THERMAL STABILITY OF MODIFIED 718 ALLOYS

AGED FOR 2000 HOURS AT 700°C

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Abstract

A change in precipitate morphology in Alloy 718 is intriguing as a primary direction for improving thermal stability and thereby improving mechanical properties at and above 650°C. Three modified 718 alloys and the conventional 718 composition were studied after aging for 2000 hours at 700°C. One of the modified alloys had far superior tensile properties, both upon testing at ambient and at 700°C, as well as stress rupture testing at 700°C and 638 MPa (92.5ksi). These results are attributed to the slower growth of the γ'/γ" precipitates, principally the smaller increase in size of the γ' precipitate, and the beneficial effect of a tungsten addition in stabilizing the γ'/γ" phases and the grain boundaries by forming M_6C type carbides.

Introduction

This paper is a continuation of our 1994 study[1] which provided results on the thermal stability of modified 718 alloys after exposure to 1000 hours at 700°C. Since this exposure may not be long enough to produce microstructural changes that would degrade mechanical properties, results are now presented after aging for 2000 hours at 700°C. The interest in extending the service range beyond the present ceiling temperature of 650°C via minor modification of the Alloy 718 composition is evident in the bibliography of our 1994 paper[1] supplemented by two other concurrent papers[2,3].

At this point, there are strong indications that minor modifications in composition produce precipitate strengthening with appropriate (final) heat treatment. For a particular grain size, a uniform array of precipitate particles of specific size and spacing achieves maximum strength and stability. However, at high temperatures and stresses, the larger particles grow while the smaller ones dissolve thereby changing the structure and behavior of the grains and degrading stability. This overaging process can be slowed by altering the balance of the elements that form γ'/γ" particles. Also, adding large atoms that diffuse slowly in the matrix would slow down the entire coarsening process.

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

Materials and Procedure

The modifications of Alloy 718 and the conventional 718 composition were vacuum induction melted and the 23 kg ingots were homogenized for 24 hours at 1100°C and then hot forged into 32mm bar stock. Specimens cut from the bars provided the compositions listed in Table I. The conventional 718 (Alloy 4) contained 0.058C, 17.76Cr, 2.80Mo, 0.98Ti, 0.73Al, 5.47Nb, 18.59Fe, 0.0031B, bal Ni (wt pct), and it was given the standard heat treatment. Details on the

Table I Chemical Composition of Alloys

Alloy	C	Cr	Mo	Ti	Al	Nb	Fe	W	B (wt.%)
3	0.056	17.58	2.85	0.97	0.86	5.51	17.00		0.0033
5	0.048	16.60	3.09	0.98	0.93	5.57	13.71	2.30	0.0019
7	0.059	17.20	2.98	1.20	1.19	4.95	19.23		0.0041

Alloy	Ti	Al	Nb	Al+Ti+Nb	Al/Ti	Al+Ti/Nb (at.%)
3	1.18	1.85	3.44	6.47	1.57	0.88
5	1.21	2.04	3.55	6.80	1.69	0.92
7	1.48	2.33	3.16	6.97	1.57	1.21

Table II Mechanical Properties after Specified Heat Treatment

Alloy	Aging Time at 700 C hr	Tensile Test Results Temp. C	Yield MPa	Ult. MPa	El %	RA %	Stress Rupture Results Temp. C	Stress MPa	Time hr
5	2000	25	1228	1528	13.3	13.1	700	638	77.9
		25	1182	1472	9.4	9.4	700	638	93.7
		700		1187	29.7	28.4			
		700		1223	24.9	34.3			
7	2000	25	1131	1421	20.4	27.0	700	638	47.0
							700	638	48.7
		700		1086	16.6	17.2			
		700		1111	18.0	17.6			
3	2000	25	1268	1508	14.5	19.4	700	638	14.7
		25	1309	1524	15.3	21.5	700	638	15.4
		700		1009	37.8	69.5			
		700		1029	38.4	71.0			
4	500	25	1278	1493	16.8	38.6	700	638	17.4
		25	1268	1484	20.0	40.5	700	638	27.2
		700		1029	33.3	66.4			
		700		1066	32.5	68.5			
	1000	25	1232	1447	21.0	33.1	700	638	19.9
		25	1309	1488	19.5	34.1	700	638	15.0
		700		1057	34.1	70.0			
		700		1070	34.0	65.1			
	2000	25	1213	1426	16.4	29.7	700	638	6.0
		25	1202	1437	18.0	32.1	700	638	6.4
		700		969	28.5	71.6			
		700		960	32.2	71.3			

heat treatments for the modified alloys were given in the 1994 paper.[1] The heat treatments produced a γ matrix grain size of ASTM5-6. The metallography, tensile and stress rupture testing was done after the 2000 hours of aging at 700°C and followed the same prior procedure[1] after 500 and 1000 hr exposure at 700°C.

Results

Mechanical Property Evaluation

The results of room temperature and 700°C (1300°F) tensile testing after exposure (aging) for 500 to 2000 hr at 700°C, as well as stress rupture tests at 700°C at 638MPa (92.5ksi) are listed in Table II. The improving tensile strength and stress rupture life with aging time at 700°C are apparent in modified Alloy 5. The tensile strength values for the three modified alloys are significantly higher than the 937 MPa (136ksi) ultimate strength obtained at 700°C on current Alloy 718, per K-M Chang[4]. Tensile properties after service exposure (aging) are important because turbine disk burst (the designer's primary concern) is by overspeed wherein the ultimate strength is approached by the average tangential stress.

The trends for the average tensile strength and elongation at 25°C and at 700°C after exposure (aging) for 500 to 2000 hr at 700°C are plotted in Figure 1 and 2. Modified Alloys 5 and 3 show the highest strength at 25°C after holding for 1000 to 2000 hour at 700°C. As expected in Figure 2, the strength values drop when tensile testing at 700°C. Noteworthy are the highest values obtained in Alloy 5 with the ultimate strength actually increasing to 1205 MPa (174 ksi). Modified Alloys 3 and 7 maintained their stability. Conventional 718 (Alloy 4) dropped in strength from 1064 MPa (154 ksi) after 1000 hour to 965 MPa (140ksi) after 2000 hour at 700°C. In regard to ductility, the values either improved or remained essentially the same with holding time at 700°C, and with all tests producing acceptable results.

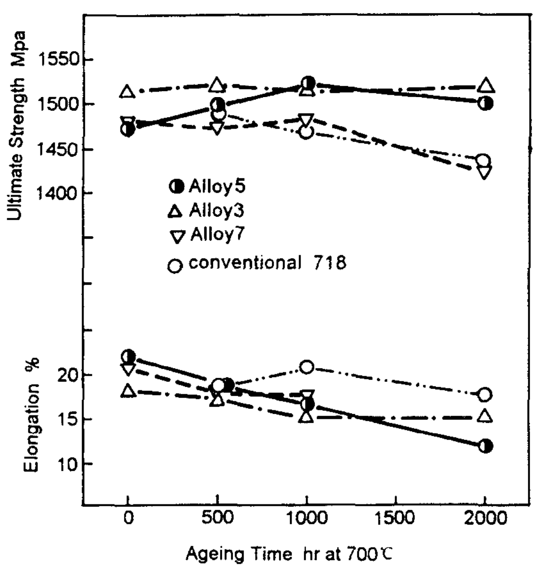

Fig.1 Variation of Ultimate Strength and Elongation at 25 ℃ with Ageing Time for Modified and Conventional 718 Alloys

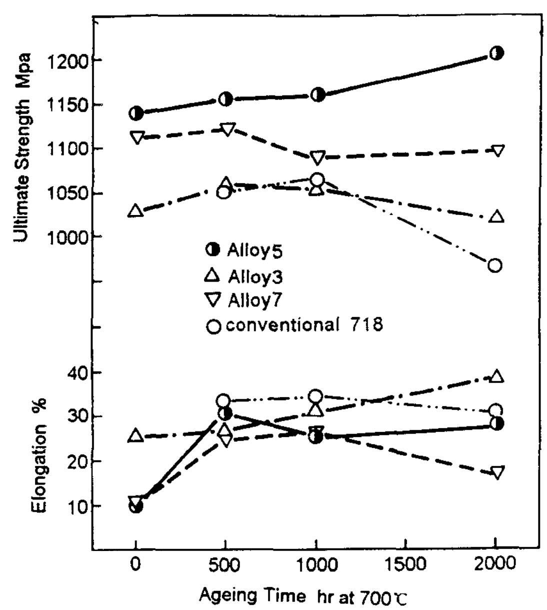

Fig.2 Variation of Ultimate Strength and Elongation at 700 ℃ with Ageing Time for Modified and Conventional 718 Alloys

The variation of rupture life at 700°C under a stress of 638 MPa (92.5ksi) after aging time at 700°C is plotted in Figure 3. The superior results for Alloy 5 over the other three alloys after 1000 hr increases even more after 2000 hr exposure and then testing. The average life of 86 hr for Alloy 5 compared to 48 hr for the next best Alloy 7 indicates that precipitate stability and solid solution strengthening improved after aging for 2000 hr at 700°C. On the other hand, conventional 718 decreased from 20 hr to 10 hr rupture life at 700°C and 638MPa as the prior aging time increased from 1000 to 2000 hr at 700°C.

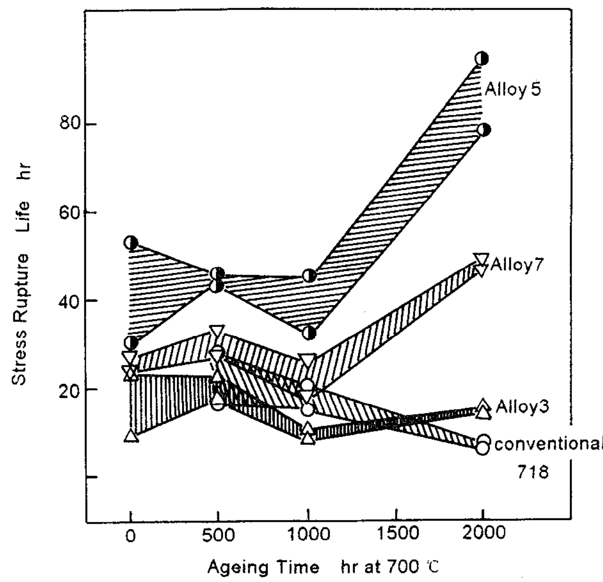

Fig.3 Variation of Stress Rupture Life with Ageing Time for Modified and Conventional 718 Alloys

<u>Coarsening Results</u>

The TEM dark and bright field images of the three modified alloys and the conventional 718 composition after 2000 hr of aging at 700°C are shown in Figure 4. The microstructures, as heat treated and after aging for 1000 hr at 700°C, were depicted and discussed in our prior study.[1] When compared to the microstructure aged for 1000 hr at 700°C, Alloy 5 still has the non-compact γ'/γ" morphology with some growth in both the γ' and γ" particles. The mean length of γ" is probably 0.036 μm and the mean size of the γ' is probably 0.029 μm. The microstructure near grain boundaries is similar. A somewhat higher amount of M_6C phase is distributed in the grain boundaries. There is no δ phase in the grain boundaries nor within the grains.

When compared to the microstructure aged for 1000 hr at 700°C, Alloy 7 still has, in large part, the compact γ'/γ" morphology after exposure to 700°C for 2000 hr. There is a little γ'/γ" precipitate of the non-compact morphology. It consists of hemispherical γ' and disk-shaped γ", which has been described as "sandwich" morphology. The mean length of the γ" is probably 0.036 μm and the mean size of γ' is probably 0.034 μm. There is a greater amount of δ phase precipitate in the grain boundaries and a tendency to grow into the grains.

When compared to the microstructure exposed for 1000 hr at 700°C, Alloy 3 still has the non-compact γ'/γ" morphology after 2000 hr at 700°C. The mean length of the γ" is around 0.055

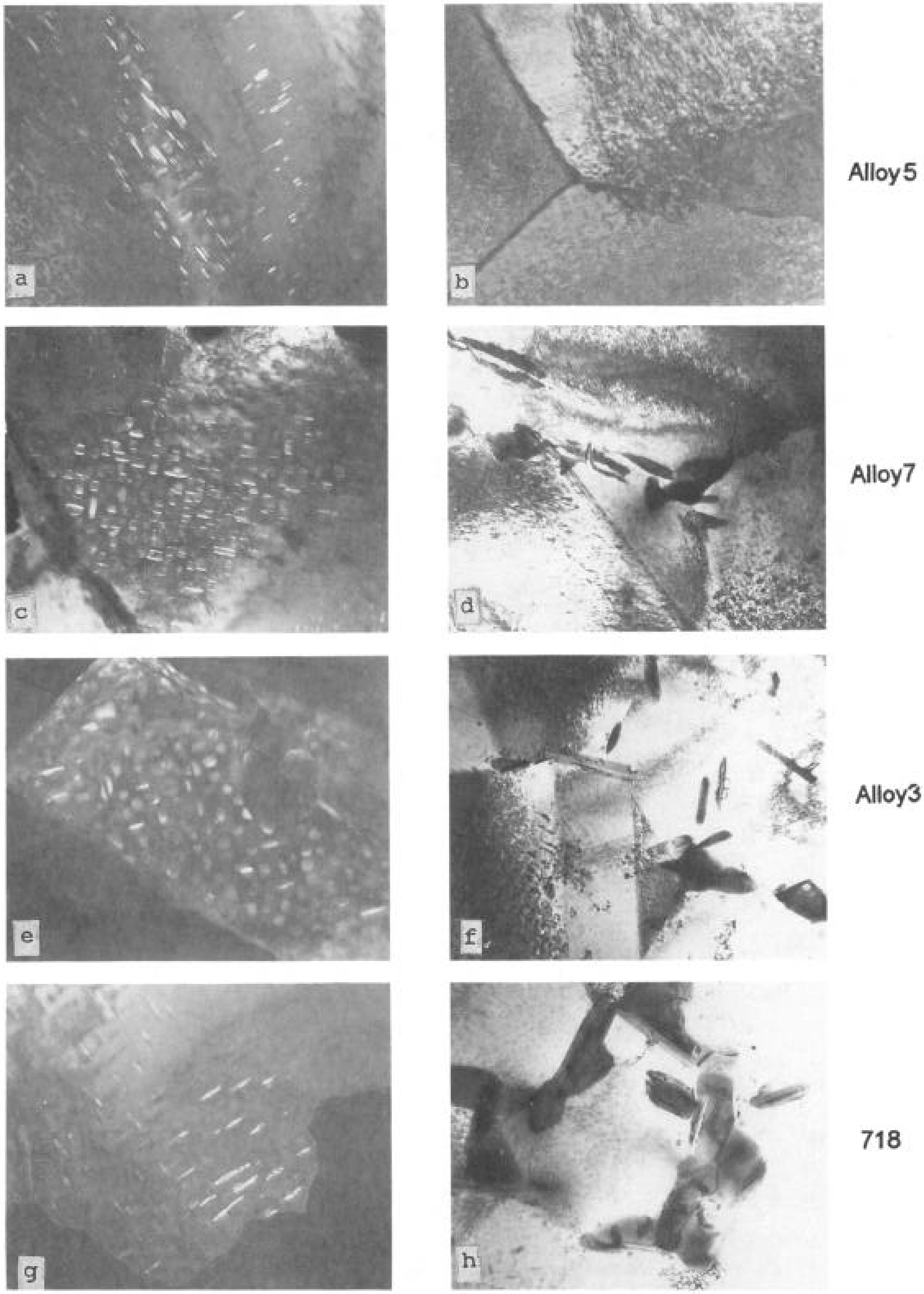

Fig.4 TEM dark and bright field images of Alloys Aged for 2000hr at 700 ℃
(a) (c) (e) (g) × 41000 (b) (d) (f) (h) × 17000

μm and the mean size of γ' is around 0.048 μm. The γ" phase has dissolved in large part and the residue phase is γ'. There is a greater amount of bar-shaped δ phase in the grain boundaries, also nearby and within the grains. The combination of these observations account for the significantly lower stress rupture and tensile strength of Alloy 3 compared to Alloys 5 and 7.

The microstructure of conventional 718 (Alloy 4) after aging for 2000 hr at 700°C is illustrated in Figure 4. Long γ" particles are seen which are probably 0.073 μm in length and the spherical γ' particles have a mean size of around 0.031 μm. It is to be noted that the length of the existing γ" phase in twice that of the modified Alloys 5 and 7. Higher amounts of bar-shaped δ particles occur in both the grain boundaries and within the grains. With the nearby δ phase precipitation, the γ" phase is, in large part, dissolved and the residue precipitation is the γ' phase. Thus, one would expect the lowest stress rupture and tensile strength results that were obtained after aging for 2000 hr at 700°C.

The variation in the mean length of γ" and the size of γ' with aging time at 700°C for the three modified 718 alloys is shown in Figure 5. The growth rate of both precipitates actually decreases between 1000 and 2000 hr at 700°C when compared to the values between 0 and 1000 hr at 700°C. Also, it should be noted that the mean length of the γ" phase is the same for Alloys 5 and 7 while the γ' size is significantly less in the case of the best performing Alloy 5 after 2000 hr at 700°C. Alloy 3 produced significantly higher values from the start of aging.

The growth rate of γ" and γ' between 1000 hr and 2000 hr aging at 700°C can be roughly calculated. For Alloy 5, the growth rate of γ" is 4 x 10^{-6} μm/hr and the growth rate of γ' is 3 x 10^{-6} μm/hr. For Alloy 7, the corresponding results are 4 x 10^{-6} μm/hr and 2 x $10^{-6}$$\mu$m/hr. For Alloy 3, the corresponding results are 3 x 10^{-6} μm/hr and 2 x $10^{-6}$$\mu$m/hr.

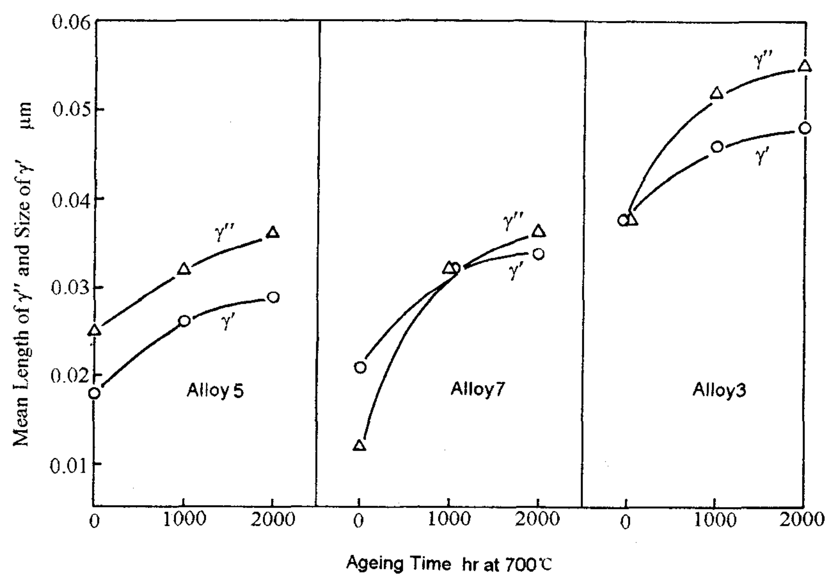

Fig.5 Variation of Mean Length of γ " and Size of γ ' with Ageing Time at 700℃ for Alloy 5, Alloy 7 and Alloy 3

Conclusions

Minor modification of the Alloy 718 composition can improve thermal stability and thereby improve mechanical properties at and above 650°C. This is shown in a modified alloy, which after aging for 2000 hr at 700°C, has far superior tensile strength, both upon testing at ambient and at 700°C, as well as stress rupture life at 700°C and 638 MPa (92.5 ksi).

The alloy has an (Al+Ti)/Nb ratio of 0.92, an Al/Ti ratio of 1.69 and (Al+Ti+Nb) of 6.80 at pct, plus 2.30 wt pct W. The superior properties are attributed to the slower coarsening behavior of the γ'/γ'' precipitates, principally the smaller increase in size of the γ' phase. The tungsten addition was beneficial in stabilizing the γ' and γ'' phases and grain boundaries by forming M_6C type carbides in the grain boundaries.

After 2000 hr of aging at 700°C, the high temperature strength and stress rupture life of Alloy 718 and our modified alloys appear to be governed by the growth (overaging) of the γ'/γ'' phases and the precipitation of the δ phase in the grain boundaries and within grains.

References

1. E. Guo, F. Xu and E.A. Loria, Superalloys 718, 625, 706 and Various Derivatives, TMS (1994), pp. 721-734.

2. E. Andrieu, N. Wang, R. Molinos and A. Pineau, Superalloys 718, 625, 706 and Various Derivatives, TMS (1994), pp. 695-710.

3. X. Xie, Q. Liang, J. Dong, W. Meng, Z. Xu, M. Chan, F. Wang, Y. Cai, J. Zhang, N. Wang, E. Andrieu and A. Pineau, Superalloys 718, 625, 706 and Various Derivatives, TMS (1994), pp. 711-720.

4. K-M. Chang, US Patent 4981644, January 1, 1991, 20pp.