Datasheet updated 2013-03-25 09:09:58 (supersedes all previous editions)

Sandvik SAF 2205

(Tube and pipe, seamless)

Sandvik SAF 2205 is a duplex (austenitic-ferritic) stainless steel characterized by:

- High resistance to stress corrosion cracking (SCC) in chloride-bearing environments
- High resistance to stress corrosion cracking (SCC) 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 steel
- Physical properties that offer design advantages
- Good weldability

STANDARDS

- UNS S31803, S32205
- EN number 1.4462
- EN name X2CrNiMoN 22-5-3
- W.Nr. 1.4462
- DIN X2CrNiMoN 22 5 3
- SS 2377
- AFNOR Z2.CND22.05.03

PRODUCT STANDARDS

Seamless tube:	EN 10216-5, 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
Bar and shapes:	ASTM A276, A479, EN 10088-3
Forged billets	EN 10088-3

Approvals

- ASME Boiler and Pressure Vessel Code, Section VIII, Div. 1 and Div. 2
- VdTÜV-Werkstoffblatt 418 (Ferritisch-austenitischer Walz- und Schmiedestahl)
- NACE MR0175/ISO 15156 (Petroleum and natural gas industries - Materials for use in H2S-containing Environments in oil and gas production - Part 1: General principles for selection of cracking-resistant materials Published:2003)
- NGS 1606 (Nordic rules for application) valid for SAF 2205 made by Sandvik
- DNV (Approval of Seamless Ferritic/Austenitic Stainless Steel Tubes and Pipes in Quality Sandvik SAF 2205)
- ASME B31.3 Process Piping

CHEMICAL COMPOSITION (NOMINAL) %

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

FORMS OF SUPPLY

Seamless tube and pipe in Sandvik SAF 2205 is supplied in dimensions up to 260 mm (10.2 in.) outside diameter. They are delivered in the solution annealed condition and either white pickled or bright annealed. They can also be delivered cold-worked without subsequent heat treatment.

Other product forms

- Welded tube and pipe
- Fittings and flanges
- Welding wire (MIG, TIG and SAW)
- Covered electrodes
- Welding strip and flux for surfacing
- Strip, annealed or cold-rolled to different degrees of hardness
- Bar
- 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 in.) may have slightly lower values. For seamless tubes with a wall thickness <4 mm we guarantee proof strength (Rp0.2) values that are 10% higher than those listed below at 20°C (68°F) and than those listed at higher temperatures. More detailed information can be supplied on request.

At 20 °C (68°F)
Tube and pipe with a wall thickness max. 20 mm (0.79 in.)

METRIC UNITS

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRC
MPa	MPa	MPa	%	%	
min.	min.		min.	min.	max.
485	500	680-880	25	25	28

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRC
ksi	ksi	ksi	%	%	
min.	min.		min.	min.	max.
70	73	99-128	25	25	28

1 MPa = 1 N/mm^2
a) $R_{p0.2}$ and $R_{p1.0}$ correspond to 0.2% offset 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-sectional area.

Seamless tube and pipe in the cold-worked condition
Intended for oil and gas production

Proof strength		Tensile strength		Elong.
$R_{p0.2}$		R_m		$A_{2"}$
MPa	ksi	MPa	ksi	%
min	min	min	min	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 in.).

The impact strength of welded Sandvik SAF 2205 is also good, despite the impact strength values in the as-welded condition being slightly lower than for weld-free material. Tests demonstrate 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 27 J (20 ft lb). If very high impact strength demands 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.

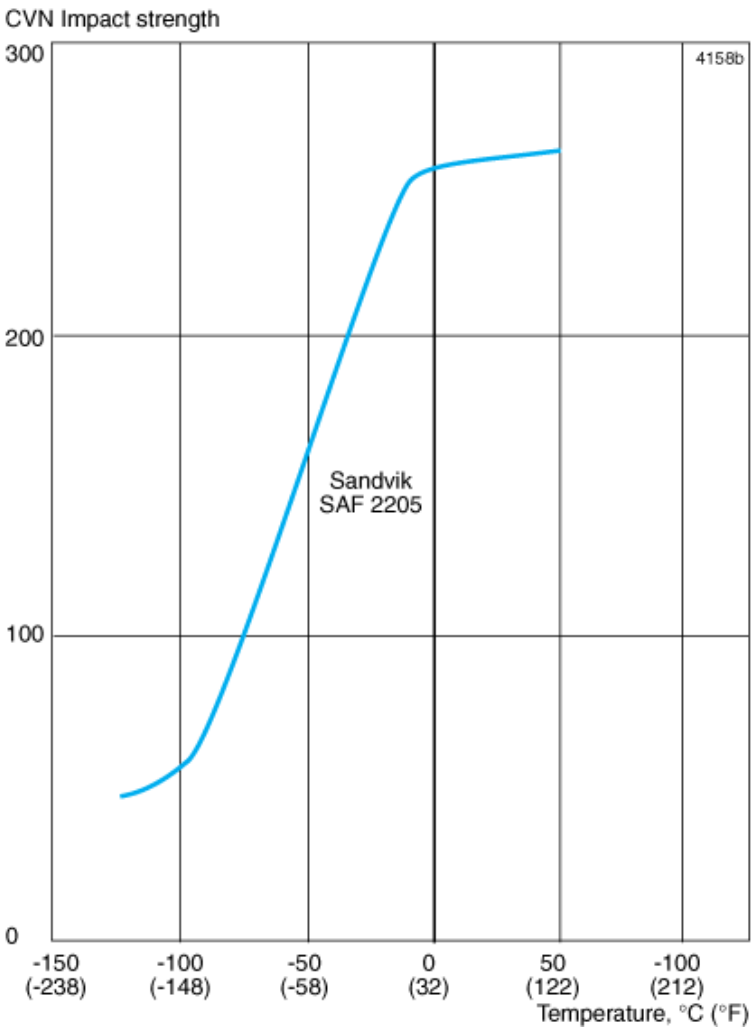


Figure 1. Curve showing typical impact strength values (Charpy-V) for SAF 2205. Specimen size 10x10 mm (0.39 x 0.39 in.).

At high temperatures
If Sandvik SAF 2205 is exposed to temperatures exceeding 280°C (540°F), for prolonged periods, the microstructure changes, which results in a reduction in impact strength. This does not necessarily affect the behavior of the material at the operating temperature. For example, heat exchanger tubes can be used at higher temperatures without any problems. Please contact Sandvik for more information.For pressure vessel applications, 280°C (540°F) is required as a maximum according to VdTÜV-Wb 418 and NGS 1606.

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

METRIC UNITS

Temperature °C	Proof strength $R_{p0.2}$ MPa min
50	415
100	360
150	335
200	310
250	295
300	280

IMPERIAL UNITS

Temperature °F	Proof strength $R_{p0.2}$ ksi min
120	60.5
200	53.5
300	48.5
400	45.0
500	42.5
600	40.0

According to ASME B31.3 the following design values are recommended for UNS S31803 (Sandvik 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/cm^3, 0.28 lb/in^3

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 conductivity

METRIC UNITS

Temperature,°C	20	100	200	300	400
	W/(m °C)				
Sandvik SAF 2205	14	16	17	19	20
ASTM TP316L	14	15	17	18	20

IMPERIAL UNITS

Temperature, °F	68	200	400	600	800
	Btu/(ft h °F)				
Sandvik SAF 2205	8	9	10	11	12
ASTM TP316L	8	9	10	10	12

THERMAL EXPANSION, METRIC UNITS [1)]

Temperature, °C	30-100	30-200	30-300	30-400
	Per °C			
Sandvik SAF 2205	13.0	13.5	14.0	14.5
Carbon steel	12.5	13.0	13.5	14.0
ASTM TP316L	16.5	17.0	17.5	18.0

1) Mean values in temperature ranges ($X10^{-6}$)

IMPERIAL UNITS

Temperature, °F	86-200	86-400	86-600	86-800
	Per °F			
Sandvik SAF 2205	7.0	7.5	8.0	8.0
Carbon steel	6.8	7.0	7.5	7.8
ASTM TP316L	9.0	9.5	9.8	10.0

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

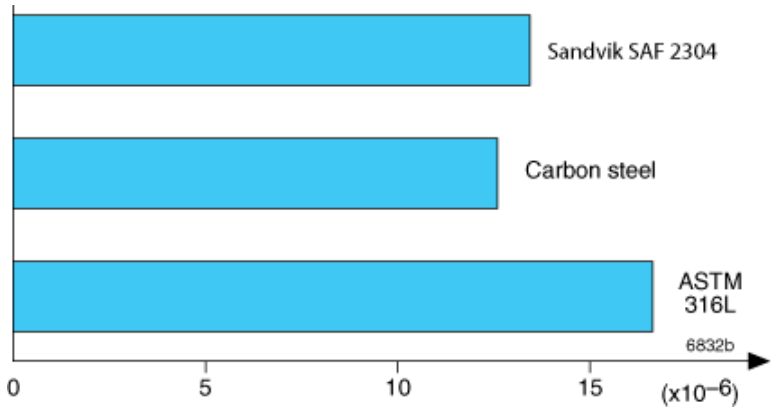


Figure 2. Thermal expansion per °C (30-100°C).

RESISTIVITY

Temperature, °C	µΩm	Temperature, °F	µΩin.
20	0.74	68	29.1
100	0.85	200	33.1
200	0.96	400	39.8
300	1.00	600	43.3
400	1.10	800	43.3

MODULUS OF ELASTICITY [1)]

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

1) ($x10^3$)

CORROSION RESISTANCE

General corrosion

In most media, Sandvik SAF 2205 possesses better resistance to general corrosion than steel of type ASTM TP316L and TP317L. The 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 Sanicro 28, or the super-duplex grade Sandvik SAF 2507.

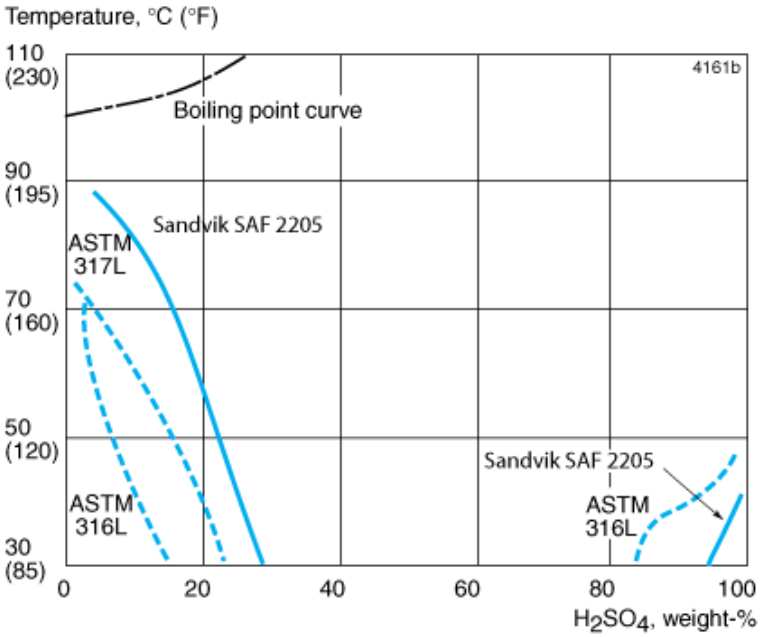


Figure 3. Isocorrosion diagram for SAF 2205, ASTM TP316L and ASTM TP317L in sulphuric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in a natural aerated stagnant test solution.

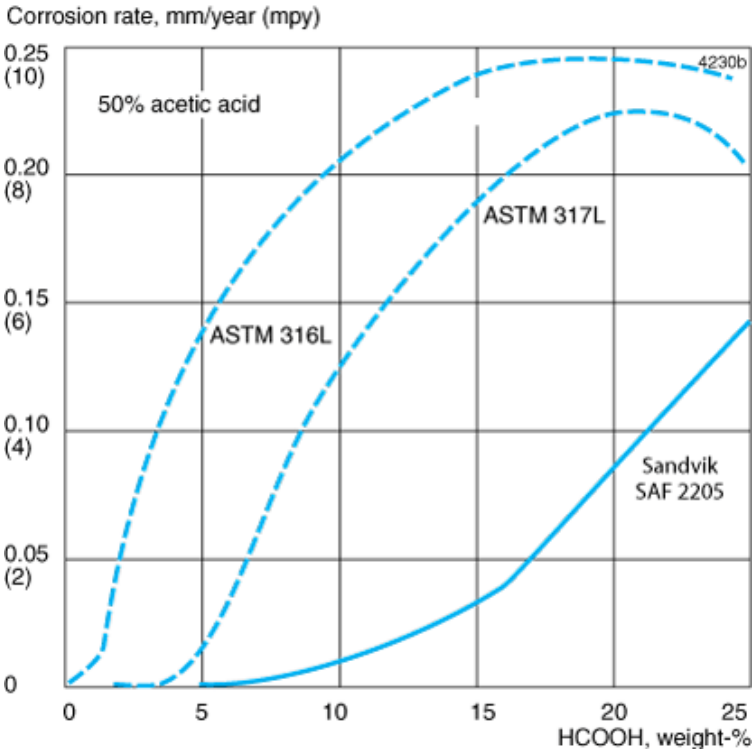


Figure 4. Corrosion rate of SAF 2205, ASTM TP316L and ASTM TP317L in boiling mixtures of 50% acetic acid and varying proportions of formic acid. Test time 1+3+3 days.

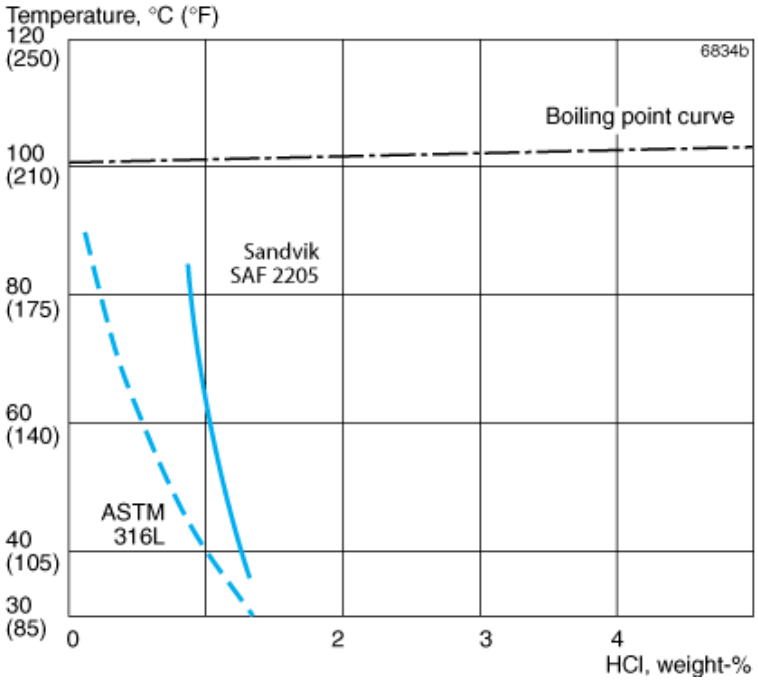


Figure 5. Isocorrosion diagram in naturally aerated hydrochloric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

Pitting corrosion

The pitting resistance of a steel is determined primarily by its chromium and molybdenum contents, but also by its nitrogen content and its slag composition and content. The manufacturing and fabrication practices, e.g. welding, are also of vital importance for actual performance in service.

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 is compared with other materials in the following table:

Grade	% Cr	% Mo	%N	PRE
Sandvik SAF 2205*	22	3.2	0.18	>35
UNS S31803	21.0-23.0	2.50-3.50	0.08-0.20	>30
Alloy 825	20	2.6	-	29
ASTM TP317L	18	3.5	-	30
ASTM TP316L	17	2.2	-	24

* Sandvik SAF 2205 has a chemical composition within UNS S32205, which is optimized within the UNS S31803 range in order to provide a high PRE value.

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. Because of the high Mo and N contents, the PRE number for Sandvik SAF 2205 is significantly higher than what would be the case with lower Mo and N contents which are still within the limits of UNS S31803.

The results of laboratory tests, to determine the critical temperature for the initiation of pitting (CPT) at different chloride contents are shown in Figure 6. The chosen testing conditions have yielded results that match well with practical experience. Thus, Sandvik SAF 2205 can be used at considerably higher temperatures and chloride contents than ASTM TP304 and ASTM TP316 without pitting. Sandvik SAF 2205 is, therefore, far more serviceable in chloride-bearing environments than standard austenitic steels.

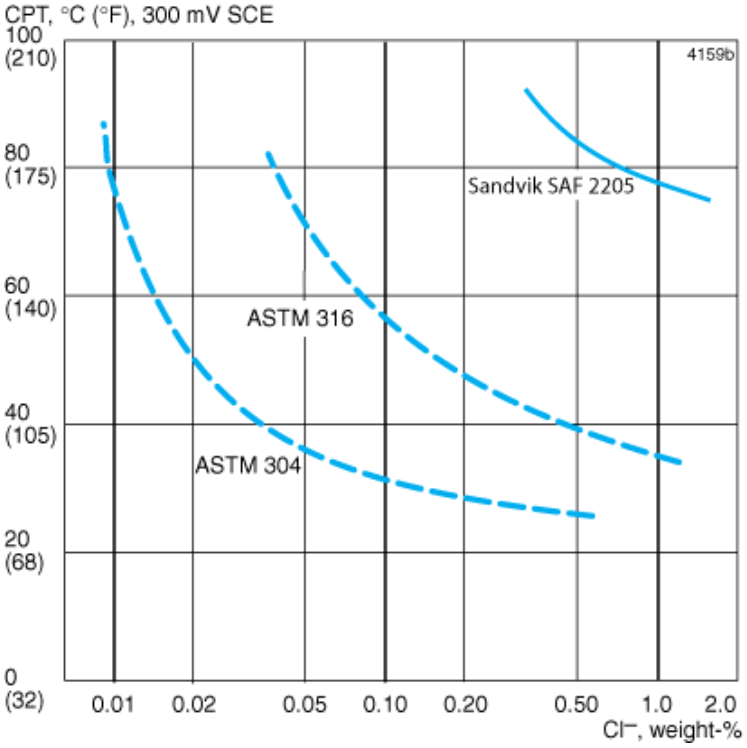
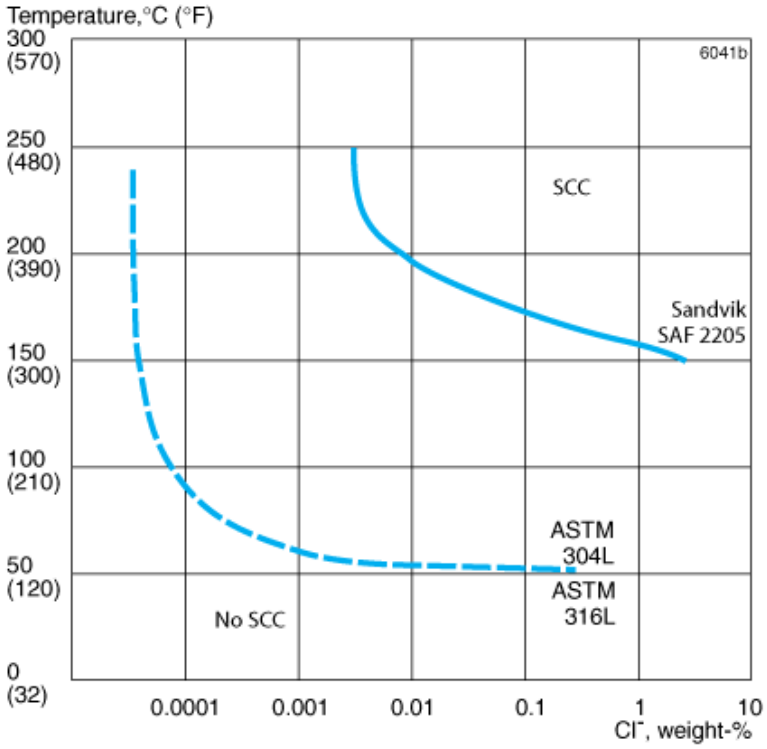


Figure 6. Critical pitting temperatures (CPT) for SAF 2205, ASTM TP304 and ASTM TP316 at varying concentrations of sodium chloride (potentiostatic determination at +300 mV SCE), pH6.0



Figure

Figure7.Resistance to stress corrosion cracking (SCC) in neutral chloride solutions with an oxygen content of about 8 ppm. Laboratory results for SandvikSAF 2205 of constant load specimens loaded to the proof strength at the test temperature.

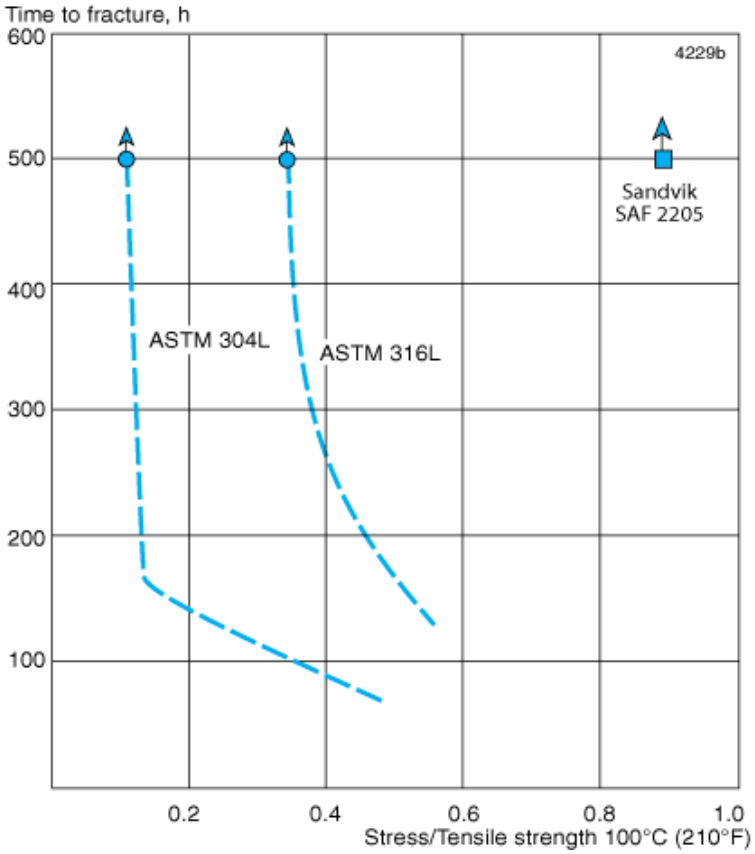


Figure 8. Results of stress corrosion cracking (SCC) tests on Sandvik SAF 2205, ASTM TP304L and ASTM TP316L in 40% $CaCl_2$, pH 6.5, at 100°C (210°F) with aerated test solution.

Stress corrosion cracking (SCC)
The standard austenitic steels ASTM TP304L and ASTM TP316L 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 reveal good resistance to stress corrosion cracking of Sandvik SAF 2205. Results from the tests are presented in Figure 7. The diagram indicates the temperature-chloride range within which Sandvik SAF 2205 and the standard steels ASTM TP304L and ASTM TP316L have low susceptibility to 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 500 h.

The diagram shows that Sandvik SAF 2205 has a much higher resistance to SCC than the standard austenitic steels ASTM TP304L and ASTM TP316L.

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 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 MR0175/ISO 15156 solution annealed and cold-worked Sandvik 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) and its hardness is not greater than HRC 36. In the solution annealed and liquid quenched condition Sandvik 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 1.5 psi (0.1 bar). According NACE MR0103 solution annealed and rapidly cooled Sandvik SAF 2205, with hardness maximum HRC 28 is acceptable in sour petroleum refining.

Figure 9 shows the results of stress corrosion cracking tests at room temperature in NACE TM 01777 test solution A 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 ASTM 410 fails at considerably lower stress.

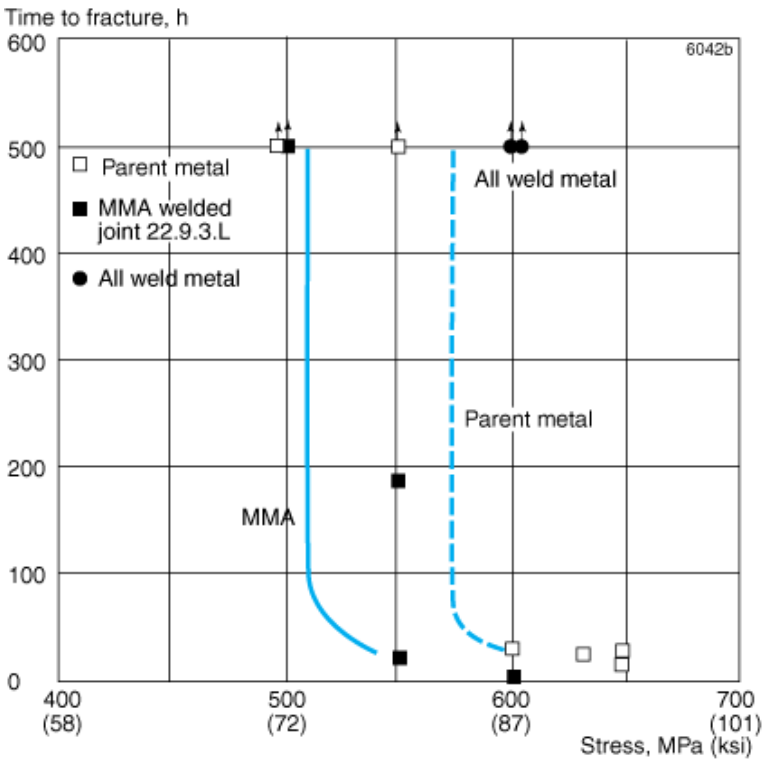


Figure 9. Results of tests according to NACE TM 0177 test solution A of SAF 2205 in welded and unwelded condition.

Intergranular corrosion
Sandvik SAF 2205 is a member of the family of modern duplex stainless steels whose chemical composition is balanced in such a way 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 PrE (Strauss´ test) presents no problems 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 ASTM 316L type.

Erosion corrosion
Steels of the ASTM 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. Under such conditions Sandvik SAF 2205 displays very good resistance because of its combination of high hardness and good corrosion resistance.

Corrosion fatigue
Sandvik SAF 2205 possesses higher strength and better corrosion resistance than ordinary austenitic stainless steels. Consequently, Sandvik SAF 2205, has considerably 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 values shown indicate the stress required to bring about rupture after $2 * 10^7$ cycles.

Grade	Stress level Specimen without notch		Specimen with notch	
	MPa	ksi	MPa	ksi
Sandvik SAF 2205	430	62	230	33
ASTM TP316L (17Cr12Ni2.5MoN)	260	38	140	20

HEAT TREATMENT

Tubes are normally delivered in the heat-treated condition. If additional heat treatment

is needed due to 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 (482°F). 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 or Sandvik 22.8.3.LSi, developed to give improved welding properties by gas metal arc welding (MIG/MAG).

For manual metal-arc welding, the covered electrode Sandvik 22.9.3.LR is recommended. These filler metals can also be used for welding Sandvik SAF 2205 to carbon steels and stainless steels. The covered electrode Sandvik 23.12.2.LR and the welding wire Sandvik 22.15.3.L, both of type AWS 309 Mo with low carbon content, can also be used.

FABRICATION

Bending
The starting force needed for bending is slightly higher for Sandvik SAF 2205 than for standard austenitic grades (ASTM TP304L and TP316L). 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 crackingstarts to increase, heat treatment is recommended even after moderate cold bending, 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 carried out in the form of solution annealing (see under Heat treatment) or resistance annealing. Hot bending is carried out at 1100-950°C (2010-1740°F) and should be followed by solution annealing.

Expanding
Compared with austenitic stainless steels, Sandvik SAF 2205 has higher proof and a tensile strengths. 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 undertaken in one operation.

Machining
Being a two-phase (austenitic-ferritic) material, Sandvik SAF 2205 will present a different tool wear profile from that of single phase steels of types ASTM TP304/304L and TP316/316L. The cutting speed must, therefore, be lower than that recommended for ASTM 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. ASTM TP304L.

A version with improved machinability, Sandvik Sanmac 2205, is available as bar and hollow bar.

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 handling, 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 equipment.

DISCLAIMER:
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. This datasheet is only valid for Sandvik materials.