TENSILE PROPERTIES AND MICROSTRUCTURE OF ALLOY 718

THERMALLY AGED TO 50,000 h[1]

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Abstract

Samples of Alloy 718 given the standard heat treatment were thermally aged from 538 to 704°C for times up to 25,000 h and aged at temperatures of 593 and 649°C up to 50,000 h. Tensile properties and microstructures of these samples show that extending the thermal exposure from 25,000 to 50,000 h at 593 and 649°C has very little additional effect, and further illustrates the long time stability of this aged hardened alloy.

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Introduction

Alloy 718 is a nickel-base superalloy that exhibits good elevated temperature strength, creep resistance, and stability. It is precipitation hardenable and strengthened by a coherent, niobium-rich, aluminum, titanium γ' and γ'' precipitate. The kinetics of the precipitation reaction is quite sluggish in this alloy, which adds to its thermal stability in applications of long times at elevated temperatures. Other investigators have documented the long term stability of Alloy 718 (1-3) and found that it still has adequate strength and ductility after tens of thousands of service hours at temperatures up to 650°C. In a previous investigation (4) of this alloy for potential use in nuclear reactors, the mechanical properties of several heats of material were determined after thermal exposures of up to 25,000 h at temperatures of 538 to 704°C. The current study adds a few more data points for one heat of Alloy 718 wherein the thermal exposure was extended to 50,000 h for temperatures of 593 and 649°C. In order to complement the mechanical data, the microstructure was evaluated.

Material

The Alloy 718 used to extend the thermal aging data base was 19 mm round bar from Heat No. 2180-6-9458, which is the U. S. Department of Energy Reference Heat (5). This is a master heat of material processed by the VIM-ESR (vacuum induction melt, electroslag remelt) method that was purchased with tighter chemistry specifications so as to ensure a "middle of the road" heat; various product forms were produced from the one melt. The chemistry and other material details are listed elsewhere (4). The stock material was given the conventional heat treatment specified in AMS 5596: 954±14°C solution anneal, 2 h; air cool; duplex age at 718±8°C, hold 8 h, furnace cool at 56°C/h to 621°C, hold at 621±8°C for 8 h, for a total duplex aging time of 18 h; and air cool. The material was then thermally exposed in air in an unstressed condition for the time and temperature specified. Tensile bars were fabricated from the stock material after the thermal exposure was completed.

Tensile Properties

The tensile tests were conducted at room temperature in compliance with ASTM E-8. Results of the current tests are listed in Table I for the 50,000 h aged material, as are room temperature tensile data from the previously reported (4) thermally aged reference heat Alloy 718 (plate material, some of which was aged under stress). Fig. 1 shows the effects of long term thermal aging at 593 and 649°C on yield and ultimate tensile strength, and Fig. 2 illustrates the effects on ductility. The reference heat shows increasing hardening after 593° aging up to 50,000 h, with most of it occurring in the first few thousand hours. Aging at 649°C results in an increase in strength in the first few thousand hours of aging and then a gradual overaging (softening) is observed. Not all heats of Alloy 718 respond the same at these long term aging temperatures. The heat used by Barker et al. (1) responded similarly to the reference heat, i.e. continued strengthening at 593°C out to 34,000 h. However, some heats from the previous Korth investigation (4) showed softening starting to occur sometime between 10,000 and 25,000 h with 593°C aging [see Fig 3 for Heat 6 response (4)]. All heats appear to show the same trend after 649°C aging: increase in strength in the first few thousand hours and then softening. Figs. 4 and 5 (taken from Ref. 4 and new 50,000 h data added) illustrate the effect of aging at 593 and 649°C on room temperature yield strength of several heats of Alloy 718.

Table I. Room Temperature Tensile Data of Alloy 718 Reference Heat After Long Term Thermal Exposure

Specimen Number	Yield Strength MPa	Ultimate Strength MPa	Total Elongation %	Reduction in Area %	Aging History Time kh	Aging History Temp °C	Aging History Stress MPa
Avg. of 4 Tests	1104	1390	26	43	0	--	--
R2-37	1169	1419	28	39	1.2	593	538
R2-31	--	1433	25	34	15.6	593	424
R4-6	1189	1461	19	34	25	593	0
7181C-1	1215	1469	25	38	50	593	0
7181C-2	1202	1458	24	37	50	593	0
R2-42	1135	1417	28	40	0.9	649	379
R4-9	1161	1423	24	39	1.0	649	0
R2-39	1142	1426	26	34	2.7	649	338
R4-12	1122	1412	21	36	5	649	0
R4-15	1034	1368	22	32	10	649	0
R4-27	987	1349	18	27	25	649	0
7182C-1	907	1307	21	25	50	649	0
7182C-2	908	1307	22	25	50	649	0

Microstructure Observations

Samples from the reference heat given the 50,000 h thermal exposure at 593 and 649°C were examined using optical, scanning electron, and transmission electron microscopy (SEM and TEM) techniques. Also, reference heat samples with 25,000 h thermal exposures at the same temperatures were examined for comparison. The intent of these examinations was not to perform a complete analysis of the various phases present, but to compare the differences between the 25,000 and 50,000 h samples.

The gross microstructural changes are summarized in Fig. 6. As seen in the figure, there appears to be hardly any change in the specimens upon aging from 25,000 to 50,000 h for a given temperature. Grains are outlined with δ phase (Ni_3Nb) and some δ are found internally. The large round particles (arrows, Fig. 6a and 6c) are Nb-rich particles that precipitated out at these long aging times. The biggest difference in the microstructure is associated with temperature; the samples aged at 593°C (Fig. 6a, 6c) contain less δ phase and smaller Nb-rich particles in contrast to those aged at 649°C (Fig. 6b, 6d). TEM results revealed that the primary matrix precipitation was γ″ (Fig. 7a). Although some γ′ (Fig. 7b) was found in all specimens analyzed, it was very sparse in the 593°C, 50,000 h aged condition. An earlier report on aging of Alloy 718 (3) indicates the transition goes $\gamma'' \rightarrow \delta + \gamma'$, thus it is expected that at these long times the amount of γ″ is declining and the amounts of γ′ and δ are increasing. However, the proportions of γ″ versus γ′ are also a function of the Nb content and aging temperature. Coarser γ″ was observed in the specimens aged at 649°C as compared to those aged at 593°C. For example, the γ″ in Fig. 7a, aged 50,000 h at 649°C, is about three times longer and twice as thick as the γ″ in a 593°C sample aged the equivalent amount of time (Fig. 7b). As the aging temperature increases, the amount of δ precipitating out at the expense of the γ″ also increases (Fig. 6 and 8). The presence of extensive amounts of δ has been associated with loss of strength in Alloy 718

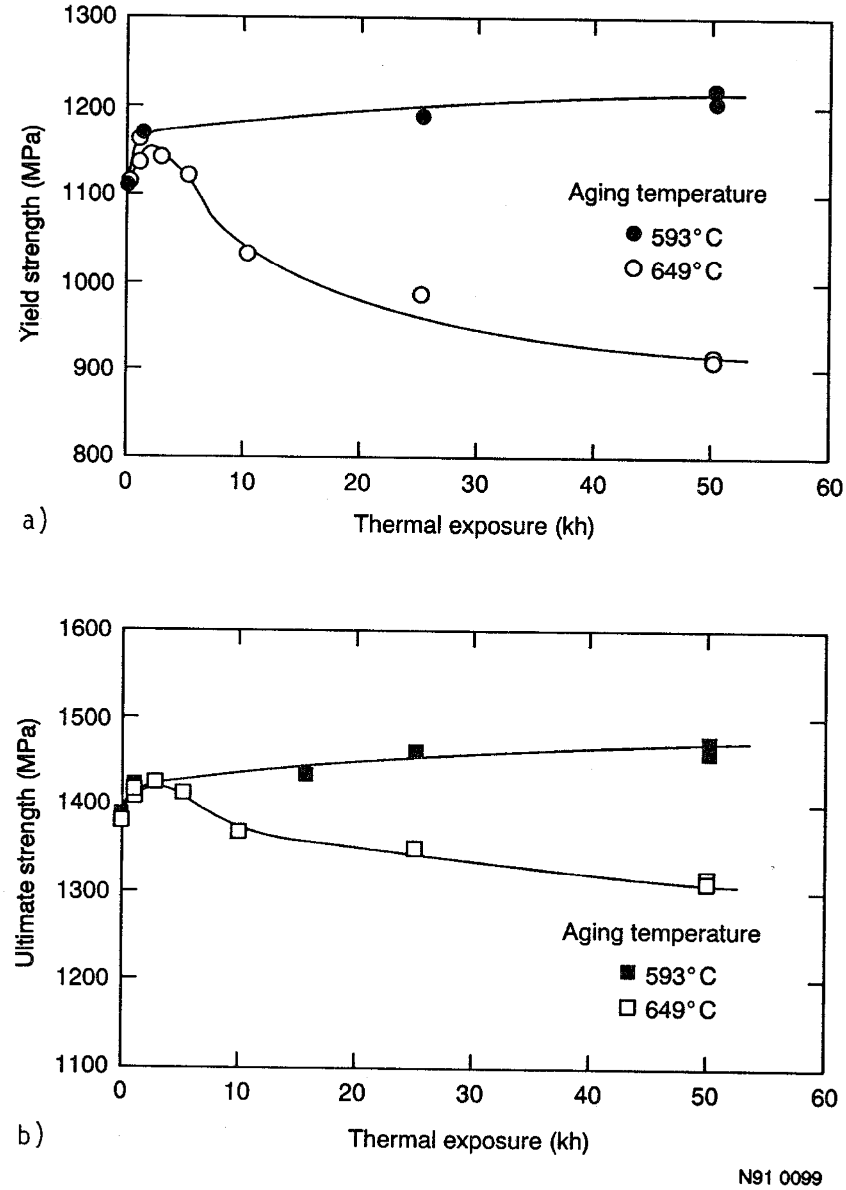


Figure 1 - Effects of long term thermal aging of the reference heat of Alloy 718 on the room temperature yield strength (a) and the ultimate strength (b).

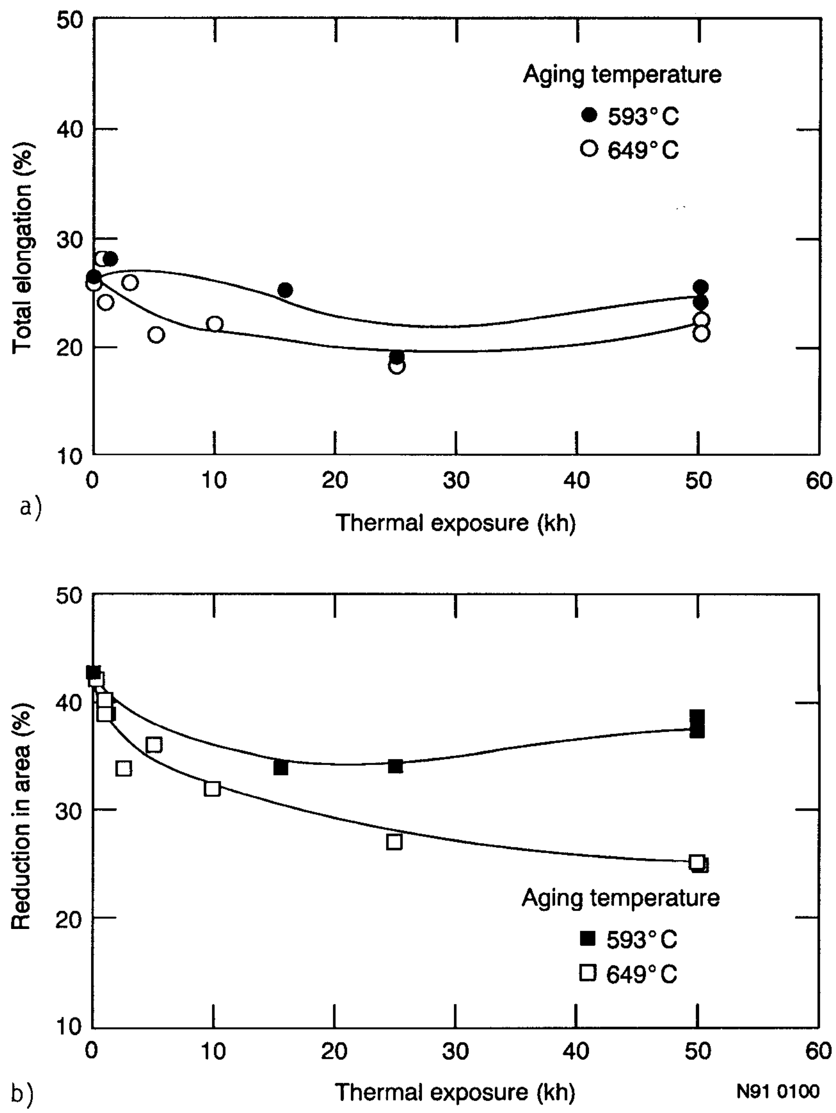


Figure 2 - Effects of long term thermal aging of the reference heat of Alloy 718 on the room temperature total elongation (a) and the reduction in area (b).

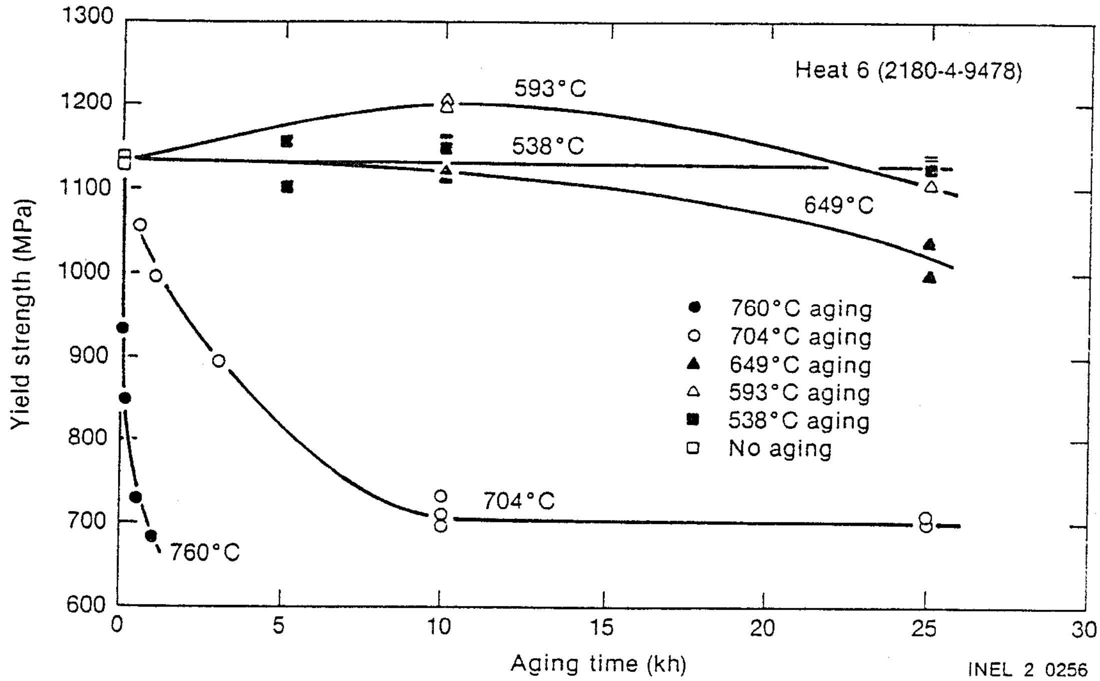


Figure 3 - Effects of thermal aging on the room temperature yield strength of Alloy 718 (Heat 6). Taken from Ref. 4.

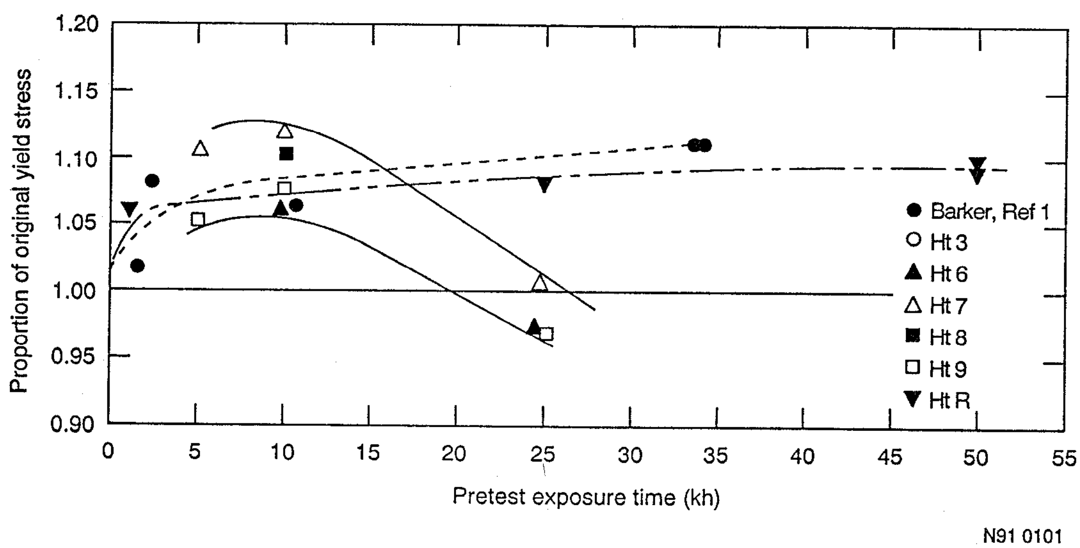


Figure 4 - Effects of 593°C exposures on the room temperature normalized yield strength of several heats of Alloy 718. (Ref. 4).

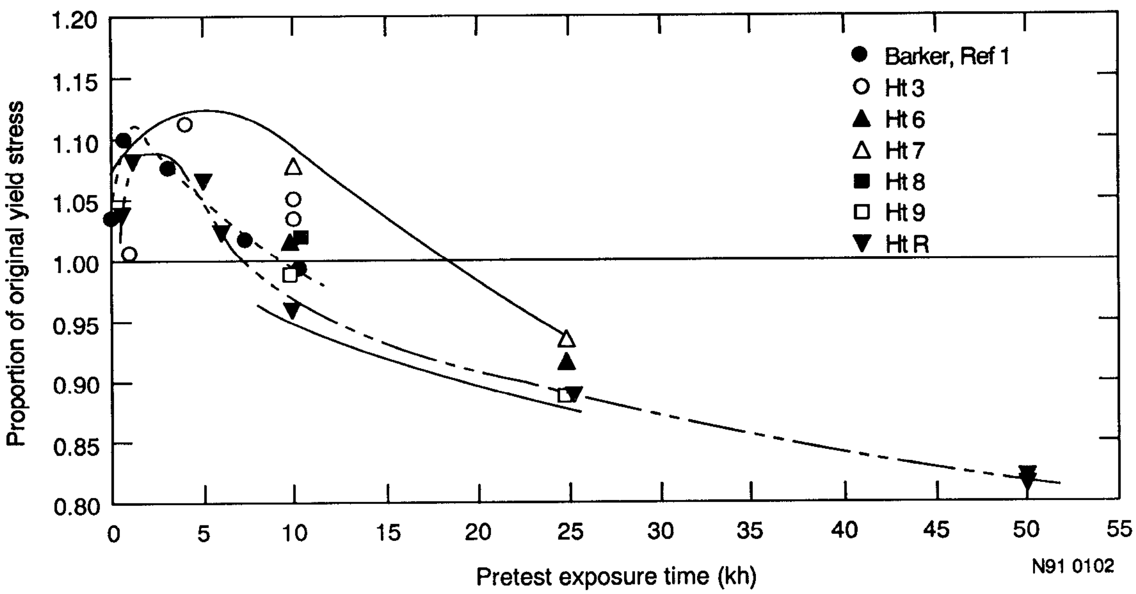


Figure 5 - Effects of 649°C exposures on the room temperature normalized yield strength of several heats of Alloy 718. (Ref. 4).

(1); the present investigation supports that finding (Fig. 1). Electron energy loss spectroscopy (EELS) found that the intergranular precipitates were not exclusively Ni_3Nb and Nb-rich particles, TiC and M(Fe,Cr)C were also observed. It is expected that TiN should also be present but none was observed in this study. This is most likely due to the limited number of particles analyzed by EELS.

Summary and Conclusions

The data base for long term aging of Alloy 718 at 593 and 649°C was extended from 25,000 to 50,000 h for one heat of material. Tensile tests were conducted on this material and the microstructure was examined. From this current information the following conclusions can be drawn:

1. Additional aging at 593°C to 50,000 h continues to increase the strength of the Alloy 718 reference heat slightly, with little change in the ductility. This heat shows continuing hardening at this temperature, similar to the heat examined by Barker, et al. and unlike some others that exhibited softening after approximately 10,000 h.

2. Extending the aging time at 649°C from 25,000 to 50,000 h showed a continuing decrease in yield and ultimate strength with a slight increase in total elongation but a small decrease in reduction in area. This may be the result of more extensive precipitation of δ as the aging time is increased.

3. The microstructure correlated well with the mechanical properties in that only subtle changes were observed in the microstructure as the thermal exposure was increased from 25,000 to 50,000 h and only subtle changes were exhibited in the mechanical properties. The phases identified in the long term aged material were consistent with those observed by other investigators for Alloy 718 given comparable thermal exposures.

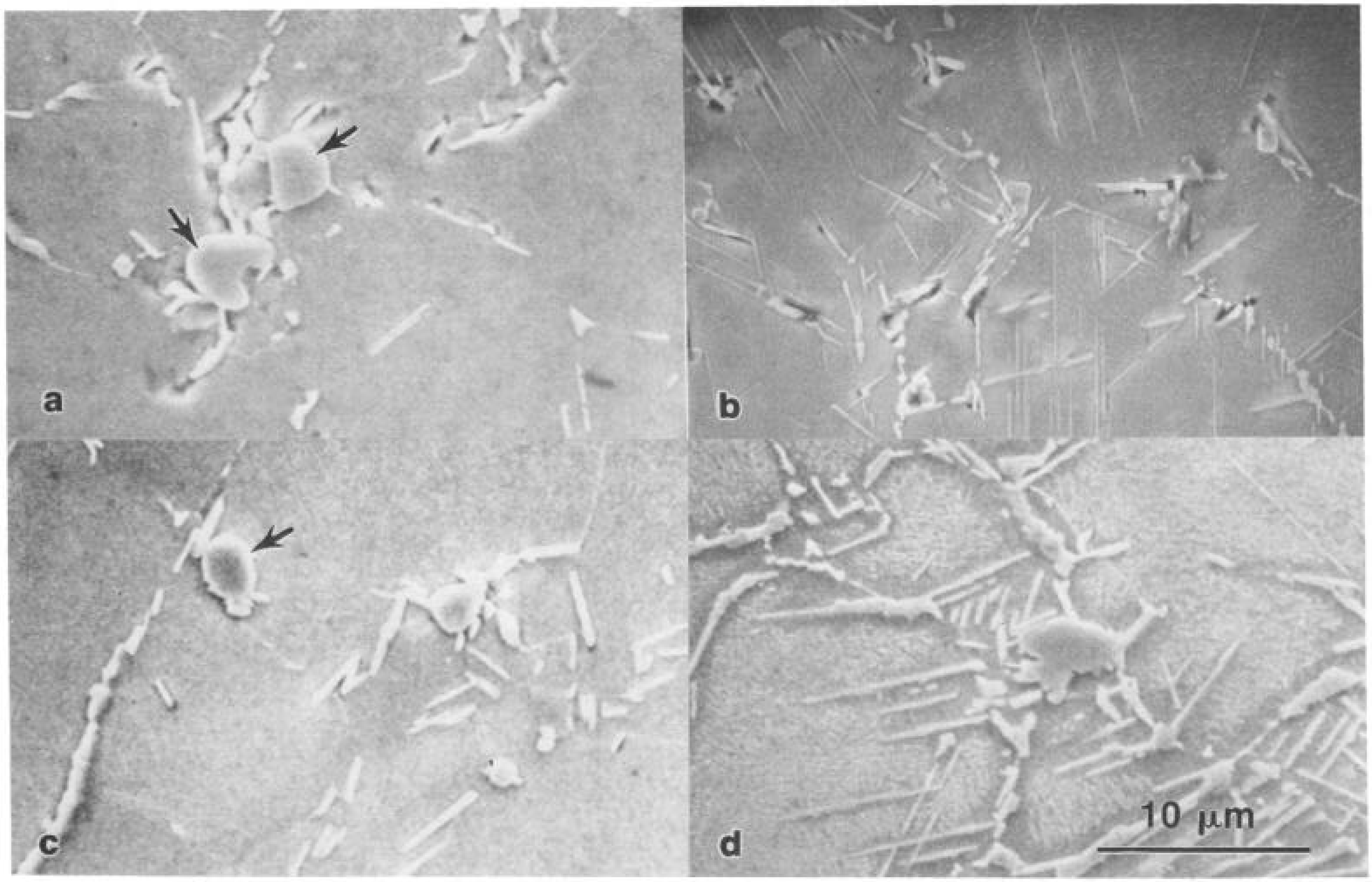
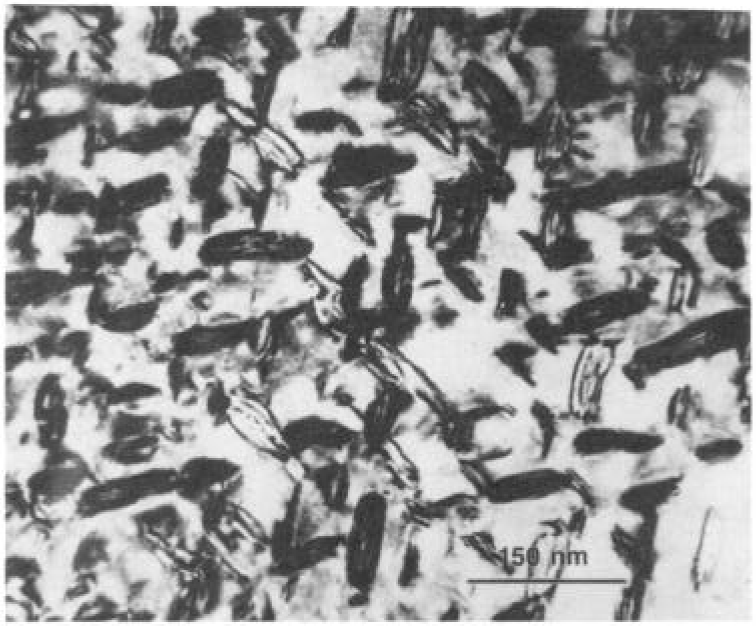


Figure 6 - SEM results on aged Alloy 718 specimens; note that little microstructural change occurs as the aging time is extended. (a) 25,000 h, 593°C. (b) 25,000 h, 649°C. (c) 50,000 h, 593°C. (d) 50,000 h 649°C.



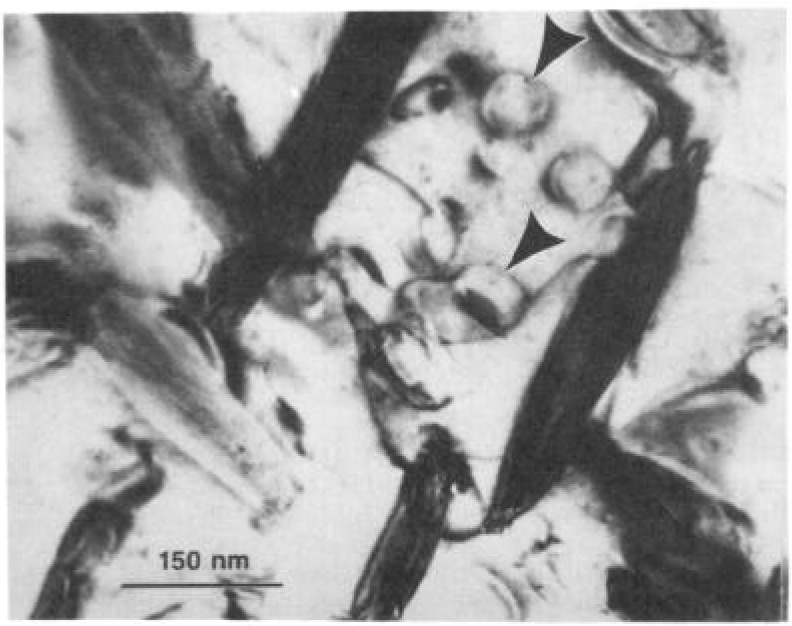


Figure 7 - TEM bright fields. (top) γ" in 50,000 h, 593°C specimen. (bottom) γ" and γ′ (arrows) in 50,000 h, 649°C specimen.

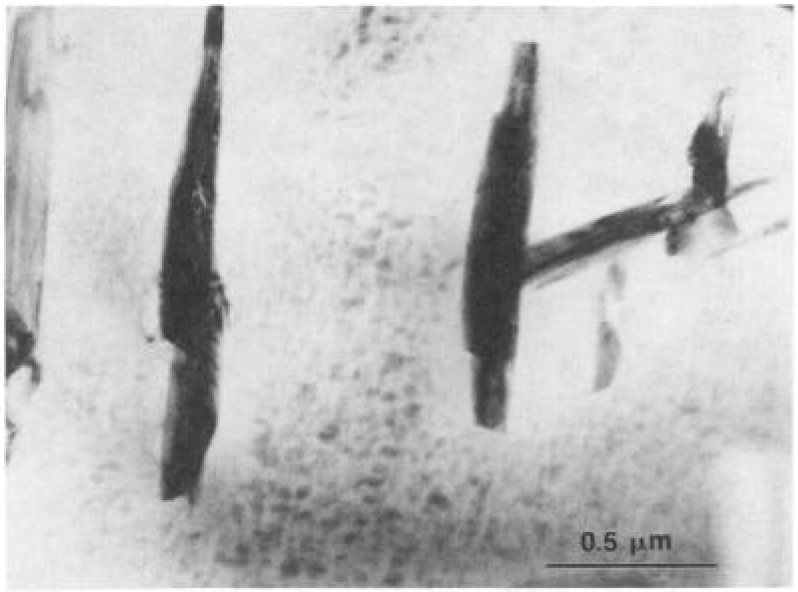


Figure 8 - δ phase (Ni_3Nb) in 50,000 h, 593°C specimen.

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