2205 - Duplex Stainless Steel

(UNS S31803 and S32205)

GENERAL PROPERTIES

2205 alloy is a nitrogen-enhanced duplex stainless steel alloy. The nitrogen serves to significantly improve the corrosion resistance of the alloy; especially in the welded condition.
Earlier duplex alloys have had moderate resistance to general corrosion and chloride stress corrosion cracking, but suffered a substantial loss of properties when used in the as-welded condition. To impart the metallurgical benefits of nitrogen to both improved corrosion performance and as-welded properties, the 2205 alloy is produced to a 0.15% minimum nitrogen content compared to the ASTM range of 0.08- 0.20% for S31803 and 0.14-0.20% for S32205. The minimum Cr, Mo and Ni contents of 2205 alloy (22.0, 3.1 and 5.5% respectively) satisfy the requirements of both the UNS S31803 and S32205 composition specifications. The typical high Cr, Mo and Ni contents of 2205 alloy give it a high PRE_N (Pitting Resistance Equivalent) of 35.8, further enhancing its corrosion resistance. The PRE_N of 2205 alloy exceeds those of types 316L and 317L stainless steels.

When heat-treated properly, the composition of 2205 alloy produces a microstructure that consists of a nearly equal mixture of austenite and ferrite phases as shown in the photomicrograph above right. The microstructure and composition of the 2205 alloy provide corrosion resistance to many environments that is superior to Types 316 or 317, and a minimum yield strength that is more than double that of conventional austenitic stainless steels.

Composition

Composition in Weight Percent per ASTM A 240

Element	S31803	S32205
Carbon	0.030 max	0.030 max
Manganese	2.00 max	2.00 max
Silicon	1.00 max	1.00 max
Chromium	21.0-23.0	22.0-23.0
Nickel	4.5-6.5	4.5-6.5
Molybdenum	2.5-3.5	3.0-3.5
Phosphorus	0.030 max	0.030 max
Sulfur	0.020 max	0.020 max
Nitrogen	0.08-0.20	0.14-0.20
Iron	Balance	Balance

Physical Properties

Property	Value	Units
Density at 72°F (22°C)	7.82 0.283	g/cm^3 lb/in^3
Melting Range	2525°F – 2625°F	1385°C – 1440°C
Thermal Conductivity at 212°F (100°C)	8.4 14.6	BTU/hr·ft·°F W/m·K
Thermal Expansion coefficient at 68-212°F (20-100°C)	7.2 13.0	μ in/in/°F μ m/m/°C
Thermal Expansion coefficient at 68-392°F (20-200°C)	7.5 13.5	μ in/in/°F μ m/m/°C
Thermal Expansion coefficient at 68-572°F (20-300°C)	7.8 14.0	μ in/in/°F μ m/m/°C
Elastic Modulus 72°F (22°C)	29.0 200	10^6 Psi GPa
Poisson's Ratio	0.3	—

The microstructure and phase balance of 2205 alloy have been designed to facilitate the production of pipe and tube products. All 2205 alloy is metallographically examined to ensure that the as-shipped product is essentially free from the presence of detrimental precipitate phases such as sigma.

The 2205 alloy is the most widely used of the duplex stainless steel and is often used in the form of welded pipe or tubular components. The alloy has also been applied as a formed and welded sheet product in environments where resistance to general corrosion and chloride stress corrosion cracking is important.

Specifications

Product Form	ASTM Specification	ASME Specification
Bar	A 182, A 276, A 479	SA-182, SA-276, SA-479
Plate, Sheet, Strip	A 240	SA-240
Pipe (Welded and Seamless)	A 790, A 928	SA-790
Tube (Welded and Seamless)	A 270, A 789	SA-789
Pipe Fittings	A 815	SA-815

MECHANICAL PROPERTIES

Typical Room Temperature Properties

Typical mechanical properties for annealed 2205 alloy material at room temperature are listed below:

Mechanical Properties

Property	ASTM A 240 S31803 minimum	ASTM A 240 S32205 minimum	Typical Plate ≥3/16" (≥4.75 mm)	Typical Sheet <3/16" (<4.75 mm)
Yield Strength	65,000 psi (450 MPa)	65,000 psi (450 MPa)	75,000 psi (515 MPa)	85,000 psi (585 MPa)
Tensile Strength	90,000 psi (620 MPa)	95,000 psi (655 MPa)	110,000 psi (760 MPa)	125,000 psi (860 MPa)
Elongation (% in 2 inches)	25%	25%	35%	30%
Hardness	31 HRc (293 HBN) maximum	31 HRc (293 HBN) maximum	235 HBN	27 HRc

2205 alloy flat rolled products typically exhibit some anisotropy. Typically, the transverse direction is the strongest and least ductile, while about 15 degrees from the rolling direction is the weakest. The adjacent graph shows data for sheet products tested at 15 degree intervals.

The 2205 alloy has been approved for use under Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code (for S31803) to a maximum temperature of 600°F (316°C). Use of S32205 is approved for nuclear construction by Code Case N-741. The strength of the 2205 alloy is indicated by the maximum allowable stress values given in the ASME Boiler and Pressure Vessel Code reproduced below, and compared to values for Type 316L stainless steel.

Maximum Tensile Stress Per ASME code*

Maximum Metal Temperature °F (°C)	S31803 ksi (MPa)	S32205 ksi (MPa)	S31603 ksi (MPa)
100 (40)	25.7 (177)	27.1 (187)	16.7 (115)
200 (100)	25.7 (177)	27.1 (187)	14.2 (96.3)
300 (150)	24.8 (171)	26.2 (181)	12.7 (87.4)
400 (200)	23.9 (165)	25.2 (174)	11.7 (81.2)
500 (250)	23.3 (161)	24.6 (170)	10.9 (76.0)
600 (300)	23.1 (160)	24.3 (168)	10.4 (72.5)

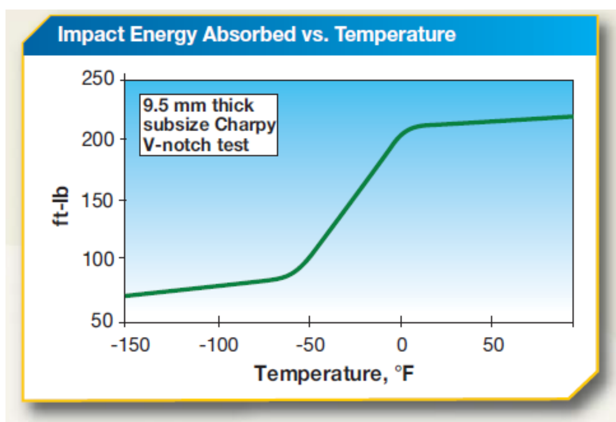
*For use when deformation is not acceptable.

Such relatively high maximum allowable stress values can be used advantageously in process unit design. The stress values that are given below apply to plate, sheet, strip, seamless tubing and pipe products. A factor of 0.85 is applied when considering welded tubing or pipe products.

Impact Properties

Duplex 2205 alloy may undergo a transition from a ductile mode of fracture at higher temperatures to a brittle mode of fracture at lower temperatures when subjected to impact loading. The ductile-to- brittle transition temperature can be substantially increased by exposing the alloy for extended periods of time at temperatures in the range from 650 to 1000°F (343-530°C). Consequently, this temperature range must be avoided in fabrication and service.

Improper welding procedures, such as welding with straight chromium stainless steel filler metals, will increase the susceptibility of the weld to brittle impact behavior. The data presented to the right are from tests conducted on 3/8 inch (0.95 cm) thick 2205 unwelded plate samples in an annealed and rapidly cooled condition.



The 2205 alloy will (for full size specimens) exhibit Charpy impact energies far greater than the 40 ft-lb (54 J) at -40°F (-40°C) minimum specified by ASTM A 923. 2205 alloy also passes the NORSOK minimum impact energy requirement at -50°F (-46°C) of 45J average and 35J single specimen minimum. If specified, this toughness will be demonstrated by test prior to shipment.

Effect of Elevated Temperature on Mechanical Properties An upper temperature limit of 600°F (316°C) has been placed on the use of 2205 alloy in the ASME Boiler and Pressure Vessel Code due to what is known as "885°F (475°C) Embrittlement." This means that the ferrite phase of 2205 alloy may be embrittled after exposure to temperatures from 650 to 1000°F (343-538°C). The 885°F (475°C) embrittlement is reversible by heat treating the alloy at a temperature above 1100°F (590°C). However, another embrittling range exists from about 1200°F (649°C) to 1830°F (1000°C) due to the precipitation of excess phases that are detrimental to both impact and corrosion properties. A full anneal and rapid cooling treatment is required to eliminate the latter form of embrittlement and is also the preferred manner of relieving forming stresses and 885°F (475°C) embrittlement.

Fatigue Resistance

The 2205 alloy shows high resistance to fatigue. Its endurance limit at room temperature is about 45% of its tensile strength. Sheet bending fatigue data are shown to the right.

Elevated Temperature Properties

Test Temperature (°F / °C)	Yield Strength[1] ksi (MPa)	Tensile Strength ksi (MPa)	Elongation[2] (%)
200 / 93	30.2 (208)	75.2 (518)	39.5
400 / 204	26.0 (179)	66.0 (455)	28.0
600 / 316	23.1 (159)	64.2 (443)	26.0
800 / 427	21.2 (146)	62.7 (433)	25.0
1000 / 538	21.0 (145)	61.3 (423)	23.0
1200 / 649	21.1 (146)	54.4 (375)	19.5
1400 / 760	21.1 (146)	37.9 (261)	23.0
1600 / 871	16.2 (112)	22.5 (155)	48.0
1800 / 982	8.0 (55)	11.3 (78)	41.0

[1] 0.2% Offset [2] in 2-inches

CORROSION PROPERTIES

Chloride Stress Corrosion Cracking Resistance

The nickel-free ferritic steels are essentially immune to chloride stress corrosion cracking even in the extremely severe boiling 42% magnesium chloride test. Nickel- containing austenitic stainless steels, on the other hand, are highly susceptible to stress corrosion cracking (SCC). The resistance of austenitic and ferritic stainless steels to chloride stress corrosion cracking has been correlated to the nickel content of the alloys.[1]

Duplex alloys behave in a manner that is a combination of the characteristics of the austenitic and ferritic phases that make up the alloy. Certain elements tend to partition into one of the two primary phases in duplex alloys. For example, the nickel content of the ferrite phase will be lower than that of

the austenite phase relative to the bulk composition.
Consequently, the ferrite phase in 2205 alloy will provide resistance to chloride stress corrosion cracking, making it substantially better than the standard 300 series austenitic stainless steels, as shown by the data to the right. Therefore, duplex stainless steels are often preferred over austenitic stainless steels in applications where chloride SCC is a problem.

Pitting and Crevice Corrosion Resistance

A relative ranking of the resistance to chloride-ion pitting and crevice corrosion can be made by using the procedure described in ASTM Standard G 48 Method B (10% $FeCl_3 \cdot 6H_2O$) and increasing the test temperature until the onset of crevice corrosion attack is observed. The temperature at which attack is first observed is called the critical crevice corrosion temperature and can be used as a relative measure of crevice corrosion resistance. The critical crevice corrosion temperature criterion is useful for ranking alloys but does not necessarily indicate an absolute limiting temperature for the use of a particular alloy in chloride-bearing solutions.

The data provided to the right for annealed plate indicates the superior resistance of the 2205 alloy to chloride-ion crevice corrosion compared to Type 316 and Type 317 stainless steels.

The data to the right show the electrochemical critical pitting temperatures of 2205 alloy and several other stainless steels as measured according to ASTM G 150 using standard and modified test solutions. The critical pitting temperature of 2205alloy was measured to be similar to that of Type 904L and much higher than that of Type 316.

General Corrosion Resistance

The 2205 alloy is resistant to dilute reducing acids and moderate to high concentrations of oxidizing acids. The alloy is resistant to low concentrations of organic acids but should be used with caution in higher concentrations at elevated temperatures. The table to the right compares the corrosion resistance of base metal and welded samples of Type 316 and 2205 alloy in various boiling acids. The corrosion rates that follow are given in units of mils per year (MPY) and millimeters per annum (mm/a).

Intergranular Corrosion

Tests of 2205 alloy in the welded condition indicate that it resists intergranular corrosion as measured by the 16% sulfuric acid-copper sulfate (ASTM A 262 Practice E) test.

FABRICATION AND WELDING

Welding

The 2205 alloy is designed to contain approximately approximately equal amounts of ferrite and austenite in the annealed strip or plate product. Autogenous welding will increase the amount of ferrite present in the weldment and adjacent areas of the base metal. Subsequent annealing will tend to restore the balance of phases in the base metal.

However, an annealed autogenous weld can be expected to contain slightly more ferrite than the corresponding base metal. A fully ferritic weld should be avoided.

Matching filler metals are commercially available to weld the 2205 alloy. Such filler metals (AWS E2209) contain more nickel than the base metal in order to produce a phase balance within the weld that is approximately the same as the base metal. When 2205 alloy is welded to different metals, a filler metal should be chosen that contains a quantity of austenite forming elements that is sufficient to produce a partially or fully austenitic weld. The large, fully ferritic grains that may form in a weld made from ferritic fillers may lower impact ductility at room temperature.

FABRICATION AND WELDING

Heat Treatment

The 2205 alloy should be annealed between 1870 and 2010°F (1020-1100°C) and cooled quickly. Annealing near 2010°F will increase the amount of ferrite present in the microstructure compared to that resulting from annealing near 1870°F. The graph to the right provides additional information.

Forming

The 2205 alloy can be successfully cold-bent and expanded. Greater loads will be required to deform the alloy because of the higher strength of this duplex alloy in comparison to conventional austenitic materials. The ferrite phase within the duplex structure of the 2205 alloy results in an elongation that is less than that of a comparable austenitic stainless steel. The alloy should be bent to more generous bend radii than fully austenitic materials.
A minimum bend radius of at least twice the material thickness should be used.

Furthermore, the degree to which 2205 alloy tubing can be expanded into tubesheets is restricted by the lower tensile elongation of the material in comparison to conventional austenitic materials. The strength of the 2205 alloy is high relative to most tube sheet materials. Consequently, care must be taken to produce tight roller expanded joints between 2205 alloy tubing and other tube sheet materials.

Heavily cold-bent sections should be fully annealed (not just stress-relieved) after bending whenever there is the potential for stress corrosion cracking (SCC) in the service environment. Stress relief heat treatments in the 600 to 1700°F (316- 926°C) range adversely affect the properties of the alloy and should not be considered.

References for Additional Details

(1) Copson, H. R., “Effect of Composition on Stress Corrosion Cracking of Some Alloys Containing Nickel,” Physical Metallurgy of Stress Corrosion Fracture, Interscience Publishers, New York (1959).