321/321H, 347/347H - Stainless Steel: Austenitic

(UNS S32100, S34700, S34800)

GENERAL INFORMATION

ATI 321(UNS S32100), ATI 347 (UNS S34700), and ATI 348 (UNS S34800) alloys are stabilized stainless steels which offer as their main advantage an excellent resistance to intergranular corrosion following exposure to temperatures in the chromium carbide precipitation range from 800 to 1500°F (427 to 816°C). 321 alloy is stabilized against chromium carbide formation by the addition of titanium. 347 and ATI 348 alloys are stabilized by the addition of columbium and tantalum.

ATI 348 alloy has restricted cobalt and tantalum content for nuclear applications.

While 321 and 347 alloy continue to be employed for prolonged service in the 800 to 1500°F (427 to 816°C) temperature range, 304L alloy has supplanted these stabilized grades for applications involving only welding or short time heating.

321 and 347 stainless steels are also advantageous for high temperature service because of their good mechanical properties. 321 and 347 stainless steels offer higher creep and stress rupture properties than 304 alloy and, particularly, 304L stainless which might also be considered for exposures where sensitization and intergranular corrosion are concerns. This results in higher elevated temperature allowable stresses for these stabilized alloys for ASME Boiler and Pressure Vessel Code applications. The 321 and 347 alloys have maximum use temperatures of 1500°F (816°C) for code applications.

High carbon versions of all three alloys are available. These grades have UNS designations S32109 (321H) and S34709 (347H).

PRODUCT FORMS

321 and 347 stainless steel is available in plate, sheet, and strip forms.

CORROSION RESISTANCE

General Corrosion

321 and 347 alloys offer similar resistance to general overall corrosion as the unstabilized chromium-nickel 304 stainless. Heating for long periods of time in the chromium carbide precipitation range may affect the general resistance of 321 and 347 stainless in severe corrosive media.

In most environments, all three alloys will show similar corrosion resistance; however, 321 alloy in the annealed condition is somewhat less resistant to general corrosion in strongly oxidizing environments than annealed 347 alloy. For this reason, 347 stainless is preferable for aqueous and other low temperature environments. Exposure in the 800 to 1500°F (427 to 816°C) temperature range lowers the overall corrosion resistance of 321 alloy to a much greater extent than 347 alloy. 347 stainless is used primarily in high temperature applications where high resistance to sensitization is essential, thereby preventing intergranular corrosion at lower temperatures.

Intergranular Corrosion

321 and 347 stainless steels are useful in applications where the unstabilized chromium-nickel steels, such as 304 stainless steels, would be susceptible to intergranular corrosion.

When the unstabilized chromium-nickel steels are held in or slowly cooled through the range of 800 to 1500°F (427 to 816°C), chromium carbide is precipitated at the grain boundaries. In the presence of certain strongly corrosive media, these grain boundaries are preferentially attacked, a general weakening of the metal results, and a complete disintegration may occur.

Organic media or weakly corrosive aqueous agents, milk and other dairy products, or atmospheric conditions rarely produce intergranular corrosion even when large amounts of precipitated carbides are present. When thin gage material is welded the time in the temperature range of 800 to 1500°F (427 to 816°C) is so short that with most corroding media the unstabilized types are generally satisfactory. The extent to which carbide precipitation may be harmful depends upon the length of time the alloy was exposed to 800 to 1500°F (427 to 816°C) and upon the corrosive environment. Even the longer heating times involved in welding heavy gages are not harmful to the unstabilized "L" grade alloys where the carbon content is kept to low amounts of 0.03% or less. The high resistance of the stabilized 321 and 347 stainless steels to sensitization and intergranular

corrosion is illustrated by data for the 321 alloy in the Copper-Copper Sulfate –16% Sulfuric Acid Test (ASTM A262, Practice E) below. Mill annealed samples were given a sensitizing heat treatment consisting of soaking at 1050°F (566°C) for 48 hours prior to the test.

Intergranular Corrosion Test Long-Term Sensitization* Results ASTM A262 Practice			
Alloy	Rate (ipm)	Bend	Rate (mpy)
304	0.81	dissolved	9720.0
304L	0.0013	IGA	15.6
321	0.0008	IGA	9.6
347	0.0005	NO IGA	6.0
*Annealed 1100°F, 240 hours			

The absence of intergranular attack (IGA) in the 347 specimens shows that they did not sensitize during this thermal exposure. The low corrosion rate exhibited by the 321 specimens shows that even though it suffered some IGA, it was more resistant than 304L under these conditions. All of these alloys are far superior to regular 304 stainless steel under the conditions of this test.

In general, 321 and 347 alloys are used for heavy welded equipment which cannot be annealed and for equipment which is operated between 800 to 1500°F (427 to 816°C) or slowly cooled through this range. Experience gained in a wide range of service conditions has provided sufficient data to generally predict the possibility of intergranular attack in most applications. Additional information can also be found in the HEAT TREATMENT section.

WELDABILITY

Austenitic stainless steels are considered to be the most weldable of the high-alloy steels and can be welded by all fusion and resistance welding processes. Two important considerations in producing weld joints in the austenitic stainless steels are preservation of corrosion resistance and avoidance of cracking.

It is important to maintain the level of stabilizing element present in 321 and 347 alloys during welding. 321 alloy is more prone to loss of titanium. 347 alloy is more resistant to loss of columbium. Care needs to be exercised to avoid pickup of carbon from oils and other sources and nitrogen from air. Weld practices which include attention to cleanliness and good inert gas shielding are recommended for these stabilized grades as well as other non-stabilized austenitic alloys.

Weld metal with a fully austenitic structure is more susceptible to cracking during the welding operation. For this reason, 321 and 347 alloys are designed to resolidify with a small amount of ferrite to minimize cracking susceptibility. Columbium stabilized stainless steels are more prone to hot cracking than titanium stabilized stainless steels.

Matching filler metals are available for welding 321 and 347 stabilized stainless steels. The 347 filler metal is sometimes used to weld the 321 alloy.

These stabilized alloys may be joined to other stainless steels or carbon steel. Type 309 (23% Cr-13.5% Ni) or nickel-base filler metals have been used for this purpose.

COMPOSITION

The composition of these alloys are specified by ASTM A240 and ASME SA-240 specifications.

Weight Percent Maximum Unless Range is Specified		
Element	**321**	**347**
Carbon*	0.08	0.08
Manganese	2.00	2.00
Phosphorus	0.045	0.045
Sulfur	0.030	0.030
Silicon	0.75	0.75
Chromium	17.00-19.00	17.00-19.00
Nickel	9.00-12.00	9.00-12.00
Columbium+Tantalum**	--	10×C min to 1.00 max
Tantalum	--	--

Titanium**	5×(C+N) min to 0.70 max	--
Cobalt	--	--
Nitrogen	0.10	--
Iron	Balance	Balance

*Also H grade with Carbon 0.04 - 0.10%

** H grade minimum stabilizer is different formula

PHYSICAL PROPERTIES

The physical properties of 321 and 347 stainless steels are quite similar and, for all practical purposes, may be considered to be the same. The values given in the table below may be used to apply to all three steels. When properly annealed, the 321 and 347 stainless steels consist principally of austenite and carbides of titanium or columbium. Small amounts of ferrite may or may not be present in the microstructure. Small amounts of sigma phase may form during long time exposure in the 1000 to 1500°F (593 to 816°C) temperature range. The stabilized 321 and 347 stainless steels are not hardenable by heat treatment.

The overall heat transfer coefficient of metals is determined by factors in addition to thermal conductivity of the metal. In most cases, film coefficients, scaling, and surface conditions are such that not more than 10 to 15 percent more surface area is required for stainless steels than for other metals having higher thermal conductivity. The ability of stainless steels to maintain clean surfaces often allow better heat transfer than other metals having higher thermal conductivity.

Magnetic Permeability

The stabilized 321 and 347 alloys are generally non-magnetic in the annealed condition with magnetic permeability values typically less than 1.02 at 200H. Permeability values may vary with composition and will increase with cold work. Permeability of welds containing ferrite will be higher.

321/321H, 347/347H

Density		
Grade	g/cm^3	lb/in^3
ATI 321	7.92	0.286
ATI 347	7.96	0.288
ATI 348	7.96	0.289

Modulus of Elasticity in Tension
28 x 106 psi (193 GPa)

Mean Coefficient of Linear Thermal Expansion			
Temperature Range		cm/cm °C	in/in °F
°C	°F		
20 - 100	68 - 212	16.6 x 10^{-6}	9.2 x 10^{-6}
20 - 600	68 - 1112	18.9 x 10^{-6}	10.5 x 10^{-6}
20 -1000	68 - 1832	20.5 x 10^{-6}	11.4 x 10^{-6}

Thermal Conductivity			
Temperature Range		W/m·K	Btu·in/hr·ft^2·°F
°C	°F		
20 - 100	68 - 212	16.3	112.5
20 - 500	68 - 932	21.4	147.7

Specific Heat			
Temperature Range		J/kg K	Btu/lb °F
°C	°F		
0 - 100	32 - 212	500	0.12

Electrical Resistivity		
Temperature Range		microhm·cm
°C	°F	
20	68	72
100	213	78
200	392	86
400	752	100
600	1112	111
800	1472	121
900	1652	126

Melting Range	
°C	°F
1398-1446	2550-2635

MECHANICAL PROPERTIES

Room Temperature Tensile Properties

Minimum mechanical properties of the stabilized 321 and 347 chromium-nickel alloys in the annealed condition 2000°F (1093°C, air cooled) are shown in the table below. The test samples were prepared from sheet material.

Elevated Temperature Tensile Properties

Typical elevated temperature mechanical properties for 321 and 347 sheet/strip are shown below. The strength of these stabilized alloys are distinctly higher than that of non-stabilized 304 alloy at temperatures of 1000°F (538°C) and above.

High carbon 321H and 347H (UNS S32109 and S34709 respectively) alloys have higher strength at temperatures above 1000°F (537°C). ASME maximum allowable design stress data for 347H stainless reflects the higher strength of this grade in comparison to the lower carbon 347 alloy. The 321H alloy is not permitted for Section VIII applications and are limited to 800°F (427°C) use temperatures for Section III code applications.

Creep and Stress Rupture Properties

Typical creep and stress rupture data for 321 and 347 stainless steels are shown in the figures below. The elevated temperature creep and stress rupture strengths of the stabilized steels are higher than those of unstabilized 304 and 304L alloys. These superior properties for the 321 and 347 alloys permit design of pressure containing components for elevated temperature service to higher stress levels as recognized in the ASME Boiler and Pressure Vessel Code.

Impact Strength

321 and 347 stainless have excellent toughness at room and sub-zero temperatures. In the following table are Charpy V-notch impact values for annealed 347 stainless after holding the samples for 1 hour at the indicated testing temperatures. Data for 321 stainless would be expected to be similar.

Impact Strength 321 and 347 Alloys			
Test Temperature		Charpy Impact Energy Absorbed	
°C	°F	Ft-lb	Joules
75	24	90	122
-25	-32	66	89
-80	-62	57	78

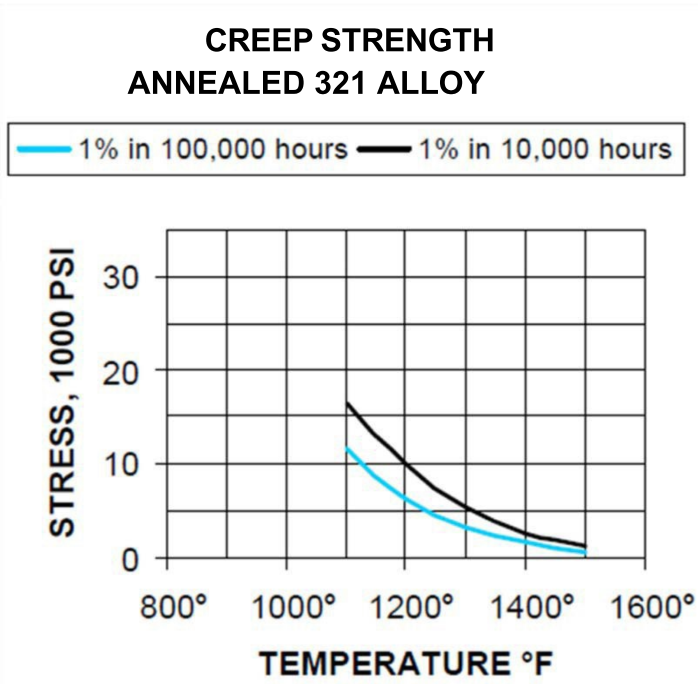
Minimum Room Temperature Mechanical Properties Per ASTM A240 and ASME SA-240						
Type	Yield Strength 0.2% Offset psi (MPa)	Ultimate Tensile Strength psi (MPa)	Elongation in 2 in. (%)	Hardness, Maximum		
				Plate	Sheet	Strip
321	30,000 (205)	75,000 (515)	40	217 Brinell	95 Rb	95 Rb
347	30,000 (205)	75,000 (515)	40	201 Brinell	92 Rb	92 Rb

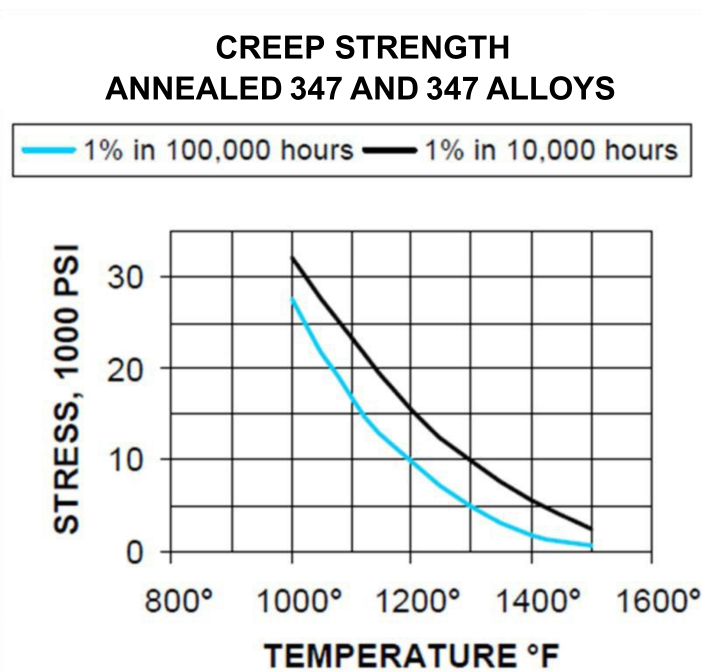
Typical Elevated Temperature Tensile Properties 321 Alloy (0.036 inch thick / 0.9 mm thick)				
Test Temperature		Yield Strength 0.2% Offset psi (MPa)	Ultimate Tensile Strength, psi (MPa)	% Elongation in 2 in.
°F	°C			
68	20	31,400 (215)	85,000 (590)	55.0
400	204	23,500 (160)	66,600 (455)	38.0
800	427	19,380 (130)	66,300 (455)	32.0
1000	538	19,010 (130)	64,400 (440)	32.0
1200	649	18,890 (130)	55,800 (380)	28.0
1350	732	19,000 (130)	41,500 (285)	26.0
1500	816	17,200 (115)	26,000 (180)	45.0

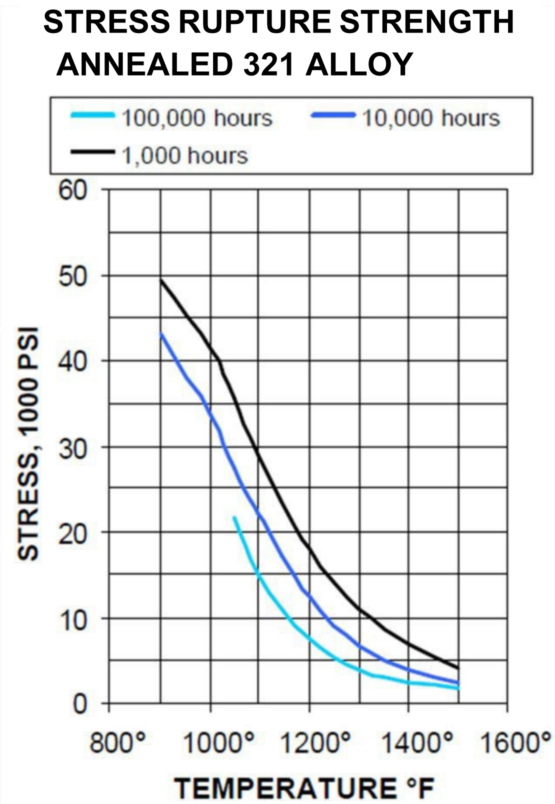
Typical Elevated Temperature Tensile Properties 347 Alloy (0.060 inch thick /1.54 mm thick)				
Test Temperature		Yield Strength 0.2% Offset, psi (MPa)	Ultimate Tensile Strength, psi (MPa)	% Elongation in 2 in.
°F	°C			
68	20	36,500 (250)	93,250 (640)	45.0
400	204	36,600 (250)	73,570 (505)	36.0
800	427	29,680 (205)	69,500 (475)	30.0
1000	538	27,400 (190)	63,510 (435)	27.0
1200	649	24,475 (165)	52,300 (360)	26.0
1350	732	22,800 (155)	39,280 (270)	40.0
1500	816	18,600 (125)	26,400 (180)	50.0

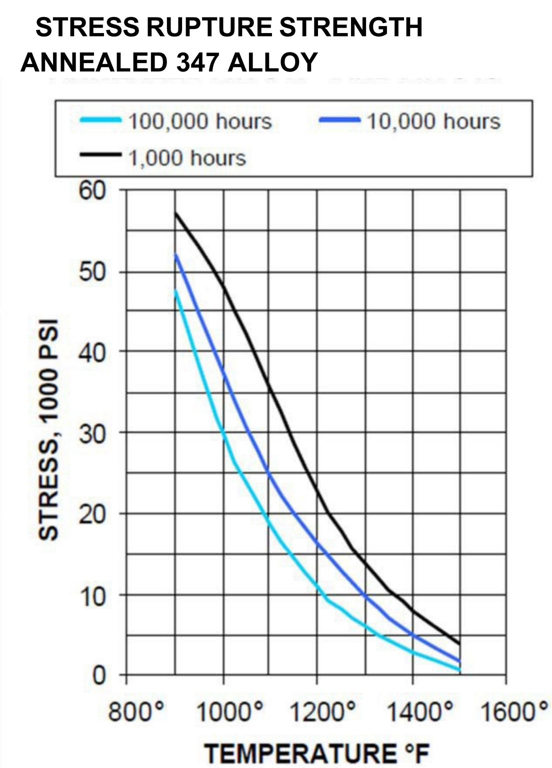
Fatigue Strength

The fatigue strength of practically every metal is affected by corrosive conditions, surface finish, form, and mean stress. For this reason, no definite values can be shown which would be representative of the fatigue strength under all operating conditions. The fatigue endurance limits of 321 and 347 stainless are approximately 35% of their tensile strengths.



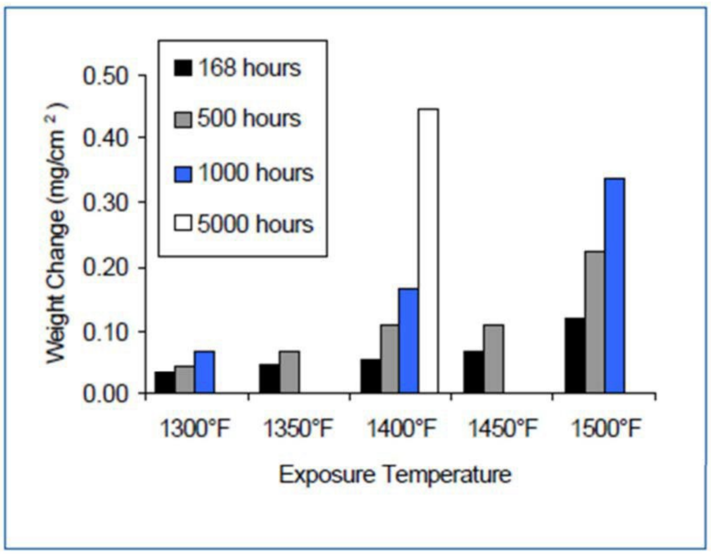



STRESS RUPTURE STRENGTH
ANNEALED 321 ALLOY
100,000 hours
10,000 hours
1,000 hours
STRESS, 1000 PSI
60
50
40
30
20
10
0
800°
1000°
1200°
1400°
1600°
TEMPERATURE °F


STRESS RUPTURE STRENGTH
ANNEALED 347 ALLOY
100,000 hours
10,000 hours
1,000 hours
STRESS, 1000 PSI
60
50
40
30
20
10
0
800°
1000°
1200°
1400°
1600°
TEMPERATURE °F

OXIDATION RESISTANCE

321 and 347 alloys exhibit oxidation resistance comparable to the other 18–8 austenitic stainless steels. Oxidation test data for 347 alloy is presented graphically and in tabular form. Specimens prepared from standard mill–finish production material were exposed in ambient laboratory air at elevated temperatures. Periodically, specimens were removed from the high temperature environment and weighed to determine the extent of scale formation. Test results are reported as a weight change in units of milligrams per square centimeter and reflect the average from a minimum of two different test specimens.



Weight Change (mg/cm²)					
Exposure Time	**1300°F**	**1350°F**	**1400°F**	**1450°F**	**1500°F**
168 hours	0.032	0.046	0.054	0.067	0.118
500 hours	0.045	0.065	0.108	0.108	0.221
1,000 hours	0.067	--	0.166	--	0.338
5,000 hours	--	--	0.443	--	--

321 and 347 alloys differ primarily by small alloying additions unrelated to factors affecting the oxidation resistance. Therefore, these results should be representative of all three grades. However, since the rate of oxidation can be influenced by the exposure environment and factors intrinsic to specific product forms, these results should be interpreted only as a general indication of the oxidation resistance of these grades.

STRESS CORROSION CRACKING

The 321 and 347 austenitic stainless steels are susceptible to stress corrosion cracking (SCC) in halides similar to 304 stainless steel. This results because of their similarity in nickel content. Conditions which cause SCC are: (1) presence of halide ion (generally chloride), (2) residual tensile stresses, and (3) environmental temperatures in excess of about 120°F (49°C).

Stresses may result from cold deformation during forming operations, or from thermal cycles encountered during welding operations. Stress levels may be reduced by annealing or stress-relieving heat treatments following cold deformation. The stabilized 321 and 347 alloys are good choices for service in the stress relieved condition in environments which might otherwise cause intergranular corrosion for unstabilized alloys.

The 321 and 347 alloys are particularly useful under conditions which cause polythionic acid stress corrosion of non-stabilized austenitic stainless steels, such as 304. Exposure of non-stabilized austenitic stainless steel to temperatures in the sensitizing range will cause the precipitation of chromium carbides at grain boundaries. On cooling to room temperature in a sulfide- containing environment, the sulfide (often hydrogen sulfide) reacts with moisture and oxygen to form polythionic acids which attack the sensitized grain boundaries. Under conditions of stress, intergranular cracks form.

Polythionic acid SCC has occurred in oil refinery environments where sulfides are common. The stabilized 321 and 347 alloys offer a solution to polythionic acids SCC by resisting sensitization during elevated temperature service. For optimum resistance, these alloys should be used in the thermally stabilized condition if service- related conditions may result in sensitization.

Pitting / Crevice Corrosion

The resistance of the stabilized 321 and 347 alloys to pitting and crevice corrosion in the presence of chloride ion is similar to that of 304 or 304L stainless steels because of similar chromium content. Generally, 100 ppm chloride in aqueous environments is considered to be the limit for both the unstabilized and the stabilized alloys, particularly if crevices are present. Higher levels of chloride ion might cause crevice corrosion and pitting. The stabilized 321 and 347 alloys pass the 100 hour, 5 percent neutral salt spray test (ASTM B117) with no rusting or staining of samples. However, exposure of these alloys to salt mists from the ocean would be expected to cause pitting and crevice corrosion accompanied by severe discoloration. The 321 and 347 alloys are not recommended for exposure to marine environments.

Halide (Chloride) Stress Corrosion Tests, 321 Alloy		
Test	**U-Bend (Highly Stressed Samples 1350°F**	
42% Magnesium Chloride, Boiling	Base Metal	Cracked, 24-71 hours
	Welded	Cracked, 24-71 hours
33% Lithium Chloride, Boiling	Base Metal	Cracked Within 18 hours
	Welded	Cracked Within 18 hours
26% Sodium Chloride, Boiling	Base Metal	No Cracks 1000 hours Cracked Within 475 hours
	Welded	Cracked Within 525-621 hours

HEAT TREATMENT

The annealing temperature range for 321 and 347 alloys is 1800 to 2000°F (928 to 1093°C). While the primary purpose of annealing is to obtain softness and high ductility, these steels may also be stress relief annealed within the carbide precipitation range 800 to 1500°F (427 to 816°C), without any danger of subsequent intergranular corrosion. Relieving strains by annealing for only a few hours in the 800 to 1500°F (427 to 816°C) range will not cause any noticeable lowering in the general corrosion resistance, although prolonged heating within this range does tend to lower the general corrosion resistance to some extent.

As emphasized, however, annealing in the 800 to 1500°F (427 to 816°C) temperature range does not result in a susceptibility to intergranular attack.

For maximum ductility, the higher annealing range of 1800 to 2000°F (928 to 1093°C) is recommended. When fabricating chromium-nickel stainless steel into equipment requiring the maximum protection against carbide precipitation obtainable through use of a stabilized grade, it is essential to recognize that there is a difference between the stabilizing ability of columbium and titanium. For these reasons the degree of stabilization and of resulting protection may be less pronounced when 321 stainless is employed.

When maximum corrosion resistance is called for, it may be necessary with 321 stainless to employ a corrective remedy which is known as a stabilizing anneal. It consists of heating to 1550 to 1650°F (843 to 899°C) for up to 5 hours depending on thickness. This range is above that within which chromium carbides are formed and is sufficiently high to cause dissociation and solution of any that may have been previously developed. Furthermore, it is the temperature at which titanium combines with carbon to form harmless titanium carbides. The result is that chromium is restored to solid solution and carbon is forced into combination with titanium as harmless carbides.

This additional treatment is required less often for the columbium-stabilized 347 alloys. When heat treatments are done in an oxidizing atmosphere the oxide should be removed after annealing in a descaling solution such as a mixture of nitric and hydrofluoric acids. These acids should be thoroughly rinsed off the surface after cleaning. These alloys cannot be hardened by heat treatment.

Cleaning

Despite their corrosion resistance, stainless steels need care in fabrication and during use to maintain their surface appearance even under normal conditions of service.

In welding, inert gas processes are used. Scale or slag that forms from welding processes is removed with a stainless steel wire brush. Carbon steel wire brushes will leave carbon steel particles in the surface which will eventually produce surface rusting. For more severe applications, welded areas should be treated with a descaling solution such as a mixture of nitric and hydrofluoric acids to remove the heat tint, and these acids should be subsequently washed off.

For material exposed to inland, light industrial or milder service, minimum maintenance is required. Only sheltered areas need occasional washing with a stream of pressurized water.
In heavy industrial areas, frequent washing is advisable to remove dirt deposits which might eventually cause corrosion and impair the surface appearance of the stainless steel.

Design can aid cleanability. Equipment with rounded corners, fillets and absence of crevices facilitates cleaning as do smooth ground welds and polished surfaces.