outokumpu
high performance stainless steel

North American Version
Imperial Units

# 2205 Code Plus Two®
# UNS S32205, S31803

## 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

## Product forms available

- Plate
- Sheet, KBR Wide Sheet, and Strip
- Pipe, Tubing, and Fittings
- Bar and Billet

## Applications

- Pressure vessels, tanks, piping, and heat exchangers in the chemical processing industry
- Piping, tubing, and heat exchangers for the handling of gas and oil
- Effluent scrubbing systems
- Pulp and paper industry digesters, bleaching equipment, stock-handling systems
- Rotors, fans, shafts, and press rolls requiring combined strength and corrosion resistance
- Cargo tanks for ships and trucks
- Food processing equipment

## General properties

Outokumpu 2205 Code Plus Two® duplex stainless steel combines excellent resistance to pitting, crevice corrosion, and chloride stress corrosion with high strength. Duplex stainless steels typically have 50-60% austenite that has formed in a ferritic matrix, as shown in the photo to the right (austenite is the lighter etched phase).

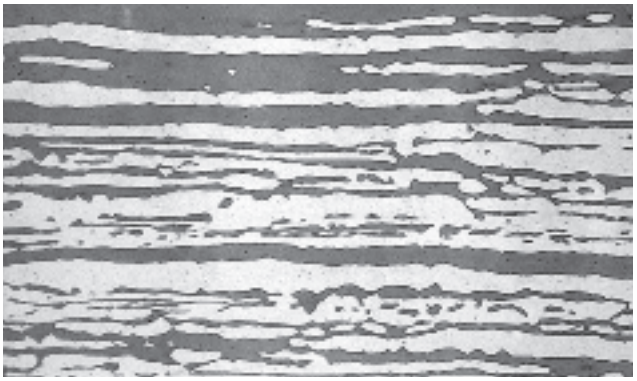
## Specifications

**UNS S32205, S31803 (wrought products)**
**UNS J92205 (cast products)**

| | ASTM | ASME |
|---|---|---|
| Plate, Sheet, Strip | A 240, A 480 | SA-240, SA-480 |
| Bar, Billet | A 276, A 479 | SA-479 |
| Pipe, Tubing | A 789, A 790, A 928 | SA-789, SA-790 |
| Forgings, Fittings | A 182, A 815 | SA-182, SA-815 |
| Castings | A 890 | |
| Testing | A 923 | |

ASME/ANSI B16.34 for A 182, A 240, A 479, A 789, A 790
ASME/ANSI B16.5, ASME/ANSI B31.1 Code Case 153
ASME/SFA 5.4, SFA 5.9, and SFA 5.22 P No.10H, Group 1
AWS/A5.4 E 2209-XX, A5.9 ER 2209, A5.22 E 2209T0-X
API 650
NACE MR0 175/ISO 15 156
ANSI/NSF 61
Tested per requirements of 3A Sanitary Standards and approved by USDA

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 developed by Outokumpu for this purpose have been formalized as the ASTM A 923 standard test method.



Typical Duplex Microstructure in 3⁄8-inch Plate, 500x.

### Composition, wt. pct.

Table 1

| Element | 2205 Code Plus Two® | ASTM S32205 | ASTM S31803 |
|---|---|---|---|
| Carbon | **0.020** | 0.030 max | 0.030 max |
| Chromium | **22.1** | 22.0-23.0 | 21.0-23.0 |
| Nickel | **5.6** | 4.5-6.5 | 4.5-6.5 |
| Molybdenum | **3.1** | 3.0-3.5 | 2.5-3.5 |
| Nitrogen | **0.18** | 0.14-0.20 | 0.08-0.20 |
| Phosphorus | **0.025** | 0.035 max | 0.035 max |
| Manganese | **1.45** | 2.00 max | 2.00 max |
| Sulfur | **0.001** | 0.020 max | 0.020 max |
| Silicon | **0.45** | 1.00 max | 1.00 max |
| Iron | **Balance** | Balance | Balance |

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.

# Structure

In the solution annealed condition from about 1925°F, 2205 Code Plus Two duplex stainless steel has a microstructure with about 40-50% ferrite. Grain size (expressed as a lamellar spacing) is fine, usually about 2-4 x 10-4 inch (5-10 µm), depending on product form.

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, thereby facilitating 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 susceptible to precipitation of intermetallic phases, usually referred to as sigma phase, although other intermetallic phases may occur. Intermetallic phases precipitate in the range of 1300-1800°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 all mill products of 2205 pass a test for the absence of intermetallic phases, such as those in ASTM A 923, or as guaranteed by the definition of Code Plus Two. It is also prudent to qualify welding procedures by a similar test.

### Characteristic Temperatures

Table 2

| | Temperature °F |
|---|---|
| Solidification Range | 2630-2525 |
| Scaling Temperature in Air | 1830 |
| Sigma Phase Formation | 1300-1800 |
| Carbide Precipitation | 840-1470 |
| 885-Embrittlement | 650-980 |
| Hot Forming | 2250-1750 |
| Solution Annealing | 1900 min, water quench |
| Stress Relief Annealing | 1900 min, water quench |

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.

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 shave less than 20 ft-lb of impact toughness.

### Mechanical Properties at Room Temperature

Table 3

| | ASTM A 240 | Typical |
|---|---|---|
| Yield Strength (0.2%), ksi | 65 min. | 74 |
| Tensile Strength, ksi | 90 min. (95 min. for S32205) | 105 |
| Elongation, % | 25 min. | 30 |
| Hardness HB | 293 max. | 256 |

### Tensile Properties at Elevated Temperatures

Table 4

| Temperature °F | 122 | 212 | 392 | 572 |
|---|---|---|---|---|
| Yield Strength (0.2%), ksi | 60 | 52 | 45 | 41 |
| Tensile Strength, ksi | 96 | 90 | 83 | 81 |

### Physical Properties

Table 5

| Temperature °F | 68 | 212 | 392 | 572 |
|---|---|---|---|---|
| Density lb/in$^3$ | 0.278 | — | — | — |
| Modulus of Elasticity psi x $10^6$ | 27.6 | 26.1 | 25.4 | 24.9 |
| Linear Expansion (68°F-T) $10^{-6}$/°F | — | 7.5 | 7.8 | 8.1 |
| Thermal Conductivity Btu/h ft°F | 8.7 | 9.2 | 9.8 | 10.4 |
| Heat Capacity Btu/lb/°F | 0.112 | 0.119 | 0.127 | 0.134 |
| Electrical Resistivity in x $10^{-6}$ | 33.5 | 35.4 | 37.4 | 39.4 |



### Time-Temperature-Precipitation Diagram for 2205 Plate with 0.14 N

Figure 1

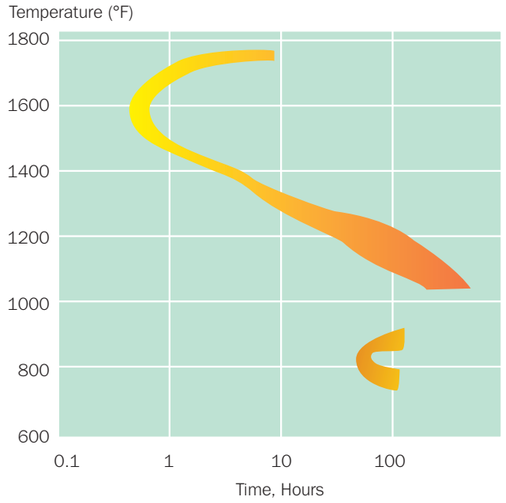



**Fig. 1** The curve corresponds to an ambient temperature Charpy V-notch impact toughness of 20 ft-lb

# Corrosion resistance

## Chemical 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 6, 2205 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.

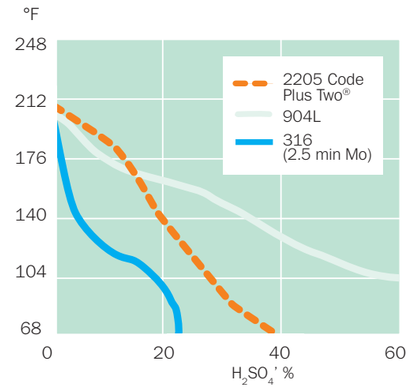
In strong chemical environments, corrosion resistance of stainless steels under oxidizing conditions generally requires a high chromium content, while reducing conditions require high nickel, as well.

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 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 illustrated with two phosphoric acid solutions in Table 7. Because 2205 is substantially better than either Type 316L or 904L in this situation, it is a good candidate for wet process phosphoric acid applications.

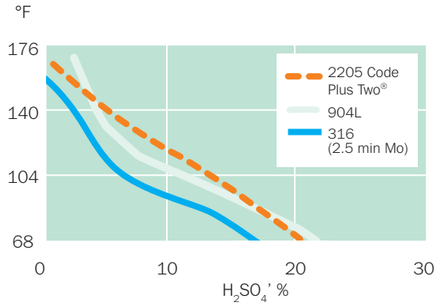
### Isocorrosion Curves 4 mpy (0.1 mm/yr), in pure sulfuric acid solution

Figure 2




### Isocorrosion Curves 4 mpy (0.1 mm/yr), in sulfuric acid solution containing 2000 ppm chloride

Figure 3




## Pitting and Crevice Corrosion

The chromium, molybdenum, and nitrogen in 2205 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 newest and most effective is determination of the critical pitting temperature (CPT) using the electrochemical methods developed by Outokumpu and adopted as ASTM G 150. 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 G 48, Practice B, the determination of critical crevice temperature (CCT) in 10% ferric chloride (6% $FeCl_3$ or 10% $FeCl_3 \cdot 6H_2O$). As shown in Figure 5, the crevice corrosion resistance of Outokumpu 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.

## Lowest Temperature (°F) at Which the Corrosion Rate Exceeds 5 mpy

Table 6

| Corrosion Environment | 654 SMO® | 254 SMO® | 904L | Type 316L (2.7 Mo) | Type 304 | Outokumpu 2507 | 2205 Code Plus Two® | Outokumpu 2304 |
|---|---|---|---|---|---|---|---|---|
| 0.2% Hydrochloric Acid | >Boiling | >Boiling | >Boiling | >Boiling | >Boiling | >Boiling | **>Boiling** | >Boiling |
| 1% Hydrochloric Acid | 203 | 158 | 122 | 86 | 86p | >Boiling | **185** | 131 |
| 10% Sulfuric Acid | 158 | 140 | 140 | 122 | — | 167 | **140** | 149 |
| 60% Sulfuric Acid | 104 | 104 | 185 | <54 | — | <57 | **<59** | <<55 |
| 96% Sulfuric Acid | 86 | 68 | 95 | 113 | — | 86 | **77** | 59 |
| 85% Phosphoric Acid | 194 | 230 | 248 | 203 | 176 | 203 | **194** | 203 |
| 10% Nitric Acid | >Boiling | >Boiling | >Boiling | >Boiling | >Boiling | >Boiling | **>Boiling** | >Boiling |
| 65% Nitric Acid | 221 | 212 | 212 | 212 | 212 | 230 | **221** | 203 |
| 80% Acetic Acid | >Boiling | >Boiling | >Boiling | >Boiling | 212p | >Boiling | **>Boiling** | >Boiling |
| 50% Formic Acid | 158 | 212 | 212p | 104 | ≤50 | 194 | **194** | 59 |
| 50% Sodium Hydroxide | 275 | 239 | Boiling | 194 | 185 | 230 | **194** | 203 |
| 83% Phosphoric Acid + 2% Hydrofluoric Acid | 185 | 194 | 248 | 149 | 113 | 140 | **122** | 95 |
| 60% Nitric Acid + 2% Hydrochloric Acid | >140 | 140 | >140 | >140 | >140 | >140 | **>140** | >140 |
| 50% Acetic Acid + 50% Acetic Anhydride | >Boiling | >Boiling | >Boiling | 248 | >Boiling | 230 | **212** | 194 |
| 1% Hydrochloric Acid + 0.3% Ferric Chloride | Boiling, p | 203ps | 140ps | 77p | 68p | 203ps | **113ps** | 68p |
| 10% Sulfuric Acid + 2000ppm Cl- + $N_2$ | 149 | 104 | 131 | 77 | — | 122 | **95** | <55 |
| 10% Sulfuric Acid + 2000ppm $Cl^-$ + $SO_2$ | 167 | 140 | 122 | <<59p | — | 104 | **<59** | <<50 |
| WPA1, High $Cl^-$ Content | 203 | 176 | 122 | ≤50 | <<50 | 203 | **113** | 86 |
| WPA2, High $F^-$ Content | 176 | 140 | 95 | ≤50 | <<50 | 167 | **140** | 95 |

bp = boiling point. p = pitting.
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 |

## General Corrosion in Wet Process Phosphoric Acids

Table 7

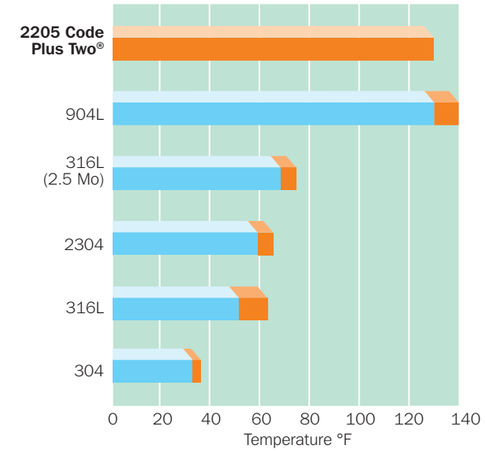
| Grade | Corrosion Rate, ipy Solution A, 140°F | Solution B, 120°F |
|---|---|---|
| **2205 Code Plus Two®** | **3.1** | **3.9** |
| 316L | >200 | >200 |
| 904L | 47 | 6.3 |

**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 | 27.5 | 0.34 | 1.3 | 1.72 | 0.4 | 0.01 | 0.3 | 0.02 | — |

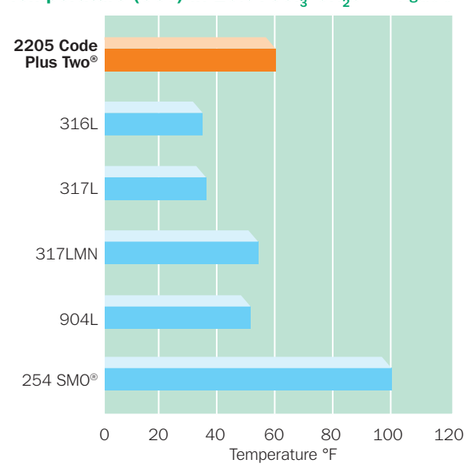
## Critical Pitting Temperature in 1M NaCl Measured Using the Outokumpu Pitting Cell

Figure 4




## Critical Crevice Corrosion Temperature (CCT) In 10% $FeCl_3 \cdot 6H_2O$

Figure 5




## Sensitization by Thermal Exposure

The very low carbon content of 2205 Code Plus Two in combination with its generally very good corrosion resistance make the steel essentially immune to intergranular corrosion caused by chromium carbide precipitation. The test practices of ASTM A 262 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 the issue of a sensitizing 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 A 923 was designed to detect the precipitation of intermetallic phases in duplex stainless steels and should be specified as a requirement for all 2205 mill products.

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 service in this temperature range, and not by exposures during fabrication. So its effect is avoided by the prohibition of the use of duplex stainless steels in the temperature range.

## 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. Because these conditions are not easily controlled and are often characteristic of the operating environment, SCC has sometimes been a barrier to the use of stainless steels. 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 8, 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 will not resist 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.

## Sulfide Stress Corrosion Cracking (SSC)

The presence of hydrogen sulfide in a chloride solution often will increase its stress corrosion-promoting capability, resulting in what is known as hydrogen or sulfide stress cracking (SSC). Materials that have high strength and contain martensite or ferrite would generally be susceptible to cracking at lower temperatures and chloride levels than they would in the absence of hydrogen sulfide. The resistance of duplex

### Stress Corrosion Cracking Resistance

Table 8

| Grade | Boiling 42% $MgCl_2$ | Wick Test | Boiling 25% NaCl |
|---|---|---|---|
| **2205 Code Plus Two®** | **F** | **P** | **P** |
| 254 SMO® | 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)

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 which 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), the yield strength of the material is no greater than 160 ksi (1100 MPa), and if its hardness is not greater than 36 HRC.

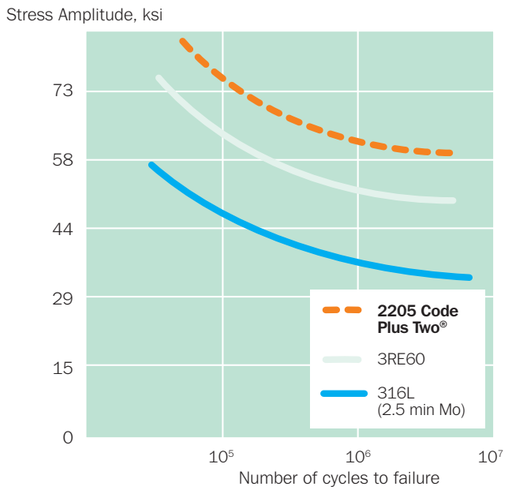
### Corrosion Fatigue

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. Outokumpu 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 Outokumpu 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 Synthetic Seawater

Figure 6




Smooth rotating bent beam at 1500 rpm (0.6-inch plate)

# Fabrication

Outokumpu 2205 Code Plus Two is a strong, tough stainless steel. As shown in Table 9, the ASME Boiler and Pressure Vessel Code allows use of 2205 up to 600°F with outstanding strength levels. In many constructions it is possible to use this strength for greater economy by downgauging from the heavier sections that would be required with Type 316L or Alloy 904L. 2205 should not be used above 600°F so that formation of undesirable phases that may reduce corrosion resistance and toughness may be avoided. 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, 1999 Addenda, 3.5 Safety Factor

Table 9

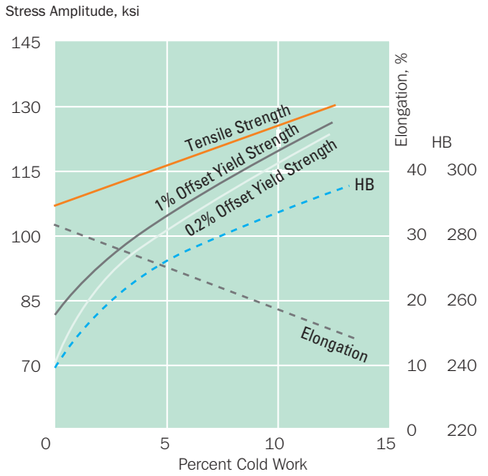
| Grade | Stress, ksi | | | | |
|---|---|---|---|---|---|
| | -20 to 100°F | 300°F | 400°F | 500°F | 600°F |
| **2205 Code Plus Two®** | **25.7** | **24.8** | **23.9** | **23.3** | **23.1** |
| 316L | 16.7 | 16.7 | 15.7 | 14.8 | 14.0 |
| 904L | 20.3 | 15.1 | 13.8 | 12.7 | 11.9 |
| Alloy G | 23.3 | 23.3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

### Cold Forming

Outokumpu 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 amount of cold working. Also because of the high strength, a somewhat larger allowance must be made for springback.

### Mechanical Properties 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

Outokumpu 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 or nonmetallic 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

Outokumpu 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 design welding procedures:

2205 Code Plus Two can be welded by: GTAW (TIG); GMAW (MIG); SMAW ("stick" electrode); SAW; FCW; and PAW. Here are some general guidelines for a good welding procedure:

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

Table 10

| Product Form | Designation | | Typical composition, % | | | | | Ferrite |
|---|---|---|---|---|---|---|---|---|
| | Outokumpu | AWS | C | Cr | Ni | Mo | N | FNA |
| Electrode | 2205 AC/DC | E 2209-17 | 0.2 | 23.0 | 9.5 | 3.0 | 0.15 | 30 |
| | 2205 PW | E 2209-17 | 0.2 | 22.5 | 9.5 | 3.1 | 0.15 | 30 |
| | 2205 basic | E 2209-15 | 0.2 | 23.0 | 9.5 | 3.1 | 0.15 | 30 |
| Wire | 2205 | — | 0.2 | 22.5 | 8.0 | 3.0 | 0.16 | 45 |
| Flux Cored Wire | 2205 | E 2209 T1-1 | 0.3 | 23.0 | 9.0 | 3.1 | 0.15 | 35 |

### Welding Consumables

Avesta Welding provides wires, coated electrodes, fluxes, and pickling pastes all formulated to produce excellent results when welding Outokumpu 2205 Code Plus Two. For these products, call Avesta Welding at 1-800-441-7343.

As shown in Table 10, the "matching" filler metal for 2205 is overalloyed with 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 for the filler metal a low-carbon austenitic stainless steel with molybdenum content intermediate to the two dissimilar metals. Outokumpu P5 (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 Outokumpu sales representative.

### Cleaning and passivation

Outokumpu 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. Guidelines for cleaning procedures are provided in ASTM A 380 and A 967.

# Technical support

Outokumpu assists users and fabricators in the selection, qualification, installation, operation, and maintenance of Outokumpu 2205 Code Plus Two duplex stainless steel. Technical personnel, supported by the research laboratory of Outokumpu, can draw on years of field experience with 2205 to help you make the technically and economically correct materials decision.

Outokumpu is prepared to discuss individual applications and to provide data and experience as a basis for selection and application of 2205 Code Plus Two.

Outokumpu works closely with its distributors to ensure timely availability of 2205 in the forms, sizes, and quantities required by the user. For assistance with technical questions and to obtain top quality 2205 Code Plus Two, call Outokumpu at 1-800-833-8703.

1082EN, Itasca, USA. October 2013.

# Working towards forever.

We work with our customers and partners
to create long lasting solutions for the tools
of modern life and the world's most critical problems:
clean energy, clean water and efficient infrastructure.
Because we believe in a world that lasts forever.

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