High Temperature Degradation of Alloy 718

after Longtime Exposures

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Abstract

An isothermal aging study was carried out on alloy 718 for up to 50,000 hours in a temperature range of 593°C to 704°C. Large structural transitions occurred as the material was aged for 25,000 hours at 649°C and in 5,000 hours at 704°C. As the matrix γ' coalesced, γ , delta, and α Cr precipitated and grew in the grain boundaries. The drop in yield strength with increasing time of exposure or at higher temperatures was attributed to the overaging of the γ' phase, while much earlier drops in Charpy impact energies was more related to the grain boundary changes.

Structures found in a stress-rupture sample which had been tested at 732° C for 5,400 hours at 69 MPa and structures found in the outer rim of 28,000 hour service turbine disk showed the same overaged structures as isothermally aged alloy 718 which had 25,000 hours aging at 649°C. The stress that can be applied to alloy 718 depends on the degree of overaging of the γ'' phase and subsequent γ' , delta, and α Cr formed at the grain boundaries.

Introduction

Components in land based gas turbine are designed to operate continuously for thousands of hours. Alloy 718 turbine disk materials are designed to run at a safe temperature below 649°C, but it is an accepted fact that disk temperatures exceed the design temperatures during operation. To date very little is known about the effects of very longtime exposures of 20,000 hours or more on the structural stability and its effect on the mechanical properties of turbine disks.

Studies have been reported on the behavior of alloy 718 which have been isothermally exposed for up to 50,000 hours (1) in a temperature range of 593°C to 704°C and on an alloy 718 disk which has seen 30,000 hours of service (2). Large similar structural changes were found in both these studies, except the changes occurred in the disk sooner due to the service stress.

As early as 1970 (3), it had been reported that in longtimes and under stress, the main strengthening phase γ' reverted to plates of delta phase + α Cr+ sigma + γ . In addition, it was found that when alloy 718 was tested under the same stress at 593°C, 649°C, and 704°C the material failed in 33,990 hours, 747 hours and 18 hours, respectively. For alloy 718, the critical temperature appeared to be 649°C in this study as well as in other reported isothermal studies.

This study is an attempt to characterize and correlate with mechanical properties the nature and amount of structural changes which occur in longtimes in a temperature range of 593°C to 760°C. By understanding the resultant structure and its effect on mechanical properties, it may be possible to determine the remaining useful life of alloy 718 material which has seen longtime service.

Procedure

Heat treated samples of alloy 718 were sealed in argon or helium filled stainless steel capsules and aged up to 50,000 hours at 593°C and 649°C, 25,000 hours at 704°C, and 5,000 hours at 760°C. Tensile, creep-rupture, continuous cycling fatigue and Charpy V impact tests were conducted on the aged material and compared to as heat treated material. Tensile yield strength and Charpy impact samples were selected for metallographic studies as these two different tests showed large differences in behavior with pretest aging times. The techniques used for the metallographic analysis of samples in this study were the same as that carried out on the previous longtime disk study (2) and the longtime S/R study in 1970 (3) so that a direct comparison could by made of structural changes in longtimes with and without stress.

Results

Mechanical Properties

The yield strength, Charpy impact and stress rupture data showed large reductions in properties as the pretest aging time and temperature increased from 593°C to 649°C and even more drastically as the samples were exposed at 704°C and 760°C. Figure 1 shows a plot of the effects of thermal aging time and temperature on the yield strength while Figures 2, 3 and 4 are plots of the effects of thermal aging as a percent of the original property on yield strength, hardness and Charpy impact energy at 593°C, 649°C, and 704°C.

Figure 2 shows that the yield strength at 593° C increases with aging time due to additional precipitation of γ''/γ' but the hardness does not change. The Charpy impact energy drops to about 65% of original value in 5,000 hours and to about 25% of its original value as the aging time increases to 50,000 hours.

At 649°C, Figure 3, the yield strength starts to decrease after 10,000 hours and decreases in 50,000 hours to about 80% of its original value yet the hardness doesn't change as much for the same aging time. The Charpy impact energy drops to 30% of its original value in 5,000 hours and continues to drop about 20% of its as heat treated value in 50,000 hours.

The effects of the 704°C thermal aging on properties is quite drastic and changes occur in much shorter times. For example, the changes in yield strength and hardness after 1,000

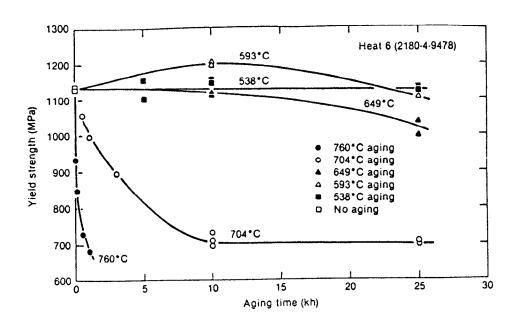


Fig. 1. Effects of thermal aging on yield strength of Alloy 718 (Heat 6) at 24°C.

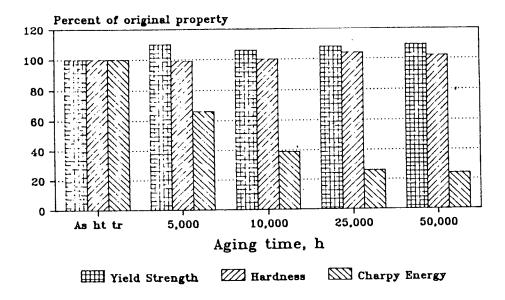


Fig. 2. Effects of Thermal Aging at 593°C on Various Properties of Alloy 718 at 24°C.

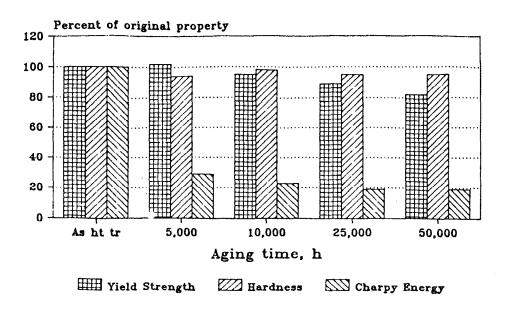


Fig. 3. Effects of Thermal Aging at 649°C on Various Properties of Alloy 718 at 24°C.

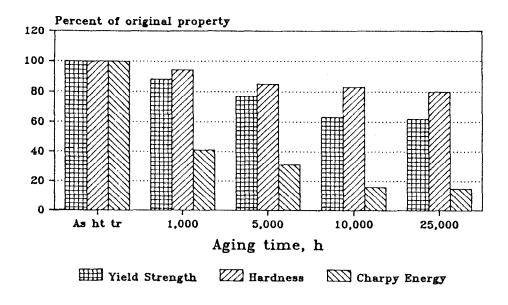


Fig. 4. Effects of Thermal Aging at 704°C on Various Properties of Alloy 718 at 24°C.

hours is similar to the effects at 25,000 hours at 649°C. After 25,000 hours the yield strength is slightly more than 60% of its original value. The Charpy energy change in 5,000 hours is similar to that in 5,000 hours at 649°C and continues to decrease with longer aging times.

Structural Study

The grain boundaries and the matrix of Tensile and Charpy impact samples were evaluated with the SEM at magnifications up to 30,000X using selective etching procedures. In the as-heated treated condition, the size of γ''/γ' precipitation is very difficult to resolve even at 30,000X. The delta plates are easily seen even at low magnifications, Figure 5.

The metallographic study shows that the γ'' transition to γ' and α Cr is first detected after 25,000 hours at 593°C and continues to grow as the aging time increases to 50,000 hours. The size of the γ' disks are of the order to 0.1-0.2 microns. The α Cr formation occurs near the existing delta plates. If the aging temperature is increased to 622°C, the γ' transition becomes more evident as the γ' disks grow to about 0.3 microns in size and the γ' precipitation is found at the grain boundaries and in between the γ' disks. Figure 6 shows the structures after 50,000 hours at 593°C and 622°C.

The γ' transition at 649°C begins after 1,000 hours. The γ' size is about 0.1 microns and continues to grow to 0.8 microns in size in 50,000 hours. The α Cr phase is also found after 1,000 hours and becomes more evident at the grain boundaries with aging time. New delta plates are forming at the grain boundaries after 25,000 hours. The greater γ' transition results in more γ in the grain boundary area and between the γ' disks. Figure 7 shows the progression of transitions with increasing aging times at 649°C.

Figure 8 shows the effect of temperature on the transition structures. The γ'' size is about 0.3 microns after 1,000 hours at 704°C and about 1 micron after only 5,000 hours. The α Cr phase and new delta formation are found at the boundaries and eminating into the grains. After 25,000 hours of aging, the grain boundaries become depleted of γ as large delta and/or sigma phase continue to grow and change the composition at the boundaries. The γ' is very sparse in amount and it is difficult to determine if the smaller plates are very large γ' or small delta phase.

Figure 9 shows the effect of 5,000 hours of aging at 760°C. The γ'' phase has disappeared and extensive delta formation and γ' precipitation has occurred. The grain boundary regions show depletion of γ' and massive particles of delta or sigma.

Discussion of Results

The transition of γ' and grain boundary formation of $\gamma + \alpha$ Cr + delta phases is noted after 25,000 hours at 593°C and as early as 1000 hours at 649°C. Since the yield strength does not change in these times and temperatures while the Charpy impact values drop sharply, the Charpy impact data reflect changes at the grain boundaries. The yield strengths become degraded only when the γ' coalesces and the γ' transition accelerates to form large amounts of α Cr, γ , and large amounts of new delta phase at the grain boundaries.

The very strong influence of higher temperatures is evidenced by the rapid changes of γ'' at 704°C. As the γ'' becomes larger and less in amount, the yield strength starts to change in as little as 1,000 hours of aging and continue to lose about 40% of yield strength after 25,000 hours at 704°C.

Examination of failed stress rupture bars of material run at 732° C and 69 MPa shows similar structures as those produced after 25,000 hours at 704° C and 5,000 hours at 760° C. Stress rupture bars of samples tested at 704° C and 255 MPa for 6048 hours showed the presence of a large amount of γ' even though considerable γ and delta were present from the transition process. Stress rupture samples tested at 649°C for 10,000 hours at 434 MPa showed a large amount of γ' still present even though some γ' transition had started to take place.

Re-evaluation of an Alloy 718 turbine disk which had been returned after 28,000 hours of service showed complete γ' transition at the top of the post similar to structures which were found after 25,000 hours at 704°C and/or 5,000 hours at 760°C. Thus, the amount and

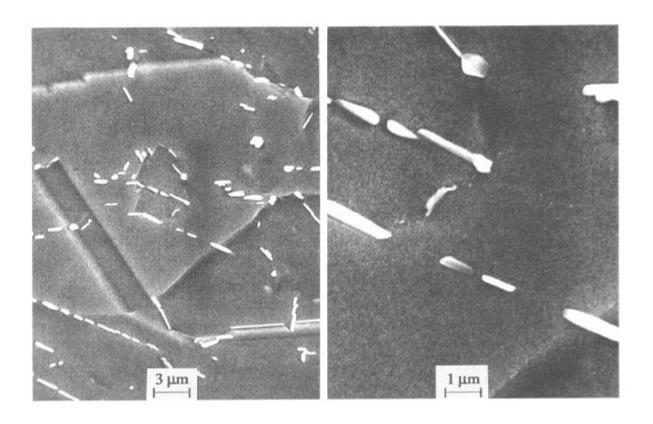


Fig. 5. As-Heat Treated Structure.

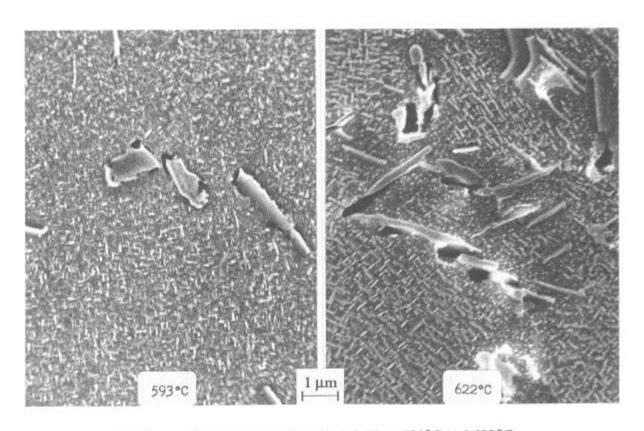
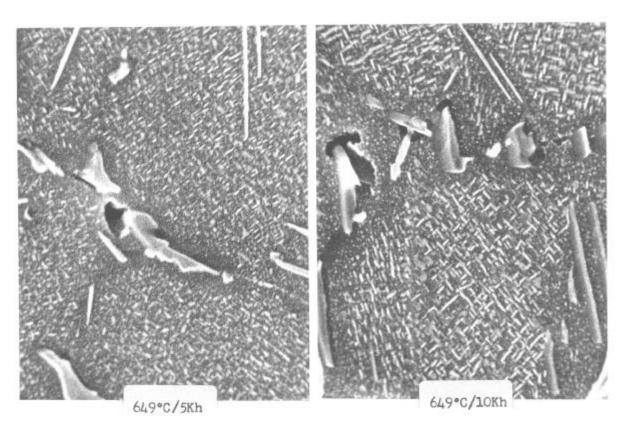


Fig. 6. Structural Transitions in 50 Kh at 593°C and 622°C.



1 μm ⊢

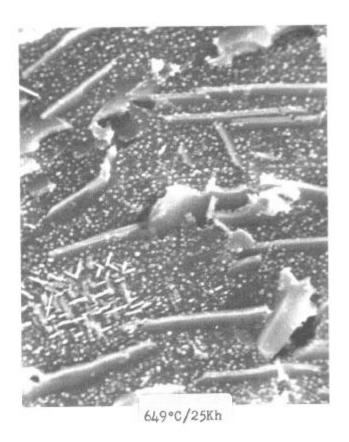
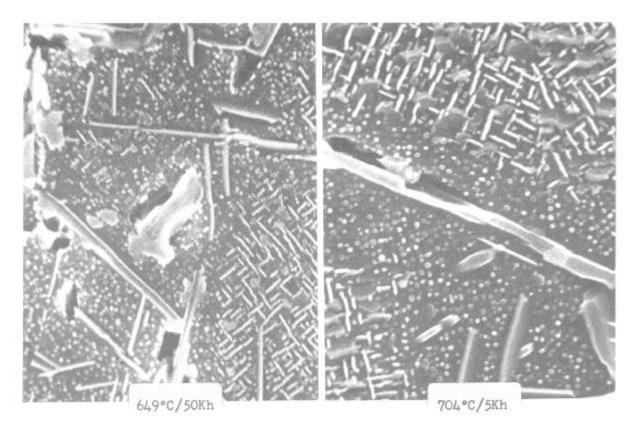


Fig. 7. Structural Transitions at 649°C.



1 μm

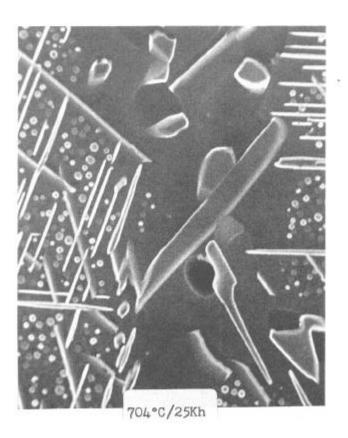
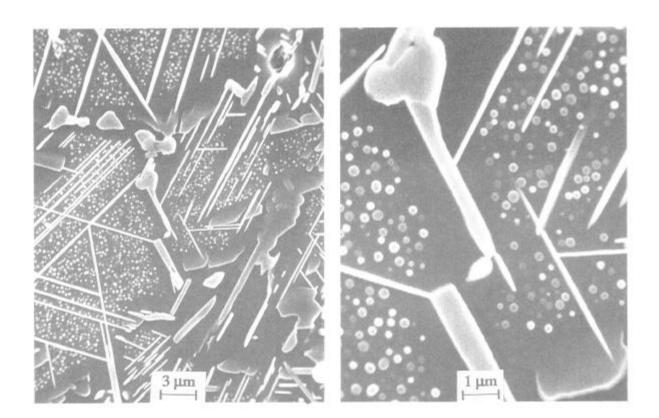


Fig. 8. Structural Transitions at 649°C and 704°C.



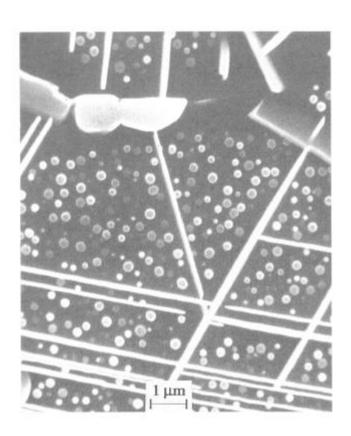


Fig. 9. Structural Transitions in 5Kh at 760°C.