309/309S, 310/310S - Stainless Steel: Austenitic

(UNSS30900/S30908/S31000/S31008)

General Information

309 and 310 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 alloys like Type 304.

Product Forms

Both alloys are available in plates, sheets, and strip product forms in a wide variety of sizes and finishes.

Chemical Composition

Chemistry limits are from ASTM A167 and ASTM A240 specifications unless otherwise noted. All values are given in weight percent and are maximum levels unless a range is specified.

	Type 309 (UNS S30900)	Type 309S (UNS S30908)	Type 309H (UNS S30909)	Type 309Si (DIN 1.4828)	Type 310 (UNS S31000)	Type 310S (UNS S31008)	Type 310H (UNS S31009)	Type 310Si (DIN 1.4841)
C	0.20	0.08	0.04 min 0.10 max	0.20	0.25	0.08	0.04 min 0.10 max	**0.20**
N	---	---	---	0.11	---	---	---	**0.11**
Mn	2.00	2.00	2.00	2.00	2.00	2.00	2.00	**2.00**
P	0.045	0.045	0.045	0.045	0.045	0.045	0.045	**0.045**
S	0.030	0.030	0.030	0.015	0.030	0.030	0.030	**0.015**
SI	0.75	0.75	0.75	1.50 min 2.50 max	1.50	1.50	0.75	**1.50 min 2.50 max**
Cr	22.00 min 24.00 max	22.00 min 24.00 max	22.00 min 24.00 max	19.00 min 21.00 max	24.00 min 26.00 max	24.00 min 26.00 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	12.00 min 15.00 max	11.00 min 13.00 max	19.00 min 22.00 max	19.00 min 22.00 max	19.00 min 22.00 max	**19.00 min 22.00 max**
Fe	**Balance**	**Balance**	**Balance**	**Balance**	**Balance**	**Balance**	**Balance**	**Balance**

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 alloys 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.

Physical Properties

The general physical property values for 309 and 310 alloys reported below are representative for average composition in the annealed condition.

	309		310	
Density	**lbm/in^3**	**g/cm^3**	**lbm/in^3**	**g/cm^3**
at 68ºF (20ºC)	0.29	8.03	0.29	8.03
Coefficient of Thermal Expansion	**(µin/in)·ºF**	**(µm/m)·K**	**(µin/in)·ºF**	**(µm/m)·K**
at 68º–212ºF (20º–100ºC)	8.7	15.6	8.8	15.9
at 68º–932ºF (20º–500ºC)	9.8	17.6	9.5	17.1
at 68º–1832ºF (20º–1000ºC)	10.8	19.4	10.5	18.9
Electrical Resistivity	**µΩ·in**	**µΩ·cm**	**µΩ·in**	**µΩ·cm**
at 68ºF (20ºC)	30.7	78.0	37.0	94.0
at 1200ºF (648ºC)	45.1	114.8	48.3	122.7
Thermal Conductivity	**Btu/hr·ft·ºF**	**W/m·K**	**Btu/hr·ft F**	**W/m·K**
at 68º–212ºF (20º–100ºC)	9.0	15.6	8.0	13.8
at 68º–932ºF (20º–500ºC)	10.8	18.7	10.8	18.7
Specific Heat	**Btu/lbm·ºF**	**J/kg·K**	**Btu/lbm·ºF**	**J/kg·K**
at 32º–212ºF (0º–100ºC)	0.12	502	0.12	502
Magnetic Permeability (annealed) [1]				
at 200H	1.02			
Modulus of Elasticity (annealed) [2]	**psi**		**GPa**	
in tension (E)	29 x 10^{6}		200	
in shear (G)	11.2 x 10^{6}		77	

[1] *Common value for both alloys, no units*

[2] *Common value for both alloys*

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. (50.8 mm)

309

Test Temperature		Yield Strength		Tensile Strength		Elongation
(ºF)	(ºC)	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	—	—	10.0	69	65

309S

Test Temperature		Yield Strength		Tensile Strength		Elongation
(ºF)	(ºC)	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	—

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

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

309 and 310 stainless steels 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. Selected corrosion test results for 310S stainless are collected in the following tables. All solutions are described as concentrations by weight.

Test Solution	Plain Sample	GTAW Welded Sample
50% Sodium Hydroxide	1.2	1.3
10% Sulfamic Acid	61.9	17.2
10% Sulfuric Acid ASTM A262 Practice B ASTM A262 Practice C ASTM A262 Practice E 20% Acetic Acid	111.8 5.3 3.8	112.3 5.3 3.8
45% Formic Acid	Pass 0.1	Pass 0.1
1% Hydrochloric Acid	32.5	34.2
10% Oxalic Acid	23.2	22.3
20% Phosphoric Acid	11.6	11.2
10% Sodium Bisulfate	0.4	3.2
	46.1	36.6

General corrosion—Metal loss in mils per year (MPY) after five 48 hour test periods in boiling solutions for samples with a 2B finish

Test Solution	As-Received	Sensitized
Huey Test	3.5	6.7
Boiling 65% Nitric Acid	4.2	31.0
Boiling 70.6% Nitric Acid	3.6	18.6
Boiling 96.1% Sulfuric Acid	47.1	50.2
Huey Test results for Type 310S (metal loss in mils per year)		
Plain	Welded	
6.9	10.5	

10% Ferric Chloride rubber band test ASTM G–48 70°F (21.1°C), 72 hours, average of two tests (weight loss in mg/cm^2)

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

SCC results ASTM G123 boiling solutions		
Test Solution	**Plain Sample**	**Welded Sample**
25% Sodium Chloride (pH=1.5)	(1) OK after 1344 hours	
	(2) OK after 1344 hours	
	(3) OK after 1344 hours	
26% Sodium Chloride	(4) OK after 1344 hours	—
	(1) OK after 1006 hours (1) OK after 1006 hours	(2) OK after 1006 hours (2) Cracked after 1006 hours[1]
33% Lithium Chloride	(1) Cracked after 126 hours	(2) Cracked after 174 hours
	(1) Cracked after 120 hours	(2) Cracked after 120 hours
42% Magnesium Chloride	(1) Cracked after 30 hours	(2) Cracked after 46 hours
	(1) Cracked after 46 hours	(2) Cracked after 46 hours
50% Sodium Hydroxide	(1) OK after 196 hours	(2) OK after 196 hours
	(1) OK after 196 hours	(2) OK after 196 hours

1 Broke from bolt hole to edge

Certain applications specify the use of 310 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. In such cases the use of 310L stainless may be advantageous. The high chromium content combined with restricted levels of carbon (a specified maximum of 0.015%), silicon, phosphorous, sulfur and molybdenum provide the 310L alloy with outstanding resistance to intergranular attack in this environment. Please refer to the Technical Note on this grade for more information.

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 twenty percent (by weight) chromium. Replacing iron with nickel also generally improves an alloy's high temperature behavior. 309 and 310 alloys 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 gain 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 are 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 Cr_2O_3. At higher temperatures the tendency is for further oxidation to CrO_3, which has a high vapor pressure. The rate of oxidation is then split into two parts—scale thickening by formation of Cr_2O_3 and the thinning effect of CrO_3 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 800°C (1470°F) 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 (350–900°C or 660–1650°F) and at a carbon activity greater than unity. It can result in catastrophic local attacks via the formation of deep craters through a complex mechanism which converts solid metal to 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 higher temperatures (above about 1000°C or 1832°F) 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, Types 309 and 310 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.

Fabrication Characteristics

309 and 310 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 work. The chips produced are stringy and tough, yet they retain a significant degree of ductility. Tooling should be kept sharp and 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 309 and 310 alloys 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 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 309 and 310 alloys. 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).

Types 309 and 310 exhibit a relatively high coefficient of thermal expansion, 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. If low carbon is required “L” electrodes (e.g. ER309L) can be used. 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 tint. 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 recrystallized 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 309 and 310 alloys. 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 5-25% HNO_3 (65% initial strength) and 0.5-3% HF (60% initial strength) in aqueous solution. Higher concentrations of hydrofluoric acid leads 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, 309 and 310 alloys 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. Other alloys such as 301, 304, and 316 stainless steels are often processed to various levels of cold work when material is needed in quarter, half, or full hard condition. The relevant Technical Data Sheets contain further information.

Availability & Specifications

309 and 310 alloys are available as plate, sheet, and strip. These alloys are widely used as high temperature/high strength alloys and are covered by a wide variety of specifications. A selected list is included here for flat rolled products; the entire list is extensive.

The specifications for 309 and 310 stainless steels (UNS S30900 and S31000) were developed long before the invention of modern steelmaking practices and analytical methods. As a consequence, the carbon range for these alloys is extremely broad (from zero to 0.20 percent maximum). With the introduction of modern steelmaking processes such as argon–oxygen decarburization (AOD), it was possible to produce lower carbon products, which were designated Types 309S (UNS S30908) and 310S (UNS 31008). These grades both have a carbon maximum of 0.08 percent, identical to that of standard Type 304 stainless steel (UNS 30400). All S30908 material falls within the range of the S30900 specification, and all S31008 material falls within the range of the S31000 specification. Like the S30400 specifications, the S30908 and S31008 specifications have no minimum for carbon content. In order to ensure the creep benefits which, come with having some carbon in the alloy, the 309H and 310H grades (UNS S30909 and S31009) were created. Each has a specified carbon range of 0.04 to 0.10 percent. Note that the H grades have lower maximum carbon (0.10 percent) than the standard grades (0.20 percent maximum). European standards for Types 309 and 310 stainless steels differ from the corresponding North American standards, particularly in the area of silicon. These slightly higher silicon content alloys are covered by Werkstoffe Numbers 1.4828 (Type 309Si) and 1.4841 (Type 310Si).

Relevant Standards—Flat Rolled Products (Plate, Sheet, Strip)

Alloy	UNS Identifier	Specification
309	UNS S30900	AISI 309 SAE 30309
310	UNS S31000	AISI 310 SAE 30310 ASTM A167
309S	UNS S30908	AISI 309S SAE 30309S
310S	UNS S31008	AISI 310S SAE 30310S ASME SA-240/SA-240M ASTM A240/A240M SAE AMS 5521 SAE J 405
309Si	DIN 1.4828	
310Si	DIN 1.4841	DIN EN 10045
309H	UNS S30909	
310H	UNS S31009	ASME SA-240/SA-240M ASTM A240/A240M
		SAE AMS 5521