Alleima

SAF™ 2205

Tube and pipe, seamless

Datasheet

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 sulfide
- 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

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- 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 H_2S-containing Environments in oil and gas production - Part 3: Cracking-resistant CRAs (corrosion resistant alloys and other alloys) (Published:2015)

NACE MR0103-2012, Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments
DNV (Approval of Seamless Ferritic/Austenitic Stainless Steel Tubes and Pipes in Quality SAF 2205)
ASME B31.3 Process Piping

Chemical composition (nominal)

Chemical composition (nominal) %

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

Applications

Due to its excellent corrosion properties, 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. 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 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 SAF™ 2205 an economical choice in many applications

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by reducing the life cycle cost of equipment.

Corrosion resistance

General corrosion

In most media, SAF™ 2205 possesses better resistance to general corrosion than steel of type ASTM TP316L and TP317L. The improved resistance of 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 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 Alleima® 2RK65 or Sanicro® 28, or the super-duplex grade SAF™ 2507.

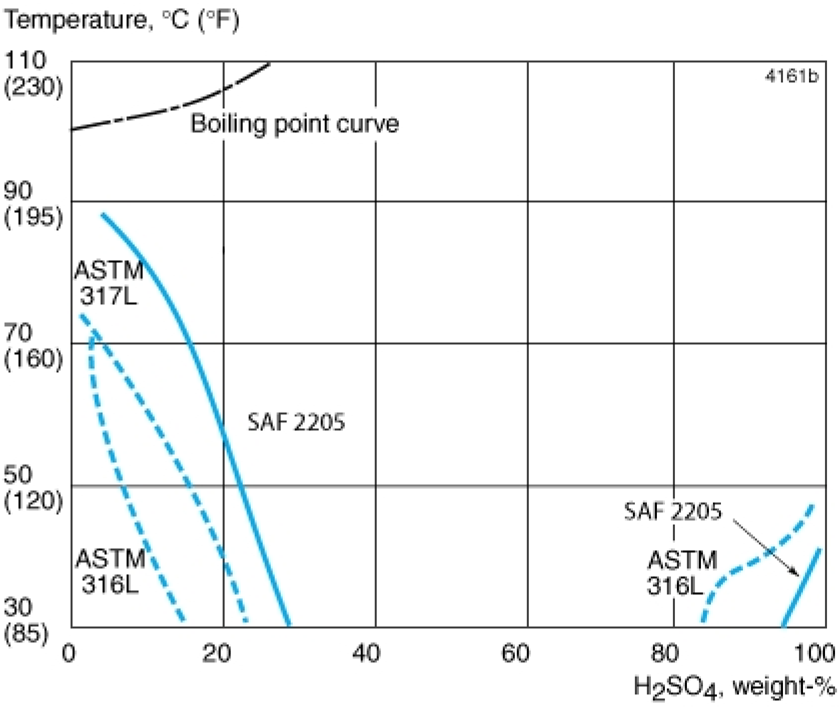

Figure 3. Iso- corrosion diagram for SAF™ 2205, ASTM TP316L and ASTM TP317L in sulphuric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in a natural aerated stagnant test solution.

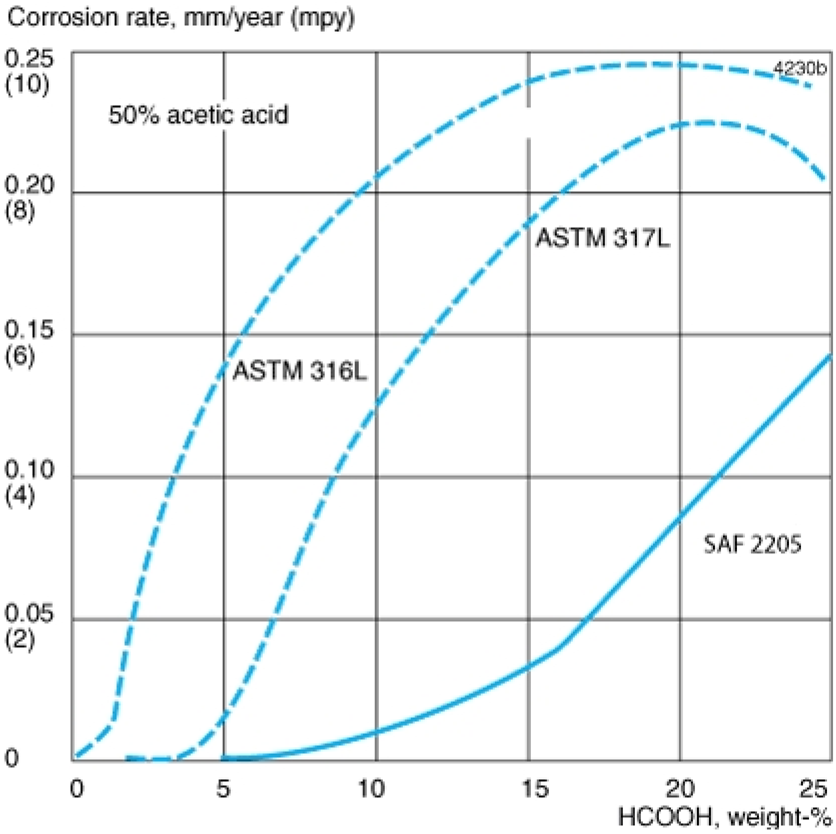

Figure 4. Corrosion rate of SAF™ 2205, ASTM TP316L and ASTM TP317L in boiling mixtures of 50% acetic acid and varying proportions of formic acid. Test time 1+3+3 days.

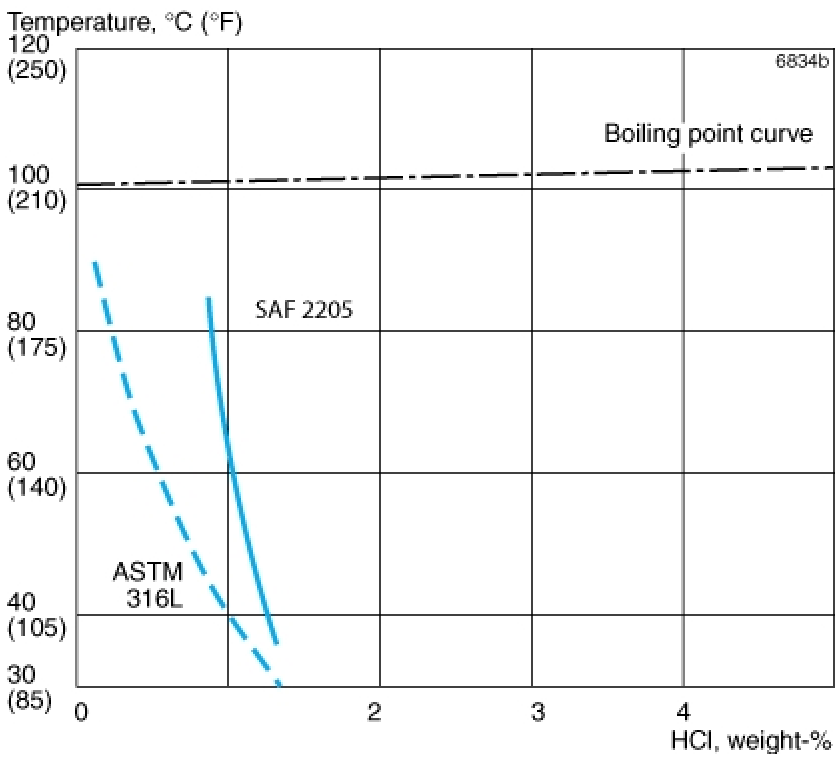

Figure 5. Iso- corrosion diagram in naturally aerated hydrochloric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

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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 SAF™ 2205 is compared with other materials in the following table:

Grade	% Cr	% Mo	%N	PRE
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

* 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 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, SAF™ 2205 can be used at considerably higher temperatures and chloride contents than ASTM TP304 and ASTM TP316 without pitting. SAF™ 2205 is, therefore, far more serviceable in chloride-bearing environments than standard austenitic steels.

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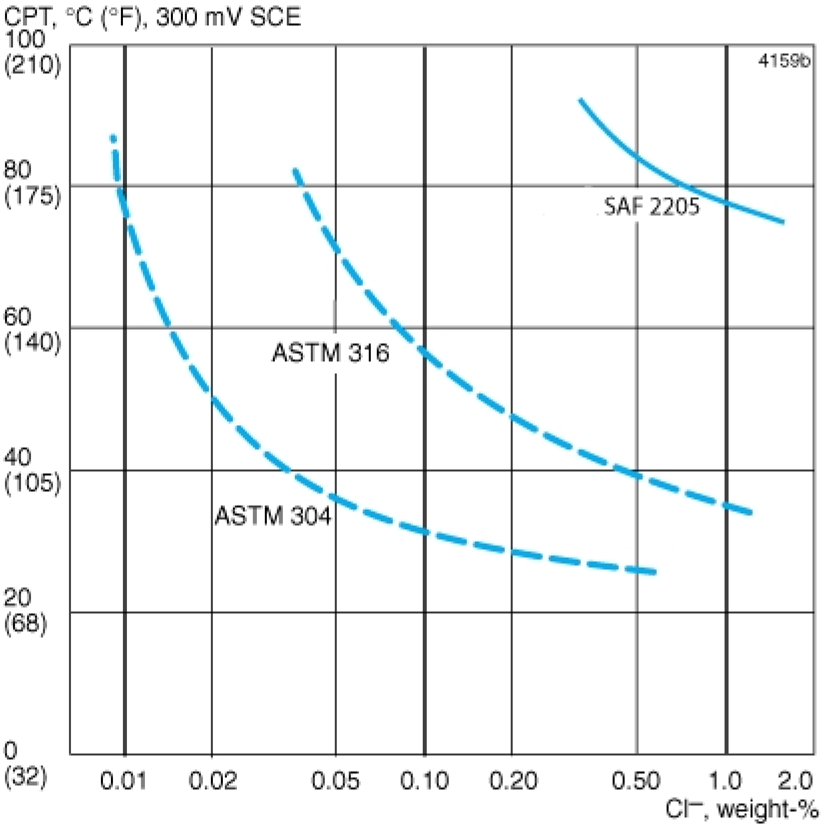

Figure 6. Critical pitting temperatures (CPT) for SAF™ 2205, ASTM TP304 and ASTM TP316 at varying concentrations of sodium chloride (potentiostatic determination at +300 mV SCE), pH6.0

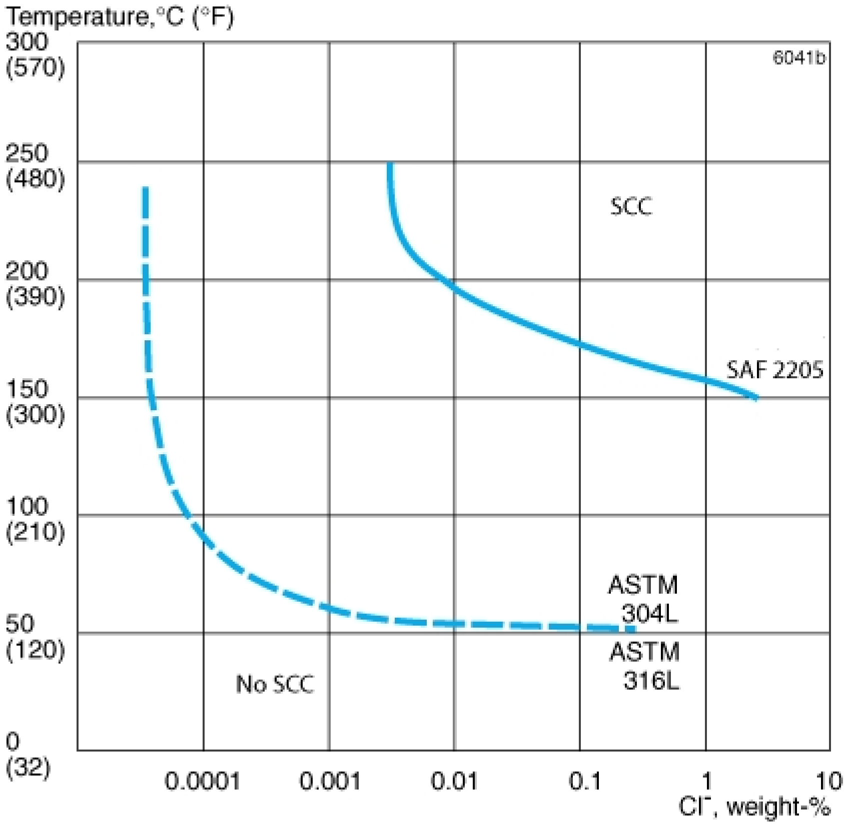

Figure Figure 7. Resistance to stress corrosion cracking (SCC) in neutral chloride solutions with an oxygen content of about 8 ppm. Laboratory results for SAF™ 2205 of constant load specimens loaded to the proof strength at the test temperature.

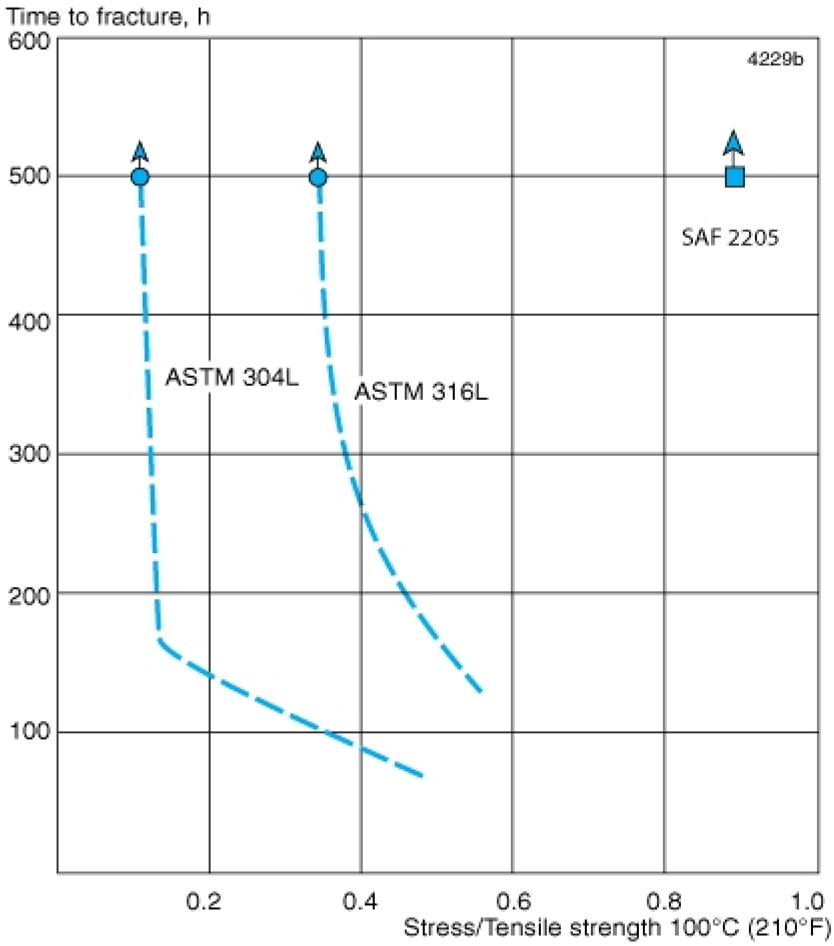

Figure 8. Results of stress corrosion cracking (SCC) tests on SAF™ 2205, ASTM TP304L and ASTM TP316L in 40% $CaCl_2$, pH 6.5, at 100°C (210°F) with aerated test solution.

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 SAF™ 2205. Results from the tests are presented in Figure 7. The diagram indicates the temperature-chloride range within which 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 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 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 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 rapidly cooled condition 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 to NACE MR0103 solution annealed and rapidly cooled 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 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.

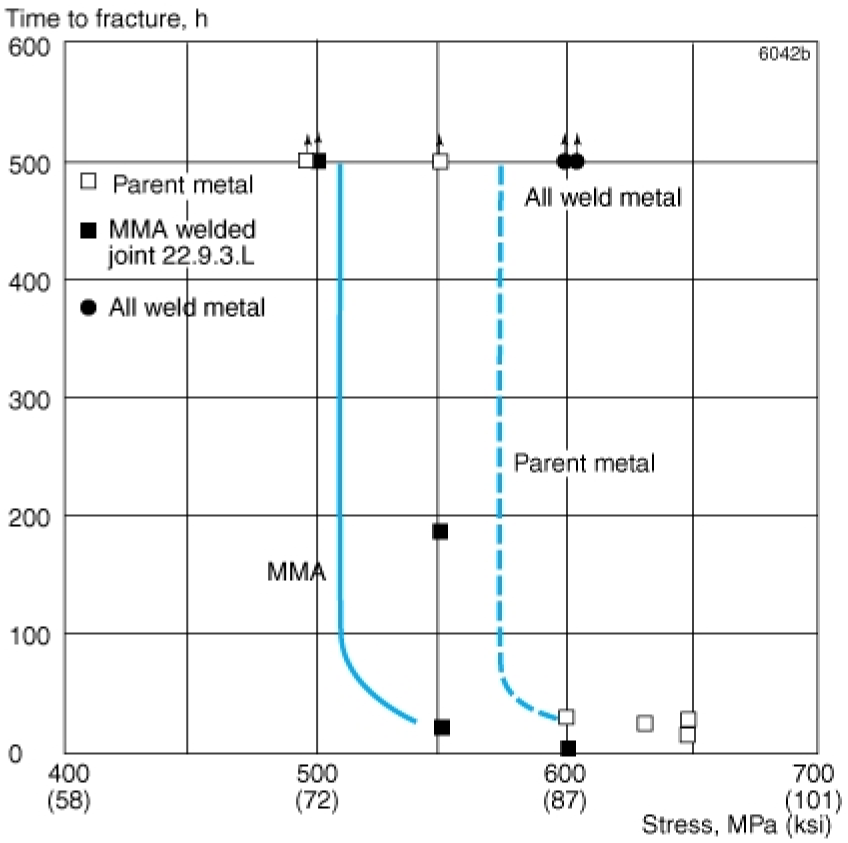

Figure 9. Results of tests according to NACE TM 0177 test solution A of SAF 2205™ in welded and unwelded condition.

Intergranular corrosion

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 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. 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, SAF 2205™ displays very good resistance because of its combination of high hardness and good corrosion resistance.

Corrosion fatigue

SAF™ 2205 possesses higher strength and better corrosion resistance than ordinary austenitic stainless steels. Consequently, 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**
SAF 2205	430	62	230	33
ASTM TP316L (17Cr12Ni2.5MoN)	260	38	140	20

Fabrication

Bending

The starting force needed for bending is slightly higher for SAF™ 2205 than for standard austenitic grades (ASTM TP304L and TP316L). 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, 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, 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

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Being a two-phase (austenitic-ferritic) material, 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, Sanmac® 2205, is available as bar and hollow bar.

Forms of supply

Seamless tube and pipe in 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
Strip, annealed or cold-rolled to different degrees of hardness
Bar
Plate, sheet and wide strip
Forged products
Cast products

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.

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	%	%	
≥485	≥500	680-880	≥25	≥25	≤28

Imperial units

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRC
ksi	ksi	ksi	%	%	
≥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	%
≥895	≥130	≥965	≥140	≥10

Impact strength

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 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.

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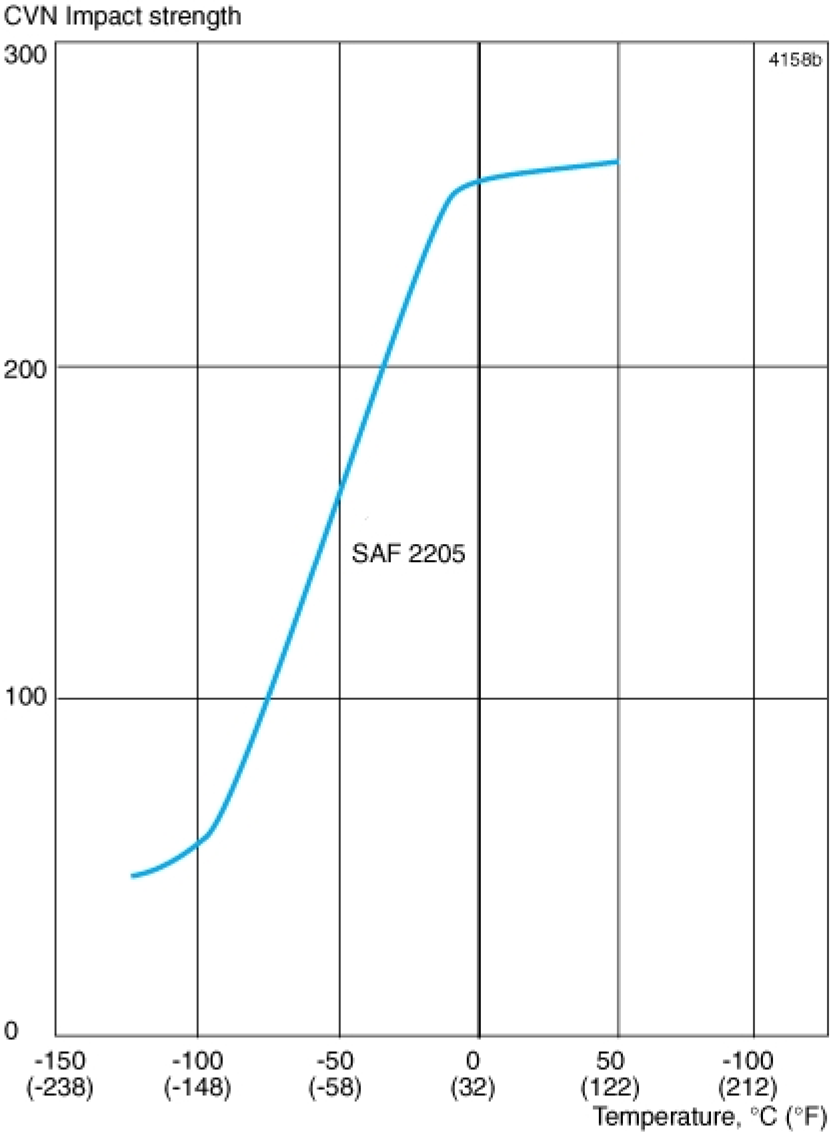

Figure 1. Curve showing typical impact strength values (Charpy-V) for SAF 2205. Specimen size 10x10 mm (0.39 x 0.39 in.).

At high temperatures

If 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 Alleima 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	Proof strength
	$R_{p0.2}$
°C	MPa
	min

50	415
100	360
150	335
200	310
250	295
300	280

Imperial units

Temperature	Proof strength
	$R_{p0.2}$
°F	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 (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

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300	550	600	0.13
400	590	800	0.14

Thermal conductivity

Metric units

Temperature,°C	**20**	**100**	**200**	**300**	**400**
	W/(m °C)				
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)				
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			
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			
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

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

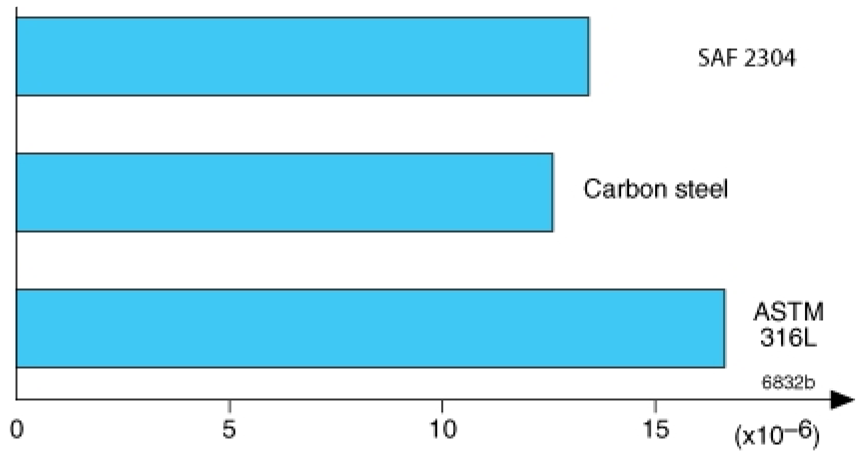

Figure 2. Thermal expansion per °C (30-100°C).

Resistivity

Temperature, °C	µΩm	Temperature, °F	µΩin.
20	0.74	68	29
100	0.85	200	33
200	0.96	400	40
300	1.00	600	43
400	1.10	800	45

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)

Welding

The weldability of SAF 2205™ is good. Welding must be carried out without preheating and subsequent heat treatment is normally not necessary. Suitable methods of fusion welding are manual metal-arc welding (MMA/SMAW) and gas-shielded arc welding, with the TIG/GTAW method as first choice.

For SAF 2205™, heat input of 0.5-2.5 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 22 9 3 N L / AWS A5.9 ER2209 (e.g. Exaton 22.8.3.L)

MMA/SMAW welding

ISO 3581 E 22 9 3 N L R / AWS A5.4 E2209-17 (e.g. Exaton 22.9.3.LR)

ISO 3581 E 22 9 3 N L B / AWS A5.4 E2209-15 (e.g. Exaton 22.9.3.LB)

ISO 14343 S 22 9 3 N L / AWS A5.9 ER2209 (e.g. Exaton 22.8.3.L) wire or strip electrodes are recommended for overlay welding of tube sheets and high-pressure vessels in cases where corrosion resistance, equal to that of SAF 2205™, is required.

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