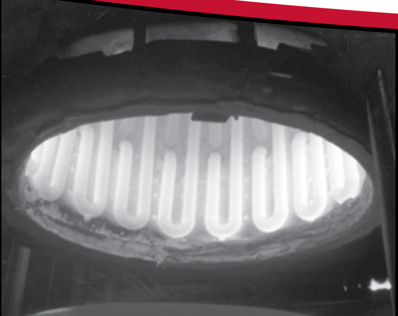
Alloy Performance Guide




People. Service. Expertise. Inventory.

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Rolled Alloys

Strength of a company lies in the strength of its people. At Rolled Alloys, our people are the core of our company. We offer nearly sixty years of experience and expertise working with specialty alloys.

From the smallest cut piece to the largest bulk order, Rolled Alloys offers a full bill of materials in plate, sheet, bar, pipe, forgings, fittings, flanges and welding consumables. Our global cutting services include: waterjets, lasers, plasmas, saws, shears, coil levelers, straighteners and billet conversion.

Rolled Alloys holds many certifications including special process approvals for GE, Rolls-Royce and Pratt & Whitney. Our employees also participate and reside on the industry leading boards including: ITA, NACE, ASTM, MTI and IHEA. Our metallurgical engineers work directly with you to assist with material selection and fabrication questions. Technical data sheets are available to download at *www.rolledalloys.com.*

Rolled Alloys' extensive global inventory consists of a diversified selection of nickel alloys, cobalt alloys, titanium alloys, stainless steels and duplex stainless steels. Our global facilities are located in Canada, China, England, France, Germany, Italy, the Netherlands, Spain, Singapore and the United States. *Rolled Alloys, global...but local.*

Application Engineers

Can't decide which of the available materials is best suited for your application? Our Application Engineering Group can help. We're one of the only companies in the world whose metallurgical engineers work directly with customers to offer suggestions for the most effective alloy based on the performance required. Our metallurgical laboratories are equipped with the latest technology for performance analysis and technical investigations.

Heat Resistant Alloys

Nominal Chemical Composition						Description
Alloy	Ni	Cr	Fe	Si	Other	
RA330® N08330	35	19	43	1.25	C: 0.05	The workhorse of the austenitic heat resistant alloys. Good strength, carburization and oxidation resistance to 2200°F. Immune to sigma phase embrittlement.
RA333® N06333	45	25	18	1.0	Mo: 3, Co: 3, W: 3, C: 0.05	A nickel based superalloy with excellent carburization, oxidation and hot corrosion resistance. It has high creep-rupture strength with an exceptional ability to withstand repeated thermal shock.
RA 253 MA® S30815	11	21	65	1.7	Ce: 0.04, N: 0.17, C: 0.08, Mn: 0.6	An advanced micro-alloyed austenitic heat resistant alloy. High creep-rupture strength and outstanding oxidation resistance through 2000°F
RA 602 CA® N06025	63	25	9	0.03	Al: 2.2, Y: 0.08, C: 0.18	One of the most oxidation resistant nickel alloys available. High strength for use in the 1800 - 2250°F range. Carburization resistant.
309 S30908	13	23	62	0.8	C: 0.05, Mn: 1.6	Austenitic, oxidation resistant to 1900°F, moderate strength. Useful in reducing sulfidizing atmospheres.
310 S31008	20	25	52	0.5	C: 0.05, Mn: 1.6	Austenitic heat resistant grade with higher chromium and nickel for oxidation resistance beyond 2000°F. Good sulfidation and hot corrosion resistance.
321 S32100	9.3	17.3	70	0.7	C: 0.04, Ti: 0.4	A titanium stabilized austenitic stainless steel commonly used for service in the 1000 - 1600°F temperature range.
600 N06600	76	15.5	8	0.2	C: 0.05, Mn: 0.3	A nickel-chromium alloy with good carburization and oxidation resistance through 2000°F.
601 N06601	61.5	22.5	14	0.2	C: 0.05, Al: 1.4, Mn: 0.3	A nickel base alloy with high chromium and an aluminum addition. Outstanding oxidation resistance to 2200°F, good strength and carburization resistance.
800H/AT N08810 X08811	31	21	45	0.4	Al: 0.4, Ti: 0.6	High strength austenitic heat resistant alloy for ASME code applications to 1650°F. Oxidation resistant to 1800°F.
446 S44600	–	25	73	0.5	C: 0.05, N: 0.1, Mn: 0.7	High chromium ferritic alloy with excellent oxidation and sulfidation resistance. Low strength.

Corrosion Resistant Alloys

Nominal Chemical Composition						Description
Alloy	Ni	Cr	Mo	Fe	Other	
AL-6XN® Alloy N08367	24	20.5	6.3	48	C: 0.02, N: 0.22	A high (6.3%) molybdenum super austenitic stainless steel, with high strength. Superior resistance to chloride pitting and crevice corrosion.
Alloy 20 N08020	33	19.5	2.2	40	C: 0.02, Cb + Ta: 0.5, Cu: 3.3	An austenitic stainless steel for sulfuric acid corrosion environments. Resists intergranular corrosion as welded. Resistant to chloride and polythionic acid stress corrosion cracking.
LDX 2101® S32101	1.5	21.5	0.3	70	Mn: 5.0, N: 0.22, C: 0.03	A lean duplex stainless steel resistant to stress corrosion cracking. Comparable to 316L in general corrosion. Economical. High strength.
2205 S32205	5.6	22.1	3.1	67	C: 0.02, N: 0.16	Duplex austenitic-ferritic stainless with high resistance to chloride stress corrosion cracking and to general corrosion. High strength.
ZERON® 100 S32760	7	25	3.5	62	C: 0.02, Cu: 0.7, W: 0.7, N: 0.22	Super duplex stainless steel with high strength and high resistance to chloride pitting corrosion and sulfuric acid. Suitable for seawater service with a minimum PRE_N of 40.
625 N06625	61	21.5	9	4	Cb: 3.6	A high strength (9%) molybdenum nickel alloy with excellent resistance to hot seawater, scrubber environments and reducing acids.
718 NACE N07718	52	19	3	19	Al: 0.5, Ti: 0.9, Cb+Ta: 5.0	718 is a precipitation hardened nickel - chromium alloy. It combines high strength in the aged condition with good corrosion resistance and weldability. Commonly used in oil and gas exploration.
304/304L S30403	9	18.3	–	70	C: 0.02	The original "18-8" stainless steel. Dual certified material combines low carbon of the "L" grade with the higher strength of 304.
316/316L S31603	10.2	16.4	2.1	69	C: 0.02	Contains molybdenum for improved chloride pitting and general corrosion resistance. Dual certified material combines low carbon of the "L" grade with the higher strength of 316.
317L S31703	11.6	18	3.1	65	C: 0.02, N: 0.05, Si: 0.4, Mn: 1.5	317L is a molybdenum containing austenitic stainless steel, with improved corrosion resistance over 304L and 316L stainless steel.

Mechanical and Physical Properties in the Annealed Condition
Plate

Alloy	UNS	Minimum Tensile Strength, ksi	0.2% Minimum Offset Yield Strength, ksi	Minimum Elongation, %	Maximum Hardness,	Modulus of Elasticity psi * 10^6	Mean Coefficient of Thermal Expansion in/in °F * 10^{-6}	Mean Thermal Conductivity Btu*ft/ft^2*hr*°F
304/304L	S30400/S30403	75	30	40	HRB 92	29	9.2	–
304H	S30409	75	30	40	HRB 92	29	9.2	–
RA330	N08330	70	30	30	HRB 90	28.5	9.8	7.2
RA333	N06333	80	35	30	HRB 95	28.5	9.2	7.2
RA 602 CA	N06025	98	39	30	–	30	9.1	6.5
RA 253 MA	S30815	87	45	40	HRB 95	29	10.6	8.6
800 H/AT	N08811/N08810	65	25	30	–	28.5	10	6.7
309S/H	S30908/S30909	75	30	40	HRB 95	28.5	9.9	7.4
310S/H	S31008/S31009	75	30	40	HRB 95	29	10.1	7.6
601	N06601	80	35	30	HRB 80	30	9.4	6.5
600	N06600	80	35	30	HRB 80	30	8.6	8.6
321	S32100	75	30	40	HRB 95	28	10.2	8.8
LDX 2101	S32101	94	65	30	HRC 30.5	29.7	7.8	9.2
2205	S32205	95	65	25	HRC 30.5	27.6	7.8	8.1
ZERON 100	S32760	109	80	25	HRC 28	29	7.3	7.5
ZERON 100 FG	S32760	125	105	16	HRC 32	–	–	–
625	N06625	111	55	30	HRC 30.5	29.8	7.8	5.7
718 NACE	N07718	150	125	20	HRC 41	–	–	–
316/316L	S31600/S31603	75	30	40	HRB 96.2	29	10.1	7.8
317/317L	S31700/S31703	75	30	35	HRB 96.2	29	10.1	7.8
AL-6XN	N08367	95	45	30	HRC 30.5	28.3	8.5	6.7
Alloy 20	N08020	80	35	30	HRC 19	28	8.7	6.7
347/347H	S34700	75	30	40	HRB 92	28	9.2	9.375

Maximum Allowable Design Stresses for ASME Boiler and Pressure Vessel Code 2007
Section VIII, Division 1, Tables 1A and 1B, for Plate

Design Stress Intensity Values, ksi, in Tension. For welded pipe and tubing a joint efficiency factor 0.85 must be applied.

Temp, °F	AL-6XN	20	304/304L	316/316L	317/317L	LDX 2101	2205	ZERON 100	400	825
100	27.1	22.9	20.0	20.0	20.0	26.9	25.7	31.1	18.7	23.3
200	27.1	22.9	20.0	20.0	20.0	26.9	25.7	31.0	16.4	23.3
300	25.7	22.6	18.9	20.0	19.6	25.6	24.8	29.4	15.2	23.3
400	24.6	22.2	18.3	19.3	18.9	24.7	23.9	29.0	14.7	23.3
500	23.8	22.1	17.5	18.0	17.7	24.7	23.3	29.0	14.7	23.3
600	23.3	22.1	16.6	17.0	16.9	24.7	23.1	29.0	14.7	23.3
650	23.1	22.0	16.2	16.6	16.5	–	–	–	14.7	23.3
700	22.9	21.9	15.8	16.3	16.2	–	–	–	14.6	23.3
750	22.8	21.8	15.5	16.1	15.8	–	–	–	14.5	23.2
800	22.6	21.8	15.2	15.9	15.5	–	–	–	14.3	23.0
850	–	–	14.9	15.7	15.2	–	–	–	11.0	22.9
900	–	–	14.6	15.6	–	–	–	–	8.0	22.8
950	–	–	14.3	15.4	–	–	–	–	–	22.6
1000	–	–	14.0	15.3	–	–	–	–	–	22.3
1050	–	–	12.4	15.1	–	–	–	–	–	–
1100	–	–	9.8	12.4	–	–	–	–	–	–
1150	–	–	7.7	9.8	–	–	–	–	–	–
1200	–	–	6.1	7.4	–	–	–	–	–	–
1250	–	–	4.7	5.5	–	–	–	–	–	–
Notes	G5	G5	G5, G12, H1 T7	G5, G12 GT8	–	Code Case 2418	G32	Code Case 2245	T10	–

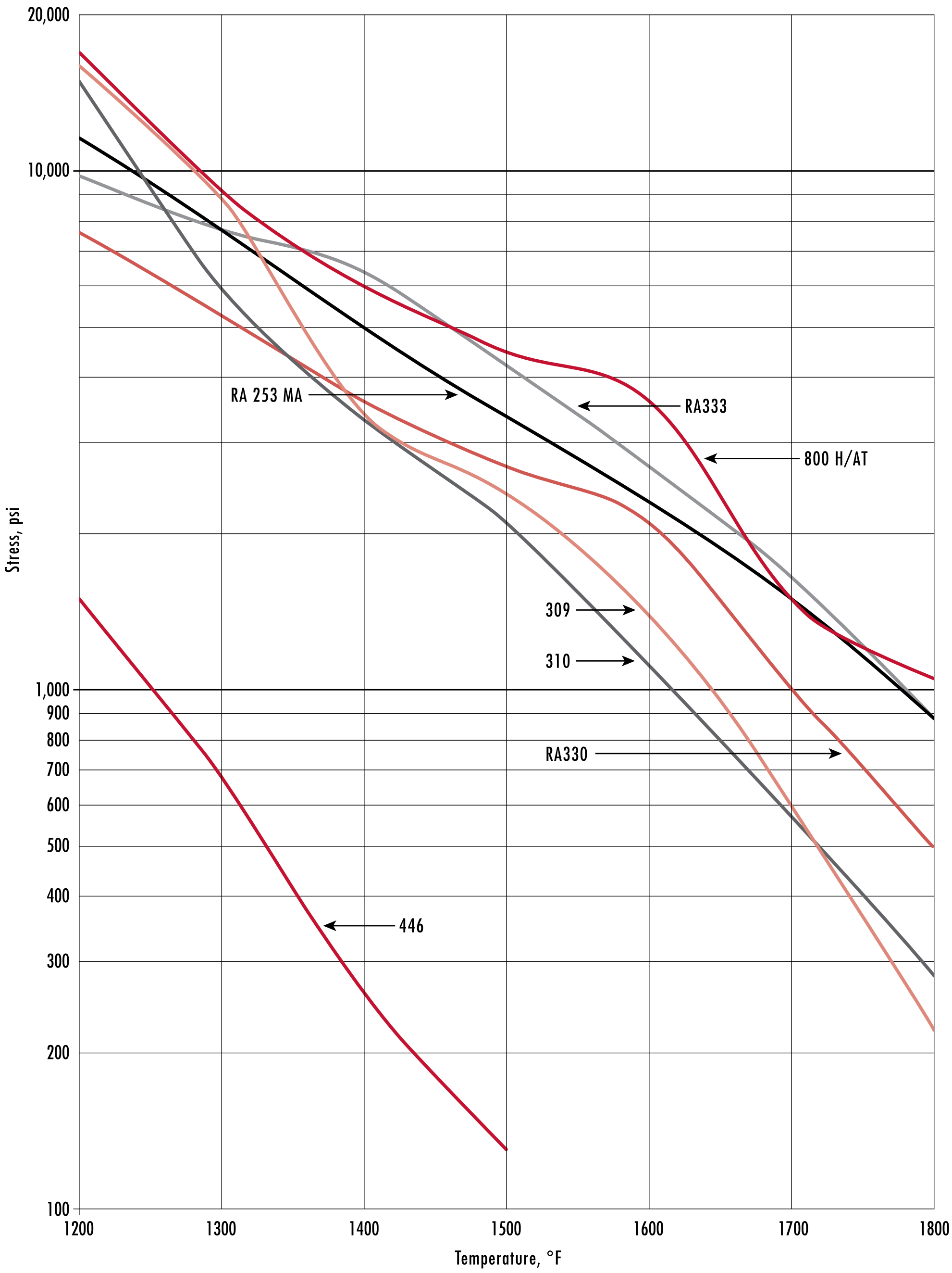
Maximum Allowable Design Stresses for ASME Boiler and Pressure Vessel Code 2007;
Section VIII, Division 1, Tables 1A and 1B, for Plate

Design Stress Intensity Values, ksi, in Tension. For welded pipe and tubing a joint efficiency factor 0.85 must be applied.

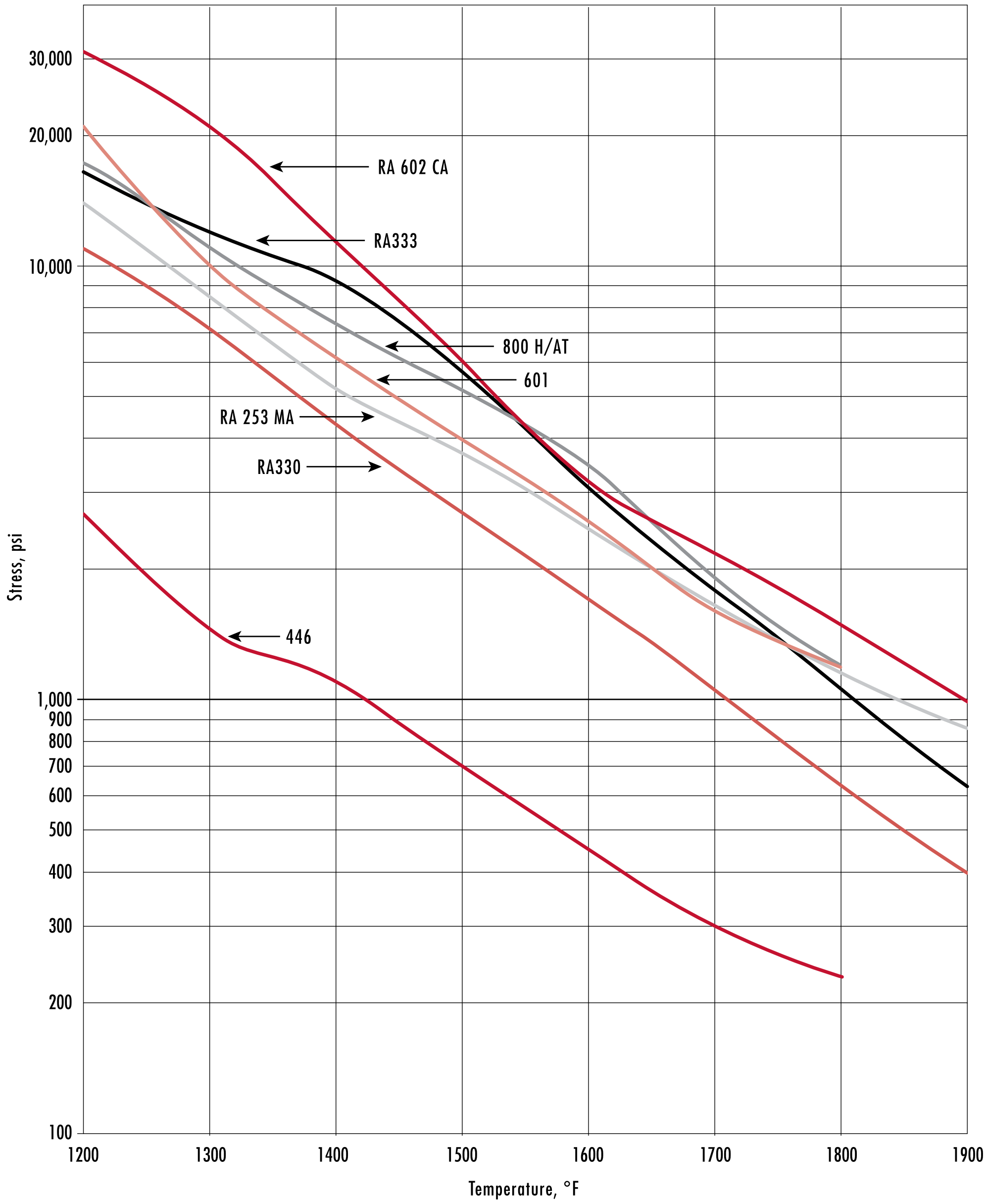
Temp, °F	410S	410	625	304H	321	309H	310H	RA 253 MA	RA330	600	800AT
100	17.1	18.6	26.7	20.0	20.0	20.0	20.0	24.9	20.0	22.9	16.7
200	17.1	18.4	26.7	20.0	20.0	20.0	20.0	24.7	20.0	22.9	16.7
300	16.8	17.8	26.7	18.9	19.1	20.0	20.0	23.3	20.0	22.9	16.7
400	16.5	17.4	26.7	18.3	18.7	20.0	19.9	22.4	19.6	22.9	16.7
500	16.3	17.2	26.7	17.5	18.7	19.4	19.3	21.8	19.4	22.9	16.7
600	15.9	16.8	26.7	16.6	18.3	18.8	18.5	21.4	18.9	22.9	16.5
650	15.6	16.6	26.7	16.2	17.9	18.5	18.2	21.2	18.5	22.9	16.1
700	15.2	16.2	26.7	15.8	17.5	18.2	17.9	21.0	18.1	22.9	15.7
750	14.7	15.7	26.7	15.5	17.2	18.0	17.7	20.8	17.7	22.9	15.3
800	14.1	15.1	26.7	15.2	16.9	17.7	17.4	20.6	17.4	22.9	15.0
850	13.4	14.4	26.7	14.9	16.7	17.5	17.2	20.3	17.0	22.4	14.7
900	12.3	12.3	26.7	14.6	16.5	17.2	16.9	20.0	16.7	16.0	14.5
950	8.8	8.8	26.6	14.3	16.4	16.9	16.7	19.1	16.1	10.6	14.2
1000	6.4	6.4	26.4	14.0	14.9	13.8	13.8	14.9	12.7	7.0	14.0
1050	4.4	4.4	26.3	12.4	9.6	10.3	10.3	11.6	10.0	4.5	13.8
1100	2.9	2.9	26.2	9.8	6.9	7.6	7.6	9.0	7.8	3.0	12.9
1150	1.8	1.8	26.1	7.7	5.0	5.5	5.5	6.9	6.0	2.2	10.4
1200	1.0	1.0	20.0	6.1	3.6	4.0	4.0	5.2	4.7	2.0	8.3
1250	–	–	15.0	4.7	2.6	3.0	3.0	4.0	3.8	–	6.7
1300	–	–	–	3.7	1.7	2.2	2.2	3.1	3.1	–	5.4
1350	–	–	–	2.9	1.1	1.7	1.7	2.4	2.4	–	4.3
1400	–	–	–	2.3	0.80	1.3	1.3	1.9	1.8	–	3.4
1450	–	–	–	1.8	0.50	1.0	0.97	1.6	1.5	–	2.7
1500	–	–	–	1.4	0.30	0.75	0.75	1.3	1.1	–	2.2
1550	–	–	–	–	–	–	–	1.0	0.90	–	1.6
1600	–	–	–	–	–	–	–	0.86	0.68	–	1.2
1650	–	–	–	–	–	–	–	0.71	0.48	–	0.91
Notes	T4	T4	–	G5	G5	G5	G5	G5	G5	G5	G5
			G22, T23, T16	G18, T7	G12, T6	G18, H1, T6	G18, T6	G40, T5	G29, H1, T12	T11	G29, T15

ASME design stresses are changed from time to time. This Rolled Alloys bulletin is an uncontrolled document. The ASME data herein may be expected to become obsolete as time goes on.

Minimum Creep Rate
0.0001 Percent Per Hour



Stress to Rupture
10,000 Hours



High Temperature Performance Guide

Least ← → Greatest				
Condition	**Not Suggested**	**Good**	**Better**	**Best**
Strength	446	600, 309, 310	RA330	RA 602 CA, RA333, 800H/AT, 601, RA 253 MA
Thermal Shock (A)	446, 800H/AT	310, 309	RA 253 MA, 601, 600	RA333, RA330
Oxidation	–	309, 800H/AT, 446	RA330, 310, 600, RA 253 MA	RA 602 CA, RA333, 601
Carburization	446, 321, RA 253 MA	310, 309, 800H/AT	RA330	RA333, 600, 601 RA 602 CA
Oxidizing Sulfur (SO_2, SO_3) (E)	600	RA 602 CA, RA333	601, RA330, 800H/AT	446, 310, 309, RA 253 MA
Reducing Sulfur (H_2S) (C)	600, 601, RA333, RA330, 800H/AT, RA 253 MA	347	309, 310, 556	446
Hot HCl Gas (Above The Dew Point)	446	RA333, RA330	RA 602 CA, 601	200
Molten Metals (D) Cu (E), Zn, Mg	600	309, 310, 316 (zinc)	AL-6XN, (in zinc) Duplex SS	446, 430, 410

(A) Good thermal shock or fatigue strength requires fine grain size. Materials which are grain-coarsened to maximize creep-rupture strength do so at the expense of thermal fatigue strength. (B) Conditions underneath deposits may be reducing, even though the atmosphere itself is oxidizing. (C) High chromium and low nickel contents are necessary for any degree of resistance to high temperature reducing, sulfidizing (H_2S) environments. (D) In general, the higher the nickel content, the more rapid the attack. Molten aluminum quickly dissolves all commercial alloys. (E) Only the ferritic alloys, such as 430 or 446, withstand copper. All austenitics are attacked intergranularly. Duplex grades have shown good resistance. *This chart is intended as guidance for what alloys might be tested in a given environment. It must NOT be used as the major basis for alloy selection, or as a substitute for competent corrosion engineering work.*

Wet Corrosion Performance Guide

Environment	Not Suggested	Good	Better	Best
Chlorides (pitting, crevice corrosion)	304L	Alloy 20, 316L, LDX 2101, 600	400 (a), 2205, 317L	AL-6XN, 625, C-276, Titanium, C22, 686, ZERON 100
Chloride Stress Corrosion Cracking	304L, 316L	LDX 2101, 904L, 2205, 317L	AL-6XN, Alloy 20, ZERON 100	400, 600, 625, 686, C-276, C22
Hydrochloric Acid	Titanium (b), 600, Alloy 20, 2205, LDX 2101, 317L	200 (a), 400 (a), 625, ZERON 100	C22, C-276, 686	Zirconium (a), HASTELLOY® B-2 (a), Tantalum, Titanium(b)
Hydrofluoric Acid	200, 600, 2205, etc.	C-276, C22, 686, 400 (N_2 purged)	400 (a), Silver (a)	Gold, Platinum
Sulfuric Acid	Titanium, 600	316L, 317L, LDX 2101, 2205	AL-6XN, 625	Alloy 20, C-276, Tantalum, ZERON 100
Phosphoric Acid (commercial)	200, 400, 316L, 317L	904L, 2205	AL-6XN, Alloy 20, ZERON 100	G-30, 625
Nitric Acid	904L, AL-6XN, 200, 400, 600	304L, Alloy 20, 2205, ZERON 100	625	Zirconium, Tantalum
Caustic	304L, 316L, 317L, Tantalum	Alloy 20, 2205, LDX 2101, ZERON 100	600, 625, 400, 686, C22, C-276	200(a)

(a) Presence of oxygen or oxidizing salts may greatly increase corrosion. (b) Titanium has excellent resistance to hydrochloric acid containing oxidizers such as $FeCl_3$, HNO_3, etc. However, titanium has very poor resistance to pure, reducing, HCl. *This chart is intended as guidance for what alloys might be tested in a given environment. It must NOT be used as the major basis for alloy selection, or as a substitute for competent corrosion engineering work.*

General Corrosion

This is the most common form of corrosion, accounting for the greatest tonnage loss of metal. It is characterized by relatively uniform attack of the entire area exposed to the corrosive environment. Rusting steel exposed to the weather is a common example. Since the attack is linear with time, the life of equipment subject to general corrosion is reasonably predictable. Localized corrosion modes, such as pitting, crevice and stress corrosion, are more difficult to predict and tend to cause premature equipment failures. Uniform corrosion rates may be stated as an average metal thickness loss with time, mils per year. A convenient rating for metals subject to uniform attack based on corrosion rates is as follows:

Rating	Corrosion Rate
Excellent	Rate less than 5 mils/year. Metals suitable for making critical parts.
Satisfactory	Rate 5 - 50 mils/year. Metals generally suitable for non-critical parts where a higher rate of attack can be tolerated.
Not Suggested	Rates over 50 mils/year. Metals usually not acceptable in the environment.

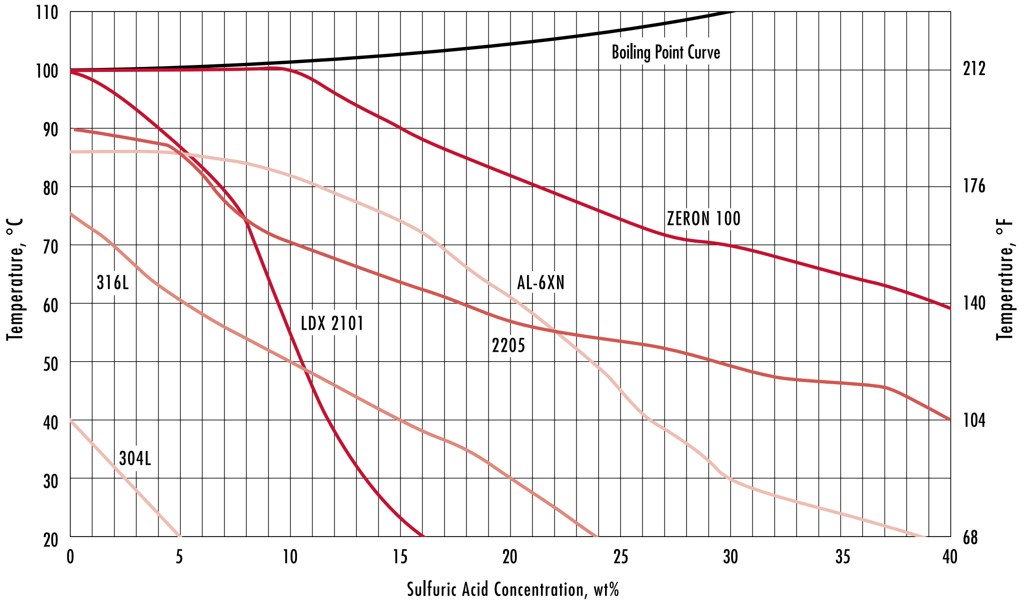
A very rough ranking of alloys by increasing resistance to general corrosion would be 304L, LDX 2101, 316L, 317L, 2205, 20, AL-6XN, ZERON 100, 625 and C-276. Alloy selection does depend upon the exact corrosive environment in question. See the Corrosion Tables for general guidance. Some specific examples include hot concentrated caustic, where commercially pure nickel or the high nickel alloy 600 are used. For sulfuric acid, additions of both molybdenum and copper are beneficial, so alloy 20 is often chosen. However, if chlorides are present in the acid, a higher molybdenum grade such as AL-6XN would be preferred. AL-6XN is used for organic acids, such as napthenic acid in refinery service. For nitric acid service chromium is beneficial, molybdenum is not, so alloys selected include 304L or a low carbon version of 310. RA333 is used when the same piece of equipment must see very high temperatures, in the red heat range, in one zone and aqueous corrosion in another.

Corrosion Rate in mils/year in boiling solutions

	304L	316L	317L	ZERON 100	2205	AL-6XN	C-276	Alloy 20	625
20% Acetic Acid	0.1	0.12	0.48	0.0	0.01	0.12	0.48	0.0	–
45% Formic Acid	15	23.41	18.3	0.36	0.50	2.40	2.76	8.4	5.0
10% Oxalic Acid	–	44.90	1.14	–	7.80	7.32	11.24	31.2	6.0
20% Phosphoric Acid	–	0.60	0.72	0.36	0.80	0.24	0.36	0.2	0.36
10% Sodium Bisulfate	–	71.57	55.9	–	25.4	4.56	2.64	7.2	3.96
50% Sodium Hydroxide	71	77.7	32.8	–	24	11.4	17.8	7.2	–
10% Sulfamic Acid	50	124.3	94.2	–	22	9.36	2.64	9.6	4.8
10% Sulfuric Acid	662	635.7	298	0.36	206	71.9	13.93	13.2	37
1% Hydrochloric Acid	85	226	54.2	<0.36	–	58.7	10	39.6	1.0
65% Nitric Acid (A262 Practice C)	8.9	22.1	–	10.6	20.06	26.2	900.1	–	21

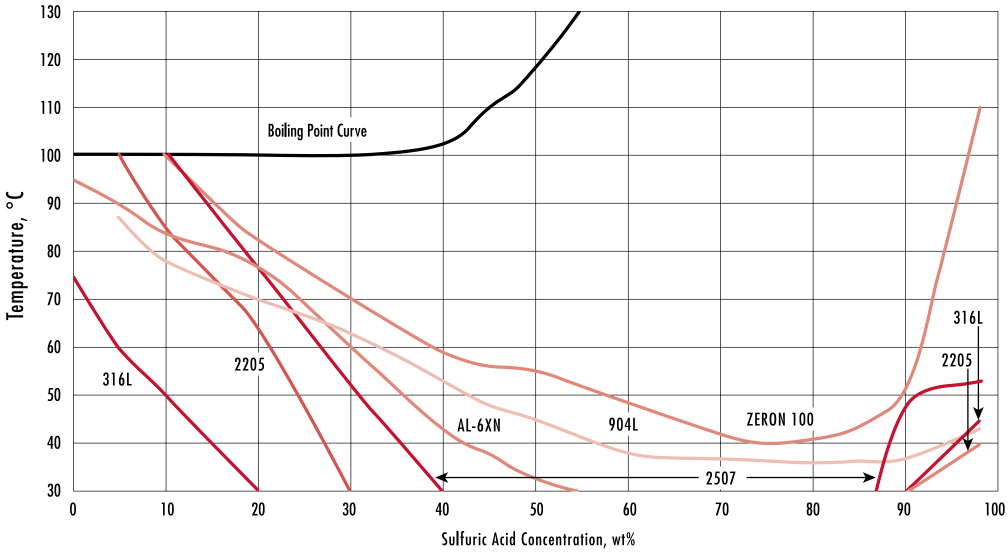
Sulfuric Acid

Iso-corrosion Curves, 4 mpy



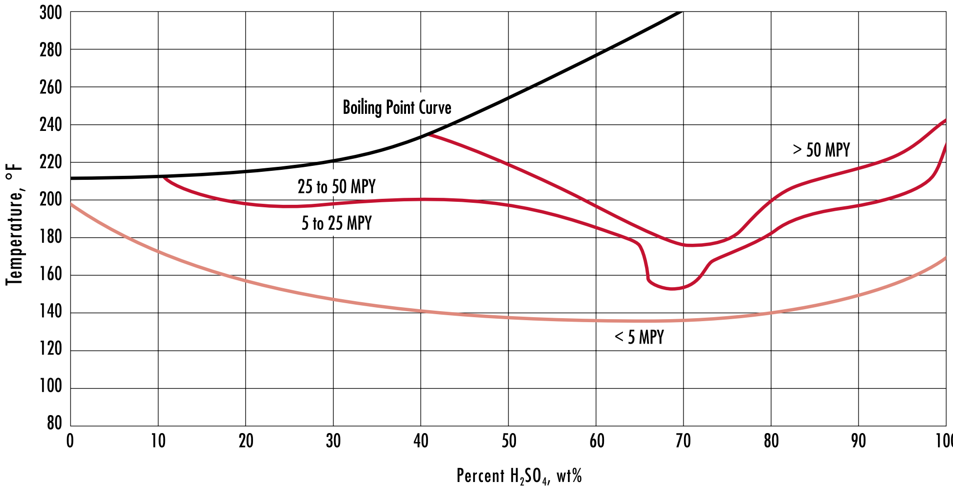
Sulfuric Acid

Iso-corrosion Curves, 4 mpy
Stainless Steels



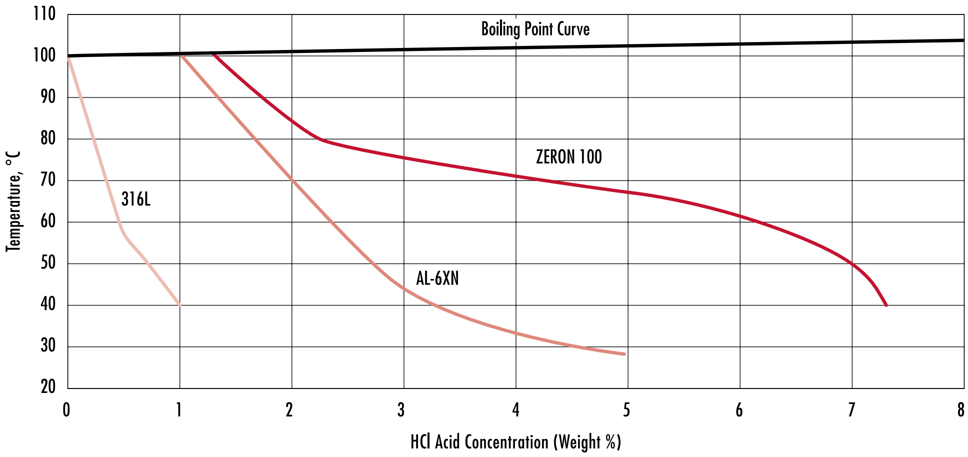
Sulfuric Acid **Alloy20**

Iso-corrosion Curves



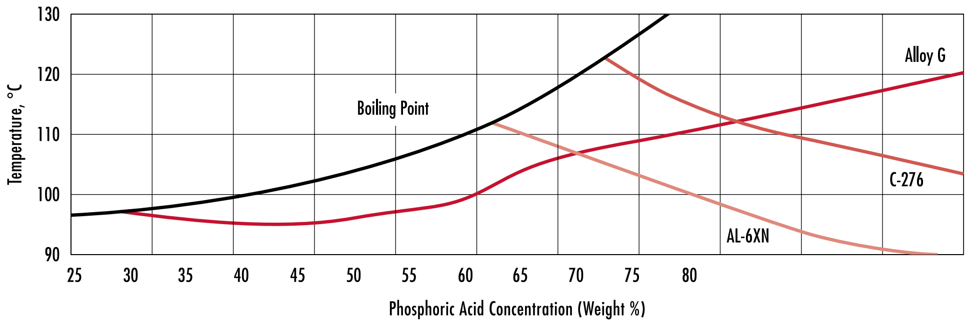
Hydrochloric Acid

Iso-corrosion Curves
0.004 ipy for Some Stainless Steels in Hydrochloric Acid



Phosphoric Acid

Iso-corrosion Curves
0.004 ipy for Alloys in Pure Phosphoric Acid



Pitting and Crevice Corrosion

Pitting and crevice corrosion are most often caused by chlorides. Molybdenum is the alloying element that primarily provides resistance. Nitrogen enhances the effect of molybdenum. A measure of resistance to pitting corrosion is the Critical Pitting Temperature, or CPT, which is the highest temperature at which an alloy resists pitting in a given environment. Likewise crevice corrosion resistance may be quantified as the Critical Crevice Corrosion Temperature, CCCT. It is crevice corrosion, which is the limiting factor in service. AL-6XN, ZERON 100 and 625 have sufficient resistance to be a practical choice for hot seawater. The lower molybdenum grades, even 2205, are usually unsuitable for use in seawater. For the highest level of localized corrosion resistance alloys C-276, C22 or INCONEL® 686 should be considered.

Crevice Corrosion and Pitting Resistance

Alloy	% Mo	CCCT, °F	CPT, °F	PRE_N
316L	2.1	<28	68	24
LDX 2101	0.3	<28	68	26
317L	3.2	35	94	29
317LMN	4.4	68	–	33
2205	3.1	68	120	35
904L	4.4	75	130	36
ZERON 100	3.5	108	180	41
AL-6XN Alloy	6.2	110	172	44
Alloys 625	9.0	113	–	51
C22	13	–	–	64
C-276	15.5	130	>217	67

CCCT - 10% $FeCl_3 \bullet 6H_2O$, per ASTM G 48 Practice B, CPT - 1 M NaCl, per ASTM G 150, $PRE_N = Cr + 3.3\,Mo + 16N$

Stress Corrosion Cracking

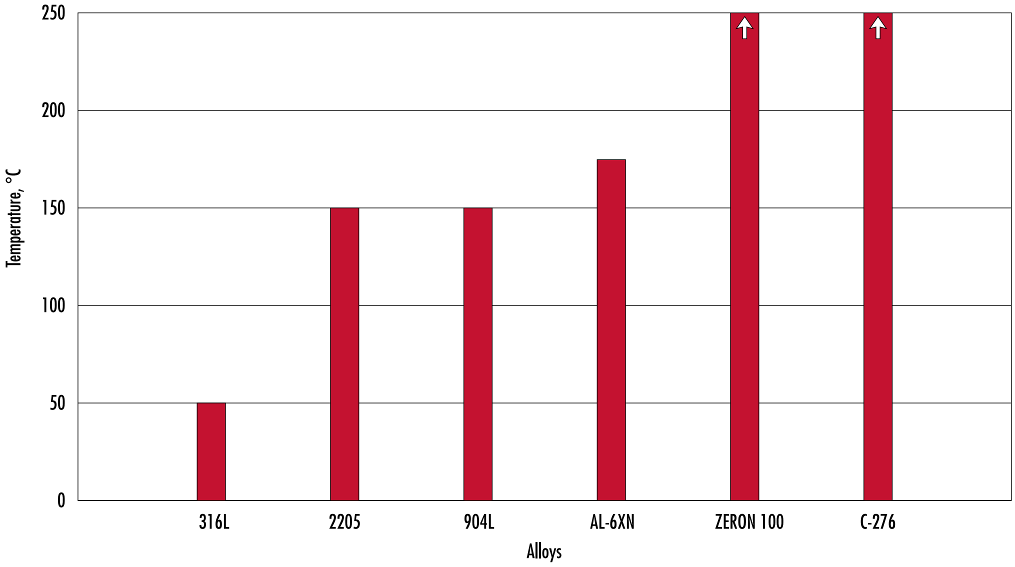
Stress corrosion cracking (SCC) is the mode of failure for a significant percentage of 304L and 316L stainless chemical process equipment. For SCC to occur in stainless steels three general conditions must be met: there is a source of tensile stress, temperatures must be above 120°F, and aqueous chlorides must be present. The source of tensile stress is usually a combination of residual forming and welding stresses. Chlorides concentrate from trace amounts present in the cooling water and/or from the product itself. If chlorides cannot be eliminated, or prevented from concentrating, an alloy change may be considered.

A cost-effective choice is a duplex stainless such as LDX 2101, 2205 or ZERON 100. These grades may handle many of the environments, which crack 316L over a few years time. More severe, or low pH, environments require higher nickel grades such as AL-6XN, Allloy 20, ZERON 100 or 625. Alloys with 45% or more nickel are considered practically immune to chloride SCC.

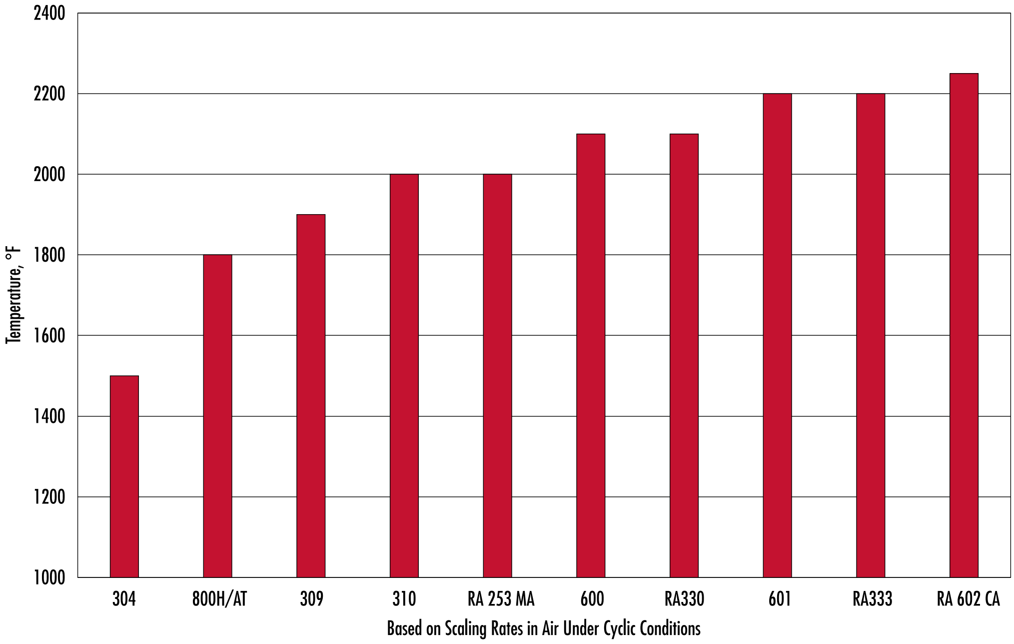
Stress Corrosion Cracking Resistance U-bent samples in boiling chloride solutions

	Alloy											
Solution	304L	316L	317L	LDX 2101	2205	ZERON 100	AL-6XN	20	625	C-276	C22	INCONEL 686
26% NaCl (1000 hrs)	F	F	P	P	P	P	P	P	P	P	P	P
42% $MgCl_2$ (200 hrs)	F	F	F	F	F	Not Tested	P	P	P	P	P	P
40% $CaCl_2$ (500 hrs)	F	F	Not Tested	P	Not Tested	Not Tested	P	P	P	P	P	P

Threshold Temperatures for Chloride SCC in 3% sodium chloride

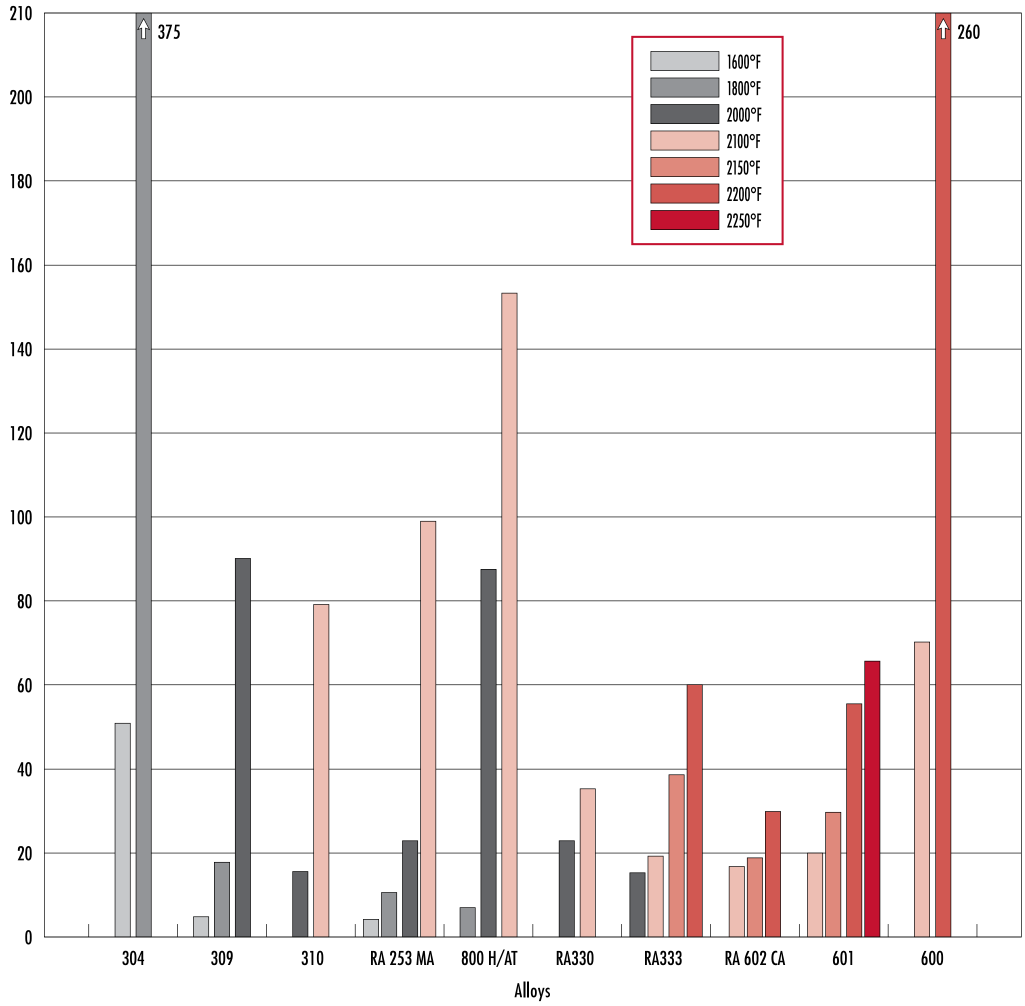


Maximum Suggested Temperatures for Heat Resistant Alloys



High Temperature Oxidation Resistance

Exposed For 1640 Hours - Cycled Every 160 Hours



Welding Data
Like Metal Fillers

Suggested Weld Fillers For Like Metal Joints

Base Metal	P Number	P Group	Weld Fillers			
			Bare Wire		Covered Electrodes	
			Grade	Specification	Grade	Specification
AL-6XN	45	–	625	ERNiCrMo-3	112	ENiCrMo-3
Alloy 20	45	–	320LR	ER320LR	320LR	E320LR
LDX 2101	10H	–	2209	ER2209	2209	E2209
2205	10H	–	2209	ER2209	2209	E2209
ZERON 100	10H	–	ZERON 100X	ER2594	ZERON 100X	E2595-15
600	43	–	82	ERNiCr-3	182	ENiCrFe-3
625	43	–	625	ERNiCrMo-3	112	ENiCrMo-3
718 NACE	–	–	718	AMS 5832	–	–
317L	8	1	317L	ER317L	317L	E317L-17
RA 253 MA	8	2	RA 253 MA	–	RA 253 MA-17	–
309	8	2	309	ER309	309	E309-16
310	8	2	310	ER310	310	E310-15
RA330	46	–	RA330-04	–	RA330-04-15	–
RA333	–	–	RA333	–	RA333-70-16	–
RA 602 CA	–	–	RA 602 CA	ERNiCrFe-12	RA 602 CA	ENiCrFe-12
304L	8	1	308L	ER308L	308L	E308L-15
316L	8	1	316L	ER316L	316L	E316L-17
321	8	1	347	ER347Si	347	E347-15
304H	8	1	308H	ER308H	308H	E308H-17
800H/AT	45	–	617	ERNiCrCoMo-1	117	ENiCrCoMo-1

Suggested Fillers
Dissimilar Metal Fillers

Suggested Weld Fillers for Heat Resistant Alloys

	Carbon or Low Alloy Steel	446	304, 316, 321	RA 253 MA	RA 602 CA
RA333	RA333, 82, RA182	RA333, 82, 182	RA333, 82	RA333	RA333, RA 602 CA
RA330	RA330-04, 82	RA330-04, 82	RA330-04, 82	RA333, RA330-04	617, RA333
800H/AT	RA330-04, 82	RA330-04, 82	RA330-04, 82	RA333, RA330-04	617, RA333
RA 602 CA	82	82	82	RA333	RA 602 CA
600	82, 182	82, 182	82, 182	RA333	182, RA 602 CA
601	82, 182	82, 182	82, 182	RA333	RA 602 CA
RA 253 MA	309	309	309	RA 253 MA	RA333
310	82, 309	309, 310	309	RA 253 MA, 309	RA333
309	82, 309	309	309	RA 253 MA, 309	RA333
446	309, 310	309, 310	309, 308	RA 253 MA, 309	82, 182

Suggested Fillers

Dissimilar Metal Fillers

Suggested Weld Fillers for Corrosion Resistant Alloys.

	Nickel 200/201	400	600	625	C22, C-276, Alloy 686	AL-6XN, Alloy 825, Alloy 20	Carbon, Low Alloy and Nickel	Austeitic Stainless	Duplex & Super Duplex Stainless
Nickel 200/201	Nickel 61 Nickel 141	60, Nickel 61	82, Nickel 61	625, 82, Nickel 61	686CPT, C22, 82, Nickel 61	625, 82, 61	82, Nickel 61	82, Nickel 61	686CPT, 82, Nickel 61, C22
400	190, Nickel 141	60, 625 112, 190	625, 82	625, 82, Nickel 61	686CPT, 625, 82, C22	625, 82	625, 82, 60	625, 82	686CPT, 625, 82, C22
600	112, 182, Nickel 141	625, 112	82 182	625, 82	686CPT, 625, 82, C22	625, 82	625, 82	82	686CPT, 82, C22
625	112, 182, Nickel 141	112, Nickel 141	112, 182	625 112	686CPT, 625, C22	625	625, 82	686CPT, 625, 82	686CPT, C22
C-276, C22	686CPT, Nickel 141	686CPT, 112	686CPT, 82	686CPT, 112	686CPT, C22 686CPT	686CPT, 625	686CPT, 625, 82	686CPT, 625, 82	686CPT
AL-6XN, 20	Nickel 141	112, 182	112, 182	112, 686CPT, C22	686CPT, 112, 122	625, 686CPT 112, 686CPT	625, 82	625, 309LMo, C22	686CPT, 625, C22
Austenitic Stainless	112, 182, Nickel 141	112, 182, MONEL® 190	112, 182	686CPT, 112	686CPT, 182, C22	309LMo, 112	316L, 309L	316L 316L	ZERON 100X, 2209
Duplex & Super Duplex Stainless	686CPT, Nickel 141, C22	686CPT, C22,	686CPT, 122, C22	686CPT, 112, C22	686CPT, C22	686CPT, 122, C22	309L	ZERON 100X, 2209	ZERON 100X ZERON 100X

Welded electrodes for SMAS (below highlighted diagonal) / Filler metals for GMAW, GTAW and SAW (above highlighted diagonal)

Machining

The alloys described on the following page work harden rapidly during machining and require more power to cut than mild steels. The metal is "gummy" with chips that tend to be stringy and tough. Machine tools should be rigid and used to no more than 75% of their rate capacity. Both work piece and tool should be held rigidly; tool overhang should be minimized. Rigidity is particularly important when machining titanium, as titanium has a much lower modulus of elasticity than either steel or nickel alloys. Slender work pieces of titanium tend to deflect under tool pressures causing chatter, tool rubbing and tolerance problems.

Make sure that tools are always sharp. Change to sharpened tools at regular intervals rather than out of necessity. Titanium chips in particular tend to gall and weld to the tool cutting edges, speeding up tool wear and failure. Remember - cutting edges, particularly throw-away inserts, are expendable. Don't trade dollars in machine time for pennies in tool cost.

Machining Continued

Feed rate should be high enough to ensure that the tool cutting edge is getting under the previous cut, thus avoiding work-hardened zones. Slow speeds are generally required with heavy cuts. The tool should not ride on the work piece as this will work harden the material and result in early tool dulling or breakage. Use an air jet directed on the tool when dry cutting, to significantly increase tool life.

Lubricants or cutting fluids for titanium should be carefully selected. Do not use fluids containing chlorine or other halogens (fluorine, bromine or iodine), in order to avoid risk or corrosion problems. Sulfur-chlorinated petroleum oil lubricants are suggested for all alloys, but titanium. Such lubricants may be thinned with paraffin oil for finish cuts at higher speeds.

The speeds shown below are for single point turning operations using high speed steel tools. This information is provided as a guide to relative machinability, higher speeds are used with carbide tooling.

Alloy	Speed Surface, feet/min	Speed As a % Of B1112
AISI B1112	165	100
625	20	12
X	20	12
718	20 - 40	12-24
188	15	9
N-155	20	12
L-605 (25)	15	9
René 41	12	7
Waspaloy	20	12
A-286	30	18
321	75	45
RA330	30 - 45	18-27
RA333	20 - 25	12-15
RA 253 MA	40 - 60	28 - 35
309	70	42
310	70	42
601	25 - 35	15 - 21
800H/AT	25 - 35	15 - 21
446	75	45
Ti 6Al-4V Solution annealed Solution treated aged (STA)	– 30 - 40 15 - 45	– 18 - 30 9 - 27
304	75	45
AL-6XN Alloy	65	40
Alloy 20	65	40
2205 Duplex	50 - 65	30 - 40
303	100	60
17-4 PH Stainless Solution treated Aged H1025	– 75 60	– 45 36

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