Alloy 625 - Nickel-Base Superalloy

(UNS N06625)

INTRODUCTION

Alloy 625 alloy (UNS Designation N06625) is an austenitic nickel-base superalloy possessing excellent resistance to oxidation and corrosion over a broad range of corrosive conditions, including jet engine environments and in many other aerospace and chemical process applications. The alloy has outstanding strength and toughness at temperatures ranging from cryogenic temperature to 2000°F (1093°C). Alloy 625 alloy also has exceptional fatigue resistance.

Alloy 625 alloy derives its strength from the solid solution strengthening effects of molybdenum and columbium on the nickel-chromium matrix. These elements also contribute to the alloy's outstanding corrosion resistance. Although the alloy was developed for high temperature strength, its highly alloyed composition provides a high level of general corrosion resistance to a wide range of oxidizing and non- oxidizing environments. The levels of chromium and molybdenum provide excellent resistance to chloride ion pitting and the high level of nickel provides resistance to chloride stress corrosion cracking.

The material possesses a high degree of formability and shows better weldability than many highly alloyed nickel-base alloys. The alloy is resistant to intergranular corrosion even in the welded condition.

Alloy 625 alloy can be produced by vacuum induction melting or AOD refining. Consumable electrode remelting procedures may be used to further refine the material.

FORMS AND CONDITIONS AVAILABLE

Alloy 625 alloy is available in plate, sheet and strip and long product forms. The alloy is supplied in the annealed conditions generally specified.

Alloy 625

SPECIFICATIONS

Alloy 625 alloy is covered by the following specifications:

Product Form	AMS	ASTM	ASME
Castings	5401		
Castings	5402		
Seamless or Welded Tubing	5581		
Sheet, Strip and Plate	5599	B443	SB-443
Bar, Forgings and Rings	5666		
Welding Wire	5837		
Seamless Tube and Pipe		B444	SB-444
Rod and Bar		B446	SB-446
Welded Tube		B704	SB-704
Welded Pipe		B705	SB-705
Fittings		B366	SB-366

TYPICAL ANALYSIS

Element	Percent
Carbon	0.05
Manganese	0.30
Phosphorus	0.010
Sulfur	0.003
Silicon	0.25
Chromium	22.0
Nickel	Balance
Molybdenum	9.0
Columbium plus	3.5
Tantalum Titanium	0.3
Aluminum	0.3
Iron	4.0

CORROSION AND OXIDATION RESISTANCE

The high level of chromium and molybdenum in the Alloy 625 alloy provides a high level of pitting and crevice corrosion resistance to chloride contaminated media, such as sea water, neutral salts and brines.

Typical Data in Chloride Solutions

Crevice Test in 10 Percent Ferric Chloride	Type 316	Alloy 625
Onset Temperature °F (° C) for Attack in ASTM Procedure G-48	<32 (<0)	104-113 (40-45)

Panel Exposures in Sea Water

Panel Location	Type 316	Alloy 625
Flowing Sea Water	Crevice Attack 1 Month	No Attack 18 Months
Tidal Zone	Crevice Attack 1 Month	No Attack 18 Months
Partial Mud Burial	Crevice Attack 1 Month	No Attack 18 Months

The alloy is resistant to a variety of corrosive media from highly oxidizing to moderately reducing.

Tests in geothermal brines indicate Alloy 625 alloy is highly resistant to hot geothermal fluids comparable to AL 29-4-2® stainless and Titanium Grade 2.

Tests in simulated flue gas desulfurization environments show Alloy 625 alloy highly resistant to the environment in comparison to alloys such as Type 316 and comparable to C-276 nickel alloy.

The following data are illustrative. Typical corrosion rates are in mils per year (mm/a).

Boiling Organic Acid Solutions

Alloy	45% Formic	10% Oxalic	88% Formic	99% Acetic
Alloy 625	5.0 (0.13)	6.0 (0.15)	9.0 (0.23)	0.4 (0.01)
Type 316	11 (0.28)	40 (1.02)	9.0 (0.23)	2.0 (0.05)

Dilute Reducing Acids - Boiling Solutions*

Alloy	1% Sulfuric	5% Sulfuric	10% Sulfuric	1% Hydrochloric
Alloy 625	2.2 (0.06)	8.9 (0.23)	25.3 (0.64)	36.3 (0.92)
Type 316	25.8 (0.65)	107 (2.72)	636 (16.2)	226 (5.74)

* Sulfuric acid test samples activated before tests and hydrochloric acid test samples tested without activation.

Miscellaneous Environments

Environment	Alloy 625	Type 316
20% Phosphoric Acid	0.36 (<0.01)	0.2 (<0.01)
10% Sulfamic Acid	4.80 (0.12)	63.6 (1.61)
10% Sodium Bisulfate	3.96 (0.10)	41.6 (1.06)

Chloride Stress Corrosion Cracking Resistance

Test	Alloy 625	Type 316	Alloy 20
42% Magnesium Chloride	No Cracks 1000 Hours	Cracks <24 Hours	Cracks <100 Hours
26% Sodium Chloride	No Cracks 1000 Hours	Cracks 600 Cracks	No Cracks 1000 Cracks

Oxidation Resistance

Alloy 625 alloy has excellent oxidation and scaling resistance at temperatures up to 2000°F (1093°C). It is superior to many other high temperature alloys under cyclic heating and cooling conditions. The following graph compares the weight loss of several stainless steel alloys to Alloy 625 alloy under cyclic oxidation at 1800°F (982°C).

PHYSICAL PROPERTIES

Physical Constants

Density, lb./in.^{3}	0.305
g/cm^3	8.44
Specific Gravity	8.44
Melting Range, °F	2350-2460
°C	1280-1350
Specific Heat, Btu/lb. °F	0.098
Joules/kg•K	410
Magnetic Permeability, 75°F, 200 oersted	1.0006

Electrical Resistivity

Temperature		Electrical Resistivity microhm–cm
°F	°C	
70	21	128.9
100	38	129.6
200	93	131.9
400	204	133.9
600	316	134.9
800	427	135.9
1000	538	137.9
1200	649	137.9
1400	760	136.9
1600	871	135.9
1800	982	134.9
2000	1093	133.9

Thermal Properties

Temperature		Linear Coefficient of Thermal Expansion (a) (Units of 10^{-6})		Thermal Conductivity (b)(c)	
°F	°C	/°F	/°C	Btu- ft/ft^2	W/m•K
-250	-157	–	–	4.2	7.3
-200	-129	–	–	4.3	7.4
-100	-73	–	–	4.8	8.3
0	-18	–	–	5.3	9.2
70	21	–	–	5.7	9.9
100	38	–	–	5.8	10.0
200	93	7.1	12.8	6.3	10.7
400	204	7.3	13.1	7.3	12.6
600	316	7.4	13.3	8.2	14.2
800	427	7.6	13.7	9.1	15.7
1000	538	7.8	14.0	10.1	17.5
1200	649	8.2	14.8	11.0	19.0
1400	760	8.5	15.3	12.0	20.8
1600	871	8.8	15.8	13.2	22.8
1700	927	9.0	16.2	–	–
1800	982	–	–	14.6	25.3

(a) Average coefficient from 70 F (21° C) to temperature shown.

(b) Measurements made at Battelle Memorial Institute.

(c) Material annealed 2100° F (1149° C).

Modulus Data

Temperature		Modulus of Rigidity (G)		Elastic Modulus (E)		Poisson's Ratio (a) (µ)
°F	°C	Units of 10^6 psi	Units GPa	Units of 10^6 psi	Units GPa	
70	21	11.4	79	29.8	205	0.308
200	93	11.2	77	29.2	200	0.310
400	204	10.8	75	28.4	195	0.312
600	316	10.5	72	27.5	190	0.313
800	427	10.1	70	26.6	185	0.312
1000	538	9.7	67	25.6	175	0.321
1200	649	9.2	63	24.4	170	0.328
1400	760	8.7	60	23.1	160	0.329
1600	871	8.2	57	–	–	–

(a) Poisson's ratio (µ) computed from the relation:

$$\mu = \frac{E-2G}{2G}$$

MECHANICAL PROPERTIES

Typical Short Time Tensile Properties as a Function of Temperature

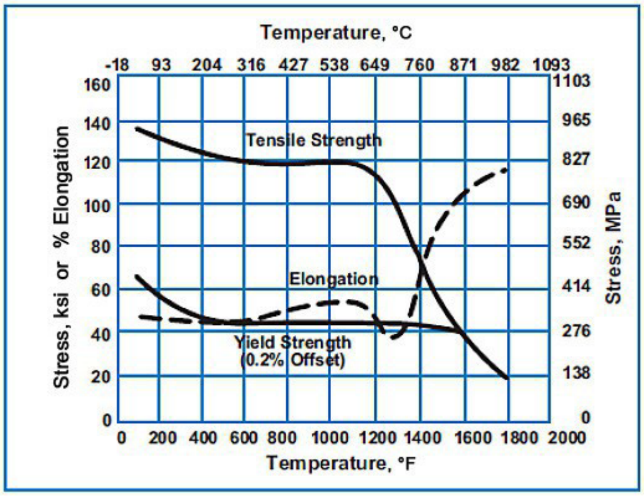
Typical room temperature tensile properties of material annealed at 1920°F (1065°C) follow.

Yield Strength (0.2% Offset)	Ultimate Tensile Strength	Elongation (% in 2")
63,000 psi (430 MPa)	136,000 psi (940 MPa)	51.5

The typical room temperature tensile properties of material solution annealed at 2150°F (1177°C) follow.

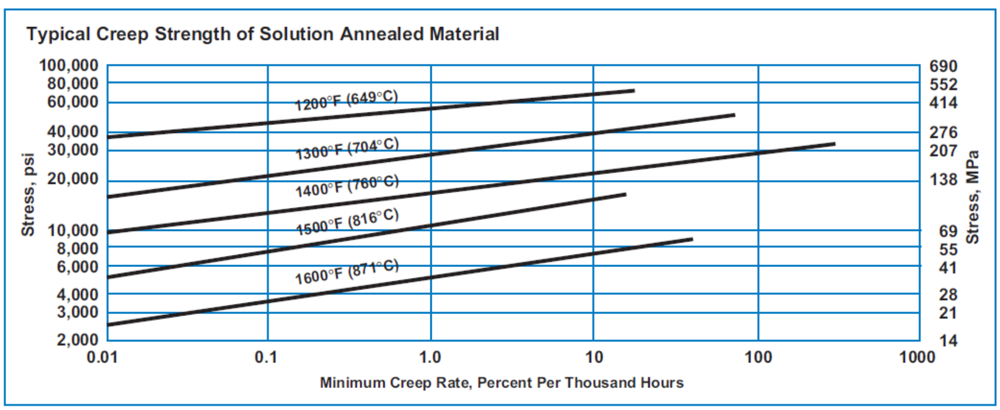
Yield Strength (0.2% Offset)	Ultimate Tensile Strength	Elongation (% in 2")
49,500 psi (340 MPa)	115,500 psi (800 MPa)	67

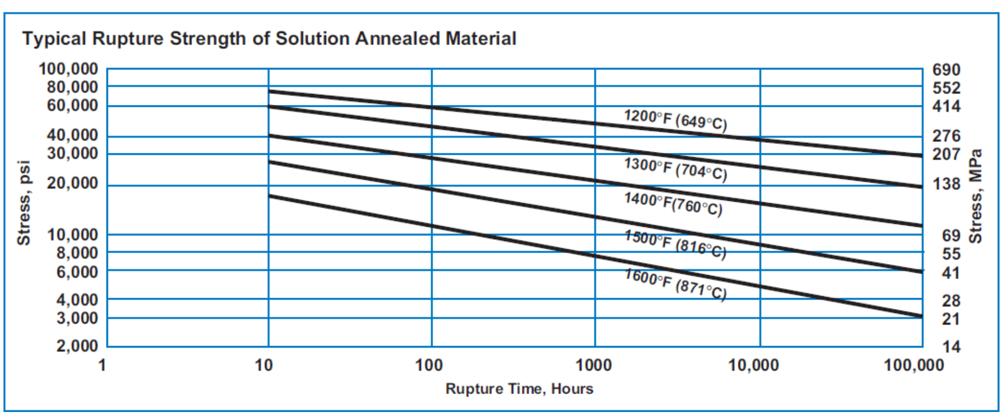
The short time elevated temperature tensile properties of the Alloy 625 alloy annealed at 1950°F (1066°C) are shown in the following graph.



Creep and Stress Rupture Properties

Typical creep and rupture strengths of solution annealed (refer to the section on heat treatment) Alloy 625 alloy follow.





Impact Resistance

The Alloy 625 alloy maintains high impact resistance at low temperature as shown below.

Typical Alloy 625 Impact Properties

Test Temp.		Orientation	Impact Energy (a)	
°F	°C		Ft-lbs	Joules
85	30	Longitudinal	49	66
85	30	Transverse	49	66
-110	- 79	Longitudinal	44	60
-110	- 79	Transverse	41.5	56
-320	-196	Longitudinal	35	47
-320	-196	Transverse	35	47

(a) Charpy Keyhole Specimens (Mean Value of 3 Tests)

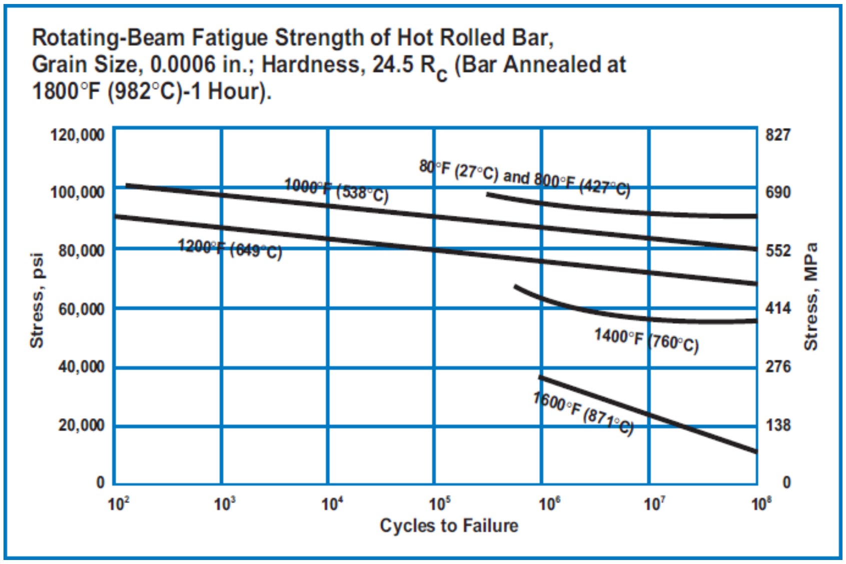
Impact properties may be expected to decrease with extended service in 1200 to 1600°F (649 to 871°C) range.

FATIGUE RESISTANCE

The room temperature endurance limit for cold rolled sheet, mill annealed (1950°F, 1066°C) and tested in completely reverse bending (constant deflection) was found to be 46,000 psi (315 MPa) or about 35 percent of tensile strength. The constant load rotating beam test provides a higher estimate of fatigue limit (approximately 65 percent of tensile strength). The latter may be influenced by the work hardening behavior of the Alloy 625 alloy. Typical room and elevated temperature fatigue properties (rotating beam test) for mill annealed bar and plate products are shown below.

Formability

The Alloy 625 alloy is capable of being formed like the standard austenitic stainless steels. The material is considerably stronger than conventional austenitic stainless steels and consequently requires higher loads to cause the material to deform. During cold working, the material work hardens more rapidly than austenitic stainless steels. The combination of high initial strength and work hardening rate may necessitate need for intermediate anneals if the cold deformation is extensive.



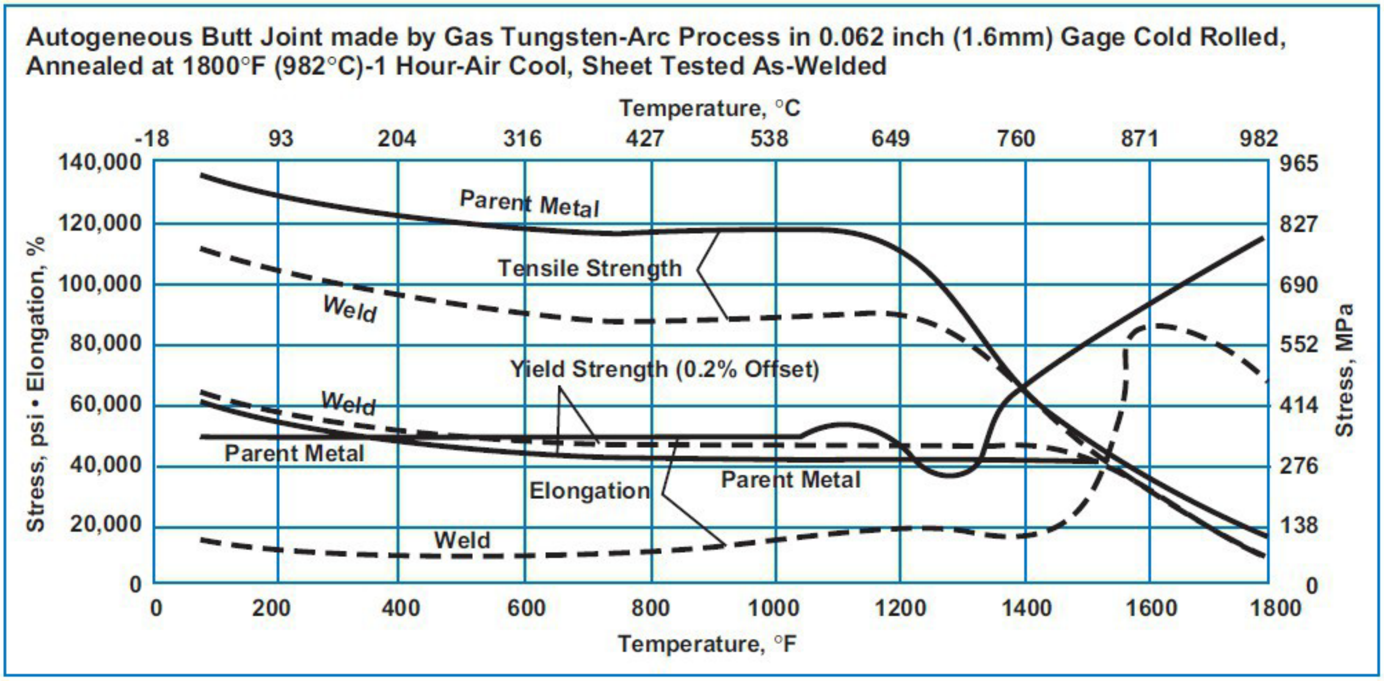
Effect of Cold Reduction on Properties of Plate Annealed at 2150°F (1177°C)

Cold Reduction %	Hardness Rockwell C	Yield Strength (0.2% Offset)		Tensile Strength		Elongation, %	Reduction of Area, %
		psi	(MPa)	psi	(MPa)		
0	88Rb	49,500	341	115,500	796	67.0	60.4
5	94Rb	77,500	534	121,000	834	58.0	58.1
10	25	102,500	707	130,000	896	47.5	54.6
15	32	112,500	776	137,000	945	39.0	51.9
20	34	125,000	862	143,000	986	31.5	50.0
30	36	152,000	1048	165,000	1137	17.0	49.3
40	39	167,000	1151	179,500	1238	12.5	41.9
50	40	177,000	1220	189,500	1307	8.5	38.0
60	44	180,500	1245	205,000	1413	6.5	32.7
70	45	201,000	1386	219,000	1510	5.0	25.4

Welding

The Alloy 625 alloy can be readily welded by conventional processes used for austenitic stainless steel, including fusion and resistance methods. The material should be in the mill annealed condition and thoroughly descaled and cleaned before welding. Preheating is not required and post weld treatment is not needed to maintain or restore corrosion resistance.

Typical short-time elevated temperature tensile properties of welds made on mill annealed material by the gas tungsten-arc (GTAW) process are shown below.



Heat Treatment

Alloy 625 alloy is furnished with one heat treatment for optimum properties up to 1200°F (649°C) and another for optimum properties above 1200°F (649°C). The standard anneal at a minimum of 1600°F (871°C) is used for service temperatures up to 1200°F (649°C). When optimum high temperature creep and rupture properties are required, as for service above 1200°F (649°C), a solution anneal at 2000°F (1093°C) minimum is used. In the solution annealed condition, a subsequent stabilization anneal at 1800°F (982°C) minimum is sometimes specified to further increase resistance to sensitization.

Common Applications- Grade 1

- Equipment for the production of super phosphoric acid
- Plants for the treatment of radioactive waste
- Production pipe systems and linings of risers in oil production
- Offshore industry and seawater exposed equipment
- Sea water piping in shipbuilding
- Stress corrosion cracking resistant compensators
- Furnace linings
- Tubes in geothermal power plants