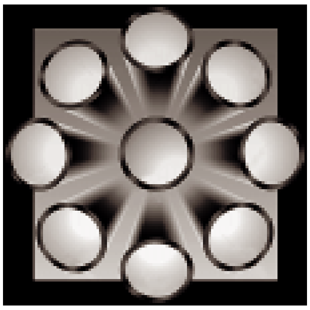

Seamless tube

Sandvik SAF 2205

SANDVIK Steel

S-1874-ENG May 2000 • Cancels all previous editions

Sandvik SAF 2205™ is a duplex stainless steel (austenitic-ferritic). It is characterised by:

- *high resistance to stress corrosion cracking in chloride-bearing environments*
- *high resistance to stress corrosion cracking in environments containing hydrogen sulphide*
- *high resistance to general corrosion, pitting and crevice corrosion*
- *high resistance to erosion corrosion and corrosion fatigue*
- *high mechanical strength – roughly twice the proof strength of austenitic stainless steels*
- *physical properties that offer design advantages*
- *good weldability*

CHEMICAL COMPOSITION (NOMINAL), %

C max	Si max	Mn max	P max	S max	Cr	Ni	Mo	N
0.030	1.0	2.0	0.030	0.015	22	5	3.2	0.18

STANDARDS

Type of steel

UNS S31803, UNS S32205 *
EN 1.4462 **
EN name X 2 CrNiMoN 22-5-3 **
W.-Nr. 1.4462
DIN X 2 CrNiMoN 22 5 3
AFNOR Z 2 CND 22-05-03
SS 2377

Product standards

Seamless tube: NFA 49-217
Seamless and welded tube: ASTM A789
Seamless and welded pipe: ASTM A790
Flanges and valves: ASTM A182
Fittings: ASTM A182; A815
Plate, sheet and strip: ASTM A240, EN 10088-2 **
Bars and shapes: ASTM A276, EN 10088-3 **

Approvals

Approved by the American Society of Mechanical Engineers (ASME) for use in accordance with ASME Boiler and Pressure Vessel Code, section VIII, div. 1 and section VIII, div. 2, Case 2067-2

** Approval for inclusion in ASTM A789, A790 and A928 is pending.*

*** According to EN 10088, valid for sheet/plate, strip, semifinished products, bars, rods and sections (not for pressure purpose).*

VdTÜV-Werkstoffblatt 418 (Ferritisch-austenitischer Walz- und Schmiedestahl)
NACE MR 0175 (sulphide stress cracking resistant material for oil field equipment)
NGS 1606 (Nordic rules for application) valid for Sandvik SAF 2205 made by Sandvik
DnV (Approval of Seamless Ferritic/Austenitic Stainless Steel Tubes and Pipes in Quality Sandvik SAF 2205)
ASME B31.3 Chemical Plant and Petroleum Refinery Piping

FORMS OF SUPPLY

Seamless tube and pipe– Finishes and dimensions

Seamless tube and pipe in Sandvik SAF 2205 is supplied in dimensions up to 260 mm outside diameter. The delivery condition is either solution annealed and white pickled, or solution annealed in a bright annealing process. They can also be delivered cold-worked without subsequent heat treatment.

Other forms of supply

- Welded tube and pipe
- Fittings and flanges
- Wire electrodes and filler wire/rods
- Covered electrodes
- Strip electrodes and flux for surfacing
- Strip, annealed or cold-rolled to different degrees of hardness
- Bar steel
- Plate, sheet and wide strip
- Forged products
- Cast products

MECHANICAL PROPERTIES

The following values apply to material in the solution annealed condition. Tube and pipe with wall thicknesses above 20 mm (0.787 inch) may have slightly lower values. For seamless tubes with a wall thickness <4 mm we can guarantee proof strength ($R_{p0.2}$) values that are 10% higher than those listed below at 20°C (68°F) as well as those listed at higher temperatures. More detailed information can be supplied on request.

At 20°C (68°F)

Tube and pipe with wall thickness max. 20 mm (0.79 inch)

Metric units

Proof strength $R_{p0.2}$ [a] MPa min.	$R_{p1.0}$ [a] MPa min.	Tensile strength R_m MPa	Elong. A [b] % min.	Elong. $A_{2"}$ % min.	Hardnesss HRC max.
450	500	680-880	25	25	28

Imperial units

Proof strength $R_{p0.2}$ [a] ksi min.	$R_{p1.0}$ [a] ksi min.	Tensile strength R_m ksi	Elong. A [b] % min.	Elong. $A_{2"}$ % min.	Hardnesss HRC max.
65	73	99-128	25	25	28

1 MPa = 1 N/mm²

a) $R_{p0.2}$ and $R_{p1.0}$ correspond to 0.2% and 1.0% offset yield strength, respectively.

b) Based on $L_0 = 5.65\sqrt{S_0}$, where L_0 is the original gauge length and S_0 the original cross-section area.

The hardness HRC is maximum 28.

Seamless cold-worked tube and pipe

Intended for oil and gas production

Proof strength $R_{p0.2}$ MPa min.	ksi min.	Tensile strength R_m MPa min.	ksi min.	Elong. $A_{2"}$ % min.
895	130	965	140	10

Impact strength

Sandvik SAF 2205 possesses good impact strength both at room temperature and at low temperatures, as is evident from figure 1. The values apply for standard Charpy-V specimens (10 x 10 mm, 0.39 x 0.39 inch).

The impact strength of welded Sandvik SAF 2205 is also good, although the impact strength values in the as-welded condition are slightly lower than for weld-free material. Tests have shown that the impact strength of material welded by means of gas-shielded arc welding is good in both the weld metal and the heat-affected zone down to -50°C (-58°F). At this temperature, the impact strength is a minimum of 27J (20 ft lb). If very high impact strength requirements are made on the weld metal at low temperatures, solution annealing is recommended. This restores the impact strength of the weld metal to the same level as that of the parent metal.

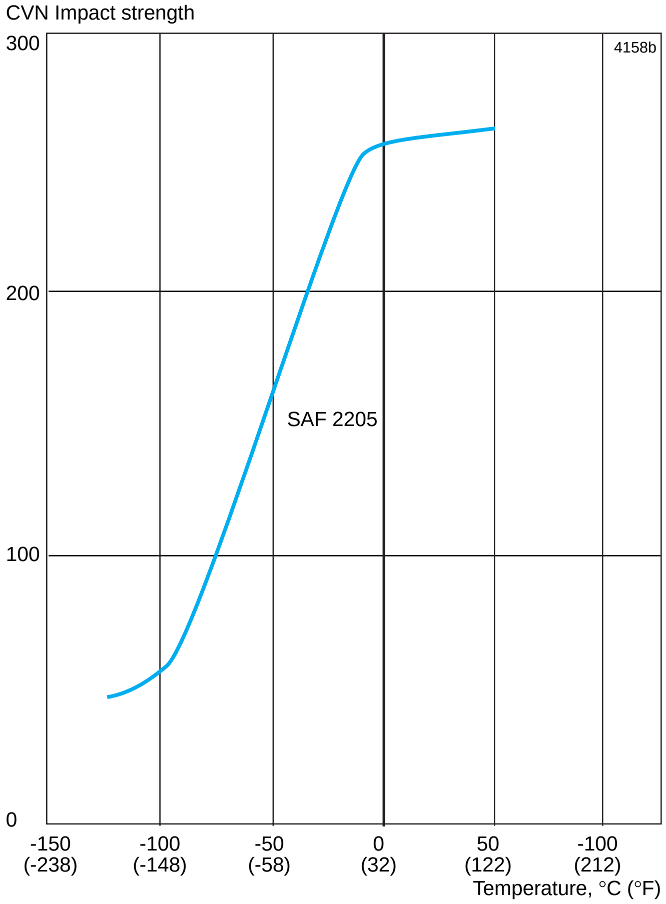

Figure 1. Curve showing typical impact strength values (Charpy-V) for SAF 2205. Specimen size 10x10 mm (0.39 x 0.39 inch).

At high temperatures

If Sandvik SAF 2205 is exposed for prolonged periods to temperatures exceeding 280 °C (540 °F), the microstructure changes which results in a reduction in impact strength. This effect does not necessarily affect the behaviour of the material at the operating temperature. For example, heat exchanger tubes may be used at higher temperatures without any problems. Contact Sandvik for advice.

For pressure vessel applications, 280 °C (540 °F) is required as maximum according to VdTÜV-Wb 418 and NGS 1606.

Tube and pipe with wall thickness max. 20 mm (0.79 inch)

Metric units

Temperature °C	Proof strength $R_{p0.2}$ MPa min.	$R_{p1.0}$ MPa min.	Tensile strength R_m MPa min.
100	370	420	630
150	345	385	600
200	330	360	580
250	320	350	570
300	310	340	560

Imperial units

Temperature °F	Proof strength $R_{p0.2}$ ksi min.	$R_{p1.0}$ ksi min.	Tensile strength R_m ksi min.
200	54.0	61.5	92.0
300	50.5	55.5	87.0
400	48.0	52.0	84.0
500	46.0	50.0	82.5
600	44.5	49.0	81.0

According to ASME B31.3 the following design values are recommended for UNS S31803 (SAF 2205)

Temperature °F	°C	Stress ksi	MPa
100	38	30.0	207
200	93	30.0	207
300	149	28.9	199
400	204	27.9	192
500	260	27.2	188
600	316	26.9	185

PHYSICAL PROPERTIES

Density, 7.8 g/cm³, 0.28 lb/in³

Thermal conductivity

Metric units

Temperature, °C	20	100	200	300	400
	W/(m °C)				
SAF 2205	14	16	17	19	20
AISI 316L	14	15	17	18	20

Imperial units

Temperature, °F	68	200	400	600	800
	Btu/(ft h °F)				
SAF 2205	8	9	10	11	12
AISI 316L	8	9	10	10	12

Specific heat capacity

Temperature, °C	J/(kg °C)	Temperature, °F	Btu/(lb °F)
20	480	68	0.11
100	500	200	0.12
200	530	400	0.13
300	550	600	0.13
400	590	800	0.14

Thermal expansion, mean values in temperature ranges ($x10^{-6}$)

Metric units

Temperature, °C	30-100	30-200	30-300	30-400
	Per °C			
SAF 2205	13.0	13.5	14.0	14.5
Carbon steel	12.5	13.0	13.5	14.0
AISI 316L	16.5	17.0	17.5	18.0

Imperial units

Temperature, °F	86-200	86-400	86-600	86-800
	Per °F			
SAF 2205	7.0	7.5	7.8	8.0
Carbon steel	6.8	7.0	7.5	7.8
AISI 316L	9.0	9.5	9.8	10.0

SAF 2205 has a far lower coefficient of thermal expansion than austenitic stainless steels and can therefore possess certain design advantages.

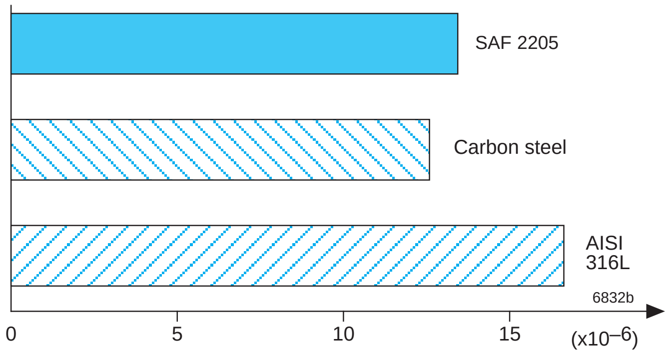

Figure 2. Thermal expansion, per °C (30-100°C).

Modulus of elasticity, ($x10^3$)

Temperature °C	MPa	Temperature °F	ksi
20	200	68	29.0
100	194	200	28.2
200	186	400	27.0
300	180	600	26.2

CORROSION RESISTANCE

General corrosion

In most media, Sandvik SAF 2205 possesses better resistance to general corrosion than steel of type AISI 316L and 317L. This improved resistance of Sandvik SAF 2205 is illustrated by the isocorrosion diagram for corrosion in sulphuric acid, figure 3, and the diagram showing the corrosion rates in mixtures of acetic and formic acid, figure 4. Figure 5 shows the isocorrosion diagram for Sandvik SAF 2205 in hydrochloric acid.

Impurities that increase corrosivity are often present in process solutions of acids. If there is a risk of active corrosion, higher alloyed stainless steels should be chosen, e.g. the austenitic grades Sandvik 2RK65 or Sandvik Sanicro 28 or the super-duplex grade Sandvik SAF 2507.

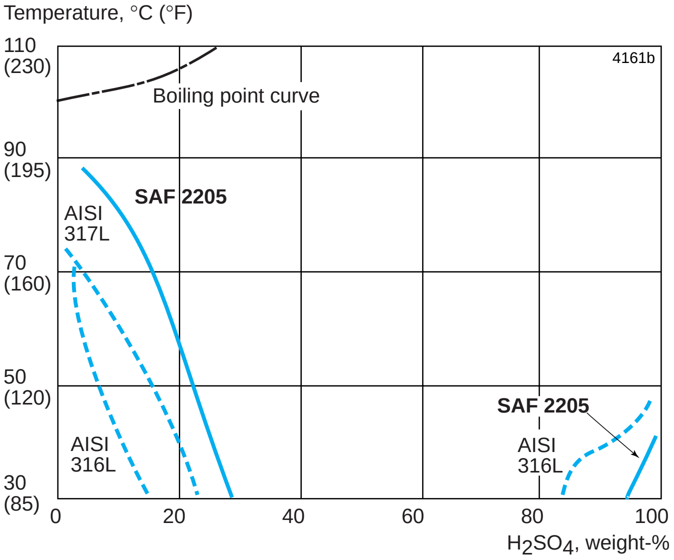

Figure 3. Isocorrosion diagram for Sandvik SAF 2205, AISI 316L and AISI 317L in naturally aerated sulphuric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

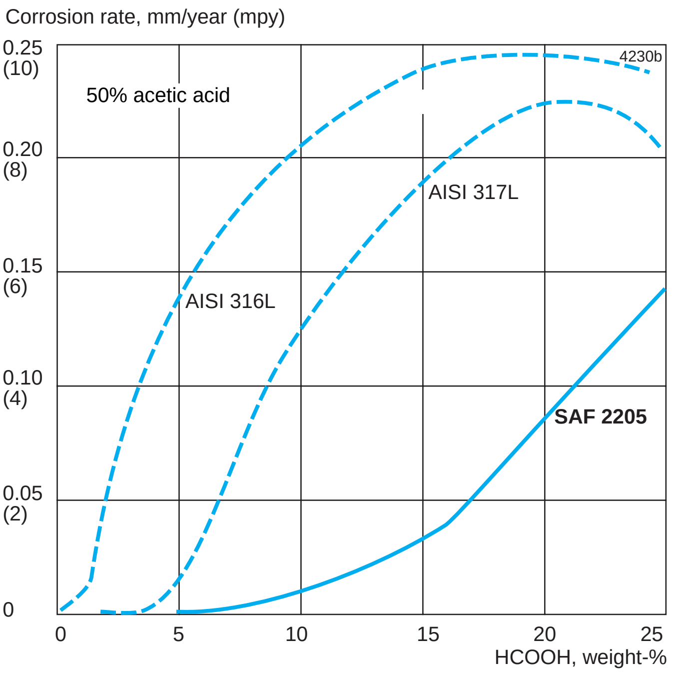

Figure 4. Corrosion rate of Sandvik SAF 2205, AISI 316L and AISI 317L in boiling mixtures of 50% acetic acid and varying proportions of formic acid. Test time 1+3+3 days.

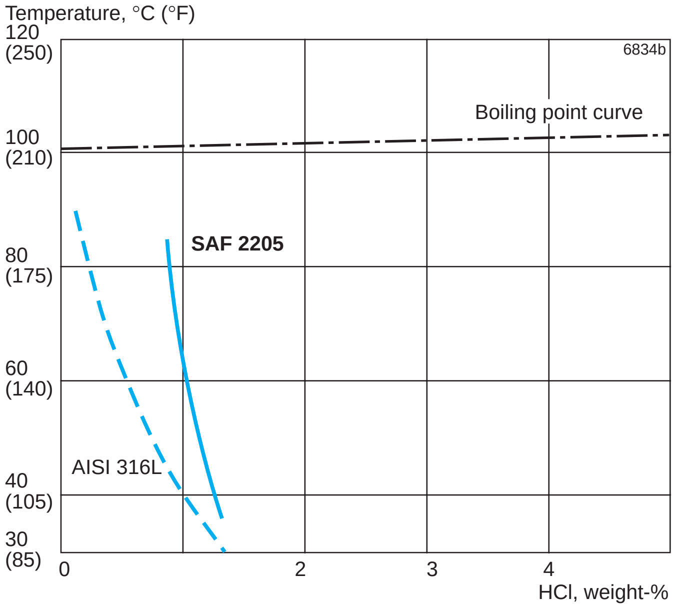

Figure 5. Isocorrosion diagram in naturally aerated hydrochloric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

Pitting corrosion

The pitting resistance of a steel is determined primarily by its chromium and molybdenum contents, but also by its nitrogen content as well as its slag composition and slag content. A parameter for comparing the resistance of different steels to pitting, is the PRE number (Pitting Resistance Equivalent).

The PRE is defined as, in weight-%:

PRE = % Cr + 3.3 x % Mo + 16 x % N

The PRE number for Sandvik SAF 2205 and some compared materials are given in the following table.

Alloy	% Cr	% Mo	% N	PRE
SAF 2205	22	3.2	0.18	>35
Alloy 825	21.5	3.0	-	31
AISI 317L	18	3.5	-	30
AISI 316L	17	2.2	-	24

The ranking given by the PRE number has been confirmed in laboratory tests. This ranking can generally be used to predict the performance of an alloy in chloride containing environments.

Laboratory determinations of critical temperature for initiation of pitting (CPT) at different chloride contents are shown in figure 6. The chosen testing conditions have yielded results that agree well with practical experience. Thus, Sandvik SAF 2205 can be used at considerably higher temperatures and chloride contents than AISI 304 and AISI 316 without pitting occurring. Sandvik SAF 2205 is therefore far more serviceable in chloride-bearing environments than standard austenitic steels.

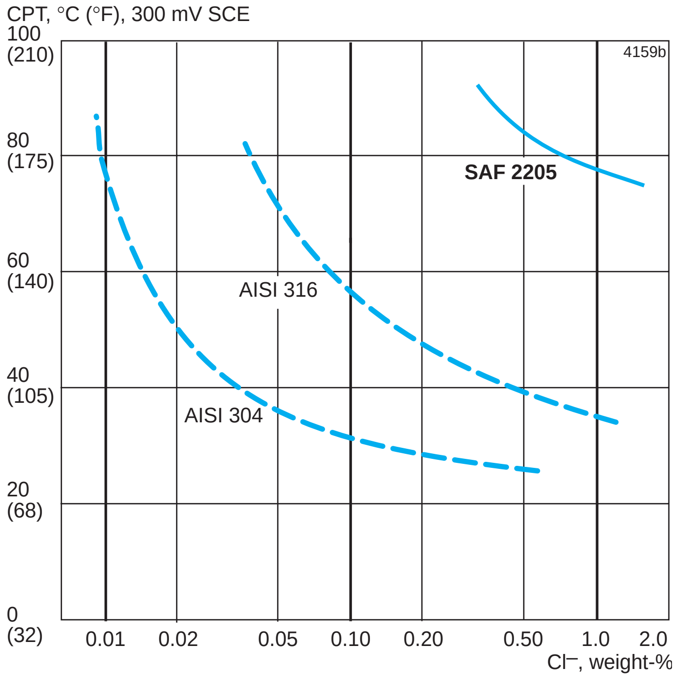

Figure 6. Critical pitting temperatures (CPT) for Sandvik SAF 2205, AISI 304 and AISI 316 at varying concentrations of sodium chloride (potentiostatic determination at +300 mV SCE), pH ≈ 6.0.

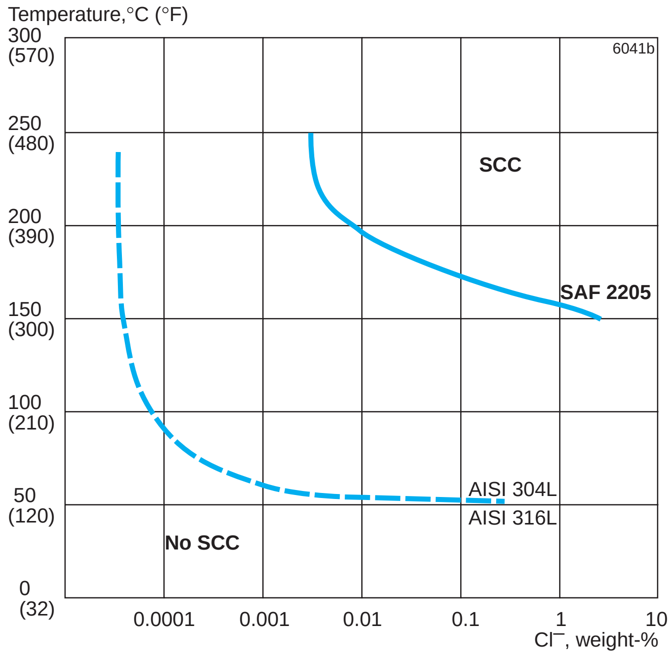

Figure 7. Resistance to stress corrosion cracking, laboratory results.

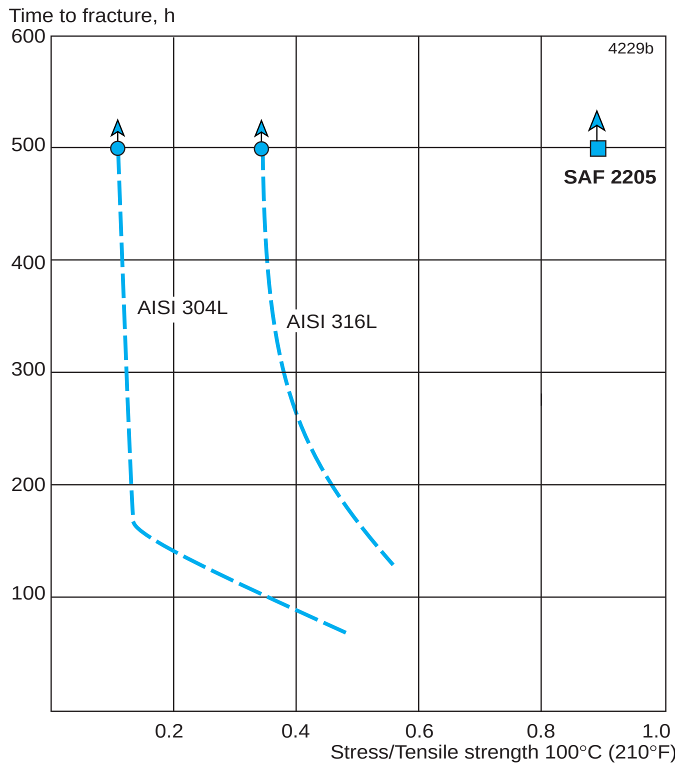

Figure 8. Results of stress corrosion cracking tests on Sandvik SAF 2205, AISI 304L and AISI 316L in 40% $CaCl_2$ at 100°C (210°F) with aerated test solution.

Stress corrosion cracking

The standard austenitic steels of the AISI 304L and AISI 316L types are prone to stress corrosion cracking (SCC) in chloride-bearing solutions at temperatures above 60°C (140°F).

Duplex stainless steels are far less prone to this type of corrosion. Laboratory tests have shown the good resistance to stress corrosion cracking of Sandvik SAF 2205. Results from these tests are presented in figure 7. The diagram indicates the temperature-chloride range within which Sandvik SAF 2205 and the standard steels AISI 304L and AISI 316L can be used without a risk of stress corrosion cracking.

Results of laboratory tests carried out in calcium chloride are shown in figure 8. The tests have been continued to failure or a max. test time of 500h. The diagram shows that Sandvik SAF 2205 has a much higher resistance to SCC than the standard austenitic steels AISI 304L and AISI 316L.

In aqueous solutions containing hydrogen sulphide and chlorides, stress corrosion cracking can also occur on stainless steels at temperatures below 60°C (140°F). The corrosivity of such solutions is affected by acidity and chloride content. In direct contrast to the case with ordinary chloride-induced stress corrosion cracking, ferritic stainless steels are more sensitive to this type of stress corrosion cracking, than austenitic steels.

Laboratory tests have shown that Sandvik SAF 2205 possesses good resistance to stress corrosion cracking in environments containing hydrogen sulphide. This has also been confirmed by available operating experience.

In accordance with NACE MR 0175 solution annealed and cold worked UNS S31803 (SAF 2205) is acceptable for use at any temperature up to 450°F (232°C) in sour environments if the partial pressure of hydrogen sulphide does not exceed 0.3 psi (0.02 bar), the proof strength of the material is not greater than 160 ksi ($R_{p0.2}$ <1100 MPa), and its hardness is not greater than HRC 36.

Figure 9 shows the results of stress corrosion cracking tests at room temperature in NACE solution with hydrogen sulphide. The high resistance of Sandvik SAF 2205 is shown in the figure by the fact that very high stresses, about 1.1 times the 0.2% proof strength, are required to induce stress corrosion cracking. The resistance of welded joints is slightly lower. The ferritic chromium steel AISI 410 fails at considerably lower stress.

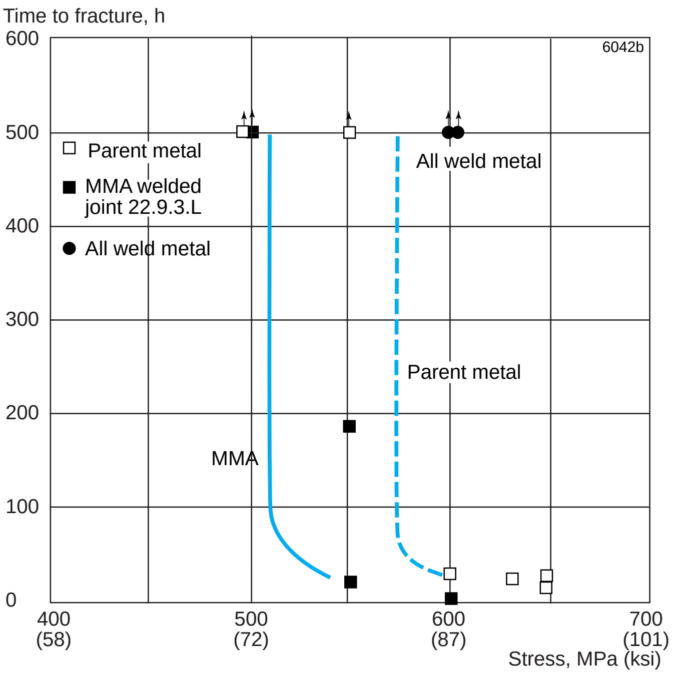

Figure 9. Results of tests according to NACE TM 0177 of Sandvik SAF 2205 in welded and unwelded condition.

Intergranular corrosion

Sandvik SAF 2205 is a member of the family of modern duplex stainless steels whose chemical composition is balanced in such a manner that the reformation of austenite in the heat-affected zone adjacent to the weld takes place quickly. This results in a microstructure that gives corrosion properties and toughness roughly equal to that of the parent metal. Testing according to ASTM A262 Practice E (Strauss' test) constitutes no problem for welded joints in Sandvik SAF 2205 which pass without reservations.

Crevice corrosion

In the same way as the resistance to pitting can be related to the chromium, molybdenum and nitrogen contents of the steel, so can the resistance to crevice corrosion. Sandvik SAF 2205 possesses better resistance to crevice corrosion than steels of the AISI 316L type.

Erosion corrosion

Steels of the AISI 316 type are attacked by erosion corrosion if exposed to flowing media containing highly abrasive solid particles, e.g. sand, or to media with very high flow velocities. Owing to its combination of high hardness and good corrosion resistance, Sandvik SAF 2205 displays very good resistance under such conditions.

Corrosion fatigue

Sandvik SAF 2205 possesses higher strength and better corrosion resistance than ordinary austenitic stainless steels. Sandvik SAF 2205 therefore also possesses better fatigue strength under corrosive conditions than such steels.

In rotary bending, fatigue tests in a 3% NaCl solution (pH = 7; 40°C (104°F) 6000 rpm), the following results were obtained. The tabulated values indicate the stress required to bring about rupture after $2 \cdot 10^7$ cycles.

Steel	Stress level Specimen without notch MPa	ksi	Specimen with notch MPa	ksi
SAF 2205	430	62	230	33
AISI 316N (17Cr12Ni2.5MoN)	260	38	140	20

HEAT TREATMENT

The tubes are normally delivered in heat treated condition. If additional heat treatment is needed after further processing the following is recommended.

Solution annealing

1020-1100°C (1870-2010°F), rapid cooling in air or water.

WELDING

The weldability of Sandvik SAF 2205 is good. Suitable welding methods are manual metal-arc welding with covered electrodes or gas-shielded arc welding. Welding should be undertaken within the heat input range 0.5-2.5 kJ/mm. Max interpass temperature is 250°C. Preheating or post-weld heat treatment is normally not necessary.

Matching filler metals are recommended in order to obtain a weld metal with optimum corrosion resistance and mechanical properties. For gas-shielded arc welding, we recommend Sandvik 22.8.3.L, and for manual metal-arc welding the covered electrode Sandvik 22.9.3.LR. Flux cored wire 22.9.3.LT is also available. These filler metals can also be used for welding Sandvik SAF 2205 to carbon steels, stainless steels and nickel alloys.

The covered electrode Sandvik 23.12.2.LR and the welding wire Sandvik 22.15.3.L, both of type AWS 309Mo with low carbon content, can also be used for this purpose.

FABRICATION

Bending

The starting force needed for bending is slightly higher for Sandvik SAF 2205 than for standard austenitic grades (AISI 304L and 316L). Sandvik SAF 2205 can be cold-bent to 25% deformation without requiring subsequent heat treatment. For pressure vessel applications in Germany and the Nordic countries heat treatment may be required after cold deformation in accordance with VdTÜV-Wb 418 and NGS 1606.

Under service conditions where the risk of stress corrosion cracking starts to increase, however, for example where the material temperature is nearly 150°C (300°F) in an oxygen-bearing environment with around 100 ppm Cl^-, heat treatment is recommended even after moderate cold bending.

Heat treatment is carried out in the form of solution annealing (see under this heading) or resistance annealing.

Hot bending is carried out at 1100-950°C (2010-1740°F) and should be followed by solution annealing.

Expanding

In comparison with austenitic stainless steels, Sandvik SAF 2205 has a higher proof strength and a higher tensile strength. This must be borne in mind when expanding tubes into tube-sheets. Normal expanding methods can be used, but the expansion requires higher initial force and should be under-taken in one operation.

Machining

Being a two-phase material (austenitic-ferritic) Sandvik SAF 2205 will present a different wear picture from that of single phase steels of types AISI 304/304L and 316/316L. The cutting speed must therefore be lower than that recommended for AISI 304/304L and 316/316L. Built-up edges and chipping are to be expected. It is recommended that a tougher insert grade is used than when machining austenitic stainless steel, e.g. AISI 304L.

Sandvik SAF 2205 also exists in a version with improved machinability, SANMAC SAF 2205, which is supplied in the form of bar. Further information is given in printed matter S-029-ENG.

APPLICATIONS

Due to its excellent corrosion properties, Sandvik SAF 2205 is a highly suitable material for service in environments containing chlorides and hydrogen sulphide. The material is suitable for use in production tubing and flowlines for the extraction of oil and gas from sour wells, in refineries and in process solutions contaminated with chlorides. Sandvik SAF 2205 is particularly suitable for heat exchangers where chloride-bearing water or brackish water is used as a cooling medium. The steel is also suitable for use in dilute sulphuric acid solutions and for the handling of organic acids, e.g. acetic acid and mixtures.

The high strength of Sandvik SAF 2205 makes the material an attractive alternative to the austenitic steels in structures subjected to heavy loads.

The good mechanical and corrosion properties make Sandvik SAF 2205 an economical choice in many applications by reducing the life cycle cost of the equipment.

FURTHER INFORMATION

Our data sheets and substantial technical information about our grades and products are available on the Sandvik Steel web-site www.steel.sandvik.com.The following printed matter can be ordered via the web-site or from our nearest Sandvik office.

General information

S-110-ENG “Pipe – tube - hollow bar, seamless standard programme in stainless” (Brochure)

S-120-ENG “Duplex stainless steels – fighting corrosion worldwide” (Brochure)

S-51-51-ENG “Duplex stainless steels for demanding applications” (Lecture)

S-51-52-ENG “LCC examples – Sandvik's stainless steel tubing” (Lecture)

S-51-53-ENG “The Sandvik Duplex Family of stainless steels. Summary of data” (Lecture)

S-51-54-ENG “Physical metallurgy and some characteristic properties of the Sandvik duplex stainless steels” (Lecture)

Mechanical properties

S-32-27-ENG “Applicability of duplex stainless steels above 300°C” (Lecture)

S-32-30-ENG “Mechanical properties of Sandvik duplex stainless steels” (Lecture)

Corrosion

S-33-43-ENG “Chloride-induced stress corrosion cracking of duplex stainless steel. Models, test methods and experience” (Lecture)

Fabrication

S-51-39-ENG “Fabrication and practical experience of duplex stainless steels” (Lecture)

Welding

S-1252-ENG “Your guide to easy welding of duplex stainless steel” (Brochure)

S-91-45-ENG “Influence of different welding conditions on mechanical properties and corrosion resistance of Sandvik SAF 2205 (UNS S31803)” (Lecture)

S-91-57-ENG “Welding practice for the Sandvik duplex stainless steels SAF 2304, SAF 2205 and SAF 2507” (Lecture)

Machinability

S-029-ENG “Stainless steels and cutting tools for better machining” (Brochure)

S-51-47-ENG “Machinability of duplex stainless steel” (Lecture)

S-51-48-ENG “Machining charts for stainless steel” (Lecture)

Process industry

S-52-83-ENG “Stainless steels for eliminating chloride-induced corrosion in ammonia/urea plants” (Lecture)

S-52-85-ENG “Duplex stainless steels in the chemical industry” (Lecture)

S-1541-ENG “The role of duplex stainless steels in oil refinery heat exchanger applications”

S-156-ENG “The role of duplex stainless steels in petro-chemical heat exchanger applications”

Oil & gas

S-13323-ENG “Engineering diagram Sanicro 28-110, Sanicro 28-130, SAF 2205-130” (Brochure)

S-13324-ENG “Effect of pH on the applicability of Sandvik SAF 2205” (Brochure)

S-13325-ENG "SCC resistance in H_2S / chloride environments of Sandvik SAF 2205" (Brochure)

S-133-ENG “Stainless steel products for oil and gas production” (Brochure)

S-252-ENG “Wirelines” (Brochure)

S-33-44-ENG “Testing and selection of duplex stainless steels for sour environments” (Lecture)

S-33-45-ENG “Hydrogen embrittlement of duplex stainless steels in connexion with cathodic protection” (Lecture)

S-58-10-ENG “The applicability of duplex stainless steels in sour environments” (Lecture)

S-58-11-ENG “Coated duplex pipes for TOGI project” (Lecture)

Pulp & paper

S-54-23-ENG "High-strength stainless steels and composite tubes for the pulp and paper industry" (Lecture)

Reference lists

S-12911-ENG "Sandvik SAF 2205 – The traditional duplex stainless steel" (Ref. list.)

S-13334-ENG "Sandvik Sanicro 28 and SAF 22Cr. References for the oil & gas industry, downhole applications" (Ref. list.)

Recommendations are for guidance only, and the suitability of a material for a specific application can be confirmed only when we know the actual service conditions. Continuous development may necessitate changes in technical data without notice.

Production: Sanmedia/Sandvikens Tryckeri AB, Sweden

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