New Castle Stainless Plate, LLC

2205 Code Plus Two®

UNS S32205, UNS S31803

General properties

New Castle 2205 Code Plus Two® duplex stainless steel combines excellent resistance to pitting, crevice corrosion, and chloride stress corrosion with high strength. Duplex stainless steels typi-cally have 50-60% austenite in a ferritic matrix, as shown in the photo (austenite is the lighter etched phase). 2205 Code Plus Two provides corrosion resistance in many environments that is superior to Type 317L, and a yield strength that is more than double that of conventional austenitic stainless steel.

The trademark Code Plus Two® indicates the commitment made several years ago not only to meet the requirements for S31803 as established in ASTM and ASME, but also to meet two additional requirements. The first requirement was that nitrogen should be in the 0.14-0.20% range to gain its benefits in higher strength, higher corrosion resistance, greater metallurgical stability, and superior properties after welding. The second requirement was that all material should pass a test for the absence of detrimental intermetallic phases. The tests for this purpose have been formalized as the ASTM A 923 standard test methods.

These special requirements now define a higher quality of 2205, designated S32205. S32205 is dual certifiable as S31803, but represents what the users have come to expect of 2205 steel. The minimum tensile strength of S32205 is slightly higher because of its higher nitrogen. Both S31803 and S32205 are included in the ASTM product specifications.

Design features

- High general corrosion resistance
- Pitting and crevice corrosion resistance superior to 317L austenitic stainless steel
- High resistance to chloride stress corrosion cracking
- High resistance to corrosion fatigue and erosion
- Good sulfide stress corrosion resistance
- High strength
- Excellent impact toughness
- Lower thermal expansion and higher thermal conductivity than austenitic stainless steels
- Good workability and weldability

Applications

- Pressure vessels, tanks, and heat exchangers in the chemical processing industry
- Heat exchangers for the handling of gas and oil
- Effluent scrubbing systems
- Pulp and paper industry digesters, bleaching equipment, stock-handling systems
- Cargo tanks for ships
- Food processing equipment

Chemical Composition (wt%) *Table 1*

	C	Mn	Cr	Ni	Mo	N	Other
Typical	0.02	1.2	22.4	5.6	3.1	0.18	
UNS S31803	≤0.030	≤2.00	21.0-23.0	4.5-6.5	2.5-3.5	...0.08-0.20	
UNS S32205	0.14-0.15	≤2.00	22.0-23.0	4.5-6.5	3.0-3.5	...0.14-0.20	

Microstructure

In the solution annealed condition from about 1925°F, 2205 Code Plus Two duplex stainless steel has a microstructure with about 40-50% ferrite. At high temperatures, above 2000°F, the steel will become increasingly ferritic, becoming fully ferritic at temperatures just below the melting point. Higher nitrogen increases the temperature at which austenite is stable within the duplex structure, and promotes the formation of austenite subsequent to a high temperature exposure such as in the heat-affected zone adjacent to a weld.

Like all duplex stainless steels, 2205 is suscep-tible to precipitation of intermetallic phases, such as sigma phase. Intermetallic phases precipitate in the range of 1100-1825°F, with the most rapid precipitation occurring at about 1600°F. Nitrogen delays but does not prevent the precipitation of intermetallic phases. Intermetallic phases can be highly detrimental to toughness and corrosion resistance. It is prudent to require that 2205 products pass a test for the absence of intermetallic phases, such as those in ASTM A923, or as guaranteed by the definition of Code Plus Two. It is also prudent to qualify welding procedures by a similar test.

Duplex stainless steels are also susceptible to "885-embrittlement," the precipitation of the alpha prime phase in the ferritic portion of the duplex structure. This precipitation occurs between 650-980°F, with the most rapid reaction at 885°F. This form of embrittlement seldom occurs in normal fabrication operations, but it may limit the use of 2205 duplex stainless steel above 600°F in longer-term service.

Mechanical Properties per ASTM A240 *Table 2*

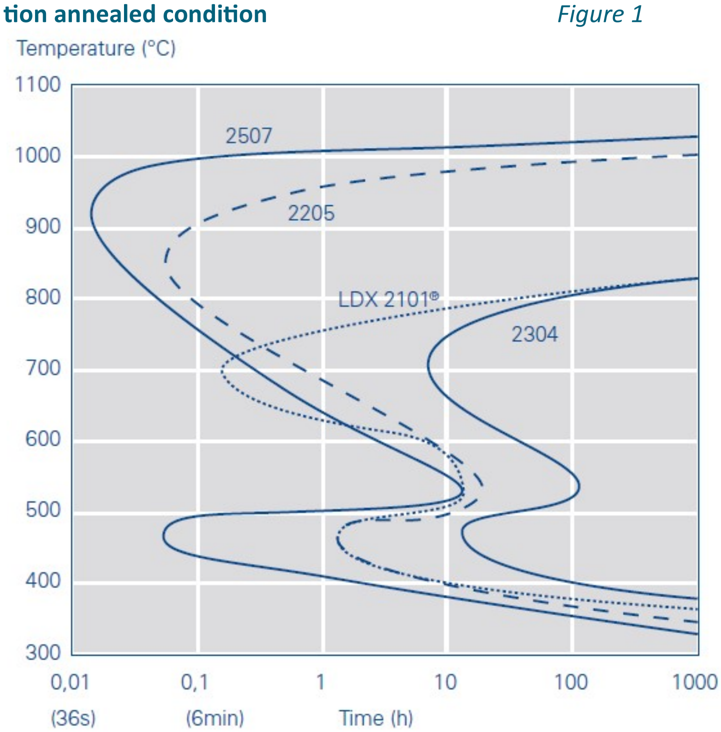
	Typical	Requirement
Yield Strength $R_{p0.2}$ (KSI)	70	65 min
Tensile Strength R_m (KSI)	97	90 min
Elongation (%)	35	25 min
Hardness (Rockwell C)	20	28 max

Physical Properties *Table 3*

	Typical
Density (lb/in^3)	0.282
Modulus of Elasticity (psi)	29×10^6
Coefficient of Thermal Expansion 68-212°F [µin/(in*°F)]	7.22
Thermal Conductivity [BTU/(hr*°F)]	8.7
Thermal Capacity [BTU/(lbm*°F)]	0.119
Electrical Resistivity (µΩ*in)	31.5

The formation of precipitates can embrittle 2205, reducing its ambient temperature ductility and toughness, and can decrease its corrosion resistance. The rate of the precipitation reactions is dependent on the chemical composition of 2205 and other metallurgical factors. Figure 1 shows a Time-Temperature-Precipitation diagram for a 2.25-inch thick 2205 plate with 0.14 percent nitrogen. The curves correspond to an ambient temperature Charpy V-notch impact toughness of 20 ft-lb. Time-temperature combinations to the right of the curve show less than 20 ft-lb of impact toughness.

Reduction of impact toughness to 50% compared to solution annealed condition *Figure 1*



Lowest Temperature at which Corrosion Exceeds 5 mpy *Table 4*

Corrosion Environment	654 SMO®	254 SMO®	904L	Type 316L (2.7 Mo)	Type 304	2205 Code Plus Two®
0.2% Hydrochloric Acid	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling
1% Hydrochloric Acid	203	158	122	86	86p	185
10% Sulfuric Acid	158	140	140	122	—	140
60% Sulfuric Acid	104	104	185	<54	—	<59
96% Sulfuric Acid	86	68	95	113	—	77
85% Phosphoric Acid	194	230	248	203	176	194
10% Nitric Acid	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling
65% Nitric Acid	221	212	212	212	212	221
80% Acetic Acid	>Boiling	>Boiling	>Boiling	>Boiling	212p	>Boiling
50% Formic Acid	158	212	212p	104	$\leq$50	194
50% Sodium Hydroxide	275	239	Boiling	194	185	194
83% Phosphoric Acid + 2% Hydrofluoric Acid	185	194	248	149	113	122
60% Nitric Acid + 2% Hydrochloric Acid	>140	140	>140	>140	>140	>140
50% Acetic Acid + 50% Acetic Anhydride	>Boiling	>Boiling	>Boiling	248	>Boiling	212
1% Hydrochloric Acid + 0.3% Ferric Chloride	>Boiling, p	203ps	140ps	77p	68p	113ps
10% Sulfuric Acid + 2000ppm Cl^- + N_2	149	104	131	77	—	95
10% Sulfuric Acid + 2000ppm Cl^- + SO_2	167	140	122	<<59p	—	<59
WPA1, High Cl^- Content	203	176	122	$\leq$50	<<50	113
WPA2, High F^- Content	176	140	95	$\leq$50	<<50	140

ps = pitting can occur
ps = pitting/crevice corrosion can occur

WPA	P_2O_5	Cl^-	F^-	H_2SO_4	Fe_2O_3	Al_2O_3	SiO_2	CaO	MgO
1	54	0.20	0.50	4.0	0.30	0.20	0.10	0.20	0.70
2	54	0.02	2.0	4.0	0.30	0.20	0.10	0.20	0.70

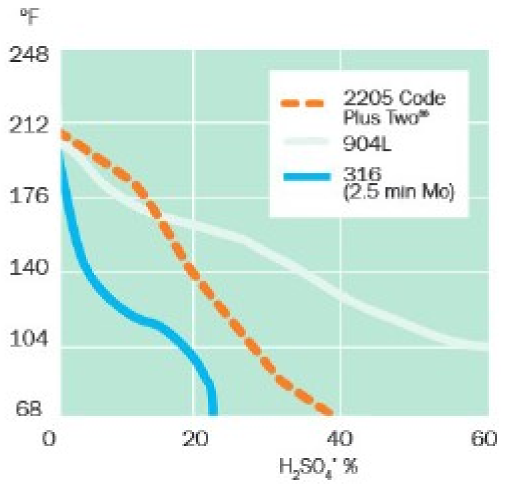
Corrosion resistance

Uniform Corrosion

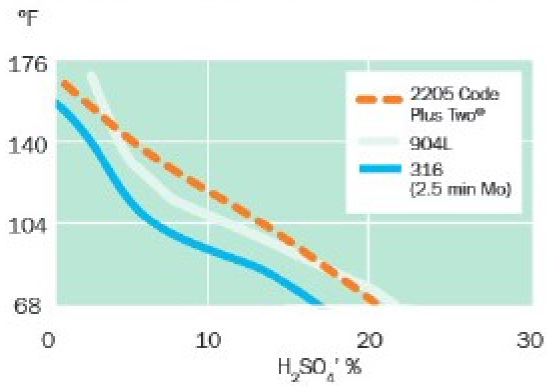
With its high chromium, molybdenum, and nitrogen contents, 2205 Code Plus Two® stainless steel shows corrosion resistance superior to that of 316L or 317L in most environments. An overview of the performance of 2205 in a large number of chemical environments is provided by the Materials Technology Institute (MTI) procedure. This procedure compares materials with standard alloys tested at the same time under identical conditions. The lowest test temperature at which the corrosion rate exceeds 5 mpy is determined. As shown in Table 4, Type 2205+2 outperforms Type 316L (with 2.7 Mo) and some other corrosion-resistant grades in many pure chemical environments, but the effect of minor species must be considered in every real engineering application. In-process coupon tests or pilot plant tests should be conducted for any new application.

In aggressive chemical environments, corrosion resistance of stainless steels under oxidizing conditions generally requires a high chromium content, while reducing conditions require high nickel, as well. Molybdenum increases pitting resistance in halides or other species that may affect the steel's corrosion potential. The high chromium content of 2205 produces good resistance to nitric acid, and to many organic acids and caustic solutions. 2205 will resist some neutral or reducing acids at low

Isocorrosion Curves 4 mpy (0.1mm/yr), in pure sulfuric acid solution *Figure 2*



Isocorrosion Curves 4 mpy (0.1mm/yr), in sulfuric acid solution containing 2000 ppm chlorides *Figure 3*



to moderate concentrations and temperatures. The specific performance will depend on the kind and effect of minor additional chemical species.

Examples of these situations are shown with sulfuric acid solutions in Figures 2 and 3. 2205 will perform better than Type 316L in a solution of pure acid at low concentrations and temperatures, but will not perform as well as 904L. With chloride contamination, the corrosion resistance of all of these stainless steels is reduced, but the high chromium and molybdenum contents of 2205 give performance equal to 904L. The advantage of 2205 in a complex, mildly-reducing acid with many minor chemical species is shown with two phosphoric acid solutions in Table 5. Because 2205 is superior to either Type 316L or 904L in this situation, it is a good candidate for wet process phosphoric acid applications.

Pitting and Crevice Corrosion

The chromium, molybdenum, and nitrogen in 2205

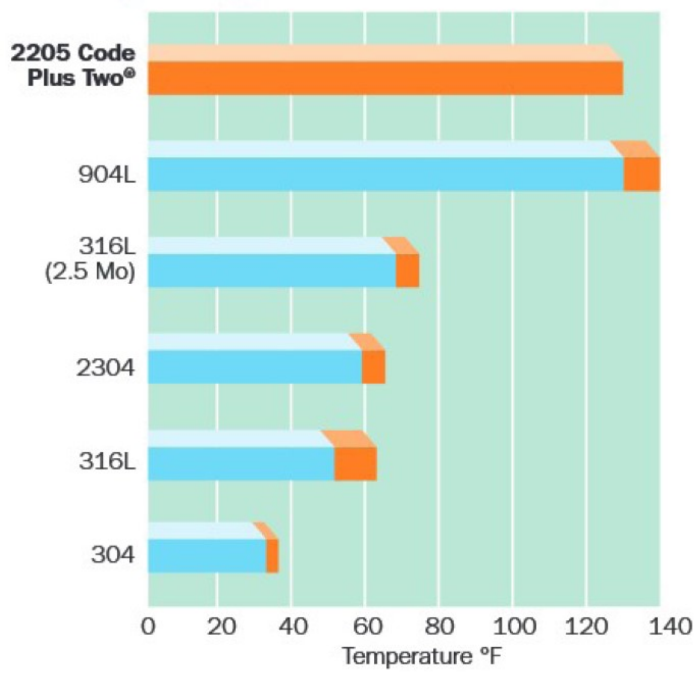
General Corrosion in Wet Process Phosphoric Acids *Table 5*

Grade	Corrosion Rate, ipy Solution A, 140°F	Corrosion Rate, ipy Solution B, 120°F
2205+2	3.1	3.9
316L	>200	>200
904L	47	6.3

Composition, Wt%

	P_2O_5	HCl	HF	H_2SO_4	Fe_2O_4	Al_2O_4	SiO_2	CaO	MgO
Sol A	54.0	0.06	1.1	4.1	0.27	0.17	0.10	0.20	0.70
Sol B	37.5	0.34	1.3	1.72	0.4	0.01	0.3	0.02	-

Critical Pitting Temperature in 1M NaCl Measured Using the Outokumpu Pitting Cell *Figure 4*

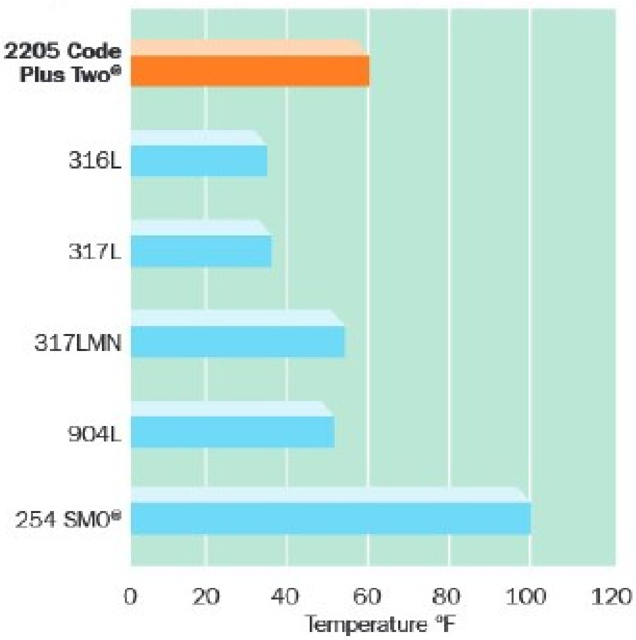


Code Plus Two also provide excellent resistance to pitting and crevice corrosion. There are many different ways to characterize resistance to pitting attack, but one of the most effective is determination of the critical pitting temperature (CPT) using

the ASTM G150 electrochemical method. These tests are extremely accurate and able to detect even the small differences of within-grade variations. As shown in Figure 4, the pitting resistance of 2205 Code Plus Two® is closely comparable to that of the highly alloyed 904L (20 Cr - 25 Ni - 4.5 Mo) and clearly superior to that of 316L.

Another commonly applied comparison test is ASTM G48,

Critical Crevice Corrosion Temperature in 10% $FeCl_3 \cdot 6H_2O$ *Figure 5*



Practice B, the determination of critical crevice temperature (CCT) in 10% ferric chloride (6% FeCl3 or 10% FeCl3 • 6H20). As shown in Figure 5, the crevice corrosion resistance of New Castle 2205 Code Plus Two exceeds that of grades often specified for moderate chloride service such as Type 316L, Type 317L, and 904L.

In service, 2205 Code Plus Two duplex stainless steel has been resistant to pitting attack by seawater on smooth, clean surfaces at ambient conditions, but is not resistant to crevice corrosion when tight crevices are imposed on the surface. Accordingly, 2205 may be considered for seawater applications when economy is important and regular maintenance is possible, but it would not be a good choice for critical applications or where regular maintenance would be difficult.

Sensitization by Thermal Exposure

The very low carbon content of 2205 Code Plus Two in combination with its good corrosion resistance makes the steel essentially immune to intergranular corrosion caused by chromium carbide precipitation. The test practices of ASTM A262 were designed for austenitic stainless steels and do not necessarily give meaningful results when strictly applied to duplex stainless steels such as 2205, especially with regard to a sensitizing heat treatment prior to testing.

The duplex stainless steels are susceptible to loss exposures leading to precipitation of phases other than chromium carbide. When the nitrogen content is too low, retarding the formation of austenite at high temperatures after welding, there is a risk of formation of chromium nitride in the ferrite. As further discussed elsewhere, exposure of a duplex stainless steel to temperatures in the range of 1100-1825°F can cause precipitation of intermetallic phases with substantial loss of corrosion resistance. These precipitates are better detected by tests for critical pitting temperature or critical crevice temperature in strong chloride environments, and not by the ASTM A 262 tests commonly used for sensitization to intergranular corrosion. ASTM A923 was designed to detect the precipitation of intermetallic phases in duplex stainless steels and should be specified as a requirement for 2205.

Very long exposure to temperatures in the 650-980°F range may lead to a loss of toughness resulting from precipitation of alpha prime phase of ferrite of the duplex. This reaction is slow enough that it is detected only after long term service in this temperature range, and not by exposures during fabrication.

Chloride Stress Corrosion Cracking (SCC)

Chloride stress corrosion cracking of austenitic stainless steels can occur when the necessary conditions of temperature, tensile stress, oxygen, and chlorides are present. Types 304L and 316L are especially susceptible to SCC, and even Type 317L is not resistant. However, the duplex nature of 2205 imparts an excellent resistance to SCC. As shown in Table 6, 2205 resists SCC in two sodium chloride-containing environments that provide meaningful results relating to many practical service applications. As with most austenitic stainless steels, 2205 duplex stainless steel is not resistant in boiling 42% magnesium chloride, but this environment is rarely encountered in service. The boiling magnesium chloride test results indicate only that 2205 can be susceptible to SCC in certain specific environments.

Stress Corrosion Cracking Resistance *Table 6*

Grade	Boiling 42% $MgCl_2$	Wick Test	Boiling 25% NaCl
2205+2	**F**	**P**	**P**
254SMO	F	P	P
Type 316L	F	F	F
Type 317L	F	F	F
Alloy 904L	F	P or F	P or F
Alloy 20	F	P	P

(P=Pass, F=Fail)

Sulfide Stress Corrosion Cracking (SSC)

The presence of hydrogen sulfide in a chloride solution often will increase the probability of stress corrosion cracking, resulting in what is known as sulfide stress cracking (SSC). The resistance of duplex stainless steels is a complex function of microstructure, stress, and the environment. Austenite favors resistance and 2205 is usually superior to the martensitic and ferritic stainless steels. For a given environment, performance is also a function of some fraction of the strength; therefore, 2205 may compare favorably with some lower-strength austenitic stainless steels, depending on the chloride concentrations and temperature. Examples of environments that contain hydrogen sulfide include sour oil and gas wells, and refinery condensates. 2205 has been successfully used in sour environments; however, before using any material in such environments, a performance analysis should be undertaken.

A test commonly used to rate materials for SSC resistance is NACE Standard Test Method TM0177. It uses a chloride-acetic acid solution saturated with hydrogen sulfide. In this test, uniaxially loaded 2205 mill-annealed specimens have withstood 500 hours without cracking at an applied stress of 1.3 times the 0.2% offset yield stress. The performance of welds will depend on the weld microstructure and filler metal.

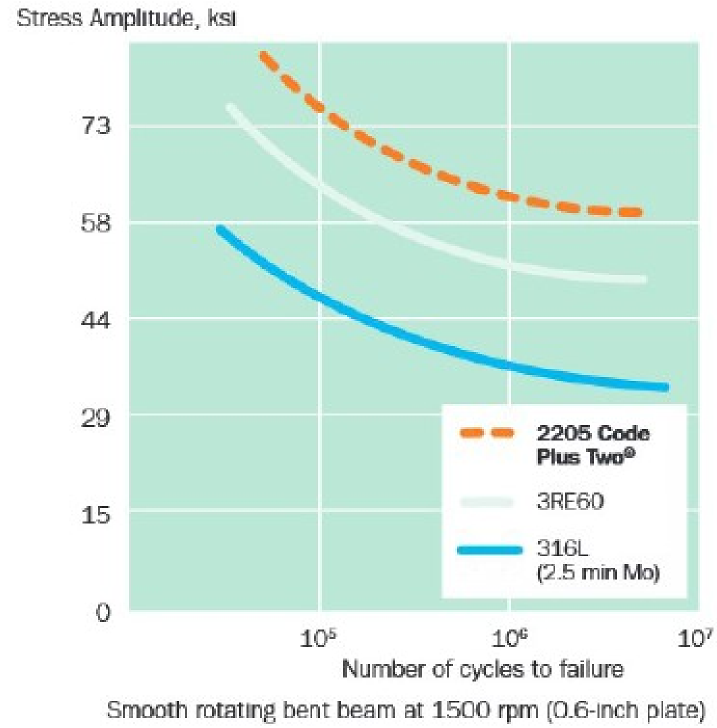
2205 is included in NACE MR0175 (Sulfide Stress Cracking Resistant Metallic Materials for Oil Field Equipment). Solution-annealed 2205 and cold worked 2205 are acceptable for use at any temperature up to 450°F (232°C) in sour environments if the partial pressure of hydrogen sulfide does not exceed 0.3 psi (20 mbar), and if its hardness is not greater than 36 HRC.

Corrosion Fatigue

There are many applications in which processing equipment is subject both to an aggressively corrosive environment and to cyclic loading. Examples may include vibratory bulk handling equipment, press rolls, and motor mounts. The corrosive environment may significantly reduce the effective fatigue strength of a steel. New Castle 2205 Code Plus Two combines high strength and high corrosion resistance to produce high corrosion fatigue strength.

As shown in Figure 6, the S-N curve for New Castle 2205 Code Plus Two shows its superiority to Type 316L and to 3RE60 (a duplex stainless steel with 18% Cr and 2.8% Mo) in synthetic seawater testing.

Corrosion Fatigue in Sythetic Seawater *Figure 6*



Fabrication

New Castle 2205 Code Plus Two is a strong, tough stainless steel. As shown in Table 7, the ASME Boiler and Pressure Vessel Code allows use of 2205 up to 600°F with outstanding strength levels. In some cases it is possible to use this strength for greater economy by thickness reductions from the heavier sections that would be required with Type 316L or Alloy 904L. 2205 should not be used above 600°F to avoid precipitation of undesirable phases that may reduce corrosion resistance and toughness. However, 2205 Code Plus Two steel can be used indefinitely at the moderate temperatures typically encountered in chemical processing and heat exchanger service.

Maximum Allowable Stress Values, ASME Boiler and Pressure Vessel Code Section VIII, Division 1, 2017 Edition 3.5 Safety Factor *Table 7*

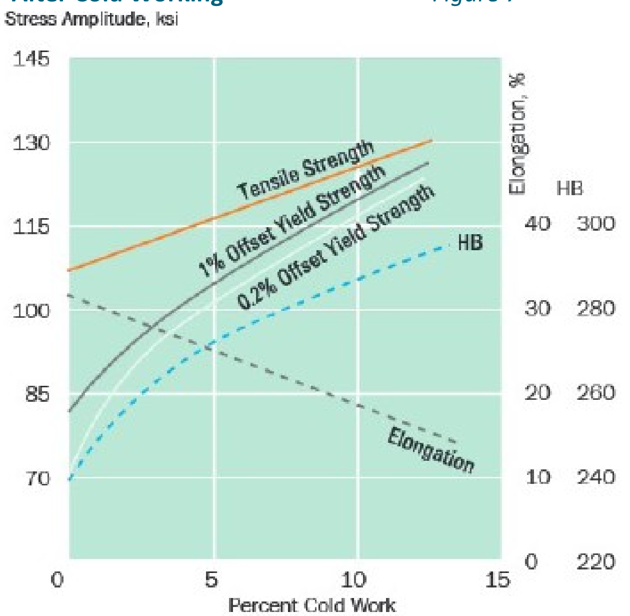
	Stress, ksi				
Grade	-20 to 100°F	300°F	400°F	500°F	600°F
2205+2	25.7	24.8	23.9	23.3	23.1
316L	16.7	16.7	15.7	14.8	14.0
904L	20.3	15.1	13.8	12.7	11.9
Alloy G	23.3	23.3	23.3	23.3	22.7

Cold Forming

New Castle 2205 Code Plus Two is readily sheared and cold formed on equipment suited to working stainless steels. However, because of the high strength and rapid work hardening of 2205, forces substantially higher than those for austenitic steels are required to cold form 2205. Figure 7 shows the mechanical properties as a function of cold working. Also because of the high strength, a somewhat larger allowance must be made for springback.

Mechanical Properites of 2205

After Cold Working *Figure 7*



Hot Forming

Forming below 600°F is recommended whenever possible. When hot forming is required, the workpiece should be heated uniformly and worked in the range of 1750-2250°F. 2205 is quite soft at these temperatures and is readily formed. Above this range, 2205 is subject to hot tearing. Immediately below this range, the austenite becomes substantially stronger than the ferrite and may cause cracking, a particular danger to “cold” edges. Below 1700°F there can be rapid formation of intermetallic phases because of the combination of temperature and deformation. Whenever hot forming is done, it should be followed by a full solution anneal at 1900°F minimum and rapid quench to restore phase balance, toughness, and corrosion resistance. Stress relieving is not required or recommended; however, if it must be performed, the material should receive a full solution anneal at 1900°F minimum, followed by rapid cooling or water quenching.

Heat Treatment

New Castle 2205 Code Plus Two should be annealed at 1900° F minimum, followed by rapid cooling, -ideally by water quenching. This treatment applies to both solution annealing and stress relieving. Stress relief treatments at any lower temperature carry the risk of precipitation of detrimental intermetallic phases.

Machining

With high-speed steel tooling, 2205 may be machined at the same feeds and speeds as Type 316L. When carbide tooling is used, cutting speeds should be reduced by about 20% relative to the speeds for Type 316L. Powerful machines and rigid mounting of tools and parts are essential.

Welding

New Castle 2205 Code Plus Two possesses good weldability. The goal of welding 2205 is that the weld metal and heat-affected zone (HAZ) retain the corrosion resistance, strength, and toughness of the base metal. The welding of 2205 is not difficult, but it is necessary to qualify all welding procedures. 2205 Code Plus Two can be welded by: GTAW (TIG); GMAW (MIG); SMAW (“stick” electrode); SAW; FCW; and PAW. Below are some general guidelines for welding 2205.

1.) As with all stainless steels, good joint preparation, alignment, and cleaning are essential for good-quality welds.

2.) Preheating of 2205 is not necessary or desirable unless it is used only to prevent condensation, or in certain unusual cases involving connecting very light sections to very heavy sections.

3.) Hot cracking is not impossible but is much less likely to occur with 2205 than with austenitic materials.

4.) Heat input should be sufficient to avoid excessively ferritic welds and heat-affected zones resulting from very rapid quenching by the base plate. Heat input should be low enough that the total time for the HAZ in the 1300-1800°F range will not be sufficient for precipitation of intermetallic phases.

5.) Weld zones should be clean before welding and well shielded by inert gas, typically dry argon, during welding. Post-weld cleaning by chemical or mechanical plus chemical means for removal of heat tint, weld spatter, or other contamination is strongly recommended.

6.) The material should be allowed to cool to below 300°F between welding passes.

7.) Welding procedures should be qualified for primary welds and permitted repairs, using tests such as those in ASTM A 923 for qualification. Welding should be performed only by welders qualified for 2205.

8.) Post-weld heat treatment is not normally necessary. If required, it should follow the heat treatment requirements discussed above.

Welding Consumables

As shown in Table 8, the weld filler metal for 2205 is designated as 2209 and is overalloyed with 9% nickel to produce welds that have, in the as-welded condition, phase balance, strength, and corrosion resistance similar to the base metal.

2205 is readily welded to carbon steel, alloy steels, or low-carbon austenitic stainless steels using a low-carbon austenitic stainless steel filler metal with molybdenum content intermediate to the two dissimilar metals. The filler metal 309 MoL has been found to be an effective and versatile filler for dissimilar welds.

Further information on the welding of 2205 is provided in the brochure, "How to Weld Type 2205 Code Plus Two® Duplex Stainless Steel." This booklet is available through your local New Castle sales representative.

Cleaning and passivation

New Castle 2205 Code Plus Two mill products are delivered with a surface that has been cleaned of oxide, embedded iron, and other foreign material. For maximum corrosion resistance, that cleanliness must be maintained or restored after handling or fabrication. The surface may be contaminated by iron from handling equipment, shears, dies, work tables, or other metal equipment. Other sources of contamination include weld slag, weld spatter, heat tint, forming lubricants, dirt, and paint. To obtain maximum corrosion resistance, the steel should be acid cleaned per the guidelines in ASTM A380 and A967.

Welding Consumables *Table 8*

Product Form	AWS	Chemistry. Wt %					FNA
		C	Cr	Ni	Mo	N	
Electrode	E2209-16	0.02	23.0	9.5	3.0	0.15	30-60
Wire	ER2209	0.02	22.5	8.0	3.0	0.15	30-60
Flux Cored Wire	E2209T1-	0.03	23.0	9.0	3.1	0.16	30-60

Technical Support

New Castle assists end users and fabricators in the selection, qualification, installation, operation, and maintenance of New Castle 2205 Code Plus Two duplex stainless steel.   New Castle, can draw on years of field experience with 2205 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 2205 Code Plus Two.

New Castle works closely with its distributors to ensure timely availability of 2205 in the sizes, and quantities required by the end user. For assistance with technical questions and to obtain top quality 2205 Code Plus Two, please call New Castle at 1-800-349-0023.

New Castle

Stainless Plate, LLC