CYCLE FATIGUE AND FATIGUE CRACK PROPAGATION OF A NICKEL BASE SUPERALLOY

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The effect of three heat treatments on low cycle fatigue and fatigue crack propagation of Inconel 718 alloy at 650°C was analysed. In general the best high temperature mechanical strength was observed in the material with fine grain size. The material with fine grain size was also tested at different frequencies in air and in vacuum and the results showed that fatigue damage was due to oxidation, while creep effect seems to be negligible.

INTRODUCTION

Inconel 718 alloy is a high strength nickel base alloy which is widely used for the construction of turbine disks (1). Typical operations of jet engine disks are such that designers need low cycle fatigue and fatigue crack propagation parameters.

The main properties of Inconel 718 are high strength at elevated temperature and good weldability (2). The best combination of ductility, tensile strength and smooth and notch stress rupture properties is obtained by developing the optimum heat treatment.

Aim of this work is the evaluation of grain size effect on low cycle fatigue (LCF) and fatigue crack propagation (FCP) behaviour of Inconel 718 alloy at 650°C.

Besides, the influence of frequency on LCF and FCP

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was investigated for the alloy with finest grain size by comparing tests in air and in vacuum.

MATERIAL AND EXPERIMENTAL PROCEDURE

The average chemical composition of the Inconel 718 nickel-base superalloy is reported in Tab. 1.

Tab. 1: Average chemical composition of the Inconel 718 alloy (wt. %).

Ni	Cr	Nb	Ti	Al	C	Fe
50-55	17-21	5.0-5.5	0.65-1.15	0.4-0.8	0.01-0.3	Bal

In order to obtain different grain sizes the alloy was treated in the following conditions:

a) annealed at 955°C for 1h, air cooled, aged at 720°C for 8h, furnace cooled to 620°C with a rate of 50°C/h, aged at 620°C for 16h: final structure with medium grain size (MGS);
b) annealed at 1093°C for 1h, air cooled, aged at 720°C for 4h, furnace cooled to 620°C with a rate of 50°C/h, aged at 620°C: final structure with large grain size(LGS);
c) a forging process followed by the a) heat treatment was used to obtain a large disk with fine grain size (FGS).

The LCF tests were performed at 650°C on hourglass specimens in diametral strain controlled conditions with a triangular wave form, a zero mean value (R=-1) and a strain rate of 10^{-2} s^{-1}. The alloy in the c) heat treatment was tested at 10^{-2} s^{-1} and 10^{-4} s^{-1}, the other experimental conditions being equal.

The FCP behaviour of the alloy in the heat treatment a) and c) was studied at 650°C. Tests were performed on single edge notch tension (SENT) specimen in load control with triangular wave-shape (R=0.1). In order to study the influence of time dependent mechanisms on fatigue crack growth rate the test frequency was varied in the range 0.01 to 10 Hz.

Some tests were also performed in vacuum with a pressure of 10^{-3} Pa for the evaluation of oxidation effects.

EXPERIMENTAL RESULTS AND DISCUSSION

Low cycle fatigue

The total strain range versus number of cycles to failure of Inconel 718 alloy with the different grain size is plotted in Fig. 1. The curves show a reduction of fatigue life when grains decrease from LGS to MGS. The FGS alloy exhibits the shortest fatigue life at high strain and the longest fatigue life when strain is below 1.2%.

At high strain, where crack starts very early and time to crack initiation can be neglected, the fatigue crack propagation occurs in mixed transgranular-intergranular mode and can be accelerated in the FGS alloy. At low strain, where time to crack initiation can be up to fifty per cent of fatigue life, the reduction of grain size can increase sensibly the time to crack initiation and consequently prolong the fatigue endurance.

Moreover the fatigue curve of the FGS alloy shows a lower slope due to a reduced ductility in respect of the slopes observed in the alloy with other grain sizes. In Fig. 2 the influence of strain rate on fatigue life in air and in vacuum for the FGS alloy is analysed. In air, the reduction of strain rate determines a decreasing of fatigue life of a factor ranging from 3 to 5. When tests are performed in vacuum the fatigue life increases markedly and the influence of strain rate disappears almost completely as observed in other nickel base superalloys (3, 4). Such a behaviour indicates that in vacuum creep is not operative and in air the increasing of damage at the lowest strain rate can be ascribed to oxidation that accelerates crack initiation and propagation.

Fatigue crack propagation

The influence of test frequency and hold time on FCP rates of Inconel 718 at 650°C is described in Figs. 3a and 3b for the LGS and FGS material respectively. In both materials the FCP rates increase when test frequency is decreased from 10 to 0.01 Hz or when a load peak hold time is added to the fatigue cycle.

The influence of microstructure on FCP rates is detectable only for frequencies less than 0.1 Hz or for hold time tests. In these conditions the FGS material shows lower FCP rates.

In Fig. 4 the experimental results obtained in vacuum tests are reported. In this environment the influence of frequency disappears indicating that an oxidative mechanism is responsible for the acceleration of FCP observed in air tests. Only for the LGS material a slightly higher FCP rate is measured in the vacuum hold time test. This effect could be attributed to a creep effect or to an insufficient vacuum level.

CONCLUSIONS

The LCF and FCP tests on Inconel 718 alloy at 650°C have shown:

- the best mechanical strength is obtained in the material with FGS structure;
- in the material with FGS structure the increase of test frequency improves the fatigue life and decreases the FCP rate;
- in vacuum tests the marked decrease of frequency effect, the increase of fatigue life and the decrease of FCP rate show that fatigue damage in air is due to oxidation.

ACKNOWLEDGMENTS

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REFERENCES

(1) Irving, R.R., Iron Age, 1981, pp 77-81

(2) Heiselstein, H.L., United States Patent Office International Nickel Company, 1962, pp 62-79.

(3) Marchionni, M., Ranucci, D. and Picco, E., High-Temperature Low-Cycle Fatigue Behaviour of IN 738 LC Alloy in Air and in Vacuum. Proc. of "High Temperature Alloys for Gas Turbines 1982", Edited by R.Brunetaud et al., D.Reidel Publishing Company, London, 1982 pp 791-805.

(4) Gabrielli, F., Marchionni, M. and Onofrio, G., Time Dependent Effects on High Temperature Low Cycle Fatigue and Fatigue Crack Propagation of Nickel base Superalloys. "Advances in Fracture Research" Proc. of ICF7, Houston Texas, 1989 pp 1149-1163.

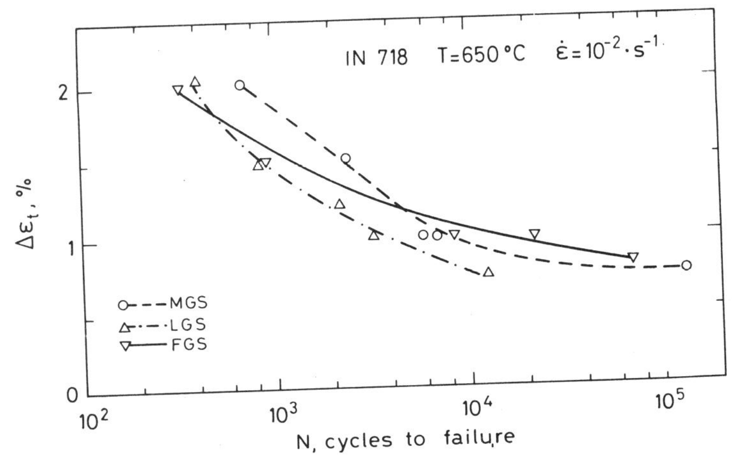


Figure 1 Influence of grain size on low cycle fatigue.

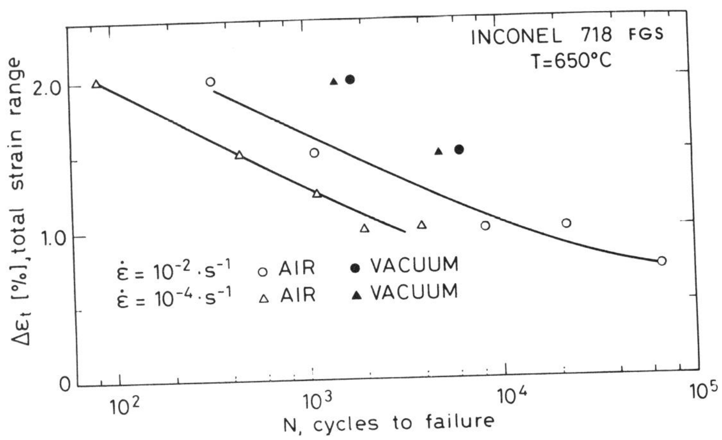
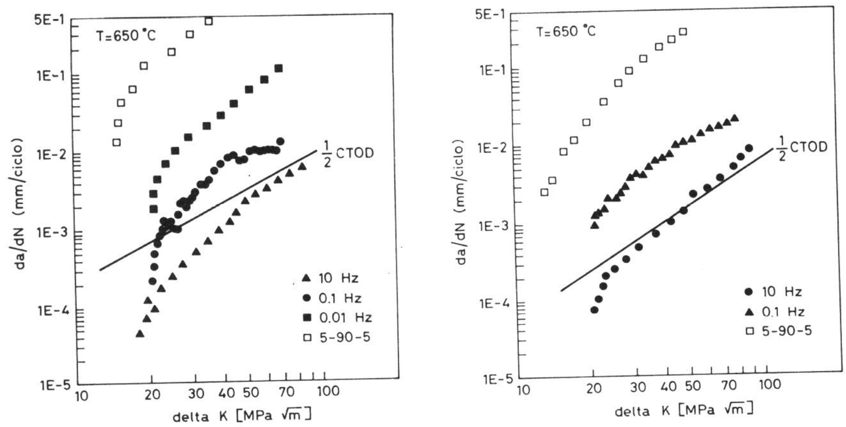
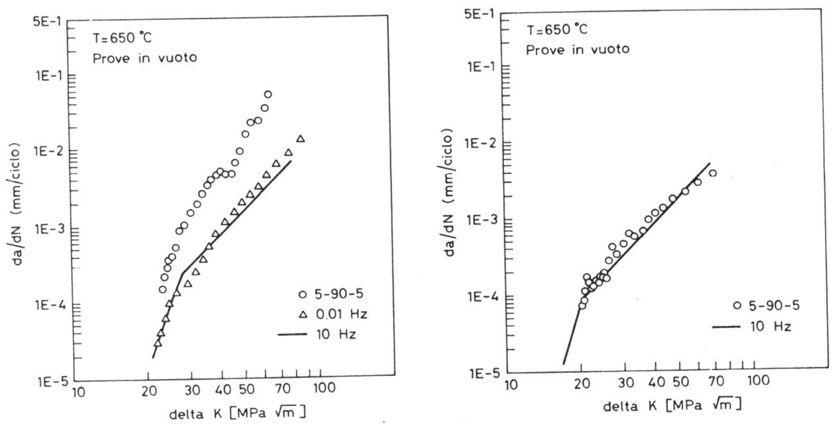


Figure 2 Strain rate and environment effect on low cycle fatigue.



a) b)

Figure 3 Influence of frequency and hold time on FCP rates in air: a) LGS material, b) FGS material.



a) b)

Figure 4 Influence of frequency and hold time on FCP rate in vacuum: a) LGS material, b) FGS material.