CERAMIQUE INCLUSION EFFECTS ON ULTRASONIC FATIGUE AT HIGH TEMPERATURE ON A POWDER NICKEL BASE SUPERALLOY: THE N18

J.Bonis*, C.Bathias* and F.Soniak†.

Ultrasonic fatigue is a resonant test method, in which a large amplitude displacement wave must be established in a resonant specimen. This testing method increases the frequency for reducing the necessary time to accumulate a large number of cycles up to 10^8. An adapted piezoelectric transducer translates 20 kHz electrical voltage signals into 20 kHz mechanical displacements. It found that the effect of stress amplitude, R ratio and temperature in ultrasonic fatigue is very similar compared to conventional fatigue. However, no fatigue limit was found between 10^6 and 10^9 cycles.

INTRODUCTION

In 1984, SNECMA has started a program concerning powder Nickel base N18 superalloy development (1). The objective of the motorist was a new high mechanical properties material for designing modern aeroplane turbine discs. The powder superalloy N18 fatigue resistance strictly depends of the inclusions cleanness. Indeed, under low loading, ceramic inclusions (example : powder atomization crucible origin) are crack initiation sites. Inclusions can be present in critical area parts where a large number of cycles are accumulated in short time. In consequence, for discs design, knowing the lifetime in function of the loading for encounter inclusion size is very important. Low cycle fatigue studies have been led but any results provided influence of inclusion for lifetime upper 10^7 cycles.

High temperature (450°C) ultrasonic fatigue tests are caried out on polished samples machined from material voluntary polluted with pertinent and control size ceramic inclusions. Experiences are conducted with several load R ratio. One way to predict the fatigue life of polluted materials is to use a statistical approach as it was made earlier by A. de Bussac and J.C. Lautridou (2). According to the fact that fatigue crack initiation up to 10^7 cycles often starts from a ceramic inclusion or porosity a deterministic model to predict fatigue life is used in this paper.

* CNAM/ITMA 2 rue Conté 75003 Paris
† SNECMA 91003 Evry.

A global discussion on relation between micrography observations, crack propagation curves and fatigue life is led in this study. The main interest of this work is to know if crack propagation from natural defect (tridimensional) can be predicted with artificial (bidimensional) crack tests. To approach the real conditions of use, all tests are realized at high temperature (450°C).

EXPERIMENTAL DEVICE

In close cooperation with SNECMA, our laboratory has developed a methodology to study ultrasonic fatigue in nickel base alloy (Astroloy and N18) to know the fatigue response of the alloys and predict fatigue damage in disks. The fatigue crack growth rates is determined between 10^{-5} to 10^{-9} mm/cycles in the range of temperature between 20°C and 750°C with R rates equal to -1. Conventional fatigue test are led at room temperature with R ratio ranging from -1 to 0.7.

Principe

Since the first 20 kHz machine was constructed in 1950 by Mason (3), ultrasonic fatigue testing is less time consuming. A schematic view of our USF system of this study is shown in Fig.1. The machine is essentially a combination of a tensile machine and an ultrasonic machine constituted of a BRANSON power generator whose frequency is held at 20 kHz. The vibration of the specimen is induced with a piezo-ceramic transducer, which generates an acoustical wave to the specimen through a power concentrator (horn) in order to obtain more important stress and an amplification of the displacement. The resonant length of the specimen and concentrator is calculated at a frequency of 20kHz (4). The dynamic displacement amplitude of the specimen extremity Uo is measured by an optic fiber sensor, which permits to measure the displacements from 1 μm to 199,9 μm, with a resolution of 0,1 μm. A system of video-camera-television is used for the detection of crack initiation and propagation.

For crack propagation an single edge notched specimen is used. For our specimen, the stress intensity factor K was calculated correctly by Wu (7) by finite element method.

For crack initiation an axisymetrical specimen is chosen. Both specimens are discribed in other papers (5 and 6).

RESULTS

Materials

To study the effect of ceramic inclusions several sizes and volume fractions of particules were introduced during proceeding. That is to say 30000 particules / kg with size 80-100 μm.

TABLE 1- Chemical composition of Nickel base superalloy N18

Cr %	Co %	Mo %	Al %	Ti %	Hf %	C ppm	B ppm	Zr ppm
11.5	15.5	6.5	4.3	4.3	0.5	200	150	300

Fatigue crack growth at the threshold level

The Fig. 2 presents the results at high frequency to R=-1. We could see that the threshold is smaller to high temperature that at ambient temperature. Normally we could wait a fall of threshold with the increase of the temperature. But on the Fig. 3 the threshold is smaller at 400°C that at 650°C and 750°C. The curves at 400°C, at 650°C and 750°C cuts the vicinities 10^{-5}mm/cycle. Our results are comparable with those relative to the conventional fatigue of the ASTROLOY at 200°C and 600°C. The observed gaps are explained by the phenomenon of oxidization to the bottom of crack. On the crack surface of the sample used in our tests, the oxidization at 650°C and at 750°C was observed. The thresholds of N18 are a little superior to those of the ASTROLOY to ambient temperature and to 400°C. At high temperature, normally propagation crack rate increases with the temperature. But the oxidization could slow down propagation to the neighborhood threshold to a small load when the temperature is rather elevated. It could be explained by the fact that the thresholds of N18 at 650°C and at 750°C is greater as at 400°C.

Fatigue crack initiation

The figure 4. presents the results of fatigue on N18 nickel base alloy at 20 kHz and R = 0. The specimens are polished before testing. As it was established earlier for Udimet 500 there is no horizontal asymptote on the S-N curve between 10^6 and 10^7 cycles. Between 10^6 and 10^9 cycles a flat S-N curve with a uniform slope is observed. It means that the fatigue limit defined as an asymptotic value of the stress up to 10^6 is a wrong concept in this case. It is found that for long life range the initiation of the crack starts inside the specimen from a defect. It means that the number of cycles so-called for initiation depends of the size of the defect, the location of the defects and also of low crack growth rates in vacuum before the internal crack collapses at the surface of the specimen. Thus, we propose to predict the number of cycles for initiation a model presented in figure 3, using fracture mechanism concept. Ni is numerically integrated from da/dN.

$$da/dN = C\Delta K^m \quad \text{with C and m material constants} \qquad (1)$$

$$K = \quad \Delta \quad \pi a \qquad (2)$$

K was corrected for surface influence with relation propose by Isida (8). The S-N curve is modeled by tow curves: for $\Delta K < 10$, $C = 4.5 \times 10^{-27}$ and $m = 21$ after $C = 7 \times 10^{-9}$ and $m = 3$.

The computer values of Ni are plotted in figure 4 and compared with experimental data. It is showed that the number of cycles Ni from defect can be predicted from a unic crack growth curve for a give R ratio.

CONCLUSIONS

1. Using high frequency fatigue device we have shown that there is no horizontal asymptote for the N18 S-N curve. Same results were found previously with Udimet 500 (6). It seems that the standard concept of fatigue limit does not exist for this alloys.
2. Up to 10^7 cycles, defects have a basic effect on crack initiation. It is shown that a model based on fracture mechanism is useful for predict Ni.
3. A deterministic approach leads to define very long fatigue life since a statistical approach is useful for life prediction.

REFERENCES

(1) Honnorat, Y. N18, "A Damage Tolerant Alloy for Modern Fighter Aircraft Engine discs", Paper presented at "COMDEF", Airlington VA, Sept 1988.

(2) de Bussac, A. and Lautridou, J.C., Revue scientifique SNECMA n° 5 juin 1994.

(3). Mason, W.P., "Piezoelectric crystals and their application", Ultrasonics, Van Nostrand, New York, 1950.

(4) Kuz'menko, V.A. "Fatigue Strength of Structural Materials at Sonic and Ultrasonic loading Frequencies", Ultrasonics, January 1995.

(5) Bonis, J. ,Soniak, F.and Bathias, C.,"Damage cumulation of ultrasonic fatigue and low cycle", Proceeding of the 6th International Conference on Fatigue, Berlin, 1996.

(6) Wu, T., Ni, J. and Bathias, C."An Automatic Fatigue Testing System for Studying Low Crack Growth at Room and High Temperatures", STP 1231, 1995, pp.598.

(7) Wu, T.Y. and Bathias, C., Engineering Fracture Mechanics, Vol. 47, 1994, pp.683-690.

(8) Isida, M.,Trans ASME, Ser. E, J. Appl. Mech., Vol. 33, pp.674-675.

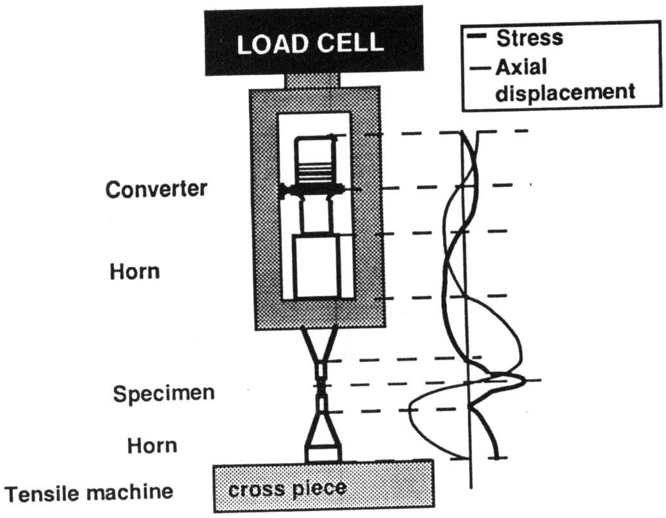

Figure 1 Schema of ultrasonic fatigue machine

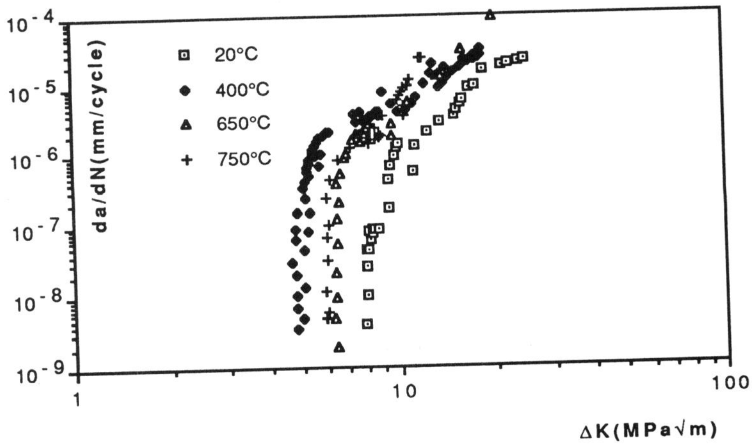

Figure 2 N18 crack growth rate in ultrasonic fatigue

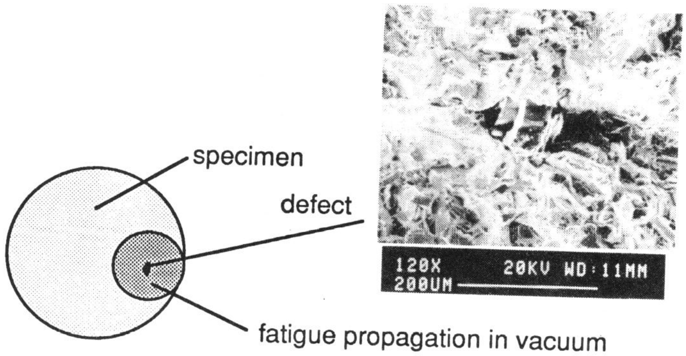

Fig.3 Model to predict Ni fatigue life up to 10^6 cycles.

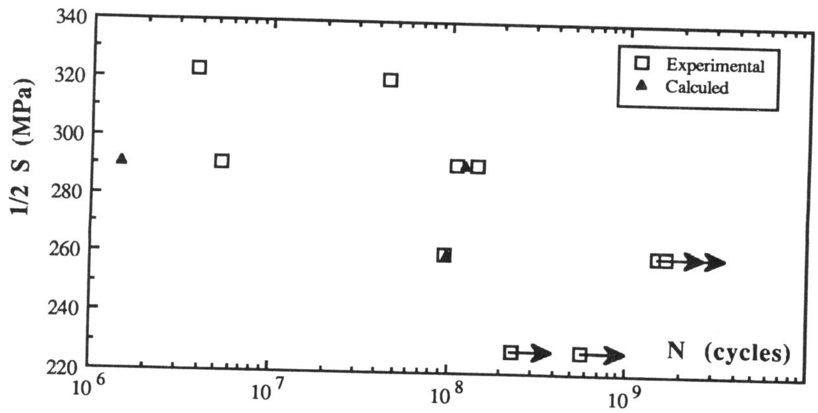

Fig 4 Ultrasonic S-N curves of N18 at 450°C, R = 0