

## EVALUATION OF ALLVAC<sup>®</sup> 718PLUS<sup>™</sup> ALLOY IN THE COLD WORKED AND HEAT TREATED CONDITION

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### Abstract

Cold worked and heat treated alloys such as 718 and Waspaloy have been successfully used as high strength, high temperature fasteners. Newly developed Allvac<sup>®</sup> 718Plus<sup>™</sup> alloy has high strength, a significant temperature advantage over alloy 718 and a cost advantage over Waspaloy. The alloy also has excellent workability, similar to alloy 718, and has demonstrated a good response to direct age processing. These characteristics suggest it may be a desirable candidate for fastener applications. The effects of a range of cold work on the mechanical properties of alloy 718Plus<sup>™</sup> are presented in comparison to traditional alloys. Both direct age and solution and age conditions are evaluated.

### Introduction

Alloy 718Plus<sup>™</sup> is a recently introduced Ni-base superalloy which extends the application temperature for alloy 718 by about 55°C. At the same time, the alloy also retains many of the desirable features of alloy 718 which have made it the most widely used superalloy. These include good hot workability, weldability and moderate cost.

Alloy 718 has found widespread application in the aerospace market for diverse applications, including cases, compressor and turbine disks, blades, shafts and fasteners. As operating temperatures exceed 649°C, however, alloy 718 is no longer suitable due to rapid overaging and loss of properties, especially high temperature creep and rupture life. Other wrought alloys, such as Waspaloy, are available with higher temperature capability, but they are typically much more difficult to manufacture and fabricate into finished parts and are also significantly more expensive than alloy 718.

Alloy 718Plus<sup>™</sup> possesses very high room temperature tensile strength, close to that of alloy 718 and higher than Waspaloy. Stress rupture properties of alloy 718Plus<sup>™</sup> are much better than those of alloy 718, by almost exactly 55°C on the Larson Miller plot, and also better than Waspaloy to at least 704°C. On the basis of these characteristics, alloy 718Plus<sup>™</sup> is currently being evaluated or actively considered for a number of applications, including cases, compressor and turbine disks, compressor blades, flash butt welded rings, castings and sheet.

The combination of improved properties and temperature capability, excellent fabricability and moderate cost suggests that fasteners would be another obvious application. This project was undertaken to develop an initial characterization of alloy 718Plus<sup>™</sup>, compared to other commercial high temperature fastener alloys.

## Experimental Procedure

Material was taken from a production scale VIM-VAR heat; chemistry shown in Table I. The ingot was initially press and GFM converted from a 432 mm diameter ingot to 203 mm billet, with a section further pressed to 102 mm square and hot rolled to 28 mm round for use in this project. The hot rolled bar was annealed at 982°C with a water quench, then centerless ground to assure a uniform diameter. Cold drawing was performed at ATI Wah Chang Huntsville using a conventional procedure with tungsten carbide dies decreasing 1.6 mm in diameter each pass, with no intermediate annealing. Material was drawn with cumulative reduction of 16%, 25% and 35% reduction in area with samples set aside for testing after each reduction. Drawing was stopped at 35% RA due to galling, most likely caused by surface damage from handling.

Table I. Chemistry in Weight Percent

C	Cr	Mo	Co	Ti	Al	Fe	Ni	Nb	W
0.02	17.9	2.7	9.0	0.7	1.5	9.3	51.7	5.5	1.0

Test blanks were cut from the solution treated hot rolled bar and the cold worked bars. All were aged at 788°C for 8 hours at temperature, furnace cooled to 704°C, held 8 hours at temperature and air cooled.

## Results and Discussion

### Hardness

Hardness results show a typical increase from the as-hot rolled condition to the cold worked and aged condition and are presented in Figure 1.

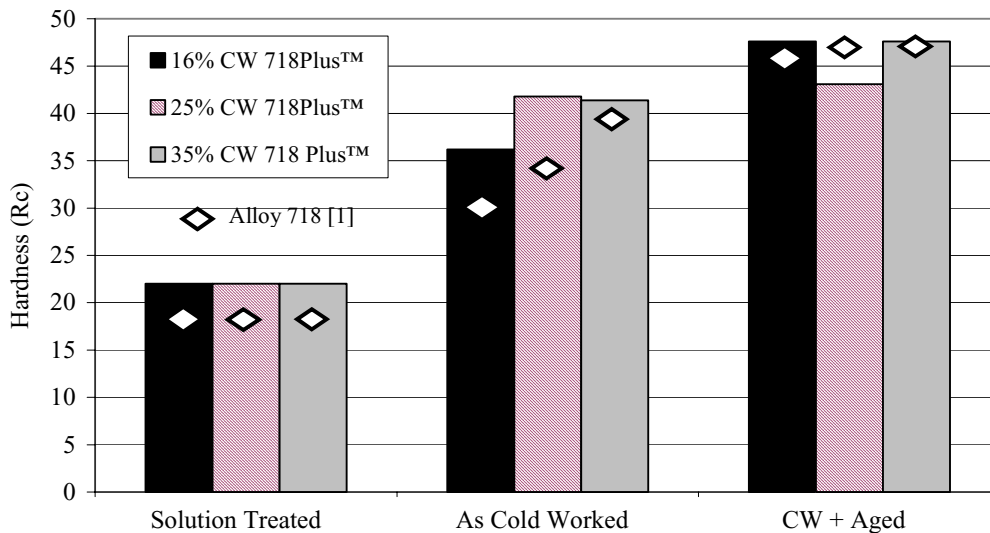


Figure 1. Hardness after each processing step

Hardness for alloy 718Plus™ in the solution treated and aged condition is quite low at RC 22. This hardness is comparable to that of alloy 718 bar of the same size solution treated at the same temperature. Hardness after cold drawing was slightly higher than that of cold drawn alloy 718. This may suggest the work hardening rate for alloy 718Plus™ is higher than for alloy 718, but more data would be required to confirm this. Cold drawing to at least 35% RA was completed without incident, and this degree of cold reduction appears sufficient to achieve very high strength after aging. Hardness after cold working and aging for alloy 718 and alloy 718Plus™ was very similar with samples all in the range of R<sub>C</sub> 43-47.

## Microstructure

Micros after hot rolling and cold working with a direct age (DA) treatment are shown in Figures 2a through 2d. The duplexed grain structure is a result of hand-mill rolling with limited total reduction but is felt to be inconsequential in terms of the test results.

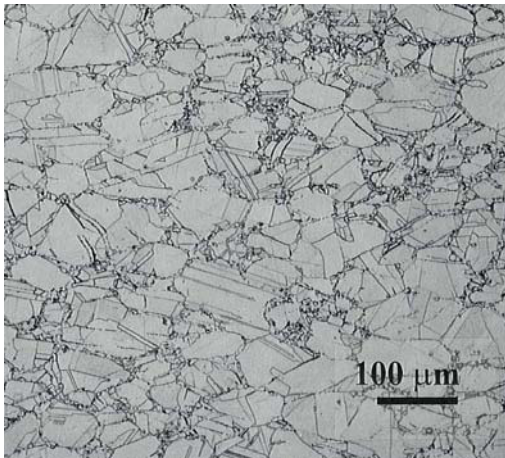


Figure 2a. As hot rolled microstructure

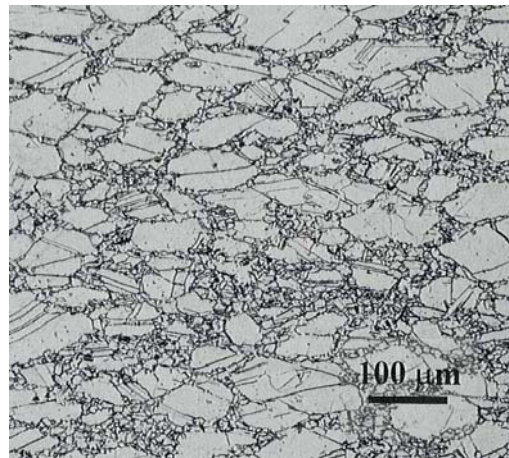


Figure 2b. Cold worked 16% and aged

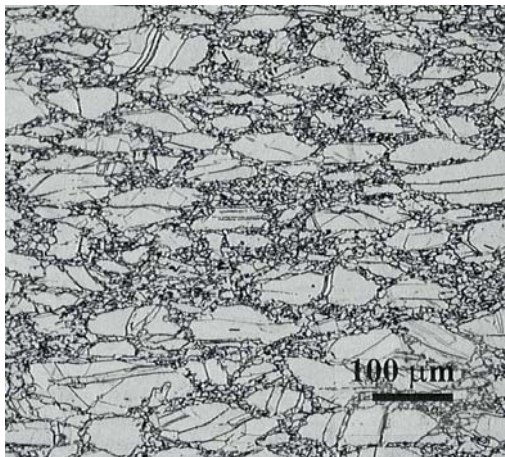


Figure 2c. Cold worked 25% and aged

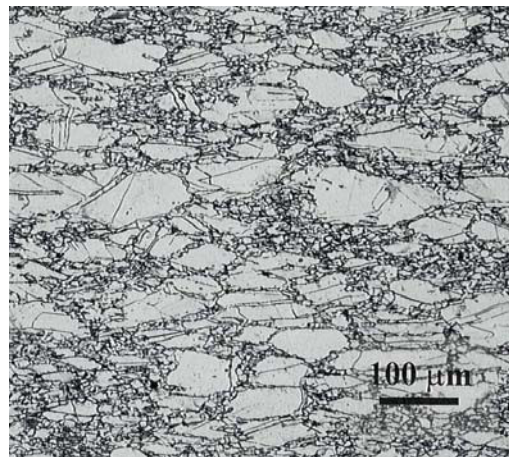


Figure 2d. Cold worked 35% and aged

Tensile Test Results: Room temperature and elevated temperature tensile results are shown in Table II. The 0% cold work tests were taken from the as-hot rolled bar after annealing at 982°C and aging, and are listed as “STA” in the heat treatment column to indicate solution treated and aged. Each result reported is an average of 2 or 3 tests.

Solution treated and aged test results as a function of temperature for alloy 718Plus™ are plotted in Figures 3, 4 and 5 along with published data for high temperature fastener alloys 718, Waspaloy, Nickelvac® A286 alloy and AEREX® 350. It is readily apparent from these figures that alloy 718Plus™ has a significant strength advantage over alloy 718 at temperatures above 650°C and over the entire temperature range compared to Waspaloy and A286. Elongation for alloy 718Plus™ over the entire temperature range remained high at 18% minimum. These data are consistent with comparisons of alloy 718, Waspaloy, A286 and alloy 718Plus™ in other product forms, including billet, rolled rings, forgings and sheet.

Table II: Room and Elevated Temperature Tensile Results

Test Temperature, °C	Cold Work	Heat Treat	Ult, MPa	Yield, MPa	Elong, %	RA, %
Room	0%	STA	1509	1109	24.1	33.3
	16%	DA	1637	1377	18.1	32.5
	25%	DA	1727	1543	14.3	27.1
	35%	DA	1818	1687	10.5	20.1
649	0%	STA	1322	973	20.7	21.8
	16%	DA	1416	1175	26.7	41.6
	25%	DA	1470	1234	25.7	46.6
	35%	DA	1547	1305	24.0	45.0
704	0%	STA	1147	939	17.9	19.6
	16%	DA	1234	1030	33.0	53.5
	25%	DA	1297	1070	29.3	58.1
	35%	DA	1313	1082	31.3	54.2
732	0%	STA	1057	894	21.0	25.4
	16%	DA	1095	886	33.6	51.2
	25%	DA	1130	921	37.5	65.1
	35%	DA	1170	944	34.4	60.3

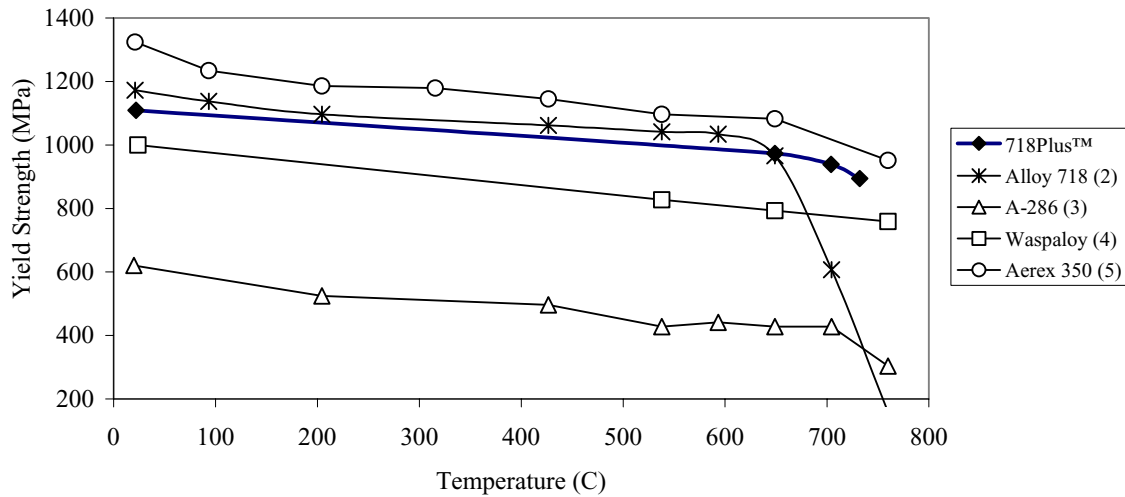


Figure 3. Effect of test temperature on room temperature tensile yield for several alloys, STA condition.

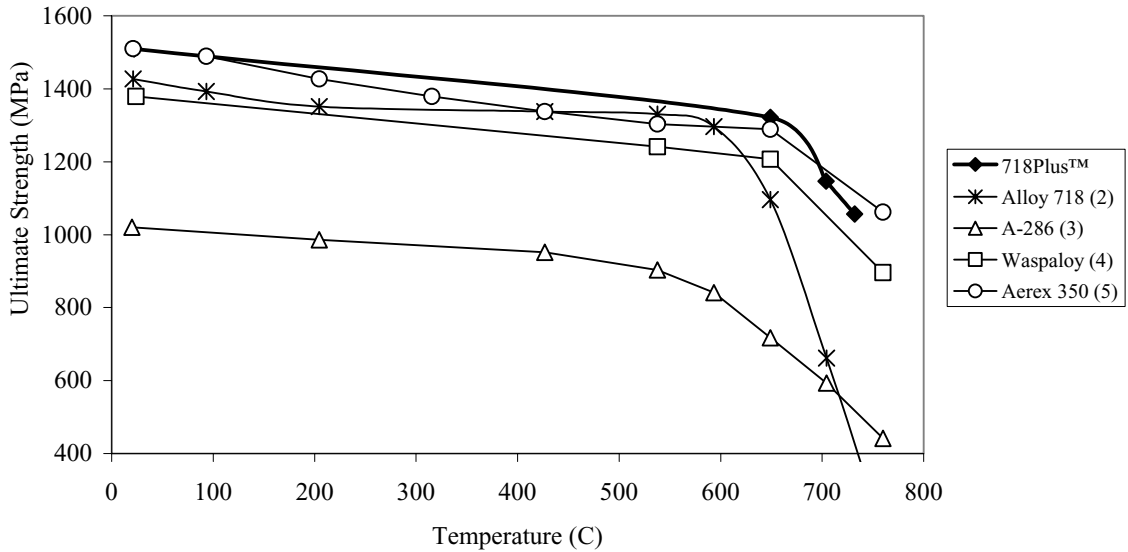


Figure 4. Effect of test temperature on room temperature tensile ultimate tensile strength for several alloys, STA condition.

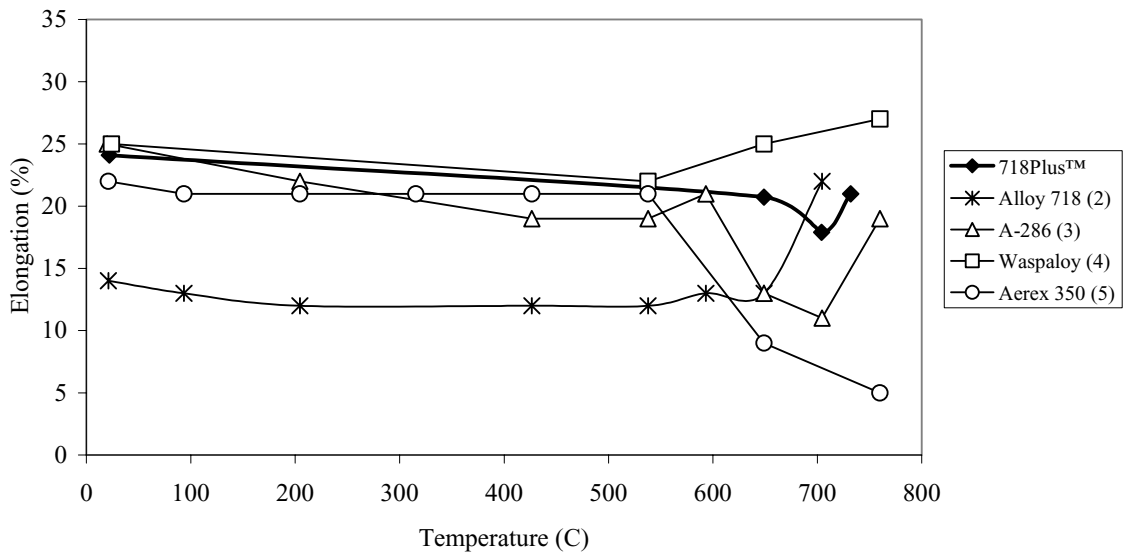


Figure 5. Effect of test temperature on room temperature tensile elongation for several alloys, STA condition.

Tensile test results for alloy 718Plus™ after cold working and aging show the alloy responds extremely well to DA processing. Room temperature strength increased significantly and in a linear manner with increasing cold work. Ductility decreased with increasing cold work but remained at reasonable levels. The comparison of room temperature DA results with other fastener alloys is shown in Figures 6 to 8. Strength and ductility were comparable for alloy 718Plus™ and alloy 718.

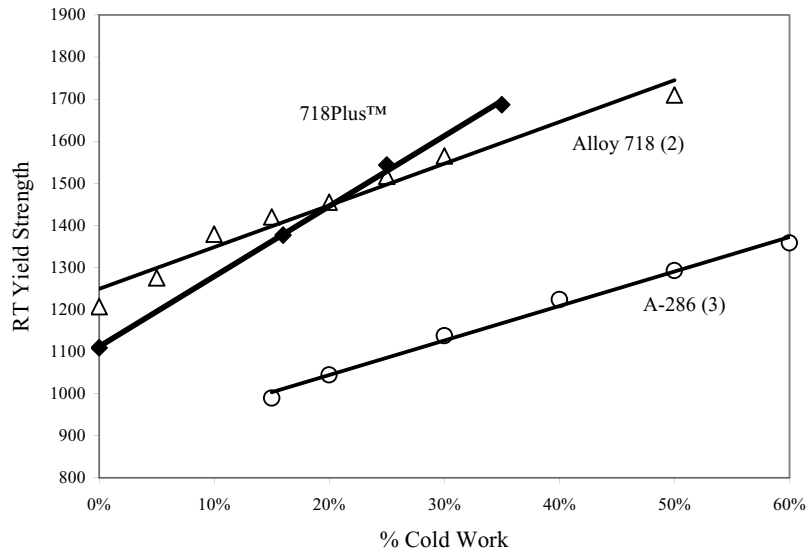


Figure 6. Room temperature yield strength by % cold work for 718Plus™ and other alloys in the cold worked and direct aged condition

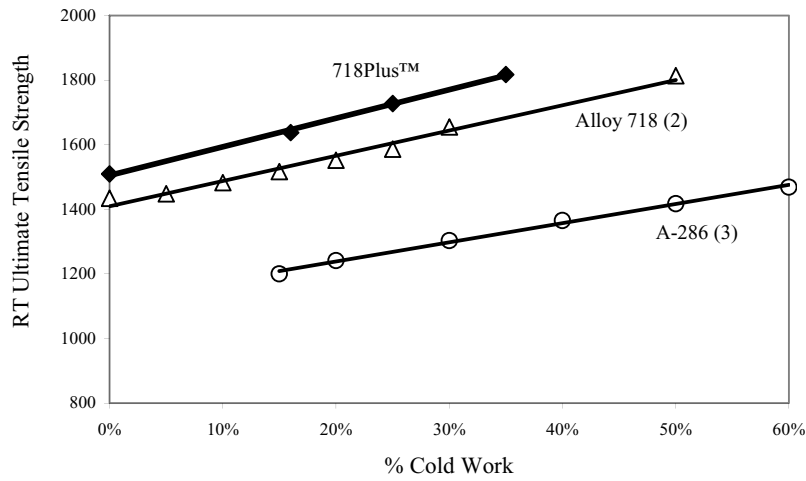


Figure 7. Room temperature ultimate strength by % cold work for 718Plus™ and other alloys in the cold worked and direct aged condition

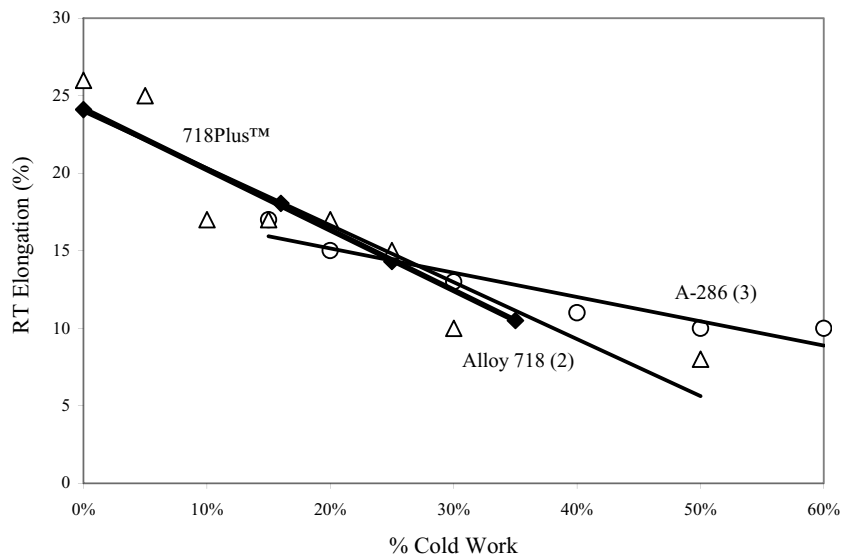


Figure 8. Room temperature tensile elongation by % cold work for 718Plus™ and other alloys in the cold worked and direct aged condition

The effects of test temperature on tensile properties of DA 718Plus™ alloy are also shown in Table II. Figure 9 shows these results graphically for the extreme tests, 0% cold work (STA) and 35% CW (DA). These data clearly show the strength advantage gained by DA is maintained to 732°C. A rather unexpected result is that ductilities for DA product increase at the elevated test temperatures to levels significantly above those of the STA product.

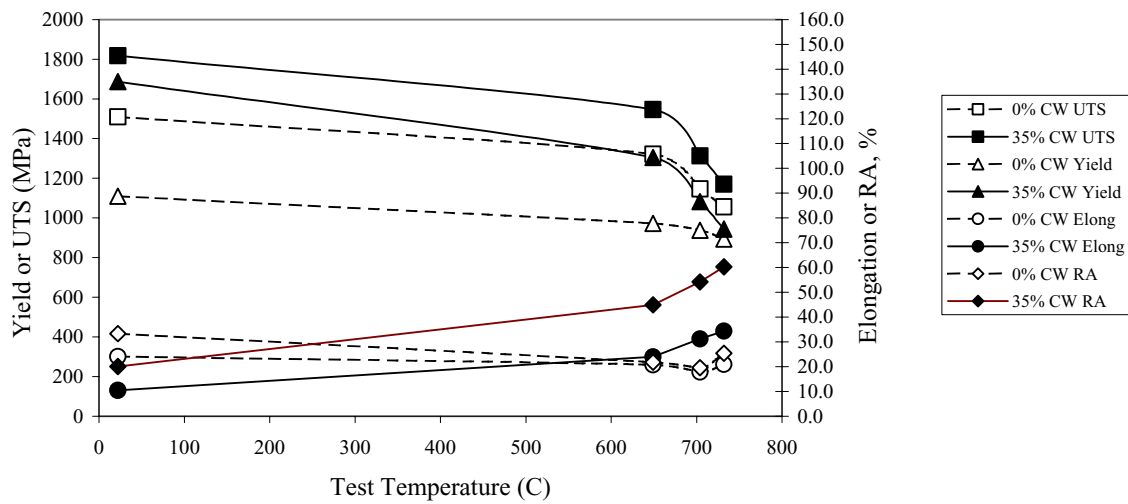


Figure 9. Test temperature effects on tensile properties, 0% and 35% cold worked AllvacP<sup>®</sup> 718Plus™.

### Stress Rupture Results

Stress rupture test results at 704°C/621 MPa are shown in Table III. Rupture life increased only slightly for alloy 718Plus™ cold drawn 25% and 35% RA over STA product. These data are shown as a single data point plotted on a previously published Larson Miller stress rupture plot for alloy 718Plus™ [6] in Figure 10. This graph shows a significant rupture life advantage over both alloy 718 and Waspaloy to at least 704°C.

Table III. 704°C/621 MPa Stress Rupture Results

CW	Heat Treat	Life, hours	Elong, %
0%	STA	101.2	37.9
16%	DA	99.4	40.0
25%	DA	126.4	31.2
35%	DA	124.1	33.8

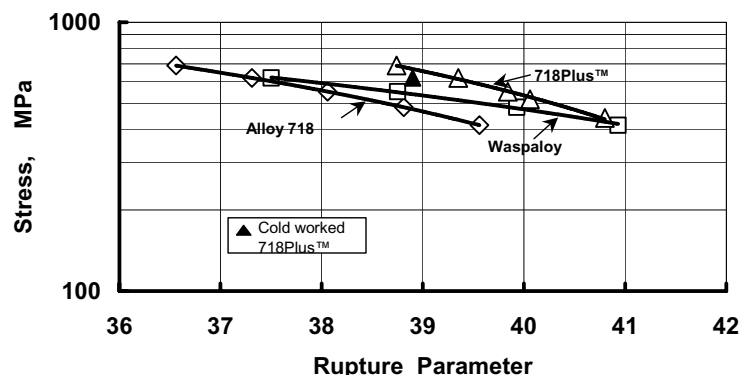


Figure 10. Larson Miller parameters for 718Plus™, Waspaloy and 718 alloys.

Table IV shows published data [7, 8] relating room temperature ultimate tensile strength versus maximum operating temperature for a number of alloys commonly used as fasteners. Alloy 718Plus™ has been added to the figures based on both STA and DA data generated from this effort. It appears that alloy 718Plus™ offers the potential to extend the operating range for fasteners to higher temperatures than alloy 718 and higher stresses than Waspaloy. The alloy can be readily manufactured in bar and coil forms suitable for the manufacture of fasteners. The alloy has good hot and cold workability and moderate cost.

Table IV. Maximum Use Temperature, °C [7, 8]

RT UTS MPa	260	316	371	427	482	538	593	649	704	760
1931			Aermet® 100* AMS6532							
1793			MP35N® AMS5844		H-11 AMS6487		MP159® AMS5842		AEREX® 350**	
1655									DA 718Plus™	
1517					CW 718 AMS5962				STA 718Plus™	
1379					A-286 AMS5726					Waspaloy AMS5708
1241	Alloy Steels	PH13- 8Mo 17-4PH				M254 AMS6304		718 AMS5662		
1103	Ti- 6Al- 4V AMS 4967	400 series stainless				A-286 AMS5853				
965								A-286 AMS5731		
827				CW 304						

### Conclusions

1. Alloy 718Plus™ appears to be a good candidate for high temperature fasteners and may be capable of extending the operating temperature range compared to the most commonly used fastener alloys.
2. Alloy 718Plus™ can be readily produced as hot rolled bar and coil, can be cold drawn with practices similar to other Ni-base superalloys and achieves very high strength while retaining reasonable levels of ductility in response to cold drawing plus direct aging.
3. Solution treated and aged property levels for 718Plus™ also show property improvements over other fastener alloys to 704°C. Tensile strength at room temperature is comparable to 718, and significantly higher than Waspaloy and A286. Tensile strength and rupture life at 704°C is superior to any of these three competing alloys.
4. Tensile strength improvements in 718Plus™ resulting from direct aging are retained to at least 732°C. Rupture life at 704°C also improved slightly from direct aging.

5. Properties, good processing characteristics and moderate cost appear to warrant additional work to evaluate alloy 718Plus™ for high temperature fasteners.

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