SANDVIK

SANDVIK 2RK65™
TUBE AND PIPE, SEAMLESS

DATASHEET

Sandvik 2RK65™ is a high-alloy austenitic stainless steel intended for use under severe corrosive conditions within the process industry. The grade is characterized by:

– Very good resistance to attacks in acidic environments, e.g. sulfuric, phosphoric and acetic acid
– Very good resistance to pitting in neutral chloride-bearing solutions
– Much better resistance to crevice corrosion than steels of the ASTM 304 and ASTM 316 types
– Very good resistance to stress corrosion cracking
– Good weldability

STANDARDS

- ASTM: '904L'
- UNS: N08904
- ISO: 4539-089-04-I
- EN Number: 1.4539
- EN Name: X1NiCrMoCu25-20-5

Product standards

- ASTM A213 (seamless/welded tube)
- ASTM A269 (seamless/welded tube)
- ASTM A312 (seamless/welded pipe)
- ASTM A240 (plate and sheet)
- ASTM A276, A479, A484 (bar)
- ASTM B677 (seamless tube and pipe)
- EN 10216-5 (seamless tube and pipe)

Approvals

- Approved for use in ASME Boiler and Pressure Vessel Code section VIII, div. 1 construction
- VdTÜV-Werkstoffblatt 421 (Austenitischer Walz-und Schmiedestahl)

CHEMICAL COMPOSITION (NOMINAL) %

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo	Cu
≤0.020	0.5	1.8	≤0.025	≤0.015	20	25	4.5	1.5

FORMS OF SUPPLY

Datasheet updated 6/19/2019 2:54:40 PM (supersedes all previous editions)

Seamless tube and pipe are supplied in dimension up to 230 mm (9.1 in.) outside diameter in the solution annealed and white-pickled condition or in the bright-annealed condition.

Tubes can be bent according to customer drawings and, on request, annealed after bending.

Fittings

90 deg. bends are manufactured as standard in Sandvik 2RK65™ according to ANSI B16.9 and, where applicable, ASTM A403. Flanges are made as standard to ANSI B16.5 in the form of slip-on flanges (class 150) and weld neck flanges (class 300), and to relevant sections of ASTM A182. Fittings can be manufactured to other standards by agreement. Other types of fittings such as reducers, tees and couplings can also be supplied on request.

Other products forms

- Welded tube and pipe
- Strip, annealed or cold-rolled to different degrees of hardness
- Wire, drawn or ground
- Bar steel
- Plate and sheet
- Forged tube-sheets
- Welding consumables

MECHANICAL PROPERTIES

The following figures apply to material in the solution annealed condition. Tube and pipe with thickness above 20 mm (0.79 in.) may have slightly lower values.

Metric units, at 20°C

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	A2"	Vickers
MPa	MPa	MPa	%	%	
					approx.
≥230	≥250	520-720	≥35 c)	≥35	160

1 MPa = 1 N/mm^2

Imperial units, at 68°F

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	A2"	Vickers
ksi	ksi	ksi	%		
					approx.
≥33	≥36	75-104	≥35 c)	≥35	160

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-section area.
c) NFA 49-217 with min 40% can be fulfilled.

Impact strength

Due to its austenitic microstructure, Sandvik 2RK65™ has very good impact strength both at room temperature and at cryogenic temperatures.

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

Datasheet updated 6/19/2019 2:54:40 PM (supersedes all previous editions)

At high temperatures

The steel should not be exposed to temperatures above about 550°C (1020°F) for prolonged periods, since this leads to precipitation of intermetallic phases, which can have an adverse effect on both the mechanical properties and the corrosion resistance of the steel.

Metric units

Temperature	Proof strength	
	Rp0.2	Rp1.0
°C	MPa	MPa
	min.	min.
100	176	205
200	155	185
300	136	165
400	125	155

Imperial units

Temperature	Proof strength	
	Rp0.2	Rp1.0
°F	ksi	ksi
	min.	min.
200	26.1	30.3
400	22.4	26.7
600	19.5	23.7
700	18.6	22.9

PHYSICAL PROPERTIES

Density: 8.0 g/cm3, 0.29 lb/in3

Thermal conductivity

Temperature, °C	W/(m °C)	Temperature, °F	Btu/(ft h °F)
20	12	68	7
100	14	200	8
200	16	400	9
300	18	600	10.5
400	20	800	11.5
500	22	1000	13
600	23	1200	14
700	25	1300	14.5

Specific heat capacity

Temperature, °C	J/(kg °C)	Temperature, °F	Btu/(lb °F)
20	460	68	0.11
100	485	200	0.12

Specific heat capacity

Temperature, °C	J/(kg °C)	Temperature, °F	Btu/(lb °F)
200	515	400	0.12
300	545	600	0.13
400	570	800	0.14
500	590	1000	0.14
600	605	1200	0.15
700	615	1300	0.15

Thermal expansion 1)

Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	15.5	86-200	8.5
30-200	16	86-400	9
30-300	16.5	86-600	9
30-400	17	86-800	9.5
30-500	17	86-1000	9.5
30-600	17.5	86-1200	9.5
30-700	17.5	86-1300	10

1) Mean values in temperature ranges ($x10^{-6}$)

Resistivity

Temperature, °C	μΩm	Temperature, °F	μΩin.
20	0.94	68	37.0
100	0.99	200	38.8
200	1.07	400	42.2
300	1.13	600	44.6
400	1.15	800	45.5
500	1.17	1000	45.8
600	1.15	1200	45.9
700	1.18	1300	46.5

Modulus of elasticity 1)

Temperature, °C	MPa	Temperature, °F	ksi
20	195	68	28.5
100	190	200	27.5
200	182	400	26.5
300	174	600	25
400	166	800	24
500	158	1000	22.5

1) ($x10^{3}$)

CORROSION RESISTANCE

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General corrosion

The steel was originally developed for use in sulfuric acid. Its good resistance is achieved by virtue of a high molybdenum content and alloying with copper. Figure 1 is an isocorrosion diagram for Sandvik 2RK65™, Sanicro® 28 and ASTM 316L in deaerated sulfuric acid.

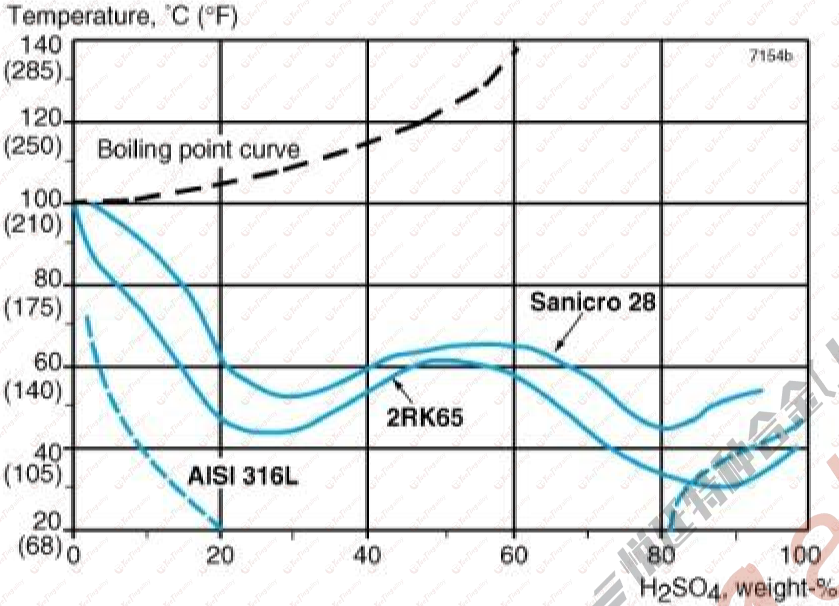


Figure 1. Isocorrosion diagram for Sandvik 2RK65, Sanicro 28 and ASTM 316L in deaerated sulfuric acid at a corrosion rate of 0.1 mm/year (4 mpy) in stagnant solution.

Figure 2 shows the isocorrosion diagram for the above steels but in naturally aerated sulfuric acid.

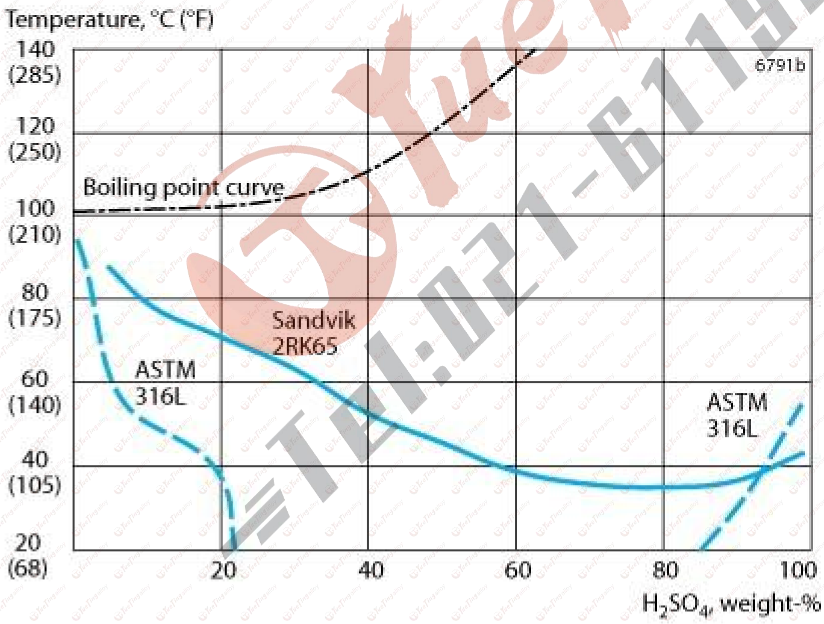


Figure 2. Isocorrosion diagram 0.1 mm/year (4 mpy) for Sandvik 2RK65 and ASTM 316L in naturally aerated sulfuric acid of chemical purity.

Technical phosphoric acid manufactured by means of the 'wet' method contains varying amounts of impurities from the starting material, the phosphate rock. The most dangerous of these impurities are chlorides, Cl^-, and fluorides in free form, F-. Sandvik 2RK65 has been used with success in many applications in phosphoric acid plants and for the handling of technical acid. However, for the severest corrosion conditions, Sanicro® 28, which was developed especially for phosphoric acid applications, provides superior corrosion resistance.

In pure acetic acid, both Sandvik 2RK65™ and ASTM 316L are completely resistant at all temperatures and concentrations at atmospheric pressure. At elevated temperatures and pressures, however, ASTM 316L will corrode while Sandvik 2RK65™ will remain resistant. Experience from acetic acid production has shown that acetic acid contaminated with formic acid is always corrosive. In acid of this kind, Sandvik 2RK65 is far more resistant than ASTM 316L, see table 1 below. Practical operating experience has confirmed the superiority of Sandvik 2RK65™ to ASTM 317L as well.

In formic acid, high-alloy Sandvik 2RK65™ shows better resistance than conventional steels of the ASTM 316L type, see Figure 3. In oxalic acid Sandvik 2RK65™ shows better performance than ASTM 316L, see Figure 4. 2RK65 is resistant (corrosion rate <0.1 mm/year) in lactic acid at all concentrations at temperatures up to or slightly below the boiling point at atmospheric pressure. This means a corrosion resistance similar to or slightly better than of ASTM 316L in lactic acid. Due to its molybdenum content, Sandvik 2RK65™ is less resistant to nitric acid than steels of the ASTM 304L and ASTM 310L types, which are commonly used in these environments.

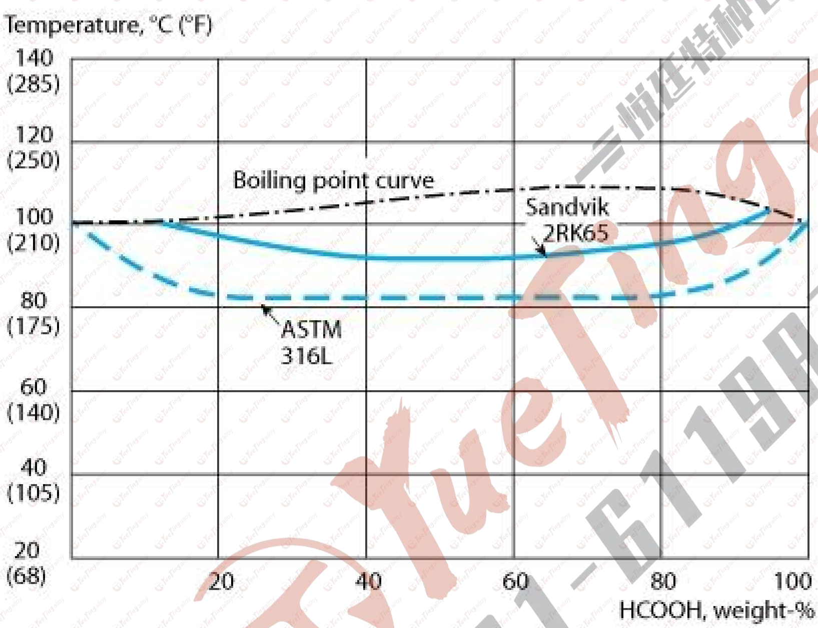


Figure 3. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65 and ASTM 316L in formic acid.

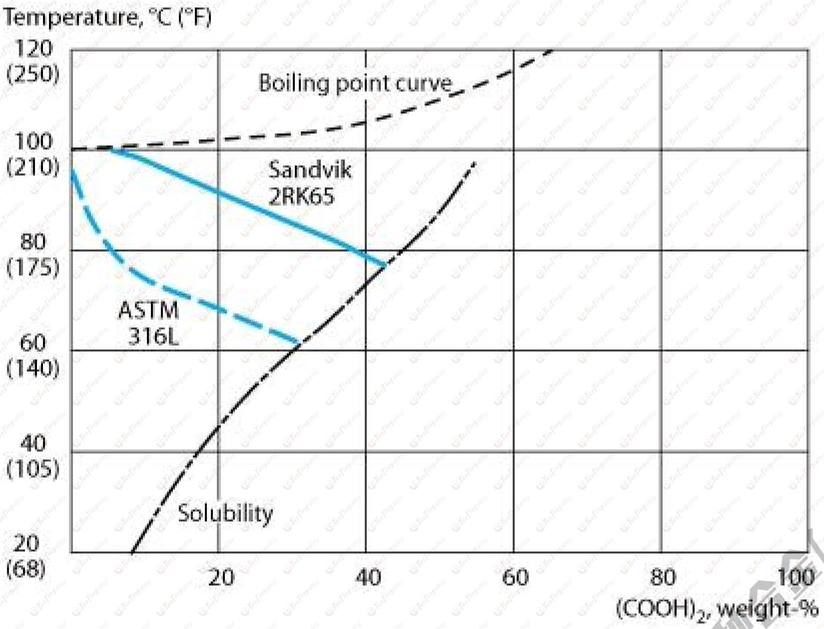


Figure 4. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65 and ASTM 316L in oxalic acid.

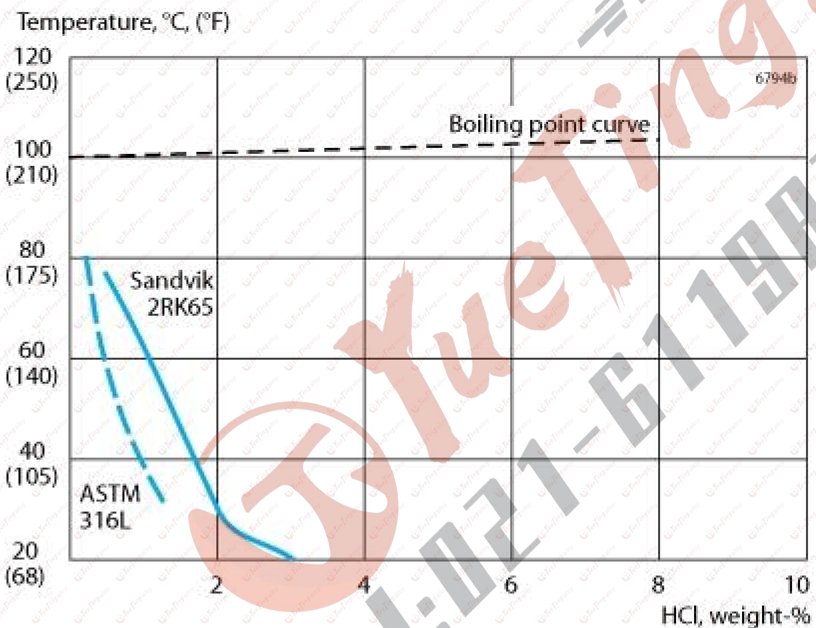


Figure 5. Isocorrosion diagram 0.1 mm/year (4 mpy) ior 2RK65 and AISI 316L in hydrochloric acid.

Datasheet updated 6/19/2019 2:54:40 PM (supersedes all previous editions)

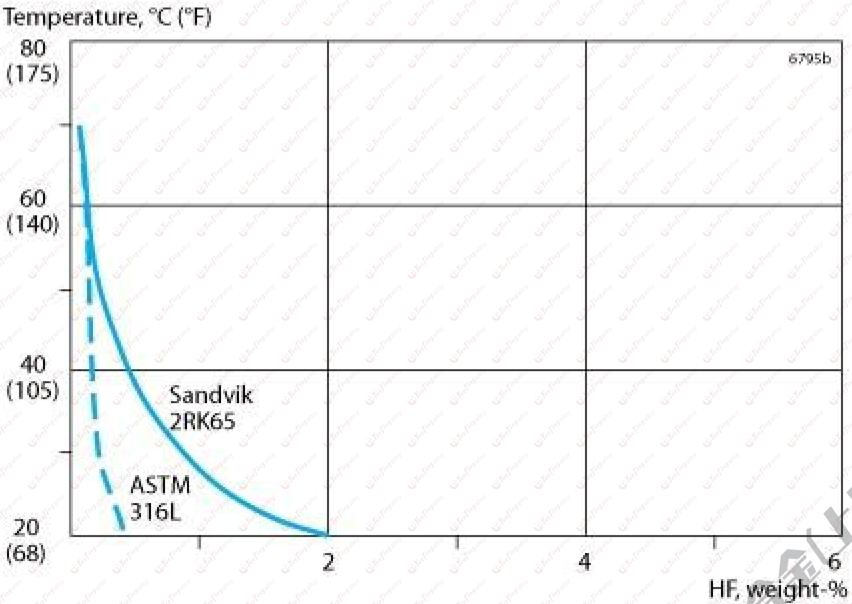


Figure 6. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65 and ASTM 316L in hydrofluoric acid.

High molybdenum content is an advantage in hydrochloric acid, and Sandvik 2RK65™, with its 4.5% Mo is consequently far more resistant than, for example, ASTM 316L. Sandvik 2RK65 is therefore suitable for use in chemical process solutions containing small amounts of hydrochloric acid. The isocorrosion diagram is presented in Figure 5. The risk of pitting should, however, be kept in mind. Also in hydrofluoric acid Sandvik 2RK65™ benefits from its high molybdenum content, although hydrofluoric acid is an even more aggressive acid compared to hydrochloric acid, see isocorrosion diagram in Figure 6.

Table 1. results of laboratory tests lasting 1+3+3 days in boiling mixtures of acetic and formic acid.

Acetic acid %	Formic acid %	Corrosion rate	mpy	ASTM 316L	mpy
		Sandvik 2RK65			
		mm/year		mm/year	
10	10	0.09	3.6	0.35	14
25	10	0.07	2.8	0.33	13
30	10	0.10	4.0	0.29	12
50	10	0.10	4.0	0.27	11

Due to its high chromium and nickel contents, Sandvik 2RK65™ possesses much better resistance in sodium hydroxide than ASTM 304 and ASTM 316, see Figure 7.

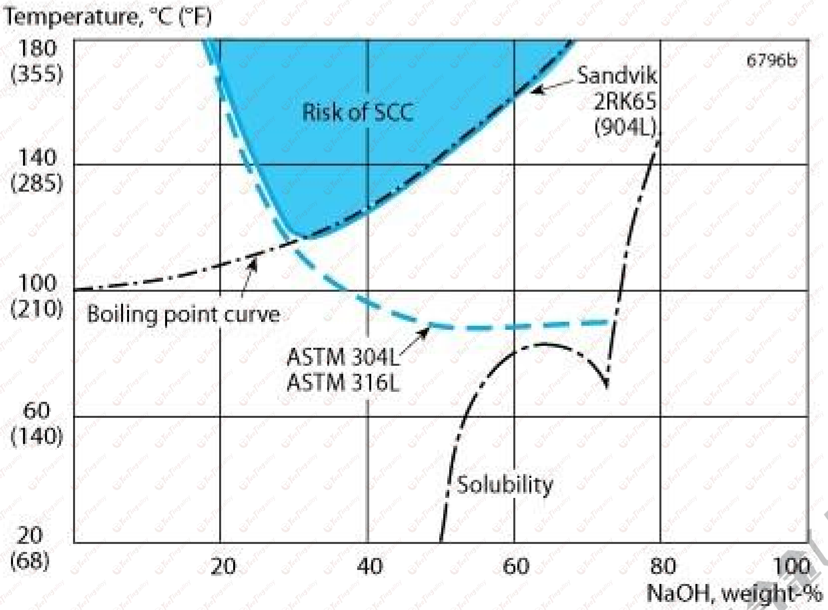
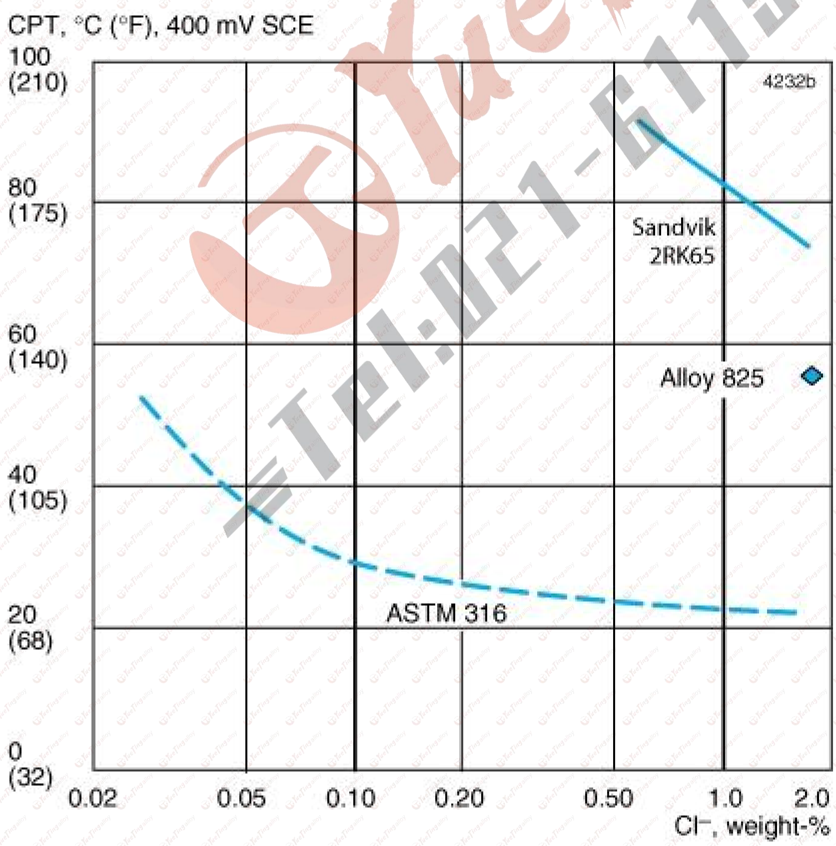


Figure 7. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65, 304L and AISI 316L in sodium hydroxide of chemical purity.

As can be seen, the risk of stress corrosion cracking (SCC) increases at high temperatures. This risk is enhanced if chlorides are present. The alloy Sanicro® 28 provides better resistance against stress corrosion cracking and also general corrosion than is the case for Sandvik 2RK65™.

Pitting corrosion

The high chromium and molybdenum contents of this steel make it very resistant to pitting. This has been verified by extensive practical experience of service involving chloride-bearing process solutions and seawater cooling.



Datasheet updated 6/19/2019 2:54:40 PM (supersedes all previous editions)

Figure 8. Mean values of critical pitting temperature (CPT) at 400 mV SCE and different Cl⁻ concentrations (NaCl solutions), pH ~ 6 (1.8%Cl⁻ corresponds to the chloride content of seawater).

As can be seen in Figure 8, the mean critical pitting temperature (CPT) for Sandvik 2RK65™ is around 75°C (165°F) at a potential of 400 mV SCE in a neutral solution (pH = 6) with the same chloride content as seawater. This value is 50°C (120°F) higher than for ASTM 316 and 20°C (68°F) higher than for Alloy 825 (21Cr42Ni3Mo).

Stress corrosion cracking (SCC)

Ordinary austenitic steels of the ASTM 304 and ASTM 316 types are susceptible to stress corrosion cracking (SCC) in chloride-bearing solutions at temperatures above about 60°C (140°F). At high temperatures, above about 100°C (212°F), chloride contents as low as in the ppm-range (10^{-4} %) are sufficient to cause stress corrosion cracking in these steels. A nickel content of 25% is sufficient to provide very good resistance under practical conditions.

Laboratory tests in calcium chloride confirm the superiority of Sandvik 2RK65™ in resisting stress corrosion cracking compared to ASTM 304 and ASTM 316. As is shown by figure 9, the threshold stress (the stress necessary to induce fracture within the maximum testing time) is considerably higher for Sandvik 2RK65™ than for ASTM 304 and ASTM 316. Sandvik 2RK65™ is resistant up to at least 0.9 times the tensile strength.

Autoclave tests at different chloride contents and temperatures provide valuable data for material selection. Also this type of testing demonstrates the good SCC-resistance of Sandvik 2RK65™, far better than ASTM 304 and ASTM 316 types of steels, see Figure 10.

It is important to be aware of the fact that the residual stresses around a weld that has not been heat treated often equal the proof strength of the material. These stresses correspond to applied stress/tensile strength ratios of only 0.3-0.5, which is sufficient to exceed the threshold stress and thereby cause stress corrosion cracking in ASTM 304 and ASTM 316.

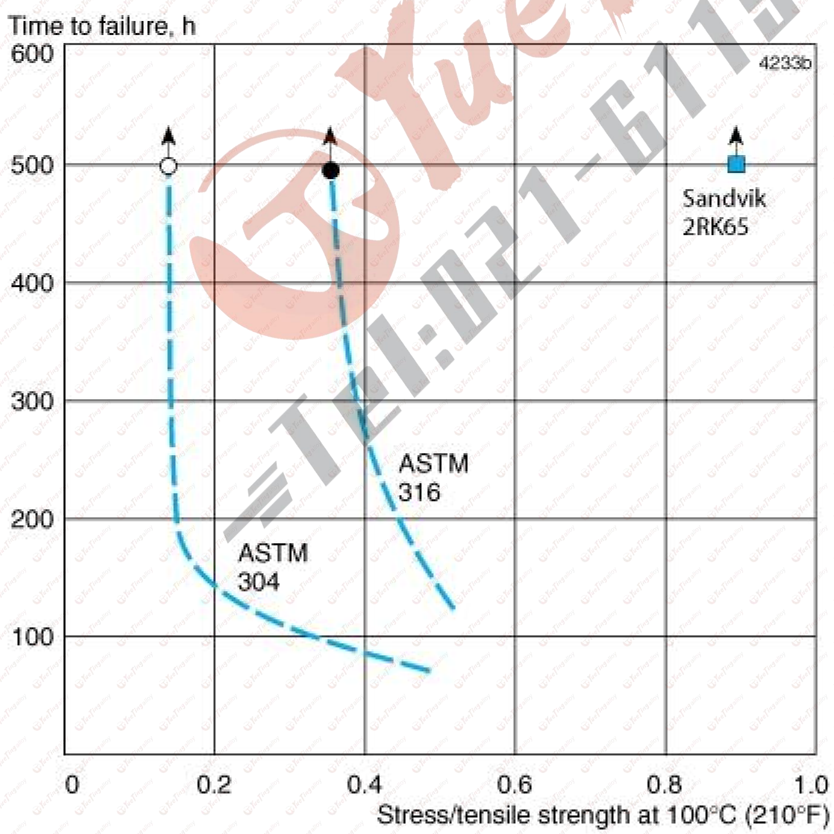


Figure 9. Results of stress corrosion cracking tests on different steel grades in 40% CaCl₂ at 100°C (210°F), pH = 6.5.

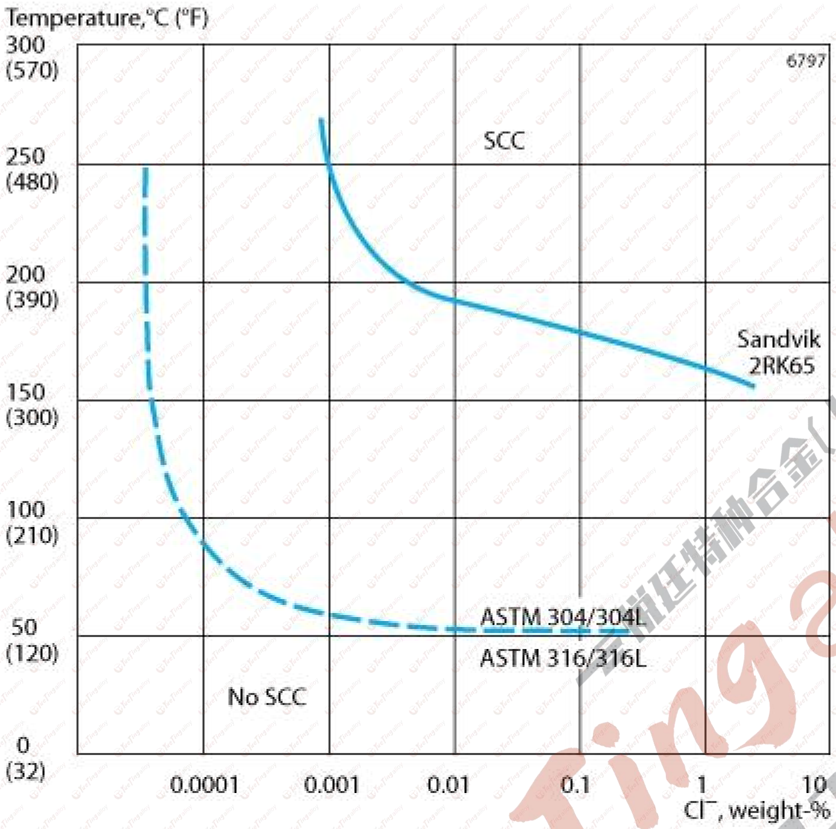


Figure 10. SCC resistance of 2RK65 in comparison to ASTM 304 and AISI 316 types of steels in neutral aerated chloride environments.

Crevice corrosion

Both laboratory tests and practical experience have shown that Sandvik 2RK65™ is substantially more resistant to crevice corrosion than ASTM 316L. This is illustrated in Table 2. Crevices should nevertheless be avoided as far as possible, especially in chloride-bearing solutions.

Table 2. Results of crevice corrosion tests in aerated stagnant NaCl solution (1.8% Cl-) pH = 6, test period 58 days. The area ratio between creviced and non-creviced surface on the specimen is 1/12.

Metric units

Grade	Initiated crevice corrosion attacks, %			Maximum depth, mm		
	50°C	60°C	70°C	50°C	60°C	70°C
Sandvik 2RK65	-	0	0	-	0	0
ASTM 316L	38	21	-	0.20	0.16	-

Imperial units

Grade	Initiated crevice corrosion attacks, %			Maximum depth, in.		
	120°F	140°F	160°F	120 °F	140 °F	160 °F

Datasheet updated 6/19/2019 2:54:40 PM (supersedes all previous editions)

Imperial units

Grade	Initiated crevice corrosion attacks, %			Maximum depth, in.		
	120°F	140°F	160°F	120 °F	140 °F	160 °F
Sandvik 2RK65	-	0	0	-	0	0
ASTM 316L	38	21	-	0.008	0.006	-

HEAT TREATMENT

Solution annealing

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

1080-1150°C (1975-2100°F), 5-30 minutes, rapid quenching in air or water.

WELDING

Sandvik 2RK65™ possesses good weldability. Welding should be undertaken without preheating. If welding is correctly performed, there is no need for subsequent heat treatment. The temperature between welding passes should not exceed 100°C (212°F). Suitable methods of fusion welding are manual metal-arc welding with covered electrodes and gas-shielded arc welding, especially the TIG and MIG methods.

Since the material is intended for use under severe corrosion conditions, welding must be carried out with care and a thorough cleaning must be performed after welding to ensure that the weld metal and the heat-affected zone will have corrosion properties close to those of the parent metal.

Welding should be undertaken with low heat input, maximum 1.0 kJ/mm. Furthermore, the diameter of electrodes used in manual metal-arc welding should be max. 2.5 mm (3/32 in.) for stock thicknesses up to 6 mm (1/4 in.) and max. 3.25 mm (1/8 in.) for heavier stock gauges. A stringer bead welding technique is recommended.

Like all austenitic stainless steels, Sandvik 2RK65 has low thermal conductivity and high thermal expansion, so welding must be carefully planned in advance to ensure that distortion of the welded joint can be kept under control. If, despite such precautions, it is believed that residual stresses might impair the functioning of the structure, it is recommended that the entire structure will be solution annealed, see under 'Heat treatment'.

Welding of fully austenitic steels often entails the risk of hot-cracking in the weld metal, particularly if the weldment is under constraint. Sandvik 2RK65, however, possesses very high purity, which reduces the risk of such cracking.

We recommend Sandvik 20.25.5.LCu wire as a filler metal for gas-shielded arc welding. Sandvik 20.25.5.LCuR covered electrodes are recommended for manual metal-arc welding. Wire Sandvik 27.31.4.LCu or covered electrodes Sandvik 27.31.4.LCuR can be used to advantage in applications where particularly good pitting resistance is required in the weld metal. When Sandvik 2RK65™ is welded to carbon steel, filler metals of nickel alloys can also be used.

BENDING

The good ductility of Sandvik 2RK65™ permits bending in the cold state to the smallest bending radii attainable with modern methods and machines. Annealing is not necessary after cold bending. If, however, the tubes have been heavily cold-worked and are to be used under conditions where stress corrosion cracking (SCC) is liable to occur, solution annealing is recommended (see under 'Heat treatment').

For pressure vessel applications in Germany, heat treatment may be required after cold deformation in accordance with VdTÜV-Wb 421. Heat treatment should be carried out by solution annealing.

APPLICATIONS

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Typical applications for Sandvik 2RK65™ are found in oil refineries and within the chemical and petrochemical industry. Sandvik 2RK65™ is also used within the pulp and paper industry, the mineral and metallurgical industry, the food industry, in seawater cooling and in many other fields.

The grade is an excellent alternative to standard austenitic stainless steels in heat exchangers using high-temperature water with chloride contamination.
