INFLUENCE OF MICROSTRUCTURE ON FATIGUE PROPERTIES OF ALLOY 718

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ABSTRACT

The influence of grain size and grain boundary delta phase on the smooth and notch high cycle fatigue property at room temperature and 650°C was investigated. This paper attempts to correlate the microstructure and fatigue property obtained during the initial development phase and certification of bar stock for compressor blades and other applications. A rotating beam fatigue machine was used to evaluate the fatigue life. All specimens were tested in the solution treated and standard aged condition. The microstructure was examined at one end of the grip portion of the specimens. The observations included grain size ranging from coarse to fine and amount of grain boundary spheroidised delta phase from moderate to nil. Grain size appears to be a significant factor influencing both the smooth and notch fatigue at room temperature and at 650°C i.e finer the grain size better the fatigue life.The delta phase did not seem to have any influence in the fatigue property in the test conditions studied. It was expected that the delta phase which has a significant influence on the notch sensitivity of this alloy at 650°C in stress rupture tests did not have the same influence on the fatigue test. This may be explained as the difference in the deformation mechanism during the stress rupture and high cycle fatigue test. In case of stress rupture test, the failure is predominantly intergranular and hence the presence of the grain boundary delta phase retards crack propagation rate, whereas under fatigue test conditions of the present study, the fractures were transgranular and as such delta phase had no effect on fatigue crack.

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Introduction

Alloy 718 is a widely used nickel-iron base superalloy which exhibits good intermediate high temperature strength, ductility and fatigue resistance [1]. The main phases found in this alloy are MC, TiN, Laves, delta, gamma double prime and gamma prime phases. Gamma double prime and gamma prime are the main strengthening phases, MC and TiN are inert phases, while delta phase is used to control grain size in wrought products [2]. In addition a certain optimum amount of delta phase at the grain boundaries is necessary for notch stress rupture ductility. The influence of grain size on creep resistance and fatigue properties is well recognised i.e finer grain size improve fatigue life and coarser improve creep resistance [3].

Pedron and Pineau have observed that delta precipitates at grain boundary drastically improve the behaviour of notched specimens in a strees rupture test [4]. They observed that, under similar test conditions and grain size, structures with grain boundary delta phase showed a life of about 255 hours as compared to 2 hours life for a material without delta phase at the grain boundaries. Thus it is seen that the mechanical properties of this alloy are greatly influenced by the grain size and combination of the various phases that may be present in the microstructure. In this paper, the effect of microstructure - grain size and area fraction of grain boundary spherodised delta phase on the smooth and notch high cycle fatigue behavior at room temperature and 650°C is investigated. Of particular interest is the influence of delta phase on the notch sensitivity at 650°C under cyclic loading.

Materials and experimental methods

Material produced from 400 mm diameter round ingots produced by VIM-VAR route is homogenized and converted on a hydraulic press to about 120 mm round billets using the standard conversion practice. These billets were further hot rolled to different mill form sizes. The range of chemistry obtained in these heats is given at table 1. The hot rolled bars were solution treated in the temperature range of 960°C to 980°C for one hour and air cooled. Depending on the size and solution treatment temperature the average grain size varied from ASTM 4 to ASTM 9. Test blanks were cut from these bars in the longitudinal direction and aged at 720°C for 8 hours, furnace cooled to 620°C and held for 8 hours and then air cooled. Test specimens were machined from these blanks to the drawings shown in figures 1 and 2. High cycle fatigue testing was conducted on a model RBF-850 High Temperature Rotating Beam Fatigue testing machine supplied by Fatigue Dynamics Inc.

TABLE 1

Range of Chemical composition of Alloy 718 heats, wt%

ELEMENT	RANGE
CARBON	0.02 - 0.035
CHROMIUM	18.3 - 18.5
MOLYBDENUM	3.1 - 3.2
TITANIUM	0.99 - 1.09
ALUMINUM	0.47 - 0.51
NIOBIUM	5.22 - 5.26
BORON	0.0052 - 0.0056
OXYGEN	0.0009 - 0.0021
NITROGEN	0.0047 - 0.0061
NICKEL	52.24 - 53.02
IRON	BASE

All tests were conducted in air at a constant frequency of 6000 rpm. Tests were conducted at room temperature and at 650°C with a stress to obtain a life between 10^6 to 10^8 cycles. The load is applied so as to subject the center section of the specimen to uniform bending moment.

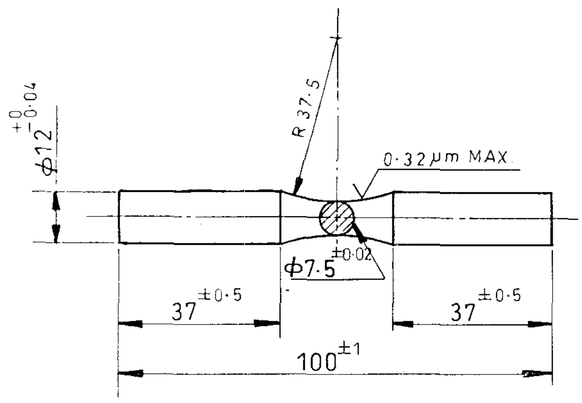


Figure 1 : Smooth specimen drawing

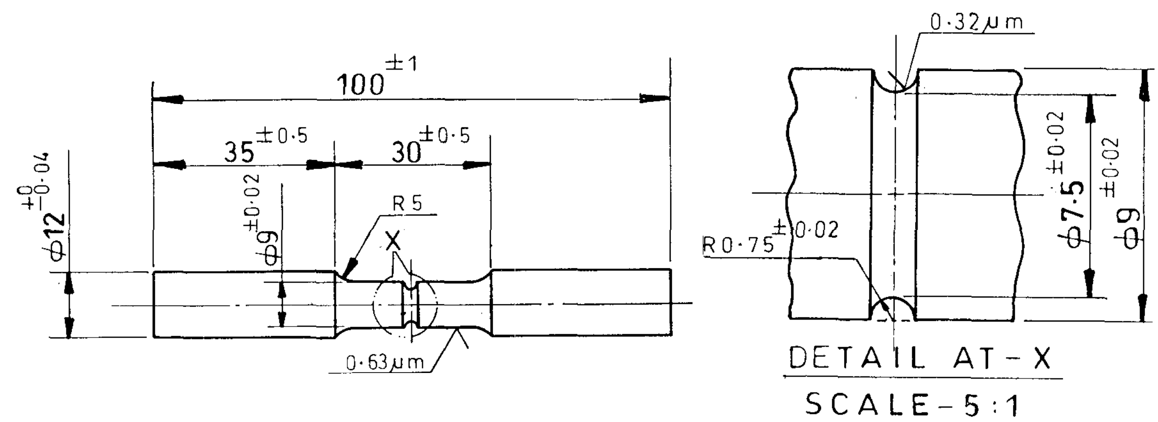


Figure 2 : Notched specimen drawing

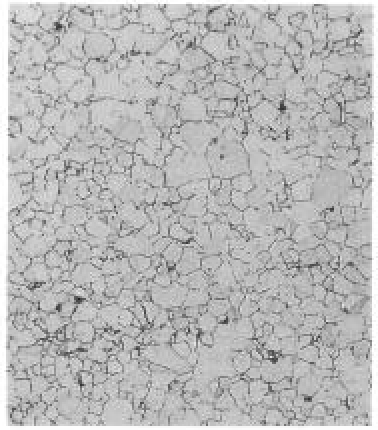
Microstructure was examined at the grip end of the test specimen and the area fraction of delta phase was determined using an Lieca image analyzer which analyses image based on mathematical morphology based on binary and grey colour image processing. This enabled to measure accurately the area fraction of the selected grey level produced for the delta phase. The actual steps involved are, select a field and detect a grey level image corresponding to delta phase, edit or adjust grey level to remove irrelevent details and finally determine the grey level image. This image is then stored in binary form and the area fraction of the grey level is measured. Several fields were measured and then averaged.

Results and observations

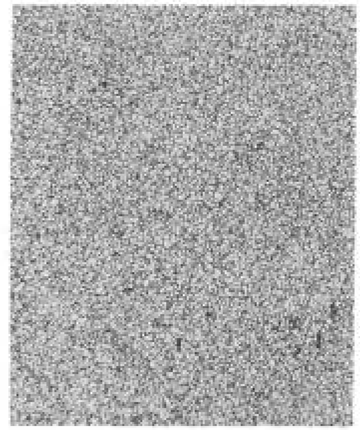
The microphotographs in figure 3 shows the range of grain size and delta phase observed in this study. The number of cycles for failure as a function of grain size for smooth and notched specimens at room temperature is shown in figures 4 and 5 and for 650°C is shown at figures 6 and 7. It is observed that when the area fraction of delta phase at the grain boundaries is constant about 11% then the fatigue life increases as the grain size decreases both for smooth and notched specimens at room temperature and at 650°C. No correlation between the amount of grain boundary delta phase and fatigue life could be observed for both smooth and notched specimens tested at either room temperature or 650°C.

Of particular interest was the effect of delta phase on the notch sensitivity at 650°C. It is well known that during notch stress rupture, an optimum amount of delta phase at the grain boundaries is very

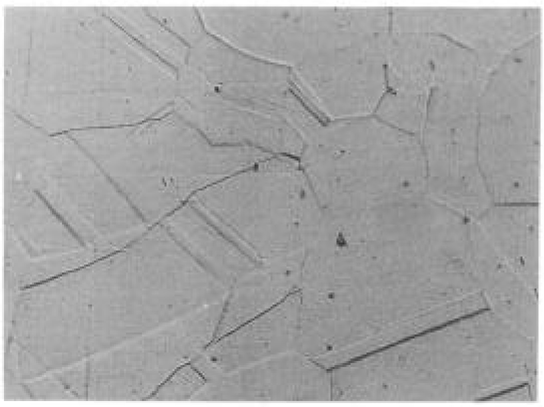
a) 100X



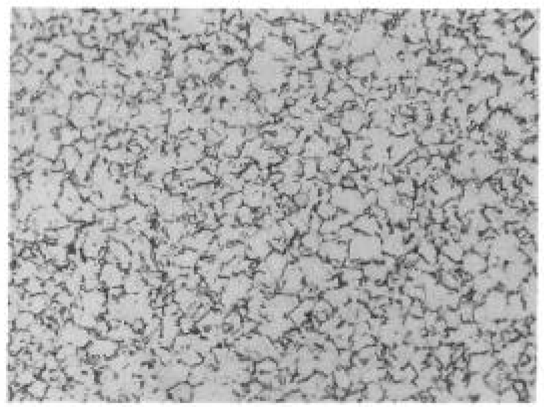
b) 100X



c) 100X



d) 500X



e) 500X

Figure 3 Alloy 718 microstructures observed. a) Grain size ASTM 4-5; b) Grain size ASTM 6 ; c) Grain size ASTM 10 ; d) Nil , spheroidised grain boundary delta phase ; e) 25 % spheroidised grain boundary delta phase.

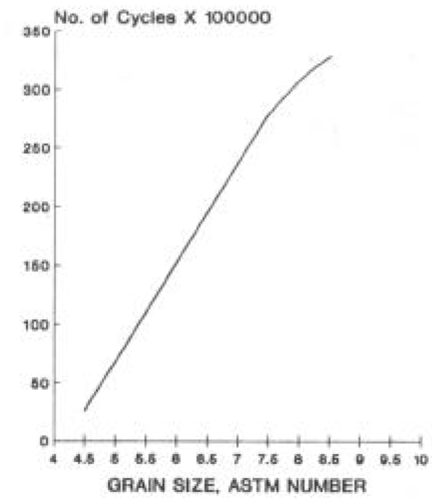


Figure 4 : Influence of grain size on fatigue life, at room temperature, smooth specimen, stress 480 Mpa,

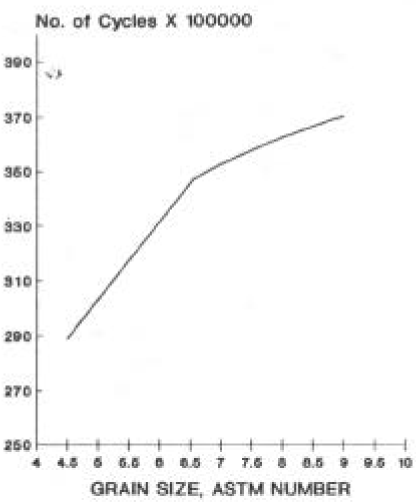


Figure 5 : Influence of grain size on fatigue life, at room temperature, notch specimen, stress 240 Mpa,

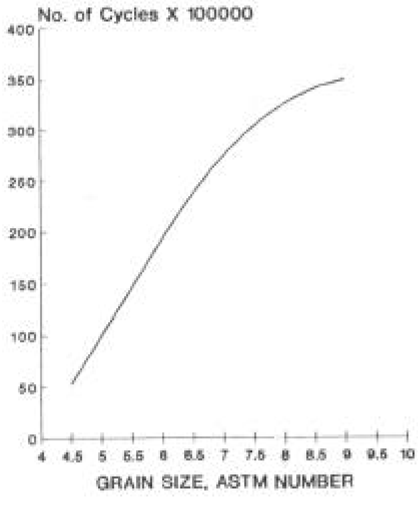


Figure 6 : Influence of grain size on fatigue life, at 650°C, smooth specimen, stress 430 Mpa,

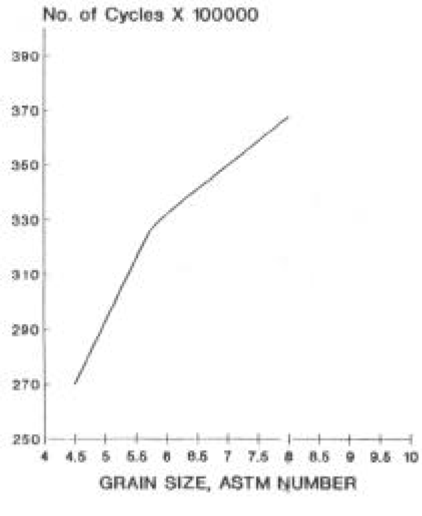


Figure 7 : Influence of grain size on fatigue life, at 650°C, notch specimen, stress 260 Mpa,

essential to obtain notch ductility [5-7]. It was expected that a similar behavior may be observed for notched specimens tested at 650°C for high cycle fatigue. However it was found that when the grain size was in the range of ASTM 6 to 7 and delta phase varied from about 0% to 29%, the notch life for all specimens tested at 260 MPa stress level exceeded 300 X 10^5 cycles and for 330 MPa stress level the fatigue limit was about 150 X 10^5 cycles. Tabel 2 shows the area fraction of delta phase and the fatigue life at 650°C for notched specimens. This clearly shows that the amount of grain boundary delta phase did not have any influence on the fatigue property. Examination of the fracture surfaces showed fracture mode to be transgranular with the conventional fatigue striations in all the specimens as shown in figures 8-12.

TABLE 2 : AREA FRACTION OF DELTA PHASE AND NOTCH FATIGUE LIFE AT 650°C. (Grain size ASTM 6-7)

AREA FRACTION	**No. OF CYCLES X 10^5**	
Stress	260Mpa	330 Mpa
NIL	329	170
9	321	
13	320	165
21	368	
29	344	180

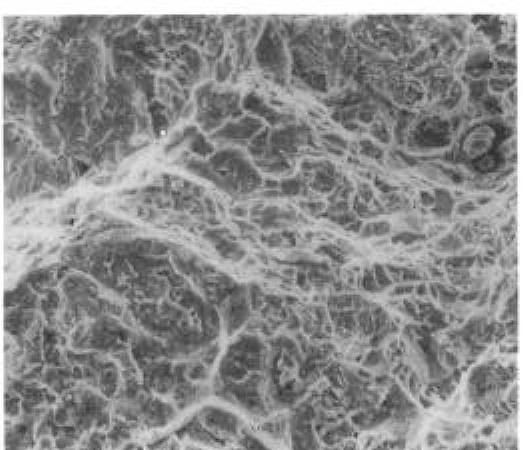


Figure.8. Fractograph of smooth specimen tested at room temperature, 500X

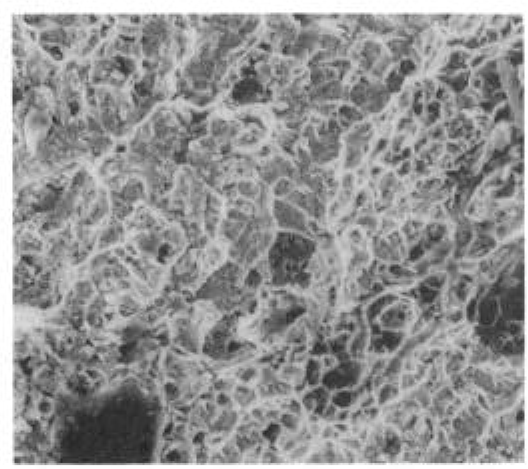


Figure.9. Fractograph of notch specimen tested at room temperature, 500X

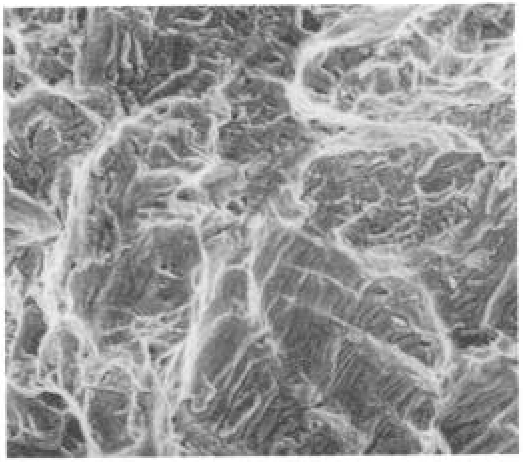


Figure.10. Fractograph of smooth specimen tested at 650°C, 500X

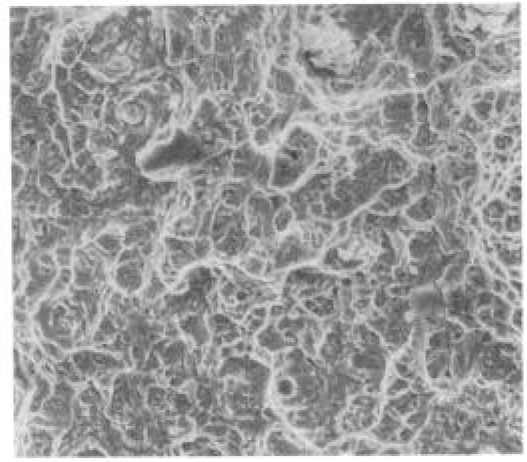


Figure.11. Fractograph of notch specimen tested at 650°C, 500X

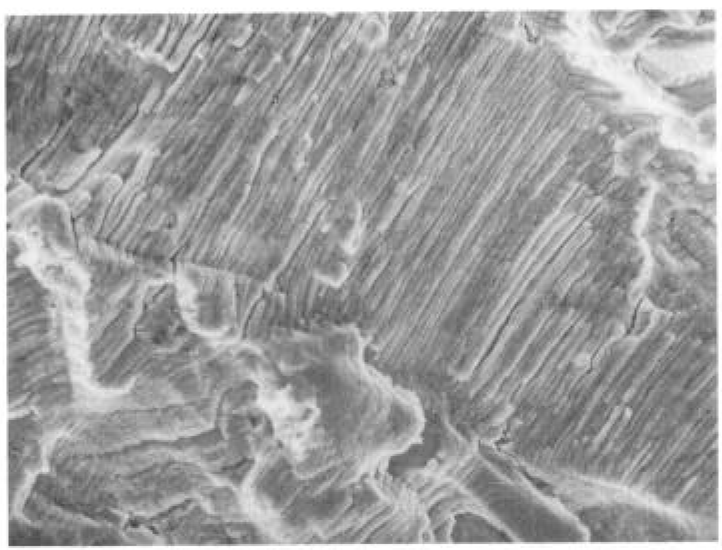


Figure.12. Factograph showing typical fatigue striations, 1000X

Conclusions

The present investigation focused on the effect of grain size and area fraction of spherodised grain boundary delta phase on the smooth and notch high cycle fatigue in alloy 718 at room temperature and 650°C.

The observed results showed that within the test parameters and range of microstructures studied, the high cycle fatigue life increases as the grain size decreases for both smooth and notch specimens tested at room temperature and 650°C. The amount of grain boundary delta phase did not have any effect on the fatigue life for any of the test conditions. Delta phase which plays a dominant role in influencing notch sensitivity at 650°C in stress rupture tests did not have any influence on high cycle fatigue at 650°C. This may be explained as the difference in deformation mechanism during a stress rupture and high cycle fatigue test. In the stress rupture test, the failure is predominantly intergranular and hence the presence of the grain boundary delta phase retarded crack propagation rate . Whereas in the case of fatigue as observed here all the fractures were transgranular and as such delta phase had no effect. It was noted by A Pineau [8] and Keh-minn Chang [9] that for the alloy 718 the fatigue fracture at 650°C is dependent upon the test frequency and that below a certain frequency the fracture mode is intergranular. In such cases the delta phase at the grain boundary may have a significant role to play.

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