New Castle
Stainless Plate, LLC

High Temperature Stainless Steels

General Properties

Type 309, 310, and 253 MA are heat resisting austenitic stainless steels typically used for applications above 1000˚F. Their high chromium and nickel contents provide comparable corrosion resistance similar to Type 304, but these grades possess higher elevated temperature oxidation and creep resistance, stress rupture, and tensile strength compared to Type 304/304L.

The lower nickel content of 253 MA is a key contributor to being cost effective. The use of cerium in combination with silicon results in superior oxidation resistance up to 2000˚F (1093˚C). Nitrogen, carbon, and cerium combine to provide creep rupture strength that is twice that of Type 310 and 309 stainless steel at 1600˚F (871˚C)

These high temperature grades are non-magnetic in the annealed condition but may become slightly magnetic as a result of welding.

Design Features

- High temperature oxidation resistance
- Enhanced high temperature strength
- High ductility and formability
- Excellent impact toughness even at cryogenic temperatures
- Good workability and weldability

Applications

- High temperature furnace components
- Muffles, retorts
- Burners, combustion chambers
- Furnace baskets and trays
- Fluidized bed combustors
- Furnace conveyor belts

Chemical Composition (wt%) Table 1

Grade	UNS	Cr	Ni	Mn	C	N	Others
253 MA	S30815	20.00-22.00	10.00-12.00	0.8	0.05-0.10	0.14-0.20	0.03-0.08 Ce
309	S30900	22.00-24.00	12.00-15.00	2	0.2	---	
309S	S30908	22.00-24.00	12.00-15.00	2	0.08	---	
309H	S30909	22.00-24.00	12.00-15.00	2	0.04-0.10	---	
310	S31000	24.00-26.00	19.00-22.00	2	0.25	---	
310S	S31008	24.00-26.00	19.00-22.00	2	0.08	---	
310H	S31009	24.00-26.00	19.00-22.00	2	0.04-0.10	---	

Specifications

These high temperature stainless steel grades can be supplied to meet AMS, ASTM, and ASME specifications.

Corrosion Resistance

These high temperature stainless steels are primarily used at elevated temperatures to take advantage of their oxidation resistance; however, these grades are resistant to aqueous corrosion due to their elevated chromium and nickel contents. Although their higher nickel contents provides marginal improvement with respect to chloride stress corrosion cracking compared to 304/316 stainless steels, these high temperature grades remain susceptible to this form of attack.

High Temperature Oxidation Resistance

Stainless steels are resistant to oxidation through selective oxidation of chromium, which forms a slow growing , very stable oxide (Cr_2O_3). 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 chromium oxide scale. As the surface scale thickens, the rate of oxidation decreases dramatically because the charged species have to diffuse through longer distances. This process, the high temperature analogue of passivation during aqueous 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 weight percent chromium. Replacing iron with nickel also generally improves an alloy's high temperature behavior and strength.

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, such as thermal cycling, mechanical damage, and excessive oxide thickness.

During oxidation, the scale in the form of chromium oxide consumes the chromium from the base metal. 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.

Sulfidation

Species other than oxygen present in the high temperature environment can cause ac-

Mechanical Properties Table 2

Grade	UNS	Yield (ksi) min	Tensile (ksi)	Elongation (%) min	Reduction of Area (%) min	Hardness Rb max
253 MA	S30815	45	87 min	40.0		95
309	S30900	30	75-100	40.0		95
309S	S30908	30	75-100	40.0	50.0	95
309H	S30909	30	75-100	40.0	50.0	95
310	S31000	30	75-100	40.0		95
310S	S31008	30	75-100	40.0	50.0	95
310H	S31009	30	75-100	40.0	50.0	95

celerated degradation of stainless steels. The presence of sulfur can lead to sulfidation attack. Sulfidation of stainless steels is a complex process and depends strongly on the relative levels of sulfur and oxygen, along with the form of sulfur present (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 chromium oxide scale and form internal chromium sulfide phases. Sulfidation is enhanced in alloys containing approximately 25% nickel and higher. Nickel and nickel sulfide form a low melting point eutectic phase, which can cause catastrophic damage to the underlying alloy at elevated temperatures. Ferritic stainless steels typically perform better than austenitic steels in oxidizing and reducing environments containing sulfur, since they contain little or nickel and do not form low melting eutectic phases.

Carburization

High levels of carbon-bearing species in the environment can result in undesired carbon diffusion 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 that 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 attack via the formation of deep craters through a complex mechanism that converts solid metal to mixture of graphite and metal particles.

Nitradation

Nitridation can occur in the presence of nitrogen gas. Oxides are generally more stable than nitrides, so in an atmosphere that contains oxygen an oxide scale typically forms. Oxide layers are efficient barriers to nitrogen diffusion, 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. The nitride precipitation can lead to higher strength levels and lower ductility.

Sensitization

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 precipitate 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 solution annealing can restore full ductility.

Fabrication Characteristics

High temperature stainless steels are widely used in the heat treatment/process industries due to their elevated temperature properties and corrosion resistance. As such, they are commonly fabricated into complex structures. With respect to carbon steel, the austenitic stainless steels exhibit a significant difference during fabrication, as they are tougher and tend to work harden rapidly. While this does not alter the general methods used for cutting, machining, and forming, it does affect the specific parameters of those methods.

Cutting and machining the austenitic stainless steels are readily accomplished using standard techniques typically employed for common mild steel, with some modifications. Their cutting behavior can be quite different as 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 the 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 lower hot ductility due to the formation of ferrite. Working at lower temperatures can cause the formation of brittle second phases due to sigma and carbide precipitation. Following hot forming, the workpiece should be cooled rapidly to less than 800˚F (427˚C) to minimize the precipitation of deleterious phases.

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. When filler metal is required, matching compositions are generally used. The elevated alloy contents of these grades can make the weld pool sluggish. If weld pool fluidity is a problem, filler metals such as ER309LSi containing silicon can enhance fluidity.

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 metals with a lower alloy content such as ER308 will increase the amount of ferrite in the weld deposit and reduce the tendency for hot cracking. However, the subsequent dilution of the base metal may decrease the corrosion and heat resistance of the weld if a lower alloy filler metal is used.

The “S” grades are relatively low in carbon. If low carbon is required “L” electrodes such as ER309L can be used. With proper welding practices, sensitization and intergranular corrosion of the heat affected zone are 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, and acid pickling will also remove heat tint. Small pieces can be treated in a bath and larger pieces can be locally pickled using a pickling paste consisting of a mixture of nitric-hydrofluoric acid 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 reasons for annealing these alloys is to produce a recrystallized microstructure with a uniform grain size and for dissolving detrimental chromium carbide or intermetallic 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 and specific cases may require further investigation. When properly annealed, these grades are primarily austenitic at room temperature, but some small quantities of ferrite may be present.

Oxide scale formation is inevitable during air annealing of stainless steel. 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. Chemical removal of scale is generally performed with mixed nitric–hydrofluoric acids. 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, these high temperature grades consist solely of austenite at room temperature and 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 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.

Technical support

New Castle assists users and fabricators in the selection, qualification, installation, operation, and maintenance of high temperature stainless steel. Technical personnel can draw on years of field experience with these grades to help you make the technically and economically correct materials decision. New Castle is prepared to discuss individual applications and to provide data and experience as a basis for selection and application of high temperature stainless steel.

New Castle works closely with its distributors to ensure timely availability of high temperature grades in the sizes and quantities required by the end user. For assistance with technical questions and to obtain top quality high temperature stainless steel, call New Castle at 1-800-349-0023.

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