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PROPERTIES AND MICROSTRUCTURE OF ALLVAC® 718PLUS™ ALLOY ROLLED SHEET

David S. Bergstrom[1] and Thomas D. Bayha[2]

[1]ATI Allegheny Ludlum, 1300 Pacific Avenue, Brackenridge, PA 15065, USA
[2]ATI Allvac, 2020 Ashcraft Avenue, Monroe, NC 28110, USA

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Abstract

Design and construction of advanced aerospace systems capable of meeting demands of access-to-space, operations in and through space, and high speed/hypersonic flight are constrained by material challenges. Requirements for airplane-like operations of reusable systems fall most heavily on the needs for improved thermal protection systems and durable, lightweight structures. Robust and affordable industrial manufacturing procedures for these material systems frequently do not exist, even for materials such as some nickel-based superalloys, which have attractive high-temperature performance, manufacturability, cost and durability.

Applications of Alloy 718 are restricted to about 649°C. Above this temperature the Ni_3Nb strengthening phase overages, and properties, particularly creep resistance, fall dramatically. There is a need for an alloy that maintains the excellent properties and processing characteristics of Alloy 718 to higher use temperatures. Allvac® 718Plus™ Alloy meets this need. The new alloy shows excellent hot-workability and weldability relative to Alloy 718, and better stress rupture and creep properties at 704°C than Alloy 718 and Waspaloy material. Only a small drop in mechanical properties is observed after long-term thermal exposure up to 760°C.

The Air Force Research Laboratory funded ATI to evaluate the suitability of 718Plus alloy rolled sheet product for elevated temperature applications. Hot- and cold-rolling practices were utilized to manufacture thin sheets of suitable thicknesses for forming into structural components. Microstructure and mechanical property characterizations were conducted to assess the sheet product capability in elevated temperature structural applications.

Introduction

The design and construction of advanced aerospace systems capable of meeting the demands of access-to-space, operations in and through space, and high speed/hypersonic flight are always constrained by material challenges. Requirements for the airplane-like operations of reusable systems fall most heavily on the needs for improved elevated temperature capability of durable, light-weight structures. Even when materials such as nickel-based superalloys with attractive high-temperature performance, manufacturability, and cost can be identified, robust and affordable industrial manufacturing procedures for these material systems frequently must be developed. Alloy development in recent years has led to numerous new compositions and heat treatment/ structure control processes for advanced properties.

Current alloys utilized in elevated temperature rolled sheet aerospace applications include 718, Waspaloy and 625 alloys. Applications of Alloy 718 are typically restricted to about 649°C [1, 2], as above this temperature the γ" (Ni_3Nb) strengthening phase overages, and properties, particularly creep resistance, fall dramatically. Waspaloy product is utilized in applications seeing higher service temperatures than Alloy 718, but has issues with formability and weldability, which makes it more difficult and costly to fabricate, advanced aerospace components from the material [1]. Alloy 625 is a solid solution/cold work strengthened alloy and has outstanding fatigue resistance, with good oxidation resistance and elevated temperature strength retention [3, 4]. Both Alloy 718 and Alloy 625 are notable for their good formability and weldability, which is critical in the manufacture of complex aerospace components.

There is a need for an alloy that has higher strength than Alloy 625 and maintains the excellent properties and processing characteristics found in these alloys. 718Plus alloy meets this need. The new alloy shows excellent hot-workability and weldability relative to Alloy 718, and better stress rupture and creep properties at 704°C than Waspaloy forgings [5]. Only a small drop in mechanical properties is observed after long-term thermal exposure up to 760°C.

ATI Allvac has extensively investigated the 718Plus alloy billet properties, both as an internal program and as part of the Metals Affordability Initiative program entitled "Low-Cost, High Temperature Structural Material" for turbine engine ring-rolling applications [5-8]. The objectives of all these programs is to develop an alloy with the following characteristics:

- 55°C temperature advantage based on the Larson-Miller, time-temperature parameter
- Improved thermal stability; equal to Waspaloy at 704°C
- Good weldability; at least intermediate to 718 and Waspaloy alloys
- Minimal cost increase; intermediate to 718 and Waspaloy alloys
- Good workability; better than Waspaloy alloy

The use of 718Plus alloy in elevated temperature applications is of interest for military systems. In particular, the manufacturing difficulties associated with alloys such as Waspaloy provide a need for a material with similar component capabilities, but with better producibility. Initial characterization shows that the alloy exhibits many similarities to Alloy 718, including good workability, weldability and intermediate temperature strength capability.

Previously published billet tensile results show that the 718Plus alloy properties are comparable to Alloy 718 at room temperature and higher at both 649°C and 704°C [5, 8]. 718Plus alloy tensile strength also exceeds that of Waspaloy from room temperature to 704°C. Tensile ductilities are very good over the entire temperature range. Rupture life for Waspaloy is the same as 718Plus alloy at 704°C, but limited creep testing shows slightly improved creep resistance at 704°C for 718Plus alloy. Stress rupture ductility for 718Plus alloy is also excellent. Similar property and processing comparisons are of interest for sheet product. To date, ATI Allvac has developed conversion processes for 718Plus alloy based on existing standard Alloy 718 processes [5].

The 718Plus alloy nominal composition is shown in Table I, compared to nominal chemistries of Alloys 718, Waspaloy and 625. The principal differences in the 718Plus alloy chemistry are the increase in total Al+Ti content, Al/Ti ratio, and the addition of Co and W.

The objective of this work is to produce sheet and provide mechanical property data for a newly developed, weldable Ni-base superalloy, 718Plus alloy. The goal is to develop a material with a superior balance of properties over existing alloys, such as Alloys 625 and 718, now used for "acreage" applications. ATI Allvac is part of an Air Force Research Laboratory - funded Technical Operations Support (TOPS) Contract. ATI Allvac is working with Universal Technology

Corporation (UTC) to manufacture and test 718Plus alloy in a variety of product forms, including rolled sheet.

Table I. Nominal Chemistry Comparison of Alloy 718, Waspaloy, Alloy 625, and 718Plus™ Alloy

Alloy	Chemistry											
	Ni	Cr	Co	Mo	W	Nb	Al	Ti	Fe	C	P	B
718	Bal	19	---	3.0	---	5.15	0.6	0.9	18.5	0.04	0.007	0.003
Waspaloy	Bal	19.4	13.3	4.3	---	---	1.3	3.0	---	0.035	0.006	0.006
625	Bal	21.5	---	9.0	---	3.6	0.2	0.2	2.5	0.05	0.007	---
718Plus	Bal	18.0	9.1	2.7	1.0	5.4	1.45	0.75	9.5	0.020	0.006	0.005

Technical Approach

Material

To provide material data for comparison to 718, Waspaloy and 625 alloys, ATI Allvac manufactured 718Plus alloy sheet using both hot- and cold-rolling processes. The AMS 5596 and 5544 specifications for Alloy 718 and Waspaloy sheet products allow both; while AMS 5599 (Alloy 625) requires cold rolling.

ATI Allvac hot rolled, annealed and heat-treated sheet material from production heat 993J. Heat 993J was VIM melted, then VAR re-melted to 508mm ingot, homogenized and forged to 381mm wide by 127mm thick slab for sheet rolling. The average billet chemistry measured for heat 993J is presented in Table II and compared to the nominal 718Plus alloy chemistry.

Table II. Average Billet Chemistry of 718Plus™ Alloy Heat 993J

	Chemistry											
	Ni	Cr	Co	Mo	W	Nb	Al	Ti	Fe	C	P	B
718Plus	52.0	18.0	9.1	2.7	1.0	5.40	1.45	0.75	9.5	0.020	0.006	0.005
Heat 993J	51.9	17.86	8.97	2.7	0.99	5.49	1.49	0.76	9.59	0.024	0.006	0.004

Hot Rolling

Niagara Specialty Metals hot-rolled the starting slab to 1.02mm, 2.5mm and 5.8mm thicknesses x 559mm width x 2.134 m length. All sheet materials were annealed and shipped to Monroe for cut up and testing. The 1.02mm sheet was rolled for the TOPS program, and those materials are the focus of this publication. Some 5.8mm thick material was provided to ATI Allegheny Ludlum for cold-rolling trials.

Cold Rolling

ATI Allegheny Ludlum cold rolled annealed 178mm wide strip of 718Plus alloy at its Technical Center. Strips were cold rolled to an intermediate gage of approximately 2.5mm, annealed, and then cold rolled to 1.27mm thick. Half of the 1.27mm gage material was re-annealed and an additional cold rolling step to produce strip with thickness of 0.25mm. The material was then given a solution anneal followed by a precipitation hardening heat treatment.

Following hot- or cold rolling to final thickness, an annealing study was conducted to determine an appropriate final annealing cycle. The materials were annealed at temperatures from 926°C to

982°C for times from 2 to 30 minutes. Temperatures above 982°C were not considered because they would approach or exceed the δ-phase solvus temperature of 999°C. Microstructural examination was performed to determine if the material had recrystallized and the grain size was measured.

Evaluation and Testing

A microstructural characterization was conducted for both hot- and cold-rolled 718Plus alloy sheet. After the sheet had reached final gage, an annealing study was conducted to determine an appropriate final anneal for each material.

Precipitation-hardened cold-rolled sheet material was tested per the matrix in Table III. Both hot- and cold-rolled sheet materials were tested at room temperature, 649°C and 704°C per ASTM E-8 and E-21. Additionally, the hot rolled materials were tensile tested at 427°C, 538°C, 760°C and 816°C as part of the AFRL TOPS program.

Table III. Mechanical Property Test Matrix for 718Plus™ Alloy Sheet

Test Type	ASTM Test Specification	Temperature °C	Direction	Number of Tests
Tensile – 1.02mm Hot Roll	E-8	20	L	6
	E-21	427, 538, 649, 704, 760, 816	L	3 per temperature
Tensile - Cold Roll	E-8	20	L	2
	E-21	649, 704	L	2
Stress Rupture	E-139	649, 704	L	2

Results

The metallurgical examination of the hot rolled 718Plus alloy sheet 1.02mm samples determined that a solution anneal of 954°C for 30 minutes was adequate to produce a fine (ASTM 11), recrystallized microstructure. Hardness tests of annealed 1.02mm hot rolled sheet gave results of 32.3 ± 0.3 Rockwell C. All hot rolled material was annealed at Niagara Specialty Metals at 954°C for this duration prior to shipping to ATI Allvac.

Hardness testing was also performed on samples of the 1.27mm- thick cold rolled material. The results of this study are shown in Table IV. Micrographs of the rolled and annealed structures are shown in Figure 1. Temperatures of 954°C or higher resulted in a recrystallized microstructure and a significant drop in hardness.

Table IV. Annealing Study on Cold-Rolled 718Plus™ Sheet

1.27mm Thick Material								
	2 Minutes		5 Minutes		10 Minutes		30 Minutes	
	Grain Size	R_C Hardness	Grain Size	R_C Hardness	Grain Size	R_C Hardness	Grain Size	R_C Hardness
927°C	NRX	40.6	NRX	39.9	NRX	39.8	NRX	38.8
941°C	PRX	37.7	PRX	33.8	PRX	36.5	PRX	35.0
954°C	PRX	26.6	9	22.3	9	21.2	8	20.8
968°C	8	21.4	8	98.4 R_B	8	97.7 R_B	8	97.6 R_B
982°C	8	98.2 R_B	8	98.5 R_B	7	98.1 R_B	7	97.5 R_B

Table IV. Annealing Study on Cold-Rolled 718Plus™ Sheet

0.25mm Thick Material				
	2 Minutes	5 Minutes	10 Minutes	30 Minutes
	Grain Size	Grain Size	Grain Size	Grain Size
927°C	NRX	NRX	NRX	NRX
941°C	PRX	PRX	PRX	PRX
954°C	8	8	8	8
968°C	8	8	8	8
982°C	8	8	8	8

NRX = Not recrystallized, PRX = Partially recrystallized

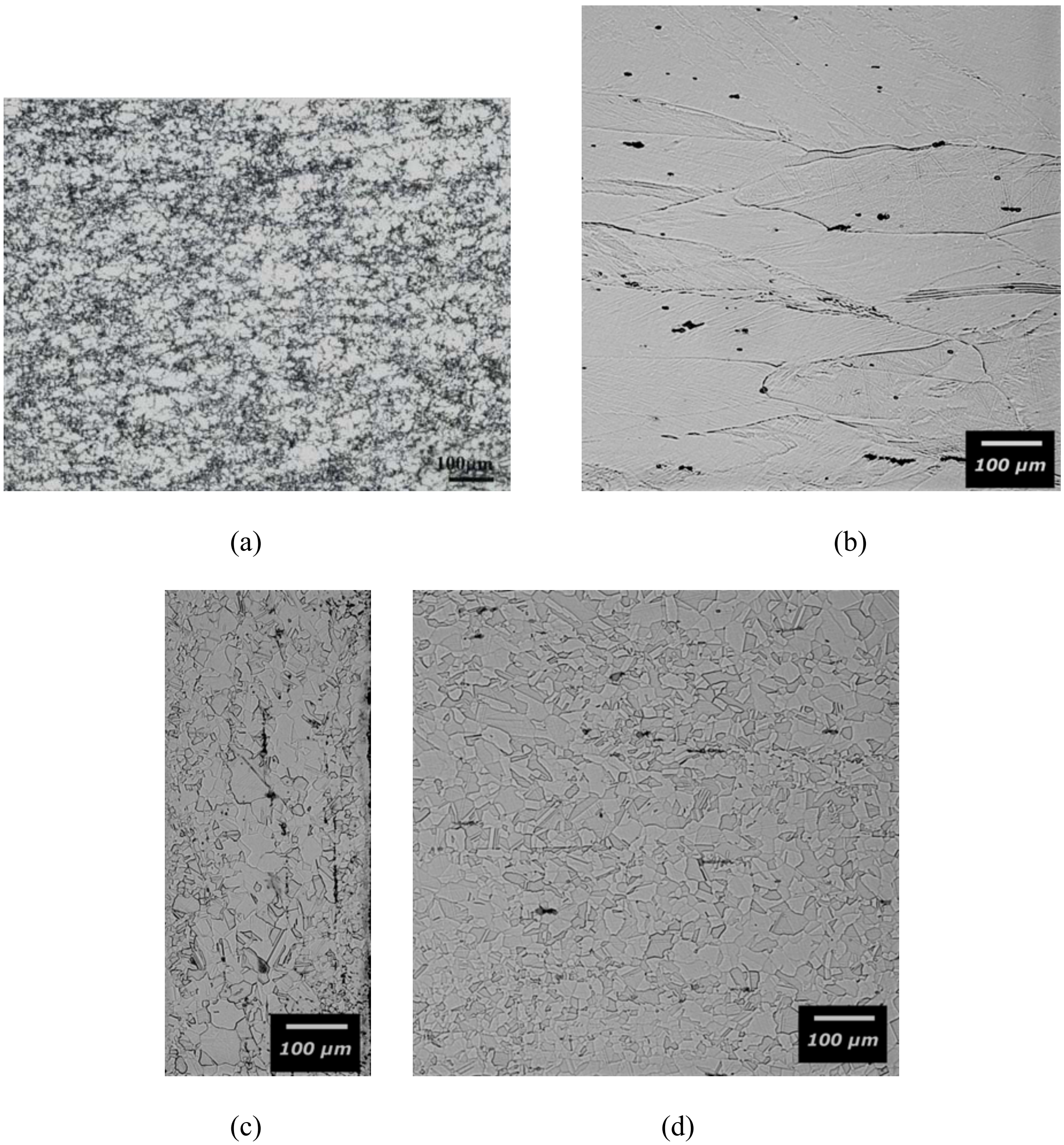


Figure 1. Micrographs of 718Plus™ alloy sheet: (a). 1.02mm gage hot rolled, annealed 30 minutes at 954°C, (b). 1.27mm gage material as cold rolled, (c). 0.25mm gage material annealed 5 minutes at 982°C, and (d). 1.27mm gage material annealed 5 minutes at 982°C.

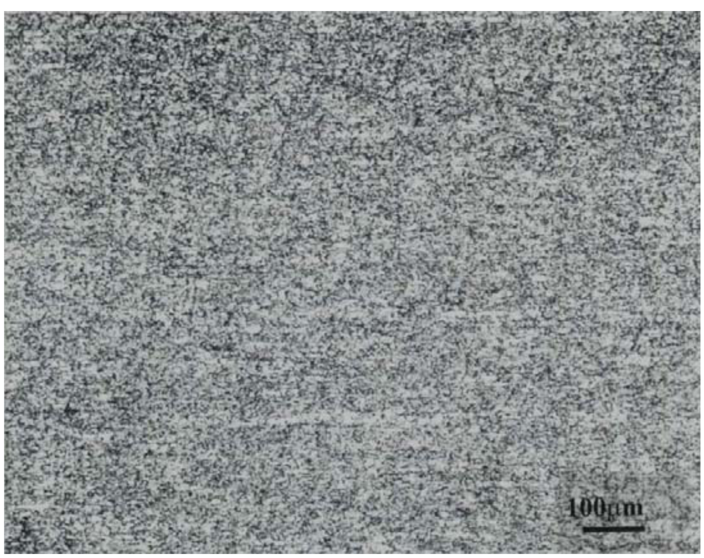
Cold rolled panels of both thicknesses were annealed at 982°C for 2 and 5 minutes. Tensile tests were performed on these materials, and the results are shown in Table V, and compared with the AMS 5596 (Alloy 718) maximum properties and the AMS 5599 (Waspaloy) minimum properties. Based on these results, 5 minutes at 982°C was chosen as the annealing cycle for cold rolled sheet materials.

Table V. Tensile Test Results for Cold-Rolled 718Plus™ Sheet Annealed at 982°C

Annealing Time at 982°C/gage	Ultimate Tensile Strength, MPa	Yield Stress MPa	Elongation %
2 Minutes (0.25mm)	1004.6	544.7	38.4
5 Minutes (0.25mm)	943.2	464.0	46.0
2 Minutes (1.27mm)	930.1	468.2	50.0
5 Minutes (1.27mm)	1008.0	566.1	45.0
AMS 5596	965 max.	552 max.	30.0 min
AMS 5599	827 min.	414 min.	30.0 min.

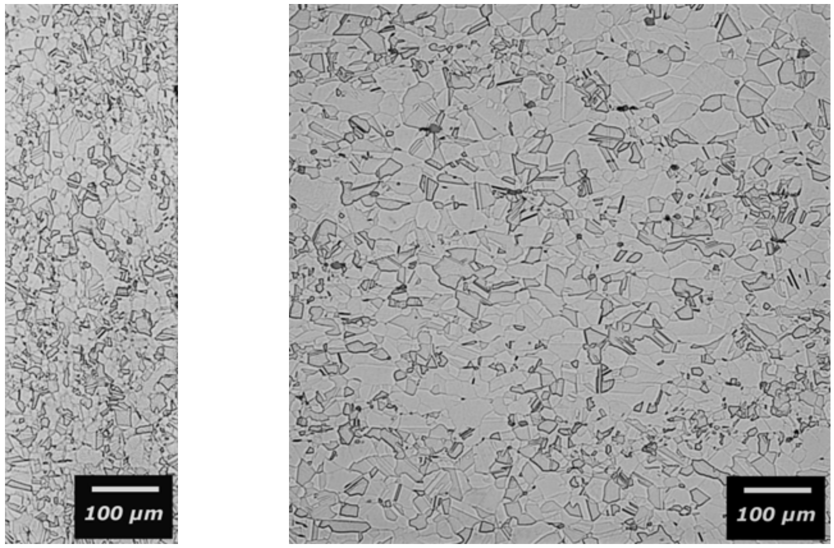
718Plus alloy thin sheet products have annealed strengths very close to the AMS 5596 maximums for Alloy 718 in all conditions evaluated. This implies that the forming characteristics of this material should be very close to Alloy 718. The strengths of the 718Plus alloy cold rolled sheet materials greatly exceed the Waspaloy specification (AMS 5599). All of the ductilities measured for 718Plus alloy exceed the minimums for both AMS specifications. Future work on the formability of 718Plus alloy sheet materials is planned.

All annealed material was then precipitation hardened using the following cycle: 2 hours at 788°C followed by a furnace cool at a rate of 38°C per hour to 649°C, an 8 hour hold at 649°C followed by an air cool. The microstructures (Figures 2 a, b and c), room and elevated temperature tensile properties (Table VI) and stress rupture resistance (Table VII) of both gages of material were then evaluated.



(a)

Figure 2(a). Micrographs of precipitation-hardened 718Plus™ alloy sheet: Hot rolled 1.02mm gage.



(b) (c)

Figures 2(b and c). (b). Micrographs of precipitation-hardened 718Plus™ alloy sheet: Cold rolled 0.25mm gage; and (c). 1.27mm gage.

Table VI. Longitudinal Tensile Test Results for 718Plus™ Hot Rolled 1.02mm Sheet, Compared with Cold Rolled 1.27mm and 0.25mm 718Plus™ alloy Sheet, All Materials Solution Treated and Aged (STA)

718Plus™ Alloy	**Property**	**Test Temperature, °C**						
		20	**427**	**538**	**649**	**704**	**760**	**816**
Hot-rolled 1.02mm STA	F_{TU}, MPa	1434.3	1225.9	1330.5	1189.8	1000.5	796.6	596.6
	F_{TY}, MPa	1149.2	1055.2	1058.4	954.7	772.9	604.2	406.1
	ε, %	7.3	5.5	7.3	24.3	35.7	36.3	45.3
Cold-Rolled 1.27mm STA	F_{TU}, MPa	1450.0	---	---	1199.0	1000.5	---	---
	F_{TY}, MPA	1032.2	---	---	893.6	810.9	---	---
	ε, %	25	---	---	11	9	---	---
Cold-Rolled 0.25 mm STA	F_{TU}, MPa	1445.9	---	---	1171.5	950.8	---	---
	F_{TY}, MPa	1053.6	---	---	917.1	771.6	---	---
	ε, %	22	---	---	10	8	---	---

A plot comparing 718Plus alloy thin sheet longitudinal tensile properties and the change in strength with elevated temperature of Alloy 718, Alloy 625 and Waspaloy products is presented in Figure 3. To make the comparison and create the curves, typical room temperature data [9, 10, 11] were combined with MMPDS plots [12], which describe the percentage reduction in tensile ultimate strength and tensile yield stress with temperature. This is an approximate measure of the elevated temperature behavior of these sheet materials.

ATI Allvac 718Plus alloy 1.02mm thick hot-rolled sheet has slightly higher room temperature yield stress compared to Alloy 718 and maintains that advantage over the range of test temperatures studied in the program. The cold-rolled materials are slightly lower in yield stress at the lowest test temperatures, but at temperatures of over 649°C, the 718Plus alloy sheet materials all have equivalent yield stress. All the 718Plus alloy data is clearly superior to the Waspaloy sheet, as is found in most other product forms. It must be noted that the lines in the plot shown in Figure 3 are approximations of the yield stress for the other sheet materials. Certainly 718Plus alloy is a competitive material on a strength basis in elevated temperature applications, even given the fact that the rolling and heat treatment for these sheet materials has yet to be optimized.

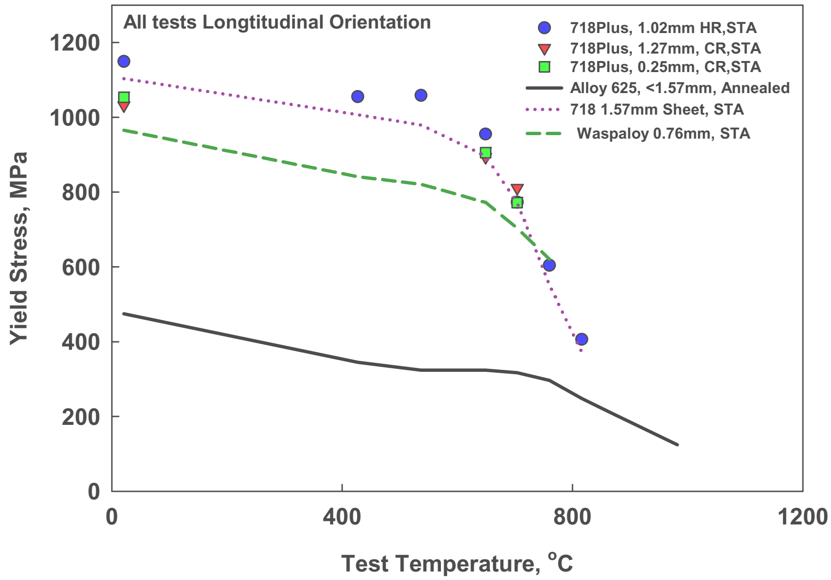


Figure 3. Elevated Temperature Tensile Yield Stress of 718Plus™ Hot rolled 1.02mm, Cold Rolled 1.27mm and Cold Rolled 0.25mm Sheet Materials Compared with Alloy 625, Alloy 718 and Waspaloy Sheet Materials.

718Plus alloy 1.02mm hot rolled sheet was tensile tested in longitudinal, transverse and 45° orientations relative to the rolling direction as part of the AFRL TOPS program. A summary of the room temperature results of these tests is presented in Figure 4. The sheet material is very isotropic, as would be expected from a fine, equiaxed microstructure. Both the longitudinal and transverse directions are equivalent and only a slight degradation (about 4%) is noted in ultimate strength for the 45° orientation tests. This is also the case for the ductility in the sheet material.

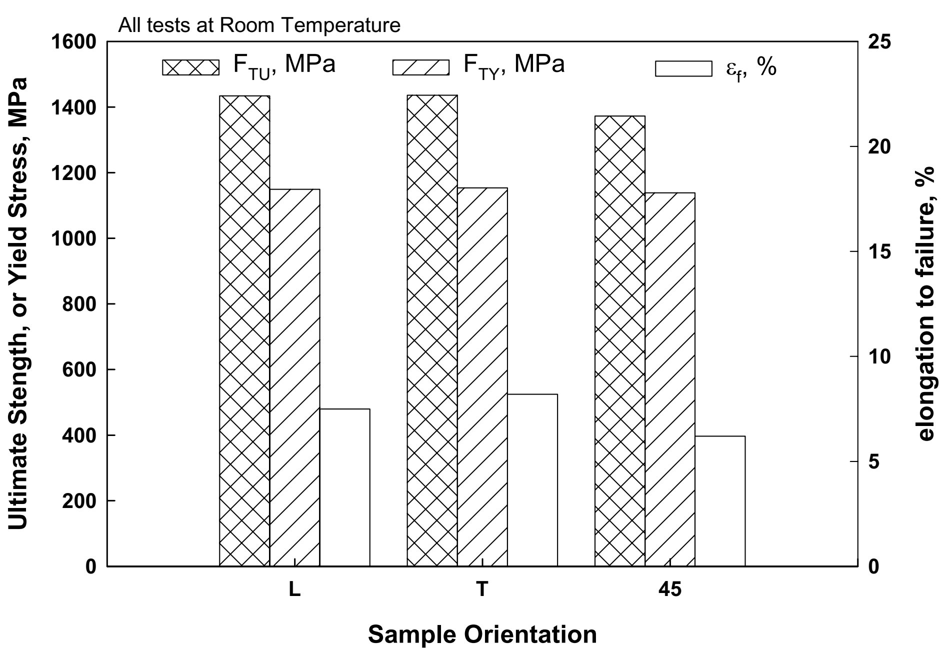


Figure 4. Isotropy of 718Plus™ Hot rolled 1.02mm Sheet Materials.

Stress rupture results for 718Plus alloy sheet products are shown in Table VII. Test data for the hot rolled sheet are presented in the table; however cold rolled sheet products are currently in testing.

Table VII. Stress Rupture Test Results for 718Plus™ Sheet Following Age Hardening

Material (gage)	Stress MPa	Temperature °C	Time to Failure hrs	Elongation %
Hot Rolled (1.02mm)	620.7	649	8.3, 13.1	21.5, 22.0
	448.2		67.6, 60.1	30.0, 29.0
Cold Rolled (0.25mm)	655.0	649		
		704		
Cold Rolled (1.27mm)	689.5	649		
		704		

Summary

1. Allvac® 718Plus™ is capable of either hot- or cold rolling to thin sheet gages for subsequent manufacture into structural application in aerospace structures.
2. Annealed tensile properties of cold rolled 718Plus alloy sheet are comparable to the AMS 5596 specification for Alloy 718 materials.
3. A fine, recrystallized microstructure can be produced in thin sheet gages utilizing either rolling technique.
4. The tensile properties of 718Plus alloy thin sheet materials are equivalent or higher than those of competitive materials such as Alloy 625, Alloy 718 and Waspaloy at room temperature.
5. At elevated temperatures, 718Plus alloy shows good strength retention in testing out to 816°C.

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References

1. R. E Schafrik, D. D. Ward, and J. R. Groh, "Applications of Alloy 718 in GE Aircraft Engines: Past, Present and the Next Five Years," *Superalloys 718, 625, 706 and Various Derivatives*, Edited by E. A. Loria, TMS (The Minerals, Metals and Materials Society), 2001, p. 1-11.

2. G. E. Korth and C. L Trybus, "Tensile Properties and Microstructure of Alloy 718 Thermally Aged to 50,000 h," *Superalloys 718, 625, 706 and Various Derivatives*, Edited by E. A. Loria, TMS (The Minerals, Metals and Materials Society), 1991, p. 437-446.

3. H. L. Eiselstein and D. J. Tillack, "The Invention and Definition of Alloy 625," *Superalloys 718, 625, 706 and Various Derivatives*, Edited by E. A. Loria, TMS (The Minerals, Metals and Materials Society), 1991, p. 1-14.

4. W. D. Klopp, *Aerospace Structural Materials Handbook*, Purdue Research Foundation, West Lafayette, IN, 1993, Volume 4, Ni-4100, p 1-58.

5. R. L. Kennedy, W.D. Cao, T. D. Bayha and R. A. Jeniski, "Developments in Wrought Nb Containing Superalloys (718 + 100°F)," *Niobium for High Temperature Applications*, ed. by

Young-Won Kim and Tadeu Carneiro, TMS (The Minerals, Metals & Materials Society), 2004, pp. 11-21. (Araxá, MG, Brazil).

6. W. D. Cao and R. L. Kennedy, "Role of Chemistry in 718 Type Alloys–Allvac® 718Plus™ Development," presented at Superalloys 2004, Seven Springs Conference, Seven Springs, PA, TMS (The Minerals, Metals & Materials Society), 2004, pp. 91-99.

7. X.B. Liu, S. Rangararan, E. Barbero, K.M. Chang, W.D. Cao, R.L. Kennedy and T. Carneiro, "Fatigue Crack Propagation Behavior of Newly Developed Allvac® 718Plus™ Superalloy," presented at Superalloys 2004, The Seven Springs Conference, Seven Springs, PA, TMS (The Minerals, Metals & Materials Society), 2004, pp. 283-290.

8. W.D. Cao and R.L. Kennedy, "New Developments in Wrought 718-Type Superalloys," *Acta Metallurgica Sinica*, Vol. 17, No. 6, 2004.

9. W. D. Klopp, *Aerospace Structural Metals Handbook*, Edition 39.1, NI-4117, Reference 3, July 1993, pp. 1-14.

10. W. D. Klopp, *Aerospace Structural Metals Handbook*, Edition 39.1, NI-4103, Reference 45, January 1995, pp. 1-26.

11. W. D. Klopp, *Aerospace Structural Metals Handbook*, Edition 39.1, NI-4208, Reference 27, September 1986, pp. 1-12.

12. Metallic Materials Properties Development and Standardization (MMPDS), DOT/FAA/AR-MMPDS-01, 2003, Chapter 6, pp. 6-21, 6-55 and 6-92.

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