309(UNS S30900) /309S (UNS S30908)/310(UNS S31000) /310S(UNS S31008)

austenitic stainless steels

General Properties

Alloy 309/309S and Alloy 310/310S austenitic stainless steels are typically used for elevated temperature applications. Their high chromium and nickel contents provide comparable corrosion resistance, superior resistance to oxidation, and the retention of a larger fraction of room temperature strength than the common austenitic Alloy 304.

Applications

Higher alloyed stainless steels generally exhibit excellent elevated temperature strength along with resistance to creep deformation and environmental attack. As such, they are used widely in the heat treatment industry for furnace parts such as conveyor belts, rollers, burner parts, refractory supports, retorts and oven linings, fans, tube hangers, and baskets and trays to hold small parts. These grades are also used in the chemical process industry to contain hot concentrated acids, ammonia, and sulfur dioxide. In the food processing industry, they are used in contact with hot acetic and citric acid.

Chemical Composition

Chemistries are taken from ASTM A167 and ASTM A240 specifications unless otherwise noted.

	Alloy 309	Alloy 309S	Alloy 310	Alloy 310S
	(UNS S30900)	(UNS S30908)	(UNS S31000)	(UNS S31008)
C	0.20	0.08	0.25	0.08
Mn	2.00	2.00	2.00	2.00
P	0.045	0.045	0.045	0.045
S	0.030	0.030	0.030	0.030
Si	0.75	0.75	1.50	1.50
Cr	22.00 min/24.00 max	22.00 min/24.00 max	24.00 min/26.00 max	24.00 min/26.00 max
Ni	12.00 min/15.00 max	12.00 min/15.00 max	19.00 min/22.00 max	19.00 min/22.00 max
Fe	Balance	Balance	Balance	Balance

Alloy composition – all values in weight percent, maximum levels unless a range is specified.

Physical Properties

<table>
<tr><th rowspan="2"></th><th colspan="2">Alloy 309</th><th colspan="3">Alloy 310</th></tr>
<tr><th>lbm/in3</th><th>g/cm3</th><th>lbm/in3</th><th colspan="2">g/cm3</th></tr>
<tr><td>Density at 68°F (20°C)</td><td>0.29</td><td>8.03</td><td>0.29</td><td colspan="2">8.03</td></tr>
<tr><td>Coefficient of Thermal Expansion</td><td>(üin/in) ·°F</td><td>(üm/m) ·K</td><td>(üin/in) °F</td><td colspan="2">(üm/m) ·K</td></tr>
<tr><td>at 68- 212°F (20 - 100°C)</td><td>8.7</td><td>15.6</td><td>8.8</td><td colspan="2">15.9</td></tr>
<tr><td>at 68- 932°F (20 - 500°C)</td><td>9.8</td><td>17.6</td><td>9.5</td><td colspan="2">17.1</td></tr>
<tr><td>at 68- 1832°F (20 - 1000°C)</td><td>10.8</td><td>19.4</td><td>10.5</td><td colspan="2">18.9</td></tr>
<tr><td>Electrical Resistivity</td><td>Ω· in</td><td>Ω· cm</td><td>Ω· in</td><td colspan="2">Ω· cm</td></tr>
<tr><td>at 68°F (20°C)</td><td>30.7</td><td>78.0</td><td>30.7</td><td colspan="2">78.0</td></tr>
<tr><td>at 1200°F (648°C)</td><td>45.1</td><td>114.8</td><td>---</td><td colspan="2">---</td></tr>
<tr><td>Thermal Conductivity</td><td>Btu/hr·ft·°F</td><td>W/m·K</td><td>Btu/hr·ft·°F</td><td colspan="2">W/m·K</td></tr>
<tr><td>at 68- 212°F (20 - 100°C)</td><td>9.0</td><td>15.6</td><td>8.0</td><td colspan="2">13.8</td></tr>
<tr><td>at 68- 932°F (20 - 500°C)</td><td>10.8</td><td>18.7</td><td>10.8</td><td colspan="2">18.7</td></tr>
<tr><td>Specific Heat</td><td>Btu/lbm·°F</td><td>J/kg·K</td><td>Btu/lbm·°F</td><td colspan="2">J/kg·K</td></tr>
<tr><td>at 32- 212°F (0 - 100°C)</td><td>0.12</td><td>502</td><td>0.12</td><td colspan="2">502</td></tr>
<tr><td colspan="6">Magnetic Permeability (annealed)1</td></tr>
<tr><td>at 200H</td><td colspan="5">1.02</td></tr>
<tr><td>Modulus of Elasticity (annealed)2</td><td colspan="4">psi</td><td>GPa</td></tr>
<tr><td>in tension (E)</td><td colspan="4">29 x 10^6</td><td>200</td></tr>
<tr><td>in shear (G)</td><td colspan="4">11.2 x 10^6</td><td>77</td></tr>
</table>

1 Common value for both alloys, no units

2 Common value for both alloys

General physical properties for base Alloy 309 and Alloy 310 austenitic stainless steels

Typical Short-Term Mechanical Properties

All tensile testing was done in accordance with ASTM E8. The data consists of the average results from a minimum of two and as many as ten samples. Yield strength was determined by the 0.2% offset method. Plastic elongation is as measured in a two inch gauge length.

Alloy 309

Test Temperature		Yield Strength		Tensile Strength		Elongation
(°F)	(°C)	ksi	MPa	ksi	MPa	%
77	25	42.0	290	90.0	621	49
400	204	35.0	241	80.0	552	46
800	427	30.0	207	72.0	497	40
1000	538	24.0	166	66.0	455	36
1200	649	22.0	152	55.0	379	35
1400	760	20.0	138	36.0	248	40
1600	871	18.5	128	21.0	145	50
1800	982	---	---	10.1	69	65

Alloy 309S

Test Temperature		Yield Strength		Tensile Strength		Elongation
(°F)	(°C)	ksi	MPa	ksi	MPa	%
77	25	50.9	351	97.1	670	44.6
200	93	44.7	308	88.8	612	29.0
400	204	37.4	258	81.7	563	34.5
600	316	33.4	230	80.2	553	31.6
800	427	29.6	204	77.1	531	32.1
900	482	30.4	210	74.7	515	32.0
1000	538	26.7	184	71.2	491	26.6
1100	593	26.5	182	65.6	452	25.5
1200	649	24.7	170	55.9	386	28.8
1300	704	23.7	163	55.7	384	---
1400	760	22.2	153	36.0	248	22.5
1500	816	20.1	138	24.7	170	64.8
1600	871	16.6	114	20.7	142	73.3
1700	927	13.1	90	15.4	106	78.7
1800	982	8.2	56	10.8	74	---
1900	1038	4.6	32	6.6	46	---

Alloy 310

Test Temperature		Yield Strength		Tensile Strength		Elongation
(°F)	(°C)	ksi	MPa	ksi	MPa	%
77	25	42.4	292	89.5	617	45
400	204	31.5	217	76.6	528	37.5
800	427	27.2	188	74.8	516	37

1000	538	24.2	167	70.1	483	36
1200	649	22.6	156	57.2	394	41.5
1500	816	19.7	136	30.3	209	66
1800	871	---	---	11.0	76	65
2000	1093	---	---	7.0	48	77

Alloy 310S

Test Temperature		Yield Strength		Tensile Strength		Elongation
(°F)	(°C)	ksi	MPa	ksi	MPa	%
77	25	45.6	314	90.5	624	42.6
200	93	41.4	286	83.4	575	41.3
400	204	36.9	254	77.3	533	35.8
600	316	34.6	239	75.2	519	35.0
800	427	30.3	209	73.6	508	33.5
1000	538	29.4	203	70.2	484	37.0
1200	649	25.8	178	57.0	393	32.0
1400	760	21.4	147	37.7	260	54.0
1600	871	16.1	111	22.5	155	56.5
1800	982	8.2	56	11.8	81	93.3
2000	1093	4.0	27	6.5	44	121.0

Aqueous Corrosion Resistance

Alloys 309/309S and 310/310S are primarily used at elevated temperature to take advantage of their oxidation resistance. However, both of these stainless grades are resistant to aqueous corrosion due to their high chromium and nickel contents.

Although their higher nickel content provides marginal improvement with respect to chloride stress corrosion cracking (SCC) compared to the 18-8 stainless steels, Alloys 309/309S and 310/310S austenitic stainless steels remain susceptible to this form of attack.

Certain applications specify the use of Alloy 310/310S stainless steel where increased resistance to aqueous corrosion is needed. An example is service in concentrated nitric acid, where preferential attack of grain boundaries may occur.

Elevated Temperature Oxidation Resistance

Metallic alloys will react with their surroundings to some degree under most conditions. The most common reaction is oxidation – metallic elements combining with oxygen to form oxides. Stainless steels are resistant to oxidation through selective oxidation of chromium, which forms a slow-growing, very stable oxide (Cr_2O_3 or chromia). Given enough chromium in the underlying alloy, a compact and adherent surface layer of chromium oxide is established which prevents the formation of other, faster growing oxides and serves as a barrier to further degradation. The rate of oxidation is controlled by transport of charged species through the external chromia scale. As the surface scale thickens, the rate of oxidation decreases dramatically because the charged species have to travel farther. This process, the high temperature analogue of passivation during corrosion at low temperatures, is known as protective scale formation.

The oxidation resistance of austenitic stainless steels can be approximated by the chromium content of the alloy. True heat resistant alloys generally contain at least 20% (by weight) chromium. Replacing iron with nickel also generally improves an alloy's high temperature behavior. Alloys 309/309S and 310/310S are highly alloyed materials and are, therefore, very resistant to oxidation.

An oxidized metal sample will increase in weight corresponding to the amount of oxygen incorporated into the scale and any internal oxidation. Measuring the change in weight of a sample which has been exposed at high temperatures for a set period of time is one way to determine the oxidation resistance of an alloy. Greater weight gains typically indicate more severe oxidation.

Oxidation is more complex than simple scale thickening. Spallation, or the detachment of the surface oxide scale, is the most common problem encountered during the oxidation of stainless steels. Spallation is typically manifested by rapidly accelerating weight loss. A number of factors can cause spallation, chief among them thermal cycling, mechanical damage, and excessive oxide thickness.

During oxidation, chromium is tied up in the scale in the form of chromium oxide. When the oxide scale spalls off, fresh metal is exposed, and the local rate of oxidation temporarily increases as new chromium oxide forms. Given sufficient scale spallation, enough chromium may be lost to cause the underlying alloy to lose its heat resistant properties. The result is the formation of rapidly growing oxides of iron and nickel, known as breakaway oxidation.

Very high temperature oxidation can lead to scale volatilization. The surface chromium oxide scale formed on heat resistant stainless steels is primarily $Cr2O\ 3$. At higher temperatures, the tendency is for further oxidation to $CrO3$, which has a very high vapor pressure. The rate of oxidation is then split into two parts – scale thickening by formation of $Cr2O3$ and the thinning

effect of $CrO3$ evaporation. The tendency is for eventual balance between growth and thinning with the scale remaining at a constant thickness. The result is continuous recession of the surface and consumption of the metal beneath. The effect of scale volatilization becomes a significant problem at temperatures above approximately 2000°F (1093°C) and is exacerbated by rapidly flowing gases.

Other Forms of Degradation

Species other than oxygen present in the high temperature environment can cause accelerated degradation of stainless steels. The presence of sulfur can lead to sulfidation attack. Sulfidation of the stainless steels is a complex process and depends strongly on the relative levels of sulfur and oxygen, along with the form of sulfur present (e.g., elemental vapor, sulfur oxides, hydrogen sulfide). Chromium forms stable oxides and sulfides. In the presence of both oxygen and sulfur compounds, a stable external chromium oxide layer often forms which can act as a barrier to sulfur ingress. However, sulfidation attack can still occur at regions where the scale has become damaged or detached, and under certain circumstances sulfur can transport across a chromia scale and form internal chromium sulfide phases. Sulfidation is enhanced in alloys containing a significant (about 25% or more) amount of nickel. Nickel and nickel sulfide form a low melting point eutectic phase which can cause catastrophic damage to the underlying alloy at elevated temperatures.

High levels of carbon-bearing species in the environment can result in undesired carbon ingress and the subsequent formation of internal carbides. Carburization generally takes place at temperatures above 1470°F (800°C) and at a carbon activity less than unity. The formation of a zone of internally carburized metal can cause undesired changes in mechanical and physical properties. Generally, the presence of oxygen will prevent carbon ingress by the formation of a protective external scale. Higher levels of nickel and silicon are somewhat effective in reducing the susceptibility of carburization. Metal dusting is a specific form of carburization attack which generally occurs at lower temperatures (660-1650°F or 350-900°C) and at a carbon activity greater than unity. It can result in catastrophic local attack via the formation of deep craters through a complex mechanism which converts solid metal to a mixture of graphite and metal particles.

Nitridation can occur in the presence of nitrogen gas. Oxides are generally more stable than nitrides so in an atmosphere which contains oxygen, an oxide scale typically forms. Oxide layers are good barriers to nitrogen ingress so nitridation is rarely a concern in air or in gases typical of combustion products. Nitridation can be a problem in purified nitrogen and is of special concern in dried, cracked ammonia atmospheres where the oxygen potential is very low. At relatively low temperatures a surface nitride film will generally form. At high temperatures (above about 1832°F or 1000°C) the diffusivity of nitrogen is fast enough that nitrogen penetrates deep into the metal and causes the formation of internal nitrides on grain boundaries and within grains. This can lead to compromised mechanical properties.

Metallurgical instability, or the formation of new phases during high temperature exposures, can adversely affect mechanical properties and reduce corrosion resistance. Carbide particles tend to precipitate at grain boundaries (sensitization) when austenitic stainless steels are held in or slowly cooled through the temperature range 800-1650°F (427-899°C). The higher levels of chromium and nickel contained in these alloys results in lower carbon solubility, which tends to increase the susceptibility for sensitization. Forced quenchant (gas or liquid) cooling is recommended through the critical temperature range, particularly for thicker sections. The time at temperature required to form chromium carbides increases with decreasing carbon content. Therefore, the low carbon versions of these alloys are more resistant but not immune to sensitization. When heated at temperatures between 1200-1850°F (649-1010°C) for long periods of time, Alloys 309/309S and 310/310S can exhibit decreased ductility at room temperature due to the precipitation of brittle second phase particles (sigma phase and carbides).

Sigma phase often forms at grain boundaries and can reduce ductility. This effect is reversible, and full ductility can be restored by reannealing at the suggested temperatures.

Elevated temperature degradation is greatly affected by the atmosphere present and other operating conditions. General oxidation data can often be used only in estimating the relative oxidation resistance of different alloys. Sandmeyer Steel Company can supply data and prior experience pertaining to specific applications on request.

Fabrication Characteristics

Alloys 309/309S and 310/310S stainless steel are widely used in the heat treatment/process industries due to high temperature properties and corrosion resistance. As such, they are commonly fabricated into complex structures. Mild carbon steel is generally treated as the standard for performance in most metal forming operations. With respect to carbon steel, the austenitic stainless steels exhibit a significant difference – they are tougher and tend to work harden rapidly. While this does not alter the general methods used for cutting, machining, forming, etc., it does affect the specifics of those methods.

Cutting and machining the austenitic stainless steels is readily accomplished using standard techniques typically employed for common mild steel, with some modifications. Their cutting behavior can be quite different – they are tougher and tend to harden rapidly during working. The chips produced are stringy and tough and retain considerable ductility. Tooling should be kept sharp and be rigidly held. Deeper cuts and slower speeds are generally used to cut below work hardened zones. Due to the low thermal conductivity and high coefficient of thermal expansion inherent to the austenitic stainless steels, heat removal and dimensional tolerances must be considered during cutting and machining operations.

The austenitic stainless steels are readily cold formable by standard methods such as bending, stretch forming, roll forming, hammer forming, flaring/flanging, spinning, drawing, and hydroforming. They work harden readily, which is manifested by steadily increasing amounts of force needed to continue deformation. This results in the need to use stronger forming machines and eventually limits the amount of deformation possible without cracking.

A relatively narrow range of temperatures can be used for effective hot working of Alloys 309 and 310 due to numerous environmental and metallurgical factors. Forging should start in the temperature range 1800-2145°F (980-1120°C) and finish no cooler than 1800°F (980°C). Working at higher temperatures results in a fall-off of hot ductility due to environmental and metallurgical factors, particularly the formation of ferrite. Working at lower temperatures can cause the formation of brittle second phases, e.g., sigma and/or sensitization. Following forging, the workpiece should be cooled rapidly to a black heat.

Welding

The austenitic grades are generally considered to be the most weldable of the stainless steels. They can be welded using all of the common processes. This is generally true of Alloys 309/309S and 310/310S. When filler metal is required, matching compositions are generally used. The elevated alloy contents of this grade can make the weld pool sluggish. If weld pool fluidity is a problem, filler metal containing silicon can help (e.g., ER309Si, ER309LSi).

Alloys 309/309S and 310/310S exhibit a relatively high coefficient of thermal expansion and low thermal conductivity and form low levels of ferrite in the solidifying weld metal. These factors can lead to hot cracking. The problem can be more severe for restrained and/or wide joints. Filler metal with a lower alloy content (e.g., ER308) will increase the amount of ferrite in the weld deposit and reduce the tendency for hot cracking. The subsequent dilution of the base metal may decrease the corrosion/heat resistance of the weld.

The "S" grades are relatively low in carbon. With proper weld practices, intergranular corrosion of the heat affected zone is unlikely. Heat tint or scale should be removed to ensure complete restoration of corrosion resistance near the weld. Grinding or brushing with a stainless steel brush can be used to remove the heat tint scale. Acid pickling will also remove heat intent. Small pieces can be treated in a bath, and larger pieces can be locally pickled using a special paste consisting of a mixture of nitric acid and HF or hydrochloric acid suspended in an inert filler. A thorough water wash should immediately follow, taking care to completely remove all traces of pickling paste.

Heat Treatment / Annealing

The primary reason for annealing these alloys is to produce a recrystalized microstructure with a uniform grain size and for dissolving detrimental chromium carbide precipitates. To ensure complete annealing, pieces should be held in the range 2050-2150°F (1120-1175°C) for approximately 30 minutes (time at temperature) per inch of section thickness. This is a general recommendation only – specific cases may require further investigation. When properly annealed, these grades are primarily austenitic at room temperature. Some small quantities of ferrite may be present.

Oxide scale formation is inevitable during air annealing of Alloys 309/309S and 310/310S. The scale that forms is generally rich in chromium and relatively adherent. The annealing scale generally must be removed prior to further processing or service. There are two typical methods for removing scale – mechanical and chemical. A combination of surface blasting prior to chemical scale removal is generally effective at removing all but the most tightly adherent scale. Silica sand or glass beads are a good choice for the blasting media. Iron or steel shot can also be used but will lead to embedded free iron in the surface which may then result in surface rusting or discoloration unless the surface is subsequently pickled.

Chemical removal of scale is generally performed with mixed nitric-hydrofluoric acids. The proper bath makeup and process temperature combination depends on the situation. A typical pickling bath used consists of 5-15% HNO_3 (65% initial strength) and 1/2-3% HF (60% initial strength) in aqueous solution. Higher concentrations of hydrofluoric acid lead to more aggressive scale removal. Bath temperatures generally range from ambient to about 140°F (50°C). Higher temperatures result in faster descaling but may attack grain boundaries aggressively, resulting in surface grooving. Acid pickling must be followed with a thorough water wash to remove all traces of pickling acids. Drying should then be used to avoid spotting and staining.

As noted, Alloys 309/309S and 310/310S consist solely of austenite at room temperature – they cannot be hardened through heat treatment. Higher mechanical strengths are attainable via cold or warm working, but these grades are generally not available in such conditions. The higher tensile and yield strengths obtainable through cold working not followed by full annealing are not stable at the higher temperatures at which these alloys are often used. Creep properties in particular may be adversely affected by the use of cold worked material at elevated temperatures.