Effect of Alpha Chromium on Long Time Behavior of Alloy 718

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Abstract

Current studies of high temperature materials have focussed on the longtime behavior of materials in an effort to extend the life of service components. High temperature materials which appear to be stable in short exposure times can become unstable when exposed in a temperature range of up to 649°C for times of 10,000 hours to 100,000 hours. Most alloys used in this temperature range are high Cr alloys and the superalloy most commonly used is alloy 718. Whether alloy 718 is used in aerospace or other industrial applications, the behavior of Cr on the formation of carbides, sigma phase, or other Cr rich intermetallic phases plays an important role in the eventual embrittlement of the material.

Alloy 718 is limited to temperatures of 649°C or below because of the occurrence of large amounts of transformations of the strengthening phase γ' to the delta plate phase with the resultant loss of impact and yield strength. In ongoing longtime behavior studies of alloy 718 at 649°C, the impact property of alloy 718 drops from 38 ft-lbs to less than 8 ft-lbs in exposures of 50,000 hours. The initial drop in impact occurs without apparent changes in the strengthening phase; however, an αCr phase is starting to form and grows with time of exposure.

The results of an ongoing study of the role of αCr on the longtime embrittled engine run turbine disks and isothermal exposed alloy 718 will be presented. The factors which affect the αCr formation will be discussed.

Introduction

The role of Cr on brittlement in high Cr ferritic steels has been studied extensively long before alloy 718 was developed. The impurities for these studies was the development of a phenomenon called "885°F embrittlement" wherein ferritic steels developed severe embrittlement after longtime exposures in a temperature range of 700°F to 1000°F.

In 1953 a structural study of ferritic alloys containing 14-17% Cr and exposed for 5-34 Kh at a temperature of 900°F was reported by Fisher, Drelis, and Carroll (1). Using TEM and x-ray diffraction they found αCr (a BCC Cr rich phase) formed which was correlated to the 885°F embrittlement. Ferritic alloys with less than 14% Cr or exposure temperatures above 1100°F did not form the αCr. However, at higher temperatures, sigma phase was found and was enhanced by low carbon contents and severe cold work.

Compositions like alloy 718 are extensions of ferritic type alloys with large enough additions of Ni to maintain a FCC matrix but also maintaining high Cr levels for oxidation/sulphidation resistance. Such alloys are used in a temperature range of 539°C to 649°C and do not form Cr carbides as are found in Ni base alloys. However, such alloys form, amongst other phases, αCr and sigma phase when exposed for longtimes in a temperature range of 539°C to 704°C.

As reported by Korth (2) and Radavich (3), alloy 718 suffers some loss of yield strength and hardness but drastic loss of impact strength with exposure time and increased temperatures.

Superalloys 718, 625, 706 and Various Derivatives
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The Minerals, Metals & Materials Society, 1997

The authors have proposed that the formation and growth of αCr was partly responsible for the severe drop in impact strength.

Because of the similarity of the ferritic and austenitic compositions, those factors which affect αCr and sigma phase behavior in ferritic alloys should also affect similar phase behavior and mechanical properties behavior in alloys like 718 and alloy 625.

The objective of this study was to determine and understand the factors involved in the formation of αCr and its role in the embrittlement of alloy 718.

Experimental

Samples of alloy 718 from retired longtime service disks and samples isothermally exposed up to 50,000 hours in a temperature range of 539°C to 704°C were re-evaluated for αCr formation using a modified electrolytic preparation technique. Both extraction of phases and x-ray analyses and SEM techniques were carried out to detect the start of αCr formation and growth with exposure times.

Results

Past metallographic studies on longtime exposed samples of alloy 718 were carried out on electropolished and electro-etched surfaces. This preparation puts the MC, TiN, δ, and γ''/γ' phases in relief while etching out the αCr and sigma phases. The presence of αCr was thus determined by holes in the microstructure. The beginning of αCr precipitation was difficult to detect when large amounts of other phases formed during long exposures at 649°C and 704°C.

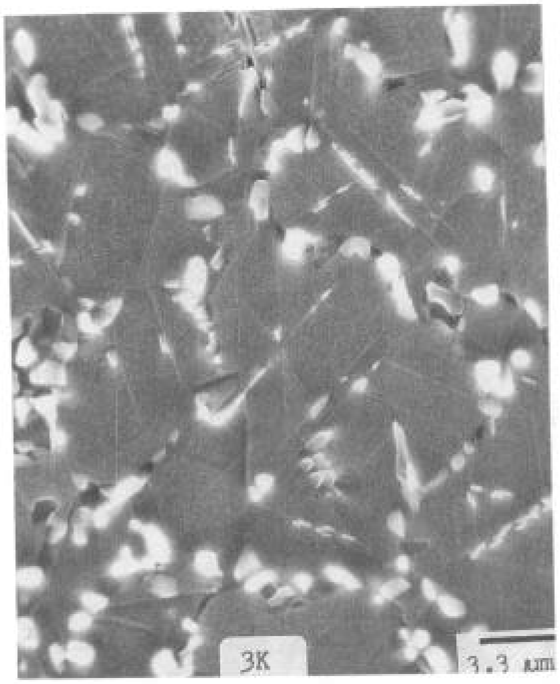
To detect the onset of αCr formation, the samples were re-electropolished for 15 seconds to put the αCr in relief and examined without etching. The αCr phase was verified by EDS analyses of the particles. However, to further confirm such particles as the αCr phase, an area was photographed before and after the electro etch to confirm the holes as the location of αCr particles.

Figure 1 shows the same area before and after etching in the rim area of a 15,000 hours retired alloy 718 disk. Figure 1a shows the presence of many αCr particles in relief while Figure 1b shows holes corresponding to the αCr particles after a CrO_3 etch. X-ray analysis of extracted residue showed a strong αCr phase to be present.

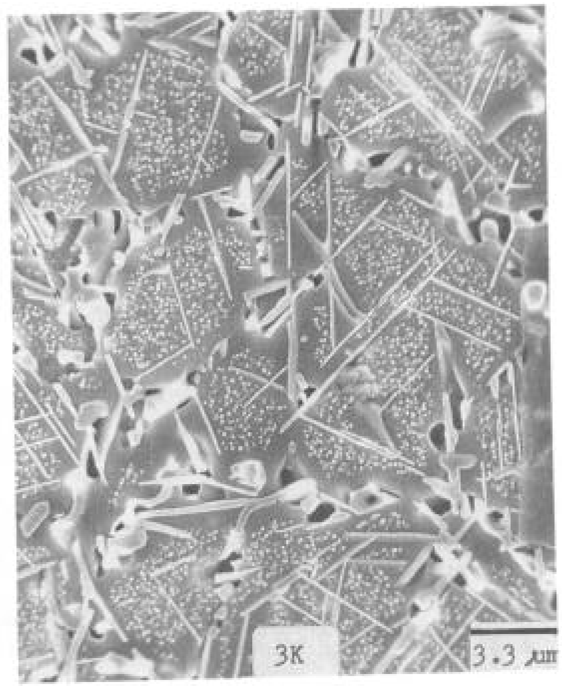
CrO_3 etched samples of alloy 718 which were exposed at 593°C, 649°C, and 704°C were studied for holes indicating αCr formation. Appreciable αCr particles were found in samples exposed at 593°C for 50 Kh, 5Kh and longer at 649°C and 1Kh and longer at 704°C. X-ray studies confirmed the increase of αCr with time and at elevated temperatures.

Selected as electropolished samples of isothermally exposed and retired disk samples were studied using SEM and EDS techniques. Results of representative structures are presented in Figures 2-5. Figure 2 shows an increase of αCr with increased exposure time at 649°C. The αCr at 704°C, Figure 3, appears to be larger but fewer in number and there is evidence of sigma phase presence. More αCr appears and an accicular structure became more evident with increased time at 704°C.

The phases found in a sample tested at 733°C for 5400 hours appeared to be both αCr and sigma phase, Figure 4. Figure 5 shows varying αCr structures in the rim areas of retired 718 disks which have had 15,000 and 28,000 hours of engine exposure. A needle shaped phase as well as discrete particles appear in the 15,000 hour disk sample while more discrete αCr particles appear in the 28,000 hour sample. While there appears to be good correlation for more αCr formation with increased exposure time, the question of how much Cr is necessary for αCr

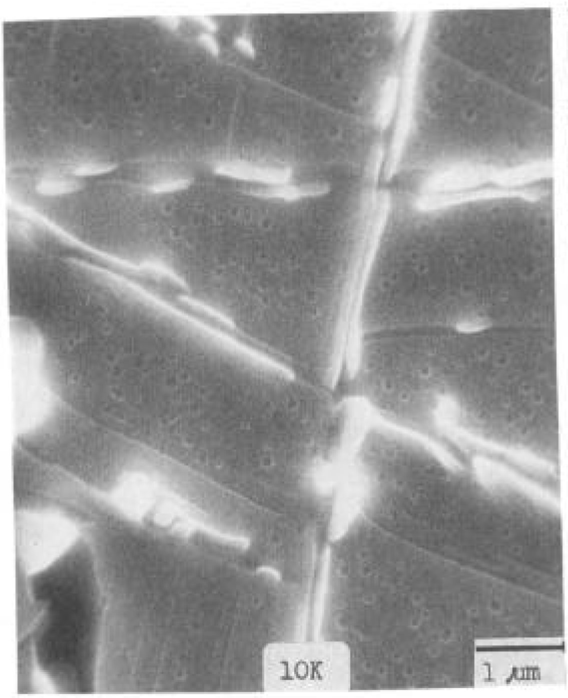


Before



After

Figure 1 αCr Phase in a 15,000h Disk Before and After Etching



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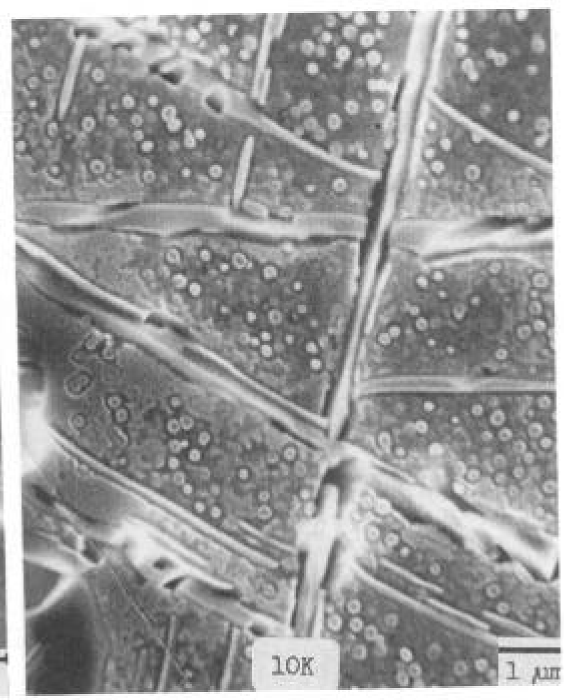

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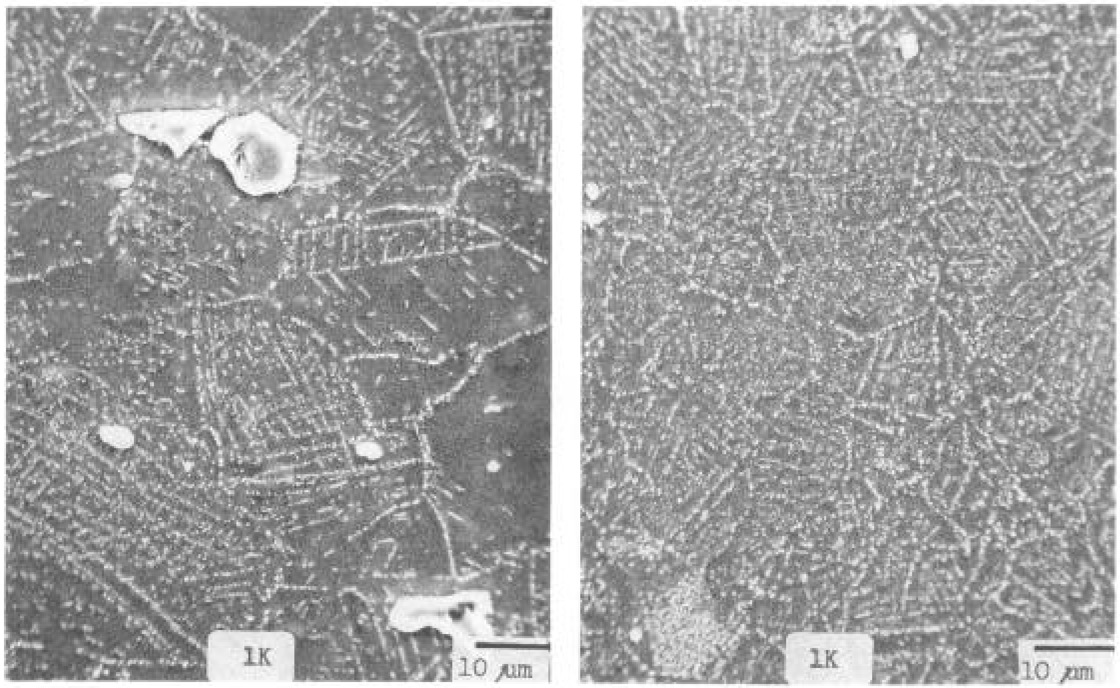
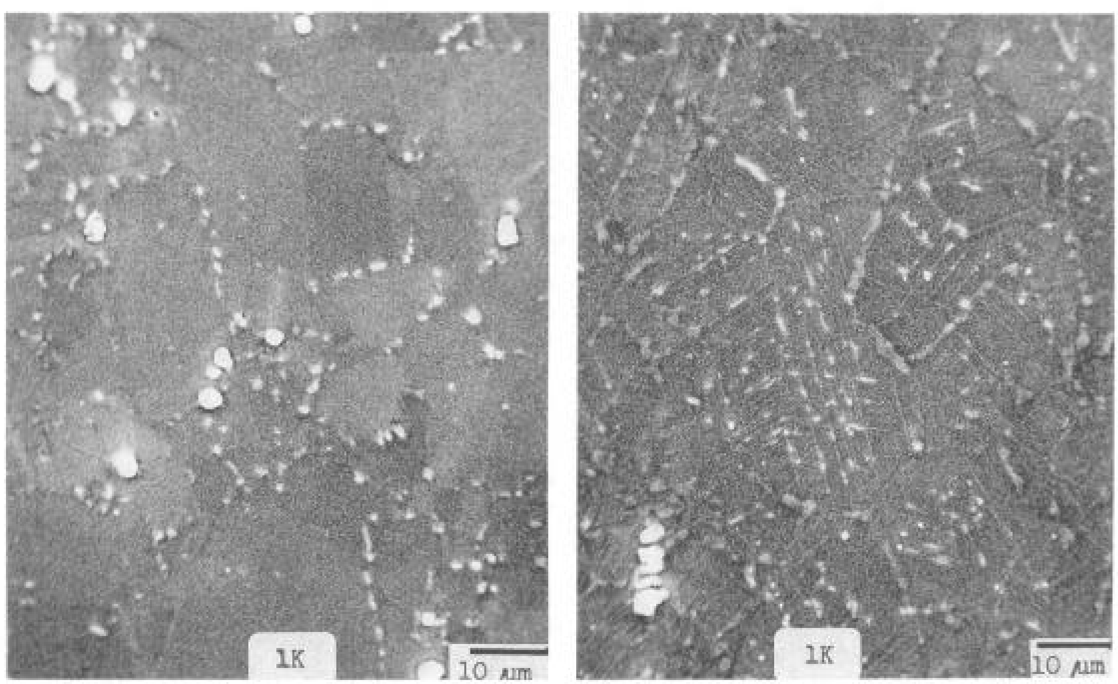


5Kh 10Kh

Figure 2 αCr Phase After 5Kh and 10Kh Exposures at 649°C



5Kh 25Kh

Figure 3 αCr Phase After 5Kh and 25Kh Exposures at 704°C

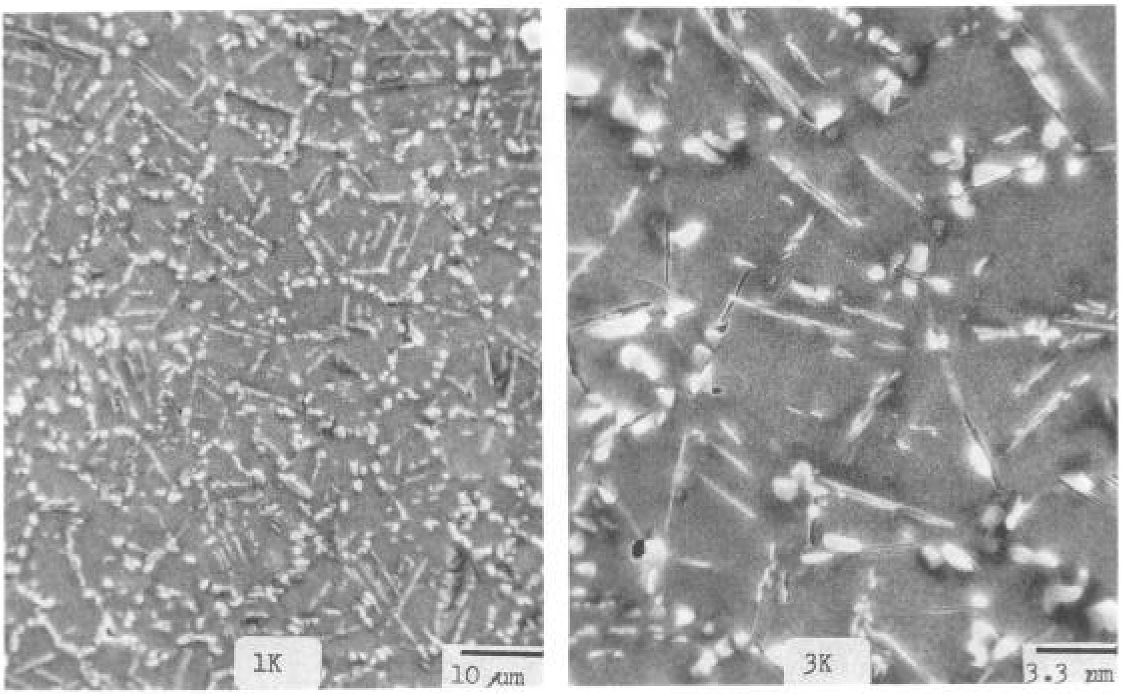
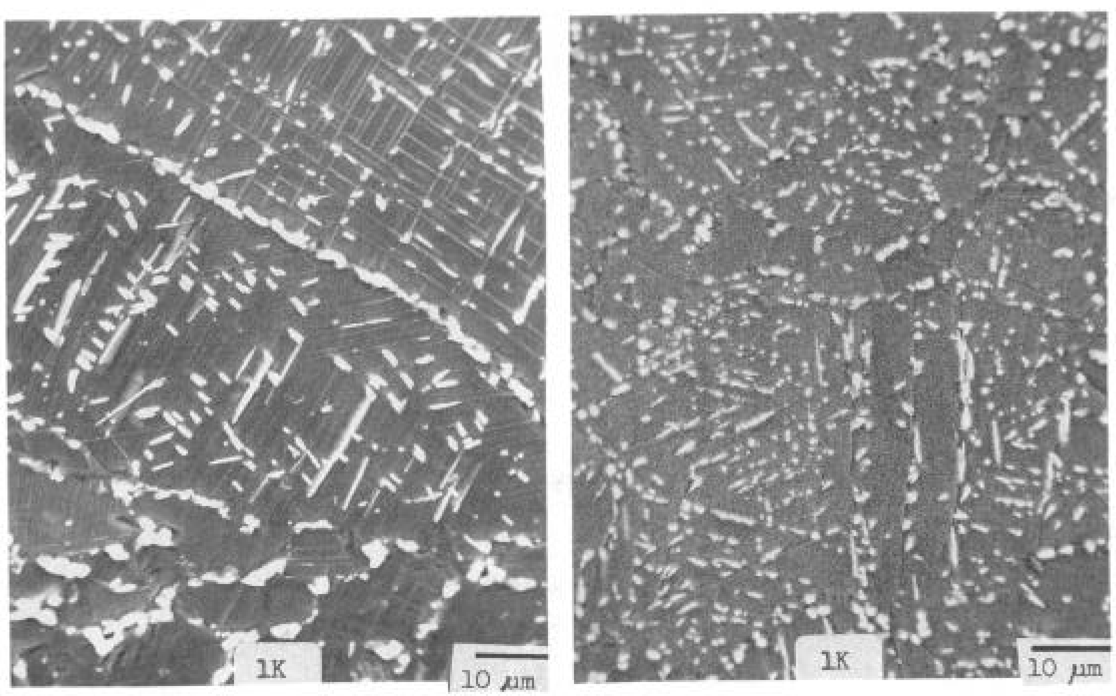
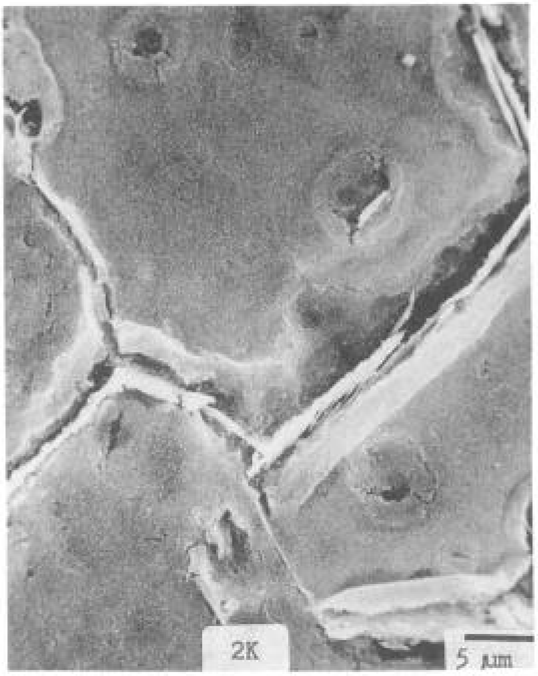


Figure 4 αCr in a S/R Test of 5400h at 733°C



15Kh 28Kh

Figure 5 αCr Precipitation in Retired Long Time Disks

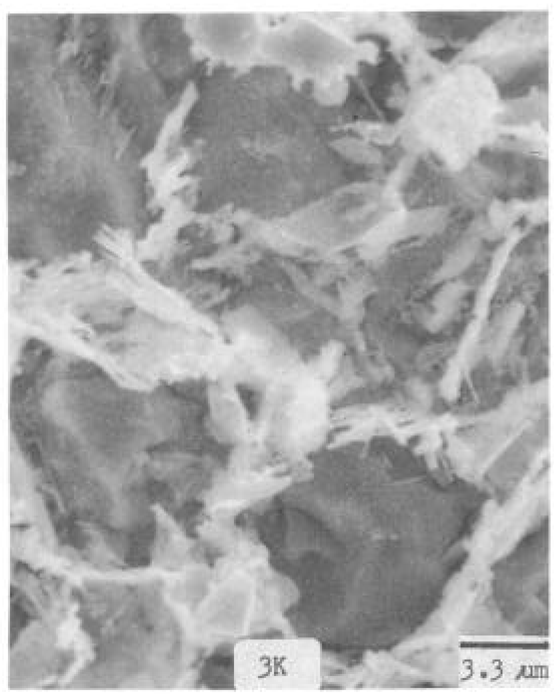


623°C/50Kh

649°C/1Kh

Figure 6 Grain Boundary αCr Films after Long Time Exposures

649°C/5Kh



704°C/1Kh

formation needs to be addressed. Since 649°C appears to be a critical temperature for formation of αCr, a sample of PWA1472 with 12% Cr was evaluated after an exposure of 1200 hours at 680°C. No αCr precipitation was found with this Cr level which agrees with the results found in ferritic steels.

Because there appears to be non-uniform precipitation of αCr as seen in Figure 2a, a sample of spray cast plus HIP alloy 718 was exposed for 1000 hours at 649°C and evaluated for αCr. No αCr precipitation was found which suggests that Cr segregation plays a role in the formation of the αCr phase.

Discussion of Results

From x-ray studies of extracted residues, no Cr carbide phase is found but only the αCr phase at the lower temperature while sigma phase begins to form at 704°C. The αCr phase is found in both retired disks and isothermally aged samples and increases in amount as exposure time increases.

From metallographic evaluations, the αCr phase appears to be associated with the delta phase whether the delta phase is in the grain boundaries or in the grains. While this suggests that the formation of delta phase produces local enrichment of Cr and the formation of αCr, the drop in impact strength in relatively short exposure times suggests that detrimental grain boundary structures have begun to grow. In Ni base alloys, such structures generally are continuous grain boundary Cr carbide films.

To verify the presence of grain boundary films, samples exposed at 623°C for 50 Kh, 1 Kh and 5 Kh at 649°C, and 1 Kh at 704°C were given an electrolytic etch in 10% HCl-methanol and re-examined on the SEM. Extensive grain boundary films were found.

Figure 6 shows the growth of grain boundary films in the various exposed samples. EDS analysis of the films show very strong Cr with a small amount of Nb which identifies the films as αCr.

Conclusions

1. αCr is the only Cr rich phase which forms in a temperature range of 539°C to 649°C while sigma phase is found at higher temperatures.

2. The αCr formation is associated with delta phase formation due to Cr enrichment as Ni, Al, and Nb are depleted from the matrix.

3. The conventional metallographic techniques do not show the true αCr morphology as does the electrolytic technique.

4. αCr films at the grain boundaries appear to be the cause of the loss of impact strength in longtime exposures at 623°C to 704°C.

References

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2. Gary E. Korth, "Mechanical Properties Test Data of Alloy 718 for Liquid Metal Fast Breeder Reactor Applications," U.S. Department of Energy Report, EG&G Idaho, Inc., Jan. 1983.

3. J. F. Radavich and G. E. Korth, "Effects of Very Long Time Aging in Alloy 718," TMS Annual Meeting, San Diego, CA, 1992.