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Sandvik 2RK65

(Plate and sheet)

Sandvik 2RK65 is high-alloy austenitic stainless steel characterized by very good resistance to general corrosion in sulphuric, phosphoric and acetic acid as well as very good resistance to pitting corrosion and stress corrosion cracking.

STANDARDS

- ASTM '904L'
- UNS N08904
- EN number 1.4539*
- W.Nr. 1.4539
- DIN X 1 NiCrMoCuN 25 20 5
- SS 2562
- AFNOR Z 1 NCDU 25.20.04

* Valid for sheet/plate, strip, semifinished products, bars, rods and sections for general purposes (not for pressure purposes)

Product standards

ASTM	A240/A480, B625
SS	14 25 62

Approvals
Approved for use in ASME Boiler and Pressure Vessel Code section VIII, div. 1 construction
NGS 685 (Nordic rules for application of SS 2562)
VdTÜV-Werkstoffblatt 421 (Austenitischer Walz-und Schmiedestahl)

CHEMICAL COMPOSITION (NOMINAL) %

C max	Si	Mn	P max	S max	Cr	Ni	Mo	Cu
0.020	1.0	2.0	0.045	0.035	19.0- 23.0	23.0- 28.0	4.0-5.0	1.0- 2.0

FORMS OF SUPPLY

Plate & sheet are delivered in the solution annealed and pickled/unpickled condition.

The size ranges available are given below.

Plate sheet and coil
Sandvik 2RK65 Plate and sheet is stocked in a wide range of sizes according to ASTM. Details of our stock programme are given below:

Sandvik Australia's Stock Program
Plate (No1 Finish)
Thickness Range - 4mm - 40mm
Widths - 1500mm, 2000mm

Sheet (2B Finish)
Thickness Range - 1.5mm - 4mm
Widths - 1500mm, 2000mm
Lengths - 3000mm, 6000mm

MECHANICAL PROPERTIES

At 20°C (68°F)
The following figures apply to material in the solution annealed condition.

Proof strength			Tensile strength	Elong.	Hardness Rockwell
$R_{p0.2}$[a)]	$R_{p1.0}$[a)]		R_m	A[b)] $A_{2"}$	
MPa ksi	MPa	ksi	MPa ksi	% %	B
min. min.	min.	min.	Min. Min.	min. min.	approx.
220 31	250	36	490 71	35[c)] 35	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 ÖS_0 where L_0 is the original gauge length and S_0 the original cross-section area.
c) The NFA 49-217 requirement of A_{min} 40 % can not generally be fulfilled.

Impact strength
Due to its austenitic structure, 2RK65 has very good impact strength both at room temperature and low temperatures. The following minimum values (Charpy-V) apply at -60 °C (-76 °F).
Specimen taken out
parallel to the direction of rolling: 96J
perpendicular to the direction of rolling: 80J

Being a fully austenitic steel 2RK65 is ductile at temperatures down to -196 °C (-320 °F).

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	
°C	$R_{p0.2}$	$R_{p1.0}$
	MPa	MPa
	min	min
100	176	205
200	155	185
300	136	165
400	125	155

IMPERIAL UNITS

Temperature	Proof strength	
°F	$R_{p0.2}$	$R_{p1.0}$
	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/cm^3, 0.29 lb/in^3

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
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	uΩm	Temperature, °F	uΩin.
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

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

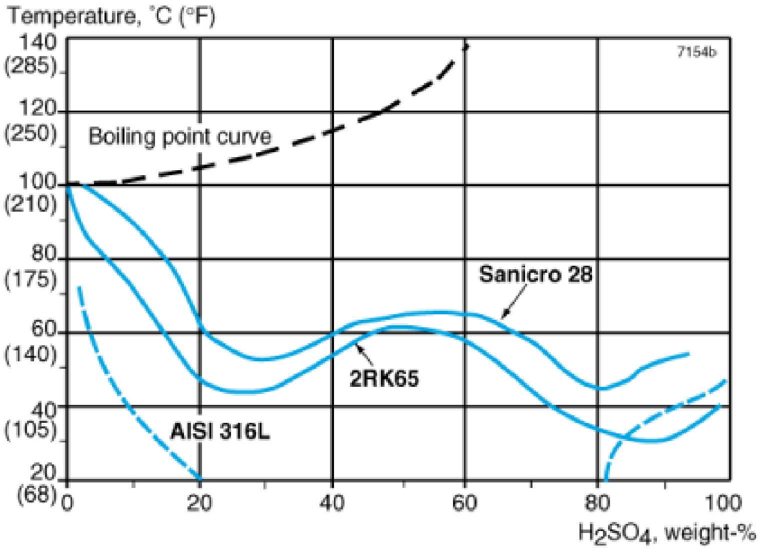

Figure 1. Isocorrosion diagram for 2RK65, Sanicro 28 and AISI 316L in deaerated sulphuric acid at a corrosion rate of 0.1 mm/year (4 mpy) in stagnant solution.

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

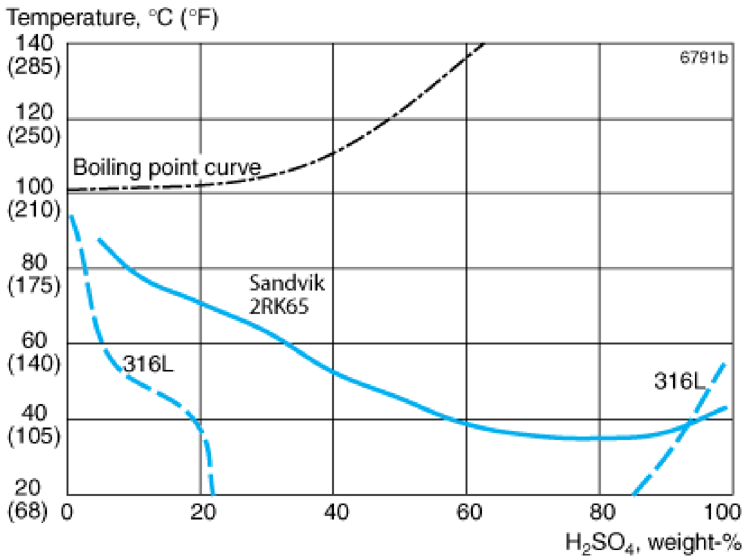

Figure 2. Isocorrosion diagram 0.1 mm/year (4 mpy) for 2RK65 and AISI 316L in naturally aerated sulphuric acid of chemical purity.

Technical phosphoric acidmanufactured 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^- . 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 2RK65 and AISI 316L are completely resistant at all temperatures and concentrations at atmospheric pressure. At elevated temperatures and pressures, however, AISI 316L will corrode while 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, 2RK65 is far more resistant than AISI 316L, see table 1 below.

Practical operating experience has confirmed the superiority of 2RK65 to AISI 317L as well.

In formic acid, high-alloy 2RK65 shows better resistance than conventional steels of the AISI 316L type, see figure 3. In oxalic acid 2RK65 shows better performance than 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 316L in lactic acid.

Due to its molybdenum content, 2RK65 is less resistant to nitric acid than steels of the AISI 304L and AISI 310L types, which are commonly used in these environments.

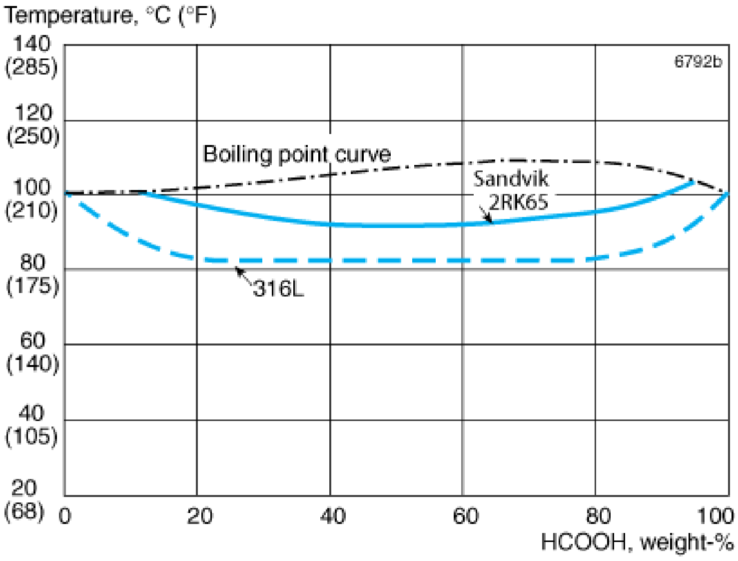

Figure 3. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65 and AISI 316L in formic acid.

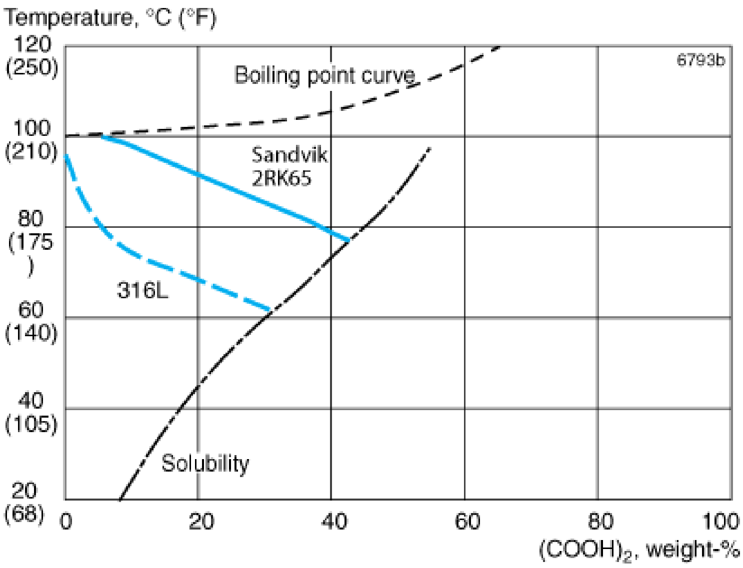

Figure 4. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65 and AISI 316L in oxalic acid.

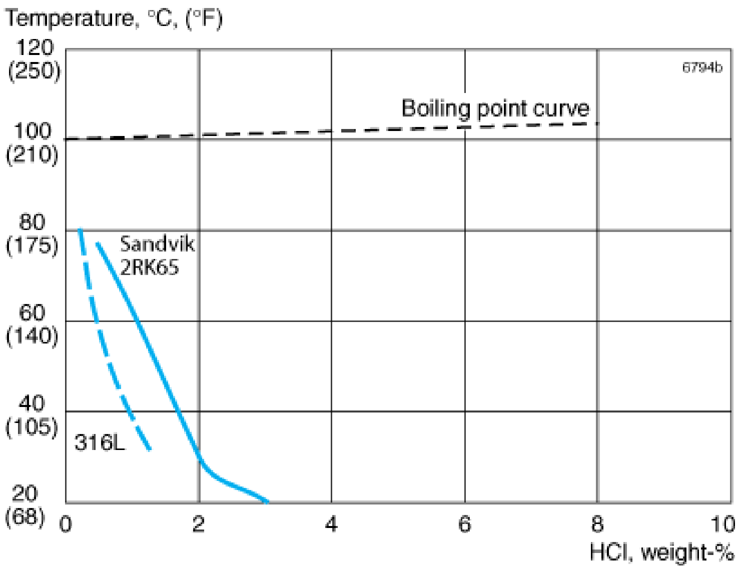

Figure 5. Isocorrosion diagram 0.1 mm/year (4 mpy) ior 2RK65 and AISI 316L in hydrochloric acid.

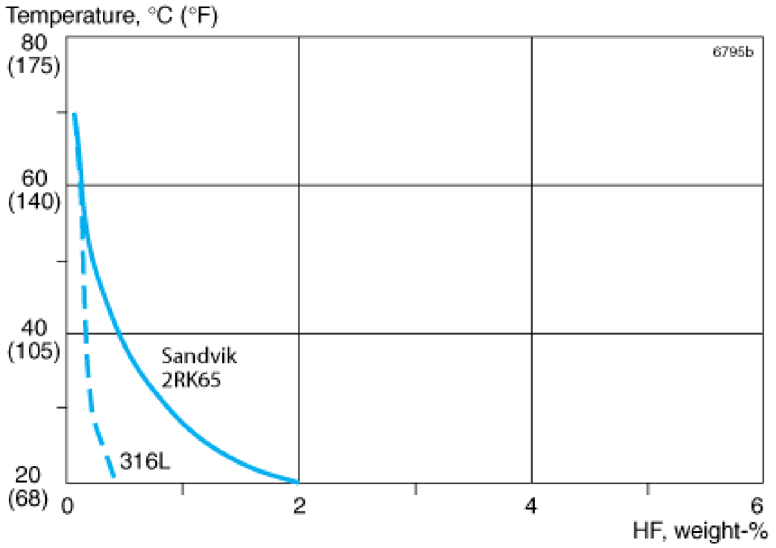

Figure 6. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65 and AISI 316L in hydrofluroic acid.

High molybdenum content is an advantage in hydrochloric acid, and 2RK65, with its 4.5% Mo is consequently far more resistant than, for example, AISI 316L. 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 2RK65 benefits from its high molybdenum content, although hydrofluoric acid is an even more aggressive acid compared to hydrochloric acid, see isocorrosion diagram infigure 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			
		2RK65 mm/year	mpy	AISI 316L mm/year	mpy
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, 2RK65 possesses much better resistance in **sodium hydroxide** than AISI 304 and AISI 316, see figure 7.

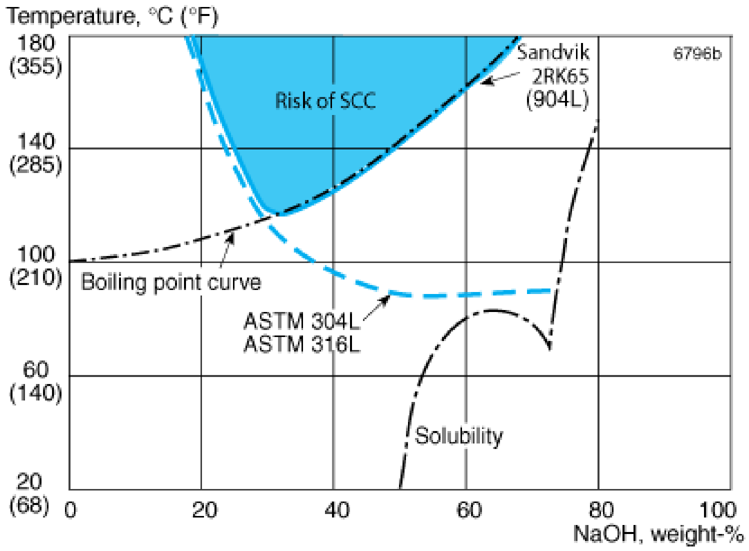

Figure 7. Isocorrosion diagram 0.1 mm/year (4mpy) ior 2RK65, 304L and AISI 316L in sodium hydrooxide of chemical purity.

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, see data sheet S-1885-ENG, provides better resistance against SCC and also general corrosion than is the case for 2RK65.

Pitting

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.

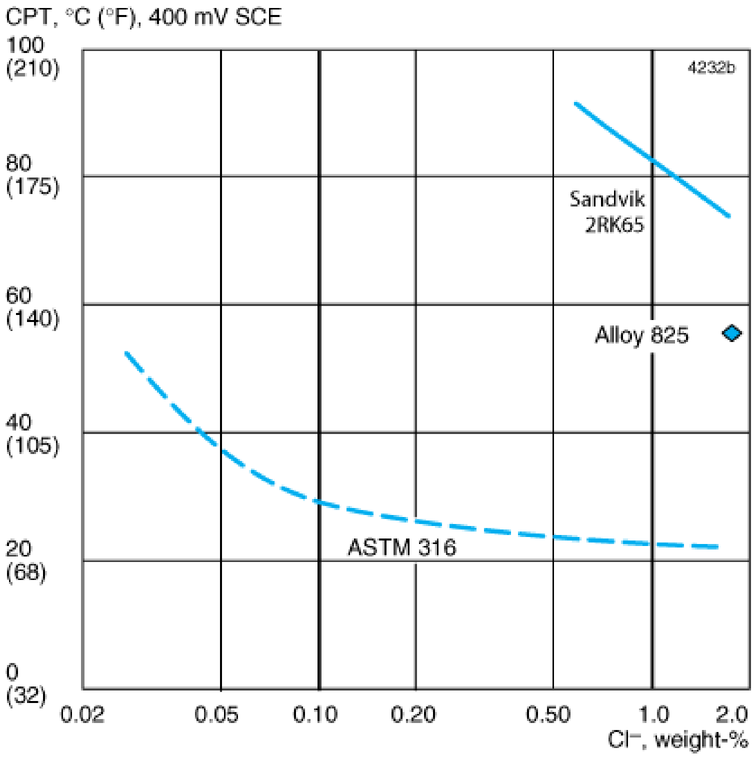

Figure 8. Mean values of critical pitting temperature (CPT) at 400 mV SCE and different Cl⁻ concentrations (NaCl solutions), pH ~ 6 (1.8%
Cl⁻ corresponds to the chloride content of seawater).

As can be seen in figure 8, the mean critical pitting temperature (CPT) for 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 AISI 316 and 20°C (68°F) higher than for Alloy 825 (21Cr42Ni3Mo).

Stress corrosion cracking

Ordinary austenitic steels of the AISI 304 and AISI 316 types are susceptible to stress corrosion cracking in chloride-bearing solutions at temperatures above about 60°C (140°F). At high temperatures, above about 100°C, 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 2RK65 in resisting stress corrosion cracking compared to AISI 304 and AISI 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 2RK65 than for AISI 304 and AISI 316. 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 2RK65, far better than 304 and 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 AISI 304 and AISI 316.

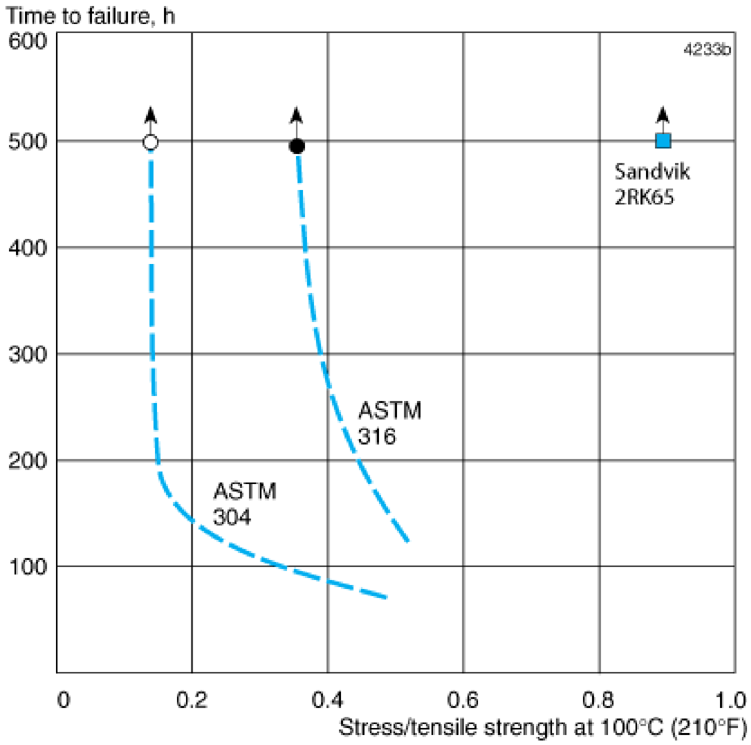

Figure 9. Results of stress corrosion cracking tests on different steel grades in 40% CaCl₂ at 100°C (210°F), pH = 6.5.

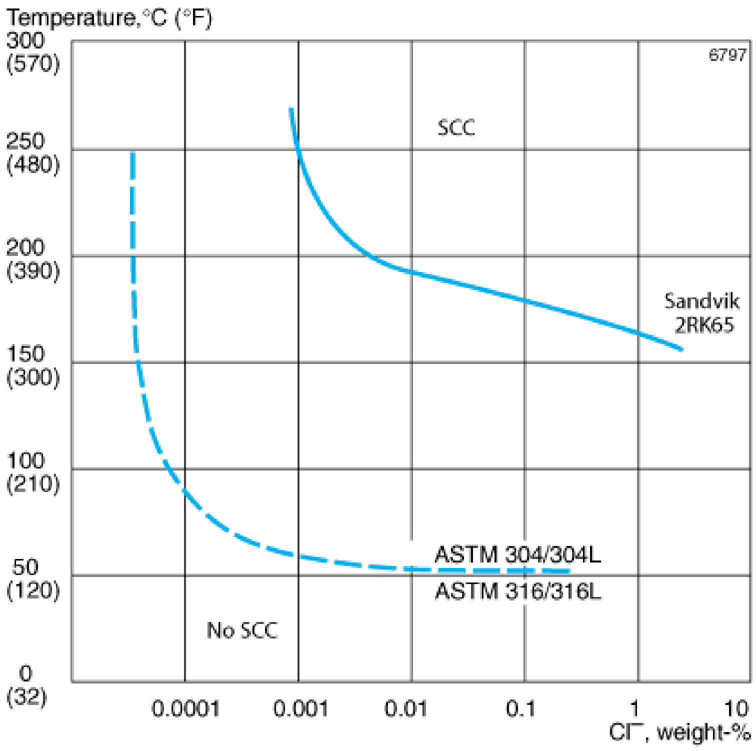

Figure 10. SCC resistance of 2RK65 in comparision to AISI 304 and AISI 316 types of steels in neutral aerated chloride environments.

Crevice corrosion
Both laboratory tests and practical experience have shown that 2RK65 is substantially more resistant to crevice corrosion than AISI 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

Steel	Initiated crevice corrosion attacks			Maximum depth		
	%			mm		
	50 °C	60 °C	70°C	50 °C	60 °C	70 °C
2RK65	-	0	0	0.20	0	0
AISI 316L	38	21	-	-	0.16	-

IMPERIAL UNITS

Steel	Initiated crevice corrosion attacks			Maximum depth		
	%			mm		
	120 °F	140 °F	160°F	120 °F	140 °F	160 °F
2RK65	38	0	0	0.008	0	0
AISI 316L	-	21	-	-	0.006	-

HEAT TREATMENT

Solution annealing
Plates and sheets 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

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 150 °C (300 °F) for materials with thicknesses up to and including 30 mm (1.2 in.) and I000 °C (2100 °F) for thicker materials. 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") for stock thicknesses up to 6 mm (1/4") and max. 3.25 mm (1/8") for heavier stock gauges. The current should not exceed 100-120 A in TIG welding. A stringer bead welding technique is recommended.

Like all austenitic stainless steels, 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 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. 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. Sandvik 27.31.4.LCu or 27.31.4.LCuR can be used to advantage in applications where particularly good pitting resistance is required in the weld metal. When 2RK65 is welded to carbon steel, filler metals of the nickel-base type can also be used.

BENDING

The good ductility of 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 material has been heavily cold-worked and is to be used under conditions where stress corrosion cracking is liable to occur, solution annealing is recommended (see under this heading).

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

Sandvik 2RK65 is a multi-purpose material for use under severe corrosive conditions. This has been proven both by laboratory tests and by extensive operational experience with the steel.

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.