EFFECT ON INCLUSIONS ON GIGACYCLE FATIGUE OF A NICKEL BASE ALLOY

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The present study deals with initiation of fatigue cracks in the gigacycle regime. A powder metallurgy nickel base alloy is tested at 20 KHz, 450°C with $-1<R<0,8$. The fracture mechanisms have been observed and analysed metallographically and micro fractographycally under a scanning electron microscope. It is found that there is a competition between inclusions, porosities and surface defects depending of R ratio.

INTRODUCTION

Submitted to loading cycles at high amplitude turbine disks are also submitted to small elastic vibration cycles at very high frequency due to mechanical, acoustical or aerodynamically origins. These small cycles can contribute to initiate cracks and provoke a catastrophic failure.

In this study, the fatigue testing machine was built in our laboratory from a piezoelectric device capable of producing 20 KHz loading cycles with different mean stress and temperature between 25°C and 800°C.

For results of fatigue limits based on 10^9 cycles, very few results can be refereed to. Therefore, the shape of SN curve beyond 10^7 cycles and the fatigue limit are not well known except using some statistical approaches.

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In an other hand, the effect of defects, that is to say, inclusions, porosities and scratches, is not obvious in the gigacycle fatigue.

Thus, this paper is devoted to the determination of very high cycle SN curve and initiation mechanisms for a nickel base alloy (N18) processed by powder metallurgy.

Materials

The chemical composition of N18 nickel base alloy is:

$Cr_{11,5}\ Co_{15,5}\ Mo_{6,5}\ Al_{4,3}\ Ti_{4,3}\ Nb_{1,5}\ HF_{0,5}$

The principal mechanical properties are:

$\sigma_y = 1050$ MPa UTS = 1500 MPa

In order to reveal the effect of defects, a pollution with ceramic inclusions (80 to 150 μm diameter) was made, using 30.000 inclusions for 1 kilogram of alloy. A comparison is done between N18 alloy with and without inclusions.

Testing conditions

The piezoelectric fatigue machine is presented by Bonis (1).

Results

The results of fatigue tests on N18 nickel alloy show that then is no asymptote on the SN curves between 10^6 and 10^9 cycles (figure 1). Depending of the stress ratio and the volume fraction of inclusions, the fatigue strength at 10^9 cycles can be 20 MPa to 100 MPa less than at

10^6 cycles. It means that the staircase method applied between 10^6 and 10^7 cycles is not correct to predict the fatigue strength at 10^9 cycles.

Comparing the effect of inclusions and porosities, it is interesting to point out the following:

- The role of the inclusions is sometimes hidden by the role of porosities when the R load ratio is equal to -1 or to 0. The scattering of the results for R = 0 in a N18 polluted of inclusions is very important. Inversely for a N18 standard, the scattering is low.

- It is very remarkable that when R = 0 or R = -1, the resistance to the gigacyclic fatigue at 450 °C is 250 MPa in the N18 with or without inclusions.

- On the contrary, when the static strain of the fatigue cycle is very high, for R = 0,8, the role of inclusions becomes preponderant. Without inclusions, the N18 fatigue limit, at 450 °C, is 155 MPa at 10^9 cycles. However, it is 125 MPa with inclusions. This is the case of damage done by the vibrations on the turbine disks.

Modelization of the gigacyclic fatigue and discussion.

Initiation zones at 10^9 cycles. In specialised literature, few results are given on this topic (1). According to our own observations and those of Murakami (2), the gigacyclic fatigue crack initiation seems to occur essentially inside the sample and not at the surface as it is observed for some shorter life (figure 2).

So we can modelize three types of crack initiation in a cylindrical sample of which the surface was polished depending on whether it is low cycle (10^4 cycles), megacyclic (10^6 cycles) or gigacyclic (10^9 cycles) fatigue (figure 3). Let's say that for the smallest numbers of cycles to rupture, the crack initiation sites are multiple and on the surface, according to the standard, at 10^6 cycles, there is only one initiation site but, for the a higher number of cycles to rupture, the initiation is located at an internal zone. What remains is to specify how and why some fatigue cracks can initiate inside the metal in gigacyclic fatigue.

Prediction of fatigue strength at 10^9 cycles. According Murakami (2), it seems the fatigue strength at 10^9 cycles can be predicted using his model with few modifications. From the present data we have verified this relation:

$$\sigma_w = \frac{C.(Hv+120)}{(\sqrt{area})^{1/6}} . \left[\frac{(1-R^3)^{\alpha}}{2} \right]$$

with:

C = 1,78 for internal and external defects
√air : Defect surface
R : Load ratio
α : 0,878 + Hv.10^4

Hv : Vickers hardness
σw : MPa
α : 0,878 + Hv.10^4

Table 1 - Application of Murakami model to N18 alloy:

R	-1	-1	0	0	0,8	0,8
Defect	Mixed	Inclusion	Porosity	Inclusion	Porosity	Inclusion
Localisation	Surface	Internal	Internal	Internal	Internal	Internal
√area (υm)	50	100	25	100	25	100
σw (MPa)	524	466	309	246	160	126
σ experimental (MPa)	525	400	280	270	160	130
Error %	0	+14	0	-9	0	-3

CONCLUSION

Experimentally we have showed that beyond 10^7 cycles, fatigue rupture can occur in N18 nickel alloy. In some cases, the difference of fatigue resistance can decrease by 100 MPa, between 10^6 and 10^9 cycles. According to our observations, the concept of infinite fatigue life on an asymptotic SN curve is not correct. Under these conditions, the fatigue limit defined with a statistical approach between 10^6 and 10^7 cycles cannot evidently guarantee an infinite fatigue life. The effect of porosities is more often in competition with inclusions to explain initiation at 10^9 cycles.

REFERENCES

(1) J. Bonis Fatigue des alliages de nickel dans le domaine gigacyclic, Thèse de doctorat- CNAM, (1997)

(2) Murakami Y. and al What happens to the fatigue limit of Bearing Steel without Non-metallic inclusions ?, ASTM , 1327, (1997).

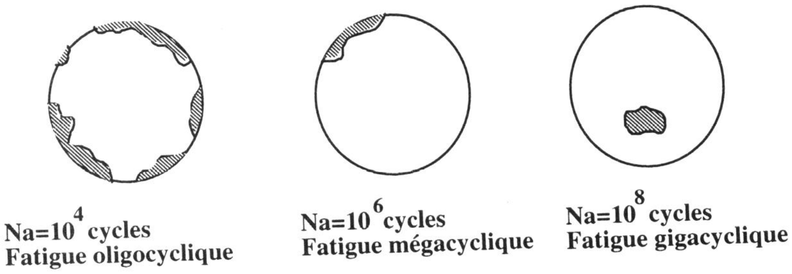

Figure 1. Fatigue crack initialisation modelization.

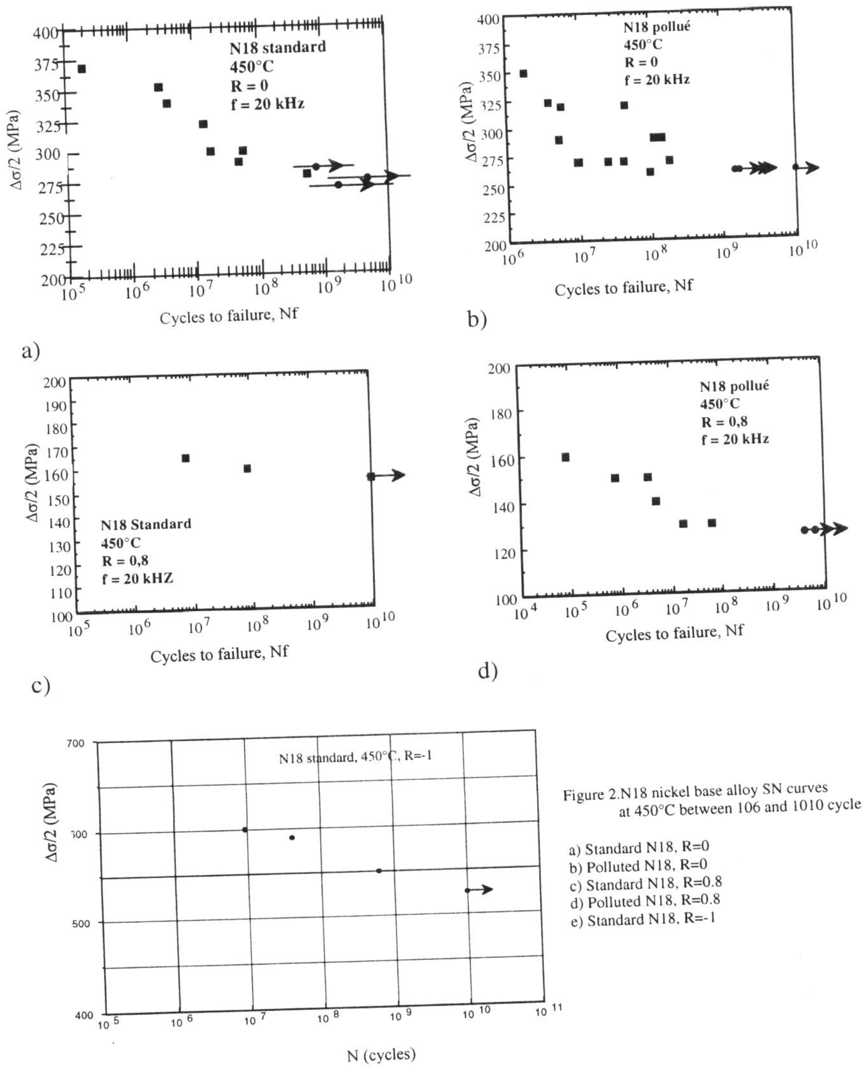

Figure 2.N18 nickel base alloy SN curves at 450°C between 106 and 1010 cycles.

a) Standard N18, R=0
b) Polluted N18, R=0
c) Standard N18, R=0.8
d) Polluted N18, R=0.8
e) Standard N18, R=-1