Sanicro® 28

Tube and pipe, seamless

Datasheet

Sanicro® 28 is a high-alloy multi-purpose austenitic stainless steel for service in highly corrosive conditions.

The grade is characterized by:

- Very high corrosion resistance in strong acids
- Very good resistance to stress corrosion cracking (SCC) and intergranular corrosion in various environments
- High resistance to pitting and crevice corrosion
- Good weldability

Standards

- UNS: N08028
- ISO: 4563-080-28-I
- EN Number: 1.4563
- EN Name: X 1 NiCrMoCu 31-27-4
- W.Nr.: 1.4563
- DIN: X 1 NiCrMoCuN 31 27 4
- SS: 2584
- AFNOR: Z1NCDU31-27-03

Product standards

Seamless tube and pipe:	ASTM B 668, EN 10216-5, SEW 400 (Feb 1991), SS 14 25 84, NFA 49-217
Plate, sheet and strip:	ASTM B 709, EN 10088-2, SS 14 25 84
Bar steel:	EN 10088-3, EN 10272, SS 14 25 84

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Fittings:	ASTM A 403 (chemical composition and mechanical properties according to ASTM B668)

Approvals

- Approved by the American Society of Mechanical Engineers (ASME) for use in accordance with ASME Boiler and Pressure Vessel Code, section III, section I (Code Case 1325-18) and section VIII, division 1.
- VdTÜV-Werkstoffblatt 483 (Austenitischer Walz- und Schmiedestahl)
- NACE MR 0103 (Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments)
- NACE MR0175/ISO 15156 (sulfide stress cracking resistant material for oil field equipment)

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
≤0.020	≤0.7	≤2.0	≤0.020	≤0.010	27	31	3.5	1.0	≤0.1

Applications

Due to its outstanding corrosion properties, Sanicro® 28 can be used in the most diverse environments. Listed below are a few examples of applications for which this alloy is particularly suitable.

Phosphoric acid

Today, Sanicro® 28 is the most widely used metallic material for evaporator tubes in the manufacture of phosphoric acid by the "wet " method. Several units have now been in service for more than 10 years. The graphite heat exchangers, replaced by Sanicro® 28, often had repeated problems with broken tubes and loss of production.

Sulphuric acid

Sanicro® 28 is a suitable material for piping and heat exchangers, particularly at concentrations of between 40 and 70% of deaerated acid and over 85%. Sanicro® 28 has approximately the same resistance as Alloy C in concentrated acid (98% H_2SO_4).

Oil and gas

Sanicro® 28 is used for production tubing, casing and liners in deep, sour gas wells. The material is also recommended for oil wells with a corrosive environment. For these purposes, tubes are supplied cold rolled with high strength. In the solution annealed condition, Sanicro® 28 is also used as piping for transporting of corrosive oil and gas and for heat exchangers in treatment facilities. Sanicro® 28 wirelines are used for lowering tools and controlling instruments in deep oil and gas wells.

Fluoride-bearing media

Fluoride-bearing off-gases can form during the manufacture of phosphoric acid and mixed fertilizers. These off-gases must be disposed of for environmental reasons. Sanicro® 28 is ideal for this purpose. Tests have shown it to be preferable to higher alloyed CrNiMo grades for the recovery of fluoride-bearing gypsum.

Nuclear power plants

Due to its high resistance to SCC, pitting and crevice corrosion, Sanicro® 28 has been selected for heat exchangers in nuclear power plants.

Seawater and chloride-bearing cooling water

Its high resistance to pitting and crevice corrosion makes Sanicro® 28 a very suitable material for seawater-carrying piping and seawater-cooled heat exchangers. This is confirmed by practical experience.

Sanicro® 28 has replaced nickel alloys, CuNi, bimetallic tubes and coated carbon steel tubes, which failed due to corrosion. The performance of Sanicro® 28 has been excellent.

In seawater-cooled heat exchangers and heat exchangers that work with chloride-bearing cooling water, Sanicro® 28 offers high corrosion resistance to both the water and the cooled medium.

When a seawater-cooled plant is shut down, there is no need to drain the piping system or flush with fresh water, provided that the shutdown period is shorter than one month and the water temperature is lower than 30°C (85°F).

The duplex stainless steel SAF™ 2507 is more resistant than Sanicro® 28 in sea water.

Corrosion resistance

General corrosion

Sanicro® 28 was originally developed for use in the manufacture of phosphoric acid, especially for heat exchangers in the concentration unit, where corrosive conditions are at their worst.

Phosphoric acid, manufactured by the "wet" method, contains varying concentrations of impurities derived from the raw material, the phosphate rock. The most dangerous of these impurities are chlorides, Cl^-, and fluorides in free form, F^-. Laboratory tests carried out in wet process phosphoric acid have shown that Sanicro® 28 is far more resistant to impurities of this kind than other high alloy materials. Figure 1 shows the corrosion rate in contaminated phosphoric acid at different chloride concentrations.

Temperature is another factor that has a great influence on corrosion. See figure 2.

Laboratory tests at 200°C (390°F) in contaminated 95% super phosphoric acid gave the following corrosion rates after 20 days: Sanicro® 28, 0.03 mm/year (1.2 mpy); Alloy 904L, 0.10 mm/year (4.0 mpy); UNS N08020, 0.23 mm/year (9.2 mpy); Alloy G, 0.03 mm/year (1.2 mpy).

Table 1 Chemical compositions of materials tested

Material	**Chemical**	**Composition**	**Nominal, %**					
	C	**Cr**	**Ni**	**Mo**	**Cu**	**W**	**Co**	**Others**
	max							
Sanicro® 28	0.02	27	31	3.5	1.0	-	-	-
Alloy 904L	0.02	20	25	4.5	1.5	-	-	-
UNS N08020	0.07	20	34	2.5	3.3	-	-	Nb
Alloy 825	0.05	21.5	42	3	2.3	-	-	Ti
Alloy G	0.03	22	45	6.5	2	1.0	2.5	Nb
Alloy C	0.08	15.5	54	16	-	4	2.5	-

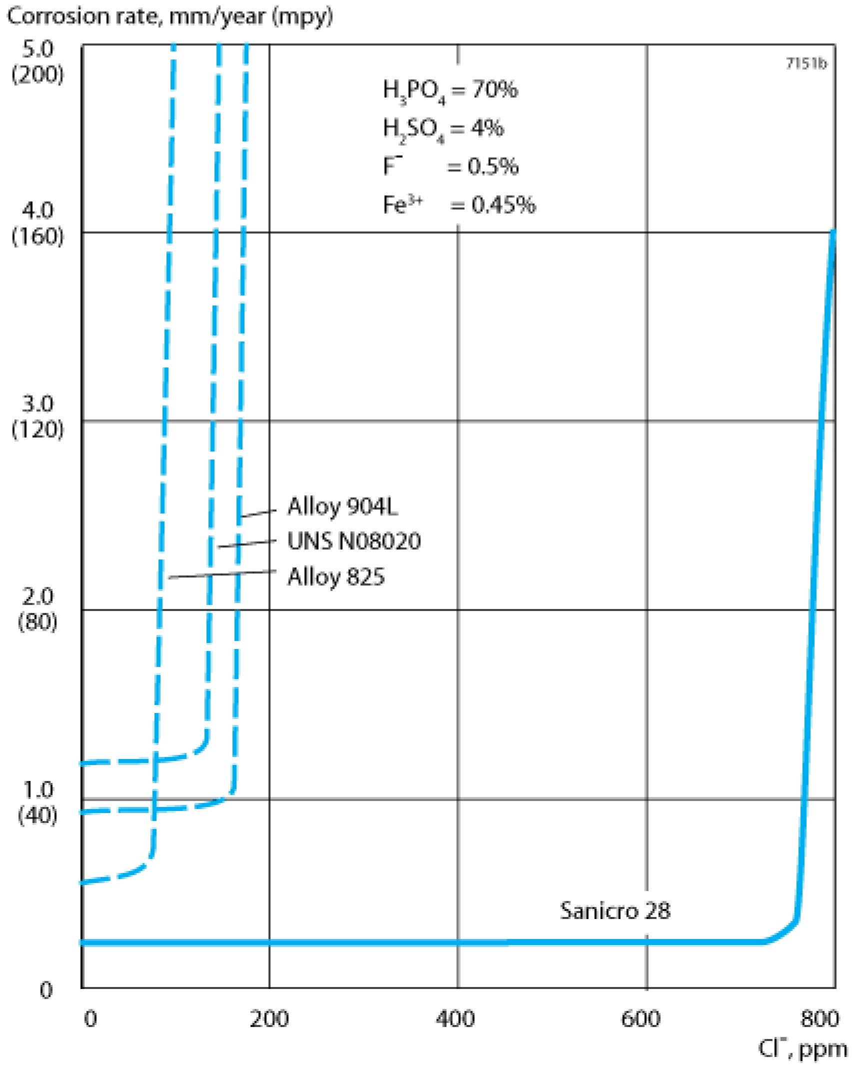

Figure 1. Corrosion rate in contaminated phosphoric acid at different chloride concentrations 100°C (210°F). Comparison of Sanicro 28 and other alloys (chemical compositions given in table 1).

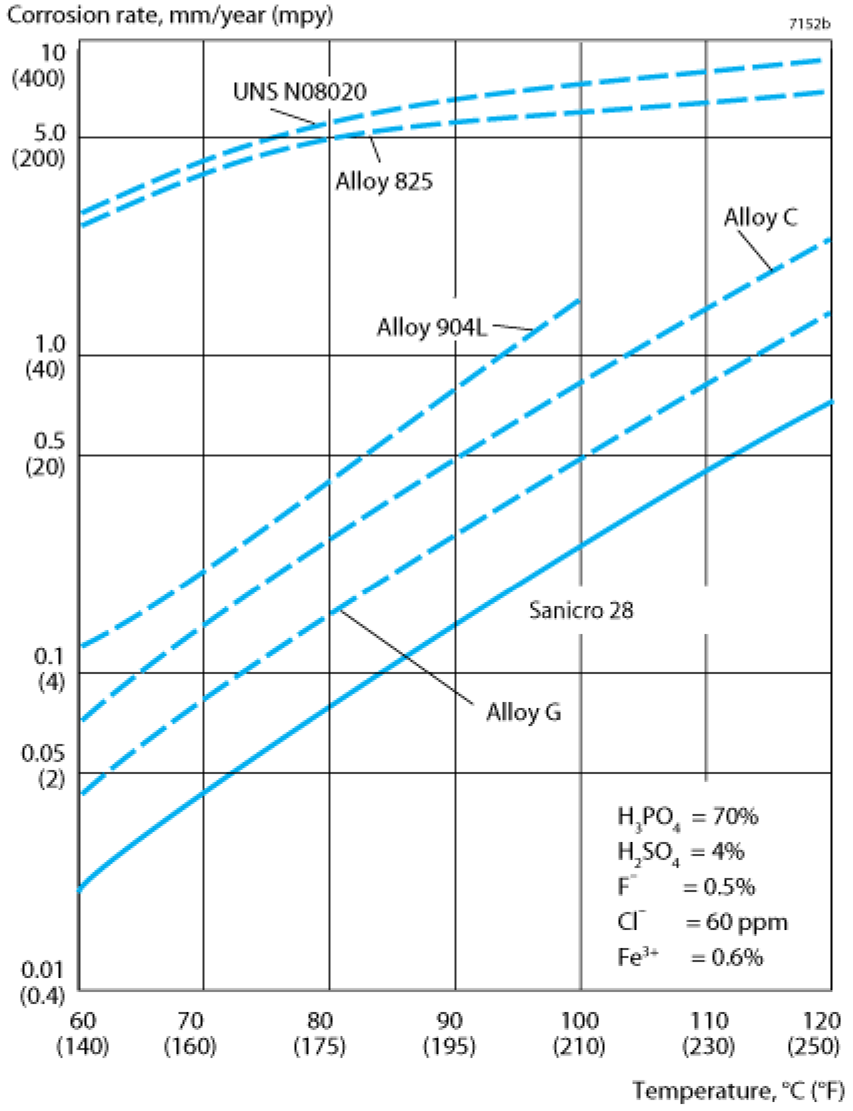

Figure 2. Corrosion rate in contaminated phosphoric acid at different temperatures for Sanicro 28 and some other alloys (chemical compositions given in table 1).

Figure 3 is an isocorrosion diagram for Sanicro® 28, Alloy 904L and ASTM 316L in deaerated **sulfuric acid**. As can be seen from the figure, Sanicro® 28 is more resistant than the other alloys. Naturally aerated sulfuric acid is more corrosive than deaerated acid in the intermediate concentration range. Sanicro® 28 exhibits very good corrosion resistance in concentrated acid.

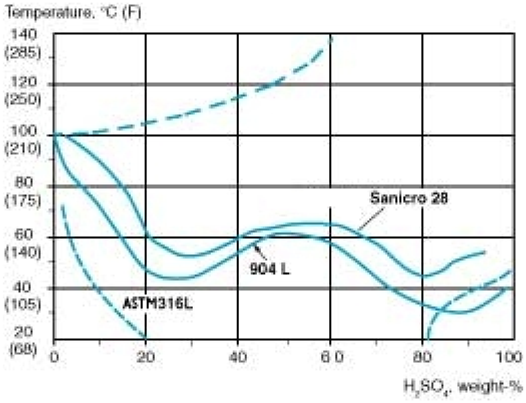

Figure 3. Isocorrosion diagram for Sanicro 28, Alloy 904L and ASTM 316L, in deaerated sulfuric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy).

Sulfuric acid is sometimes contaminated with chlorides which increases the corrosivity of the solution. However, Sanicro® 28 has good resistance, better than 904L, also in chloride contaminated sulfuric acid, especially at high concentrations. Above about 20% sulfuric acid Sanicro® 28 is even more resistant than the super-duplex stainless steel SAF™ 2507, see isocorrosion diagram in figure 4.

Sanicro® 28 is more resistant to **hydrochloric acid** than stainless steels with lower chromium and molybdenum contents and can, therefore, be used to advantage in cases where chemical process solutions are contaminated with hydrochloric acid, see isocorrosion diagram in figure 5.

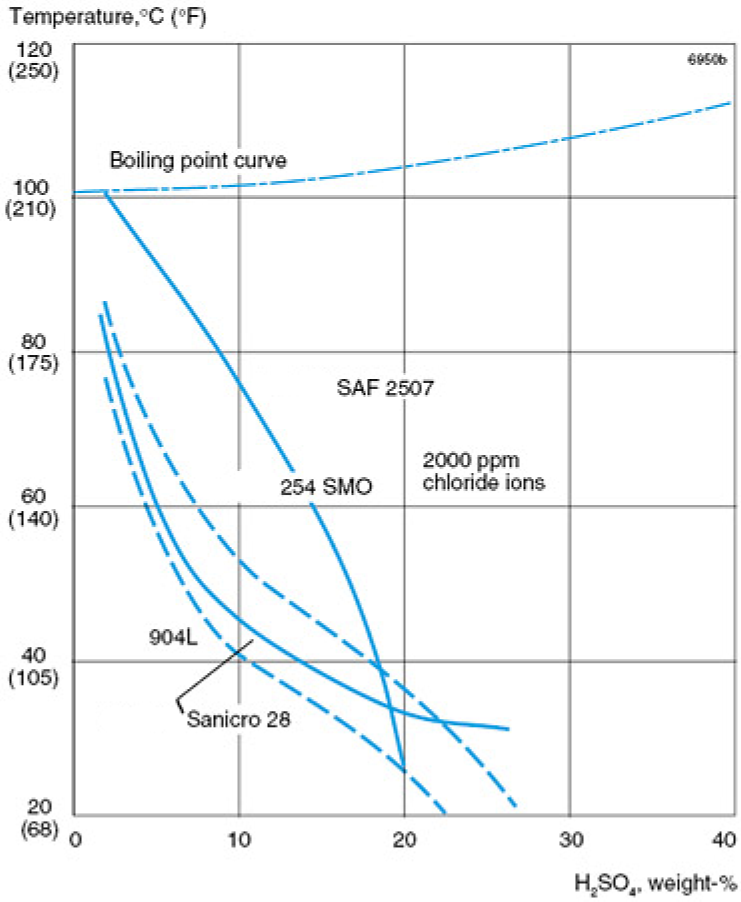

Figure 4. Isocorrosion diagram for Sanicro® 28 in sulfuric

acid containing 2000 ppm chloride ions at a corrosion rate
of 0.1 mm/year (4 mpy).

Sanicro® 28 resists **hydrofluoric and hydrofluosilicic acid** very well and can be used where these acids occur as impurities (see corrosion diagram for hydrofluoric acid, figure 6). Both Sanicro® 28 and AISI 316L are completely resistant to pure **acetic acid** at all temperatures and concentrations at atmospheric pressure. However, at elevated temperatures and pressures, AISI 316L will corrode while Sanicro® 28 will remain resistant. Acetic acid is often contaminated with formic acid, which renders it more corrosive. Laboratory tests show that Sanicro® 28 is more resistant than AISI 316 and AISI 317L in such solutions.

Sanicro® 28 is far more resistant to **formic acid** than conventional stainless steels of the AISI 316L type and more resistant than 904L, see isocorrosion diagram in figure 7. In **nitric acid** Sanicro® 28 performs also very well. In test according to ASTM A262 Practice C (Huey test, 5x48 h in boiling 65% HNO_3) corrosion rates lower than 0.15 mm/year (6 mpy) are obtained.

The high alloying contents of chromium and nickel give Sanicro® 28 considerably better resistance to **sodium hydroxide** than standard stainless steels of the type AISI 304 and AISI 316. At moderate temperatures and concentrations, Sanicro® 28 is a suitable alternative to pure nickel, which may be attacked by erosion corrosion.

At high temperatures the general corrosion rate increases. The risk of stress corrosion cracking (SCC) also increases when chlorides are present. Table 2 and 3 demonstrate the good resistance of Sanicro® 28 against general corrosion and SCC in sodium hydroxide contaminated with chlorides.

Table 2. SCC in boiling 43% NaOH + 6.7% NaCl, 142°C (288°F), 500h.

Grade	**SCC**
Sanicro® 28	No
Alloy 800	Yes, cracks <120µm
Alloy 904L	Yes, cracks <150µm

Table 3. General corrosion in NaOH and in NaOH+NaCl, mm/year.

Grade	**28%**	**28%**	**43%**	**43%**
	NaOH	**NaOH+**	**NaOH**	**NaOH+**
		8% NaCl		**6.7% NaCl**
	99 °C (210 °F)	**135 °C (275 °F)**	**135 °C (275 °F)**	**135 °C (275 °F)**
Sanicro® 28	0.008	0.008	0.074	0.045
Alloy 800	0.011	0.013	0.397	0.283
Alloy 904L	0.013	0.018	0.301	0.349

As can be seen, Sanicro® 28 is superior to both Alloy 800 and Alloy 904L.

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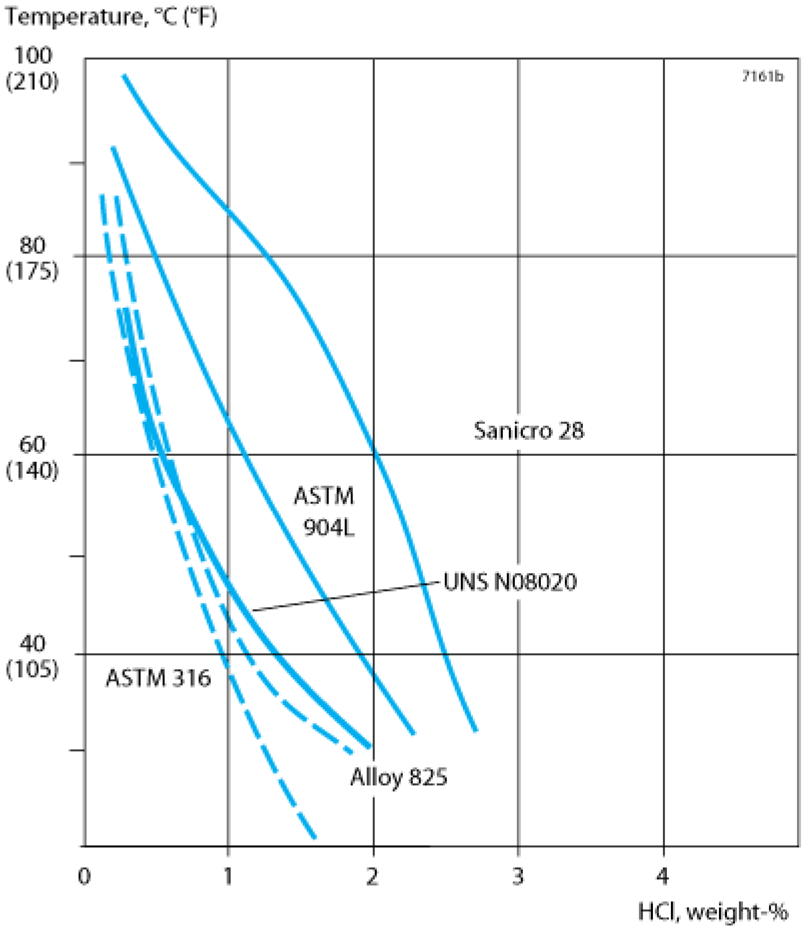

Figure 5. Isocorrosion in hydrochloric acid. The curves repesent a corrosion rate of 0.1 mm/year (4 mpy).

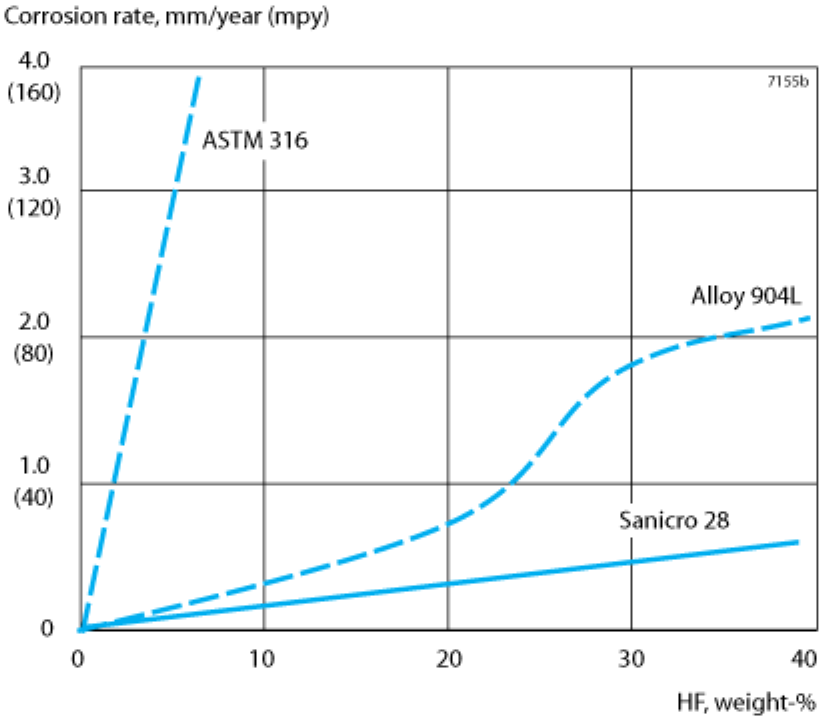

Figure 6. Corrosion rates in hydrofluoric acid at 20°C (68°F) for Sanicro 28, Alloy 904L and AISI 316.<

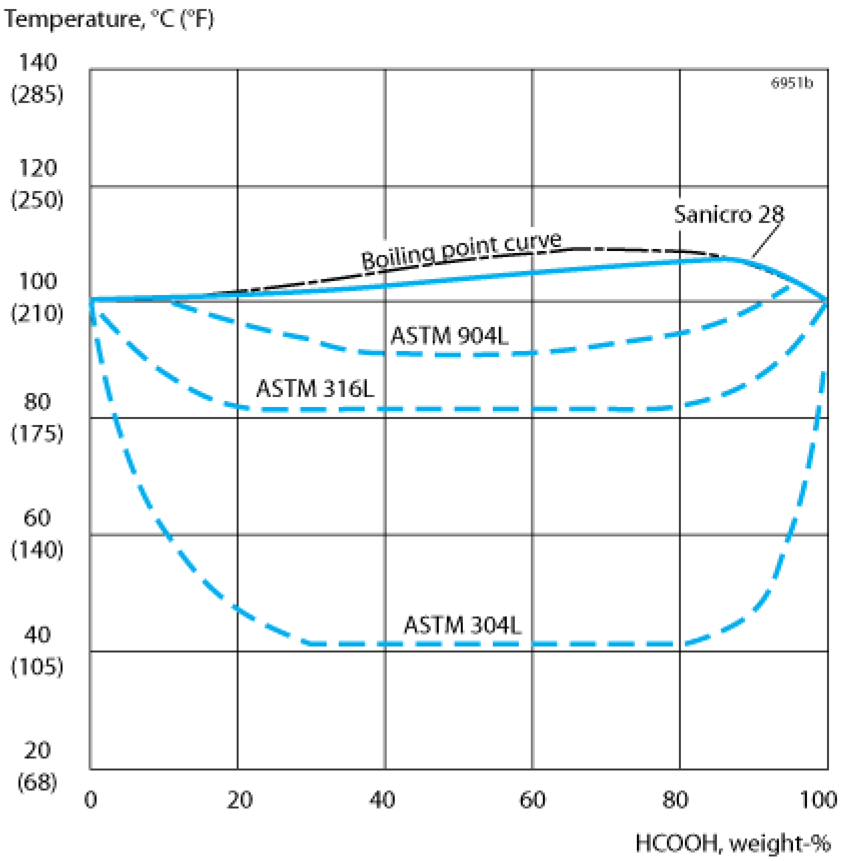

Figure 7. Isocorrosion diagram for Sanicro 28 and other alloys in formic acid at a corrosion rate of 0.1 mm/year (4 mpy).

Pitting corrosion

Sanicro® 28 can withstand very high temperatures in aggressive environments without being attacked by pitting. Figure 8 shows the critical pitting temperature (CPT) for some alloys in chloride-bearing water with a salinity comparable to that of sea water. The figure shows that Sanicro® 28 has a higher critical pitting temperature (CPT) than Alloy 904L and Alloy 825 even in acidic chloride solutions. The curves are displaced at higher temperatures in solutions with lower salinities.

Crevice corrosion

Laboratory tests show that Sanicro® 28 has good resistance to crevice corrosion. In tests according to ASTM G-48 method B (6% iron(III)chloride), the material exhibited better resistance than Alloy 825.

Stress corrosion cracking

Ordinary austenitic steels of the AISI 304 and AISI 316 types are susceptible to stress corrosion cracking (SCC) in chloride bearing solutions at temperatures above about 60°C (140°F). This susceptibility declines with increasing nickel content. Chromium contents above 20% can also be beneficial. Sanicro® 28, which is alloyed with 27% Cr and 31% Ni, exhibits very good resistance to SCC, both in laboratory tests and in practice. This is demonstrated in figure 9, which shows results of SCC tests in a 40% calcium chloride solution.

Tensile specimens which were spring-loaded to stresses close to the proof strength and tested for SCC in aerated water at temperatures of up to 200–250°C (390–480°F), were not attacked, see figure 10. These tests were performed in autoclaves with an oxygen content in the water of 4.6 to 10 ppm and a pH-value at room temperature of 4.5-7.1. The testing time was 1000 hours. The curve for AISI 316/316L and AISI 304/304L is based on experimental data and practical experience.

Sanicro® 28 also displays very good resistance to SCC in environments where hydrogen sulfide is present together with chlorides. This is true for both solution annealed and cold worked material, as well as for welded joints. For further information, see Alleima R&D lecture S-58-7-ENG.

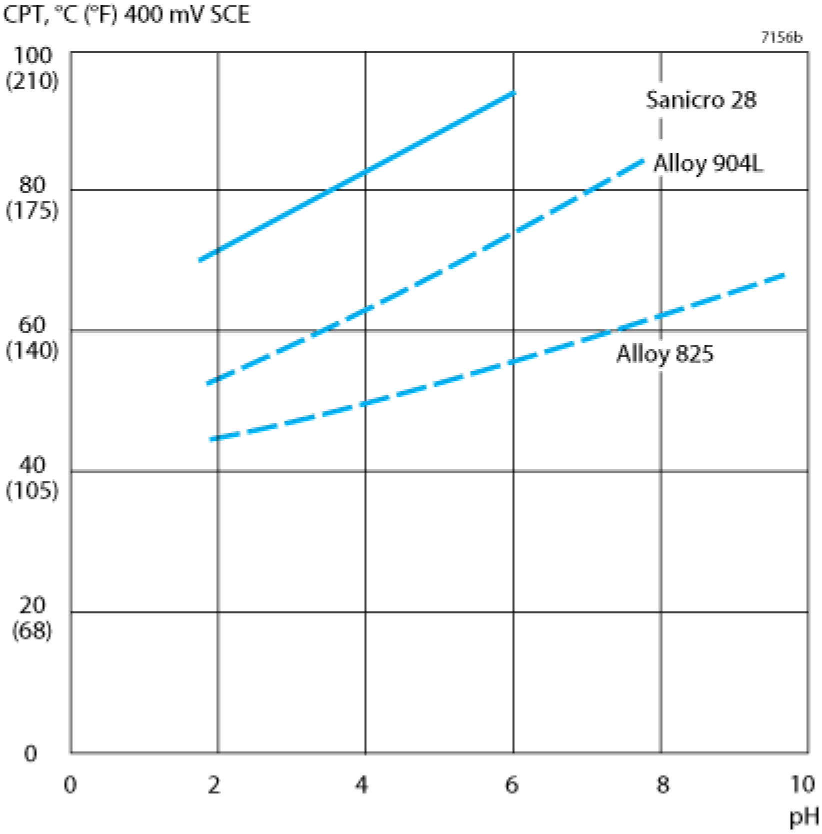

Figure 8. Critical pitting temperature (CPT) at +400 mV SCE for different alloys in synthetic seawater (3% NaCl), at different pH values (chemical compositions give in table 1).

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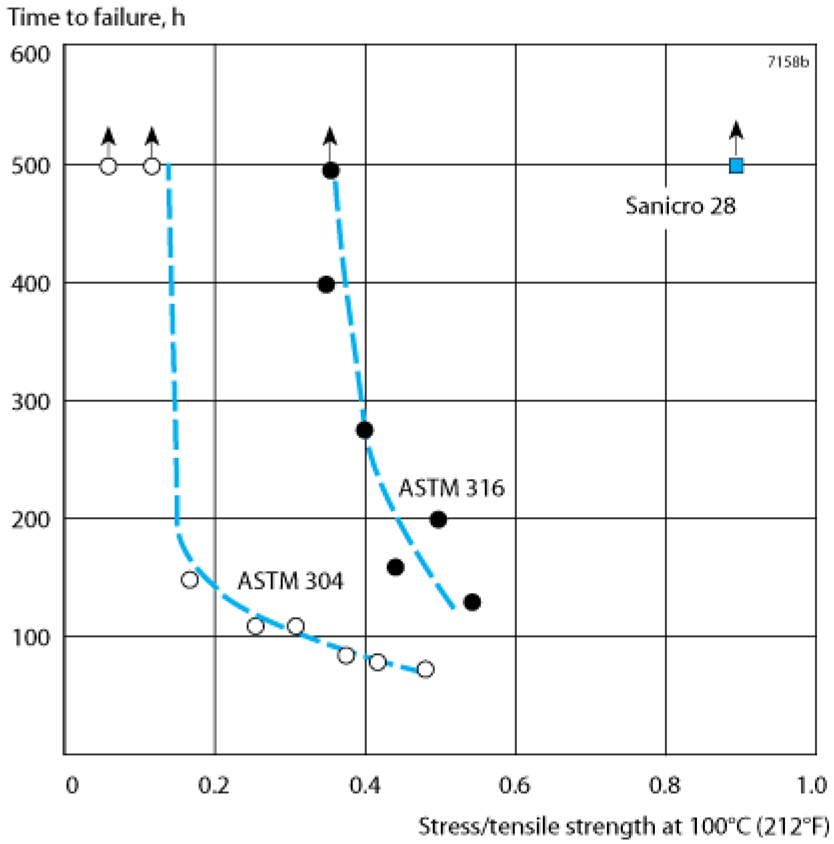
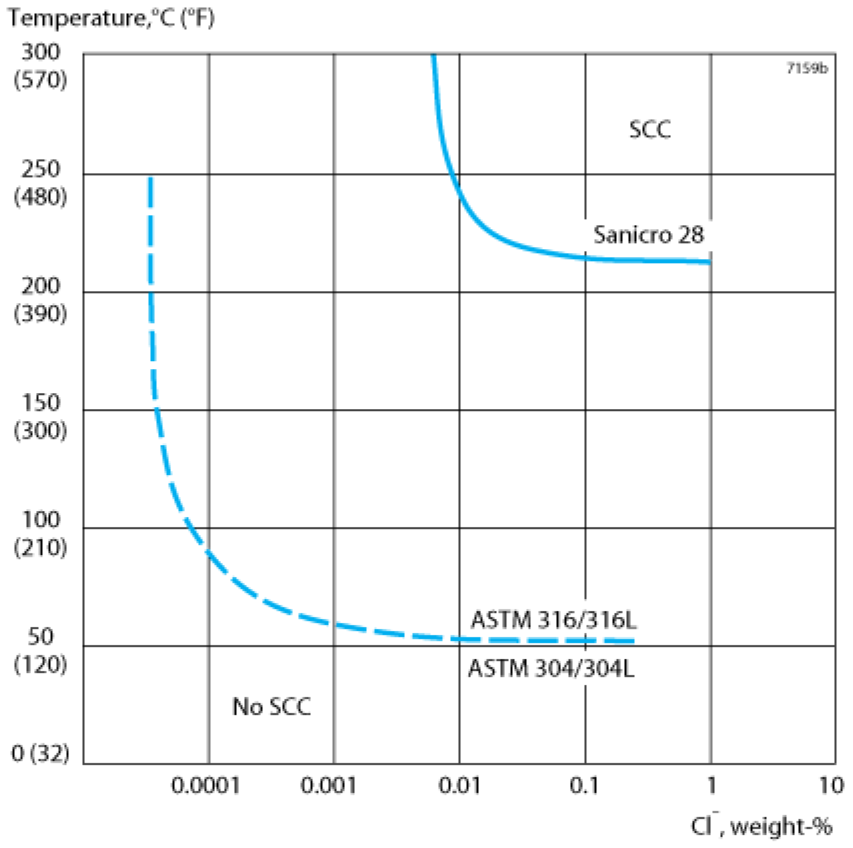


Figure 9. Results of stress corrosion cracking tests on different steel grades in 40% CaCl₂, at 100°C (210°F), pH = 6.5.



Intergranular corrosion

The TTC diagram, figure 11, shows results of intergranular corrosion testing according to ASTM G-28 (120 hours in boiling iron(III)sulphate and sulfuric acid solution). As the figure illustrates, Sanicro® 28 can be kept in the critical interval of 600-700°C (1100-1300°F) for at least 30 minutes without intergranular corrosion occurring in this highly corrosive medium. As can be seen in figure 11, Alloy 904L is more susceptible to intergranular corrosion than Sanicro® 28. In normal welding operations, heat input to the parent metal takes place for a much shorter time than 30 minutes. This means that the risk of intergranular attack after welding of Sanicro® 28 is minimal, which is also verified by tests on welded specimens.

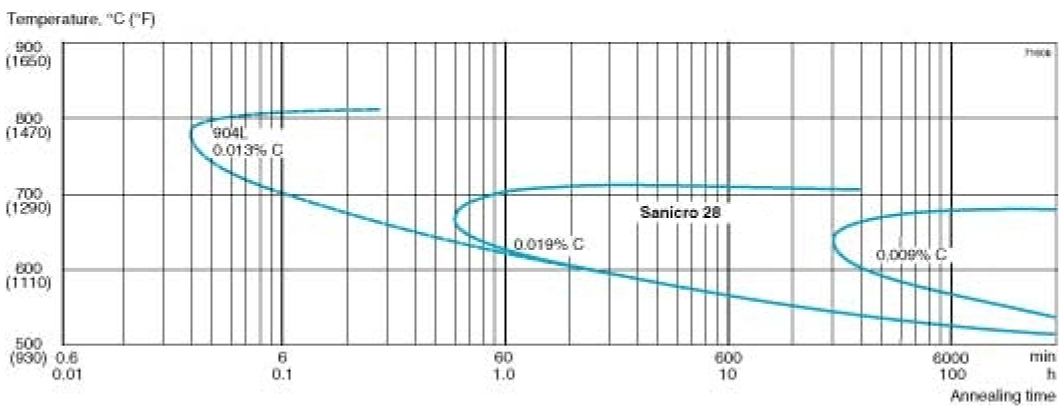


Figure 11. TTC diagram for Sanicro 28 with two different carbon contents and for Alloy 904L (Sandvik 2RK65). The curves repesent normal limit values for the carbon content.

Fabrication

Bending

The excellent formability of Sanicro® 28 permits cold bending to very small bending radii. Annealing is not normally necessary after cold bending.

For operating temperatures over 400°C (800°F), heat treatment should be carried out after bending to ensure good ductility after prolonged service times.

Expanding

Sanicro® 28 is expanded into tube sheets in the same way as standard austenitic stainless steels.

Machining

The machining of Sanicro® 28, as with other stainless steels, requires an adjustment of tooling data and machining method, in order to achieve satisfactory results. Compared to Sanmac® 316/316L, the cutting speed must be reduced by approximately 50-55% when turning Sanicro® 28 with coated, cemented carbide tools. Much the same applies to other operations. Feeds should only be reduced slightly and with care.

Detailed recommendations for the choice of tools and cutting data are provided in the brochure S-02909-ENG. Data should be selected as for steel grade Sanmac® 316/316L, while taking into account the provisions above.

Forms of supply

Seamless tube – Finishes and dimensions

Seamless tube and pipe is supplied in dimensions up to 260 mm outside diameter in the solution annealed and white-pickled condition, or solution annealed in a bright annealing process. Seamless tubes are available from stock in ANSI pipe and heat exchanger tube sizes. Details of our manufacturing and stock programme are given in catalogue S-110-ENG.

Using modern bending equipment, Alleima can bend tubes to customers' particular requirements and, if required, anneal after bending.

Materials for oil and gas production

Cold worked seamless tube and pipe

For production tubing and casing in oil and gas production. Sanicro® 28 is supplied cold worked with high strength properties (Sanicro® 28-110 and Sanicro® 28-125). Specific Oil and Gas information is available on request.

Other forms of supply

- Welded tube and pipe
- Strip, annealed or cold rolled to different degrees of hardness
- Bar steel
- Plate and sheet
- Forged products
- Cast products
- Fittings

Further details concerning sizes and finishes are available on request.

Heat treatment

Tubes are delivered in the heat treated condition. If another heat treatment is needed after further processing, the following is recommended.

Solution annealing
1100-1160°C (2010-2120°F), 10-30 minutes, quenching in water. Thin walled tubes can also be cooled rapidly in air.

Mechanical properties

The following values apply to solution annealed material, unless otherwise stated.

At 20°C (68°F)

Metric units

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	A_2"	HRB
MPa	MPa	MPa	%	%	
≥220	≥250	550-750	≥40	≥40	≤90

Imperial units

Proof strength		Tensile strength	Elong		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRB
ksi	ksi	ksi	%	%	
≥32	≥36	80-109	≥40	≥40	≤90

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.

Tube, pipe, plate and sheet with material thicknesses >20 mm (0.787") and bar with diameters >100 mm (3.937")

Metric units

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRB
MPa	MPa	MPa	%	%	
≥200	≥230	550-750	≥40	≥40	≤90

Imperial units

Proof strength		Tensile strength	Elong		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRB
ksi	ksi	ksi	%	%	
≥29	≥33	80-109	≥40	≥40	≤90

Seamless cold worked tube and pipe

Intended for oil and gas production

	Proof strength		Tensile strength		Elong.	Hardness
	$R_{p0.2}$[a)]		R_m		$A_{2"}$	HRC
	MPa	ksi	MPa	ksi	%	
Sanicro 28-110	≥760	≥110	≥795	≥115	11	≤35
Sanicro 28-125	≥860	≥125	≥895	≥130	10	≤37

Impact strength

Due to its austenitic microstructure, Sanicro® 28 has very good impact strength, both at room temperature and at cryogenic temperatures.

Tests have demonstrated that the steel fulfils the requirements according to the European standards EN 13445-2 (UFPV-2) (min. 60 J (44 ft-lb) at -270 °C (-455 °F)) and EN 10216-5 (min. 60 J (44 ft-lb) at -196 °C (-320°F)).

At high temperatures

Due to embrittlement caused by precipitation of intermetallic phases, Sanicro® 28 should not be exposed to temperatures above 600 °C (1110 °F) for prolonged periods.

According to the ASME Boiler and Pressure Vessel Code Table 1B, Sanicro® 28 is acceptable to 600°F (316°C) for Section III construction and 850°F (455°C) for Section I (Code Case 1325-18) and Section VIII, Division 1 construction.

Tube, pipe, plate and sheet with material thicknesses <20 mm (0.787") and bar with diameters <100 mm (3.937")

Metric units

Temperature	Proof strength		Tensile strength
	$R_{p0.2}$	$R_{p1.0}$	R_m
°C	MPa	MPa	MPa
	min	min	min
50	200	230	550
100	190	220	510
150	175	205	470
200	160	190	440
250	155	185	410
300	150	180	390
350	145	175	380
400	135	165	370
450	125	155	360
500	120	150	350
550	115	145	340

Imperial units

Temperature	Proof strength		Tensile strength
	$R_{p0.2}$	$R_{p1.0}$	R_m
°F	ksi	ksi	ksi

	min	min	min
120	29	33	80
210	28	32	74
300	25	30	68
390	23	28	64
480	22	27	59
570	22	26	57
660	21	25	55
750	20	24	54
840	18	22	52
930	17	22	51
1020	17	21	49

Tube, pipe, plate and sheet with material thicknesses >20 mm (0.787") and bar with diameters >100 mm (3.937")

Metric units

Temperature	Proof strength		Tensile strength
	$R_{p0.2}$	$R_{p1.0}$	R_m
°C	MPa	MPa	MPa
	min	min	min
50	180	205	550
100	160	190	510
150	150	180	470
200	140	170	440
250	130	160	410
300	120	150	390
350	115	140	380
400	110	135	370
450	105	130	360
500	100	125	350
550	95	120	340

Imperial units

Temperature	Proof strength		Tensile strength
	$R_{p0.2}$	$R_{p1.0}$	R_m
°F	ksi	ksi	ksi

	min	min	min
120	26	30	80
210	23	28	74
300	22	26	68
390	20	25	64
480	19	23	59
570	17	22	57
660	17	20	55
750	16	20	54
840	15	19	52
930	15	18	51
1020	14	17	49

Creep strength

Metric units

Temperature	**Creep rupture strength**	
	10 000 h	**100 000 h**
°C	**MPa**	**MPa**
	approx.	**approx.**
550	262	193
600	186	146
650	122	93
700	82	62

Imperial units

Temperature	**Creep rupture strength**	
	10 000 h	**100 000 h**
°F	**ksi**	**ksi**
	approx.	**approx.**
1020	38	28
1110	27	21
1200	18	13
1300	12	9

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Physical properties

Density: 8.0 g/cm^3, 0.29 lb/in^3

Relative magnetic permeability

1.003 (approximate value)

Thermal conductivity

Temperature, °C	W/(m °C)	Temperature, °F	Btu/(ft h °F)
20	10	68	5.5
100	13	200	7
200	14	400	8.5
300	17	600	9.5
400	19	800	11
500	21	1000	12.5
600	24	1100	13.5

Specific heat capacity

Temperature, °C	J/(kg °C)	Temperature, °F	Btu/(lb °F)
20	460	68	0.11
100	480	200	0.12
200	500	400	0.12
300	515	600	0.12
400	535	800	0.13
500	555	1000	0.13
600	590	1100	0.14

Resistivity

Temperature, °C	μΩm	Temperature, °F	μΩin.
20	0.99	68	39.0
100	1.07	200	42.0
200	1.16	400	46.0
300	1.22	600	48.5
400	1.25	800	49.5

Thermal expansion, mean values in temperature ranges (x10-6)

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Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	15	86-200	8
30-200	15.5	86-400	8.5
30-300	16	86-600	9
30-400	16	86-800	9
30-500	16.5	86-1000	9
30-600	16.5	86-1200	9.5
30-700	17	86-1300	9.5

Modulus of elasticity ($x10^3$)

Temperature, °C	MPa	Temperature, °F	ksi
20	195	68	28.3
100	190	200	27.6
200	182	400	26.3
300	174	600	25.1
400	166	800	23.8

Welding

The weldability of Sanicro® 28 is good. 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.

In common with all fully austenitic stainless steels, Sanicro® 28 has low thermal conductivity and high thermal expansion. Welding plans should therefore be carefully selected in advance, so that distortions of the welded joint are minimized. If residual stresses are a concern, solution annealing can be performed after welding.

For Sanicro® 28, heat-input of <1.0 kJ/mm and interpass temperature of <150°C (300°F) are recommended. A string bead welding technique should be used.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 27 31 4 Cu L/AWS A5.9 ER383 (e.g. Exaton 27.31.4.LCu)

MMA/SMAW welding

ISO 3581 E 27 31 4 Cu L R/AWS A5.4 E383-16 (e.g. Exaton 27.31.4.LCuR)

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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 Alleima materials.