Alleima® 3R60
Tube and pipe, seamless
Datasheet

Alleima® 3R60 is an austenitic chromium-nickel steel with minimum 2.5% molybdenum and a low carbon content.

Alleima® 3R60 is also available in a variant for the urea industry, Alleima 3R60 Urea Grade.

Standards

- ASTM: TP316L, TP316
- UNS: S31603, S31600
- EN Number: 1.4435, 1.4436
- EN Name: X 2 CrNiMo 18-14-3, X 3 CrNiMo 17-13-3
- W.Nr.: 1.4435, 1.4436
- DIN: X 2 CrNiMo 18 14 3, X 5 CrNiMo 17 13 3
- SS: 2353, 2343
- AFNOR: Z 2 CND 17.13
- BS: 316S13
- JIS: SU316LTP, 316TP, SU316LTB, 316TB

Product standards

- ASTM A213, A269 and A312
- JIS G3459
- JIS G3463
- EN 10216-5
- BS 3605, 3606
- DIN 17456, 17458
- NFA 49-117*, 49-217*

* Mo content 2.00-2.40%

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo
≤0.030	0.4	1.7	≤0.040	≤0.015	17.5	13	2.6

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Applications

Alleima® 3R60 is used for a wide range of industrial applications where steels of type ASTM 304 and 304L have insufficient corrosion resistance. Typical examples are: heat exchangers, condensers, pipelines, cooling and heating coils in the chemical, petrochemical, pulp and paper and food industries.

Corrosion resistance

Alleima® 3R60 has good resistance in:

- Organic acids at high concentrations and moderate temperatures
- Inorganic acids, e.g. phosphoric and sulfuric acids, at moderate concentrations and temperatures. The steel can also be used in sulfuric acid of concentrations above 90% at low temperature.
- Salt solutions, e.g. sulfates, sulfides and sulfites
- Caustic environments

Stress corrosion cracking

Austenitic steels are susceptible to stress corrosion cracking. This may occur at temperatures above about 60°C (140°F) if the steel is subjected to tensile stresses and at the same time comes into contact with certain solutions, particularly those containing chlorides. Such service conditions should therefore be avoided. Conditions when plants are shut down must also be considered, as the condensates which are then formed can develop conditions that lead to both stress corrosion cracking and pitting.

In applications demanding high resistance to stress corrosion cracking, austenitic-ferritic steels, such as SAF 2304® or SAF 2205™ are recommended. See data sheets S-1871-ENG and S-1874-ENG.

Intergranular corrosion

Alleima® 3R60 has a low carbon content and therefore better resistance to intergranular corrosion than steels of type AISI 316. The TTC-diagram, Figure 1, shows the result of corrosion testing for 24 hours in boiling Strauss solution (12% sulfuric acid, 6% copper sulphate). The resistance to grain boundary attack is much better for AISI 316L than for AISI 316. This is an advantage in complicated welding operations.

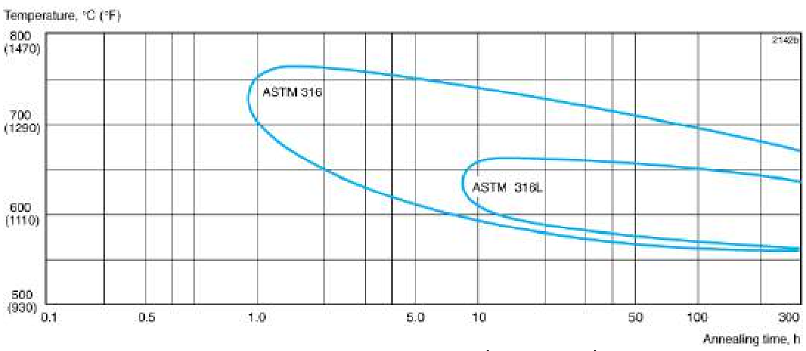

Figure 1. TTC-diagram for Sandvik 3R60 (AISI 316L) and AISI 316.

Pitting and crevice corrosion

Resistance to these types of corrosion improves with increasing molybdenum content. Alleima® 3R60, containing about 2.6% Mo, has substantially higher resistance to attack than these steels of type AISI 304 and also better resistance than ordinary AISI 316/316L steels with 2.1% Mo.

Gas corrosion

Alleima® 3R60 can be uses in

- Air up to 850°C (1560°F)
- Steam up to 750°C (1380°F)

Creep behavior should also be taken into account when using the steel in the creep range.

In flue gases containing sulfur, the corrosion resistance is reduced. In such environments the steel can be used at temperatures up to 600-750 °C (1100-1380 °F) depending on service conditions. Factors to consider are whether the atmosphere is oxidizing or reducing, i.e. the oxygen content, and whether impurities such as sodium and vanadium are present.

Bending

Annealing after cold bending is not normally necessary, but this point must be decided with regard to the degree of bending and the operating conditions. Heat treatment, if any, should take the form of stress relieving or solution annealing, see under Heat treatment.

Hot bending is carried out at 1100-850°C (2010-1560°F) and should be followed by solution annealing.

Forms of supply

Seamless tube and pipe- Finishes and dimensions

Seamless tube and pipe in Alleima® 3R60 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.

Other forms of supply

We can also deliver other product forms from stock in a grade corresponding to ASTM 316L mainly:

- Welded tube and pipe
- Fittings and flanges
- Bar steel

Sizes in stock

Seamless tube is stocked in a wide range of sizes according to ISO. Heat exchanger and instrumentation tubes are also stocked in BWG-and SWG-sizes. Hollow bar is stocked in a large number of sizes as SANMAC 316L (see data sheet S-1840-ENG). Details of our manufacturing programme are given in catalogue S-110-ENG.

Heat treatment

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

Stress relieving

850-950°C (1560-1740°F), cooling in air

Solution annealing

1000-1100°C (1830-2010°F), followed by rapid cooling in air or water.

Mechanical properties

For tube and pipe with wall thickness greater than 10 mm (0.4 in.) the proof strength may fall short of the stated values by about 10 MPa (1.4 ksi).

At 20°C

Metric units

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$ [a]	$R_{p1.0}$ [a]	R_m	A [b]	$A_{2"}$	
MPa	MPa	MPa	%	%	HRB
≥220	≥250	515-690	≥40 [c]	≥35	≤80

At 68°F

Imperial units

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$ [a]	$R_{p1.0}$ [a]	R_m	A [b]	$A_{2"}$	
ksi	ksi	ksi	%	%	HRB
≥32	≥36	75-100	≥40 [c]	≥35	≤80

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-section area.
c) NFA 49-117, 49-217 with min 45% can be fulfilled on request.

Impact strength

Due to its austenitic microstructure, Alleima® 3R60 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

Metric units

Temperature	Proof strength	
	$R_{p0.2}$	$R_{p1.0}$
°C	MPa	MPa
	min.	min.
50	200	230
100	180	215

150	165	195
200	150	180
250	140	170
300	135	160
350	130	155
400	125	150
450	120	145
500	120	145
550	115	140
600	110	135

Imperial units

Temperature	Proof strength	
	$R_{p0.2}$	$R_{p1.0}$
°F	ksi	ksi
	min.	min.
200	26	31
400	21	26
600	19	23
800	18	21
1000	17	20

Creep-rupture strength (ISO-values)

Temperature		10 000 h		100 000 h	
°C	°F	MPa	ksi	MPa	ksi
		approx.	approx.	approx.	approx.
550	1020	255	37.0	177	25.7
575	1065	214	31.0	137	19.9
600	1110	172	24.9	108	15.7
625	1155	137	19.9	86	12.5
650	1200	108	15.7	64	9.3
675	1245	83	12.0	46	6.7

700	1290	64	9.3	33	4.8
725	1335	49	7.1	25	3.6
750	1380	37	5.4	18	2.6

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	14	68	8
100	15	200	8.5
200	17	400	10
300	18	600	10.5
400	20	800	11.5
500	21	1000	12.5
600	23	1100	13

Specific heat capacity

Temperature, °C	J/kg °C	Temperature, °F	Btu/lb °F
20	485	68	0.11
100	500	200	0.12
200	515	400	0.12
300	525	600	0.13
400	540	800	0.13
500	555	1000	0.13
600	575	1100	0.14

Thermal expansion [1)]

Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	16.5	86-200	9.5
30-200	17	86-400	9.5
30-300	17.5	86-600	10
30-400	18	86-800	10

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30-500	18	86-1000	10
30-600	18.5	86-1200	10.5
30-700	18.5	86-1400	10.5

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

Modulus of elasticity [1)]

Temperature, °C	MPa	Temperature, °F	ksi
20	200	68	29.0
100	194	200	28.2
200	186	400	26.9
300	179	600	25.8
400	172	800	24.7
500	165	1000	23.5

[1)] (x10^3)

Welding

The weldability of Alleima® 3R60 is good. Welding must be carried out without preheating and subsequent heat treatment is normally not required. 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 Alleima® 3R60, heat input of <2.0 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 19 12 3 L / AWS A5.9 ER316L (e.g. Exaton 19.12.3.L)

MMA/SMAW welding

ISO 3581 E 19 12 3 L R / AWS A5.4 E316L-17(e.g. Exaton 19.12.3.LR)

ISO 14343 S 19 12 3 L / AWS A5.9 ER316L (e.g. Exaton 19.12.3.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 Alleima® 3R60, is required.

Alleima®3R65
Tube and pipe, seamless
Datasheet

Alleima® 3R65 is a molybdenum-alloyed austenitic stainless chromium-nickel steel with a low carbon content.

Standards

- ASTM: TP316L, TP316
- UNS: S31603, S31600
- EN Number: 1.4404, 1.4401
- EN Name: X2CrNiMo17-12-2, X5CrNiMo17-12-2
- W.Nr.: 1.4404, 1.4401
- DIN: X 2 CrNiMo 17 13 2, X 5 CrNiMo 17 12 2
- SS: 2348
- AFNOR: Z 2 CND 17.12, Z 6 CND 17.11
- BS: 316S11

Product standards

- ASTM A213, A269, A312
- EN 10216-5
- BS 3605, BS 3606
- DIN 17456, 17458
- NFA 49-117, 49-217
- SS 14 23 48

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo
≤0.030	0.4	1.7	≤0.040	≤0.015	17	11.5	2.1

Applications

Alleima® 3R65 is used in a wide variety of industrial applications. Typical examples are heat exchangers, condensers, pipelines, cooling and heating coils in the chemical, petrochemical, pulp and paper and food industries.

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Corrosion resistance

°General corrosion

Alleima® 3R65 has good resistance to:

- Organic acids at high concentrations and temperatures, with the exception of formic acid and acids with corrosive contaminants
- Inorganic acids, e.g. phosphoric acid, at moderate concentrations and temperatures, and sulfuric acid below 20% at moderate temperatures. The steel can also be used in sulfuric acid of concentrations above 90% at low temperature
- Salt solutions, e.g. sulfates, sulfides and sulfites

Intergranular corrosion

Alleima® 3R65 has a low carbon content and therefore better resistance to intergranular corrosion than other steels of type AISI 316.

Pitting and crevice corrosion

Resistance of these types of corrosion improves with molybdenum content. Alleima® 3R65 has substantially higher resistance to attack than steels of type AISI 304.

Stress corrosion cracking

Austenitic steels are susceptible to stress corrosion cracking. Stress corrosion cracking may occur if the steel is simultaneously exposed to the following:

- Tensile stresses
- Certain solutions, particularly those containing chlorides
- Temperatures above 60°C (140°F)

Such service conditions should therefore be avoided. Conditions when plants are shut down must also be considered, as the condensates which are then formed can develop a chloride content that leads to both stress corrosion cracking and pitting.
In applications demanding high resistance to stress corrosion cracking, austenitic-ferritic steels, e.g. SAF™ 2304 or SAF™ 2205 are recommended. See data sheets S-1871-ENG and S-1874-ENG.

Gas corrosion

Alleima® 3R65 can be used in

- Air up to 850°C (1560°C)
- Steam up to 750°C (1380°F)

In flue gases containing sulphur, the corrosion resistance is reduced. In such environments Alleima® 3R65 can be used at temperatures up to 600-750°C (1110-1380°F) depending on service conditions. Factors to consider are whether the atmosphere is oxidizing or reducing, i.e. the oxygen content, and whether impurities such as sodium and vanadium are present.

Bending

Annealing after cold bending is not normally necessary, but this point must be decided with regard to the degree of bending and the operating conditions. Heat treatment, if any, should take the form of stress-relieving or solution annealing, see under "Heat treatment".

Hot bending is carried out at 1100-850°C (2010-1560°F) and should be followed by solution annealing.

Forms of supply

Seamless tube and pipe- Finishes and dimensions

Seamless tube and pipe in 3R65 is supplied in dimensions up to 260 mm outside diameter in the solution annealed and white-pickled condition or in the bright-annealed condition.

Other forms of supply

We can also deliver other product forms from stock in a grade corresponding to 316L mainly:

- Welded tube and pipe
- Fittings and flanges
- Bar steel

Heat treatment

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

Stress relieving

850-950°C (1560-1740°F), 10-15 minutes, cooling in air.

Solution annealing

1000-1100°C (1830-2010°F), 5-20 minutes, rapid cooling in air or water.

Mechanical properties

For tube and pipe with wall thicknesses greater than 10 mm (0.4 in.) the proof strength may fall short of the stated values by about 10 MPa 2 (1.4 ksi).

At 20°C

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	515-690	≥45	≥35	≤90

At 68°F

Imperial units

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$[a]	$R_{p1.0}$[a]	R_m	A[b]	$A_{2"}$	HRB

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ksi	ksi	ksi	%	%	
≥32	≥35	75-100	≥45	≥35	≤90

1 MPa = 1 N/mm²
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.

Impact strength

Due to its austenitic microstructure, Alleima® 3R65 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.

At high temperatures

Temperature	Proof strength	
°C	$R_{p0.2}$	$R_{p1.0}$
	MPa	MPa
	min.	min.
50	200	230
100	180	215
150	165	195
200	150	180
250	140	170
300	130	160
350	120	150
400	115	145
450	115	145
500	110	140
550	110	140
600	95	120

Imperial units

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

	min.	min.
200	27	32
400	22	26
600	18	24
800	17	21
1000	16	20

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	14	68	8
100	15	200	8.5
200	17	400	10
300	18	600	10.5
400	20	800	11.5
500	21	1000	12.5
600	23	1100	13

Specific heat capacity

Temperature, °C	J/kg °C	Temperature, °F	Btu/lb °F
20	485	68	0.11
100	500	200	0.12
200	515	400	0.12
300	525	600	0.13
400	540	800	0.13
500	555	1000	0.13
600	575	1100	0.14

Thermal expansion [1)]

Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	16.5	86-200	9.5

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30-200	17	86-400	9.5
30-300	17.5	86-600	10
30-400	18	86-800	10
30-500	18	86-1000	10
30-600	18.5	86-1200	10.5
30-700	18.5	86-1400	10.5

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

Modulus of elasticity [1)]

Temperature, °C	MPa	Temperature, °F	ksi
20	200	68	29.0
100	194	200	28.2
200	186	400	26.9
300	179	600	25.8
400	172	800	24.7
500	165	1000	23.5

1) ($x10^3$)

Welding

The weldability of Alleima® 3R65 is good. Welding must be carried out without preheating and subsequent heat treatment is normally not required. 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 Alleima® 3R65, heat input of <2.0 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 19 12 3 L / AWS A5.9 ER316L (e.g. Exaton 19.12.3.L)

MMA/SMAW welding

ISO 3581 E 19 12 3 L R / AWS A5.4 E316L-17(e.g. Exaton 19.12.3.LR)

ISO 14343 S 19 12 3 L / AWS A5.9 ER316L (e.g. Exaton 19.12.3.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 Alleima® 3R65, is required.

Machining

Alleima® 3R65 has good machining properties. Tool and cutting data recommendations are the same as for steel 3R60 in brochure S-1462-ENG.

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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.

Alleima® 5R75
Tube and pipe, seamless
Datasheet

Alleima® 5R75 is an austenitic, titanium-stabilized stainless chromium–nickel–molybdenum steel.

Standards

- ASTM: TP316Ti
- UNS: S31635
- EN Number: 1.4571
- EN Name: X6CrNiMoTi17-12-2
- W.Nr.: 1.4571
- DIN: X 6 CrNiMoTi 17 12 2
- SS: 2350
- AFNOR: Z6CNDT17-12

Product standards

Seamless tube and pipe:

- ASTM A312
- EN 10216-5
- DIN 17456, 17458
- SS 14 23 50
- NFA 49-117
- ASTM A213, A269 and A312

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo
0.05	0.5	1.3	≤0.030	≤0.030	17	12	2.1

Ti=>5xC

Applications

Alleima® 5R75 is used for a variety of industrial applications. Typical examples are heat exchangers, condensers,

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pipelines, cooling and heating coils in the chemical, petrochemical and pulp and paper industries.

Corrosion resistance

General corrosion

Alleima® 5R75 has good resistance to

- Organic acids at high concentrations and temperatures
- Inorganic acids, e.g. phosphoric and sulfuric acids, at moderate concentrations and temperatures. The steels can also be used in sulfuric acid of concentrations above 90% at low temperature.
- Salt solutions, e.g. sulfates, sulfides and sulfites
- Caustic environments

Intergranular corrosion

Alleima® 5R75 has better resistance to intergranular corrosion than unstabilized steels. The addition of titanium prevents precipitation of chromium carbides in the grain boundaries after prolonged heating in the temperature range 450- 850°C (840-1560°F).

Pitting and crevice corrosion

Resistance to these types of corrosion improves with increasing molybdenum content and Alleima® 5R75 with about 2.1% Mo has substantially higher resistance than steels of type AISI 304/304L.

Stress corrosion cracking

Austenitic stainless steels are susceptible to stress corrosion cracking. This may occur at temperatures above about 60°C (140°F), if the steel is subjected to tensile stresses and at the same time comes into contact with certain solutions, particularly those containing chlorides. Such service conditions should therefore be avoided. Conditions when plants are shut down must also be considered as the condensates which are then formed can develop a chloride content that leads to both stress corrosion cracking and pitting.

In applications demanding high resistance to stress corrosion cracking, austenitic- ferritic steels, e.g. SAF™ 2304 or SAF™ 2205, are recommended. See data sheets S-1871-ENG and S-1874-ENG.

Gas corrosion

Alleima® 5R75 can be used in

- Air up to 850°C (1560°F)
- Steam up to 750°C (1380°F)

Creep behavior should also be taken into account when using the steel in the creep range. In flue gases containing sulfur, the corrosion resistance is reduced. In such environments these steels can be used at temperatures up to 600-750°C (1110-1380°F) depending on service conditions. Factors to consider are whether the atmosphere is oxidizing or reducing, i.e. the oxygen content, and whether impurities such as sodium and vanadium are present.

Bending

Annealing after cold bending is not normally necessary, but this point must be decided with regard to the degree of bending and the operating conditions. Heat treatment, if any, should take the form of stress-relieving or solution-annealing, see under "Heat treatment".

Hot bending is carried out at 1100-850°C (2010-1560°F) and should be followed by solution-annealing.

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Forms of supply

Seamless tube and pipe

Tube and pipe are normally delivered in the solution-annealed and white-pickled condition. Smaller sizes may be bright-annealed. The size range can be seen from the principal size range can be seen from Fig. 1.

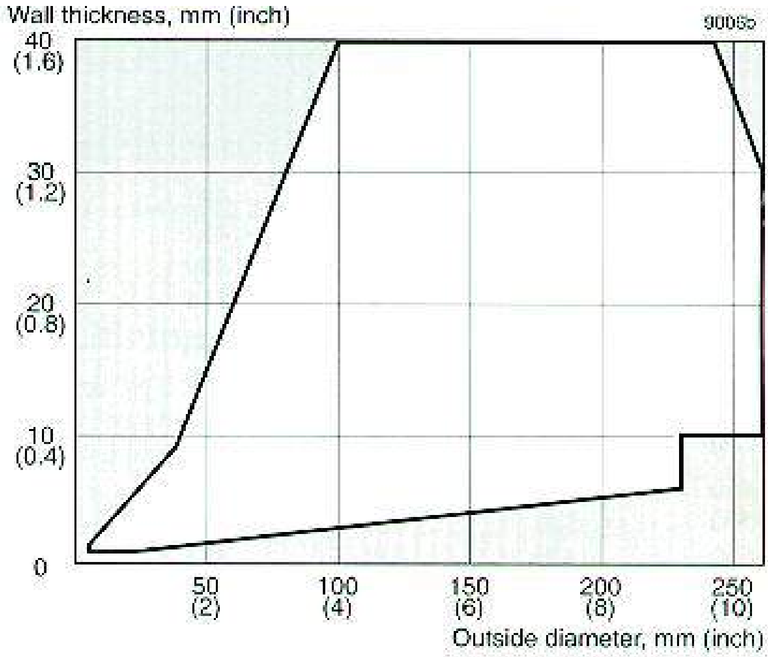

Figure 1. Principal size range for seamless tube and pipe.

Hollow bar

Hollow bar is supplied solution-annealed and white-pickled.

Sizes in stock

Seamless tube and pipe

Seamless tube and pipe are stocked in the solution-annealed and white-pickled condition in a wide range of sizes according to ISO and ANSI. Details of our manufacturing and stock programme are given in catalogue S-110-ENG.

Hollow bar

Hollow bar is stocked in a large number of sizes. Our standard size range for stock comprises 32-250 mm (1.3-9.8 inch) O.D. See catalogue S-110-ENG or S-1462-ENG.

Also available from stock are:

- Welded tube and pipe
- Fittings
- Bar steel

Heat treatment

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

Stress relieving
850-950°C (1560-1740°F), 10-15 minutes, cooling in air.

Solution annealing
1000-1100°C (1830-2010°F), 5-20 minutes, rapid cooling in air or water.

Mechanical properties

At 20°C (68°F)

Proof strength				Tensile strength		Elong	Hardness
$R_{p0.2}$ a) c)		$R_{p1.0}$ a) c)		R_m c)		A b)	Vickers
MPa	ksi	MPa	ksi	MPa	ksi	%	
							approx.
≥220	≥32	≥250	≥36	510-710	74-103	≥35 d)	155

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-section area.
c) For hot finished tube and pipe with wall thickness greater than 10 mm (0.4 in.) the minimum values for proof strength may fall short of the stated values by 20 MPa (2.9 ksi) and the range for the tensile strength is 490-690 MPa.
d) NFA 49-117 with min 45% can be fulfilled.

Impact strength

Due to its austenitic microstructure, Alleima® 5R75 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.

At high temperatures

Metric units

Temperature	Proof strength	
	$R_{p0.2}$ c)	$R_{p1.0}$ c)
°C	MPa	MPa
	min	min
50	202	234
100	185	218
150	177	206
200	167	196
250	157	186
300	145	180

350	140	175
400	136	171
450	132	167
500	129	164
550	127	157

Imperial units

Temperature	Proof strength	
	$R_{p0.2}$ d)	$R_{p1.0}$ d)
°F	ksi	ksi
	min	min
200	27.0	32.0
400	24.0	28.5
600	21.0	26.0
800	19.5	24.5
1000	18.5	23.5

d) For hot finished tube and pipe with wall thicknesses greater than 10 mm (0.4 in.) the proof strength values may be slightly lower but still fulfill the requirements according to DIN 17458 and SS 14 23 50.

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	14	68	8
100	15	200	8.5
200	17	400	10
300	18	600	10.5
400	20	800	11.5
500	21	1000	12.5
600	23	1100	13

Specific heat capacity

Temperature, °C	J/kg °C	Temperature, °F	Btu/lb °F

20	485	68	0.11
100	500	200	0.12
200	515	400	0.12
300	525	600	0.13
400	540	800	0.13
500	555	1000	0.13
600	575	1100	0.14

Thermal expansion [1)]

Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	16.5	86-200	9.5
30-200	17	86-400	9.5
30-300	17.5	86-600	10
30-400	18	86-800	10
30-500	18.5	86-1000	10
30-600	18.5	86-1200	10.5
30-700	19	86-1400	10.5

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

Modulus of elasticity [1)]

Temperature, °C	MPa	Temperature, °F	ksi
20	200	68	29.0
100	194	200	28.2
200	186	400	26.9
300	179	600	25.8
400	172	800	24.7
500	165	1000	23.5

1) ($x10^{3}$)

Welding

The weldability of Alleima® 5R75 is good. Welding must be carried out without preheating and subsequent heat treatment is normally not required. 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 Sandvik 5R75, heat input of <1.5 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 19 12 3 Nb / AWS A5.9 ER318 (e.g. Exaton 19.12.3.Nb)

MMA/SMAW welding

ISO 3581 E 19 12 3 Nb R / AWS A5.4 E318-17

Machining

Alleima® 5R75 has good machining properties. Detailed recommendations for the choice of tools and cutting data are provided in brochures S-0291-ENG and S-1492-ENG.

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Alleima® 6R35
Tube and pipe, seamless
Datasheet

Alleima® 6R35 is an austenitic, titanium-stabilized stainless chromium-nickel steel. It is suitable for wet-corrosive service but also has good mechanical strength at high temperatures.

Standards

- ASTM: TP321, TP321H
- UNS: S32100, S32109
- EN Number: 1.4541, 1.4940
- EN Name: X6CrNiTi18-10, X7CrNiTi18-10
- W.Nr.: 1.4541, 1.4878
- DIN: X6CrNiTi 18 10, X12CrNiTi 18 9
- SS: 2337
- AFNOR: Z6CNT18-10
- BS: 321S31, 321S51

Product standards

Seamless tube and pipe

- ASTM A213, A312, A269, A376, (A511)
- EN 10216-5
- BS 3059, 3605, 3606
- DIN 17456, 17458
- SS 14 23 37
- NFA 49-117, 49-217

Approvals

PED (Pressure Equipment Directive) 2014/68/EU and AD2000

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni
0.05	0.5	1.3	≤0.030	≤0.015	17.5	10.5

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Ti=>5xC

Applications

Good resistance to hydrogen sulfide gas and intergranular corrosion coupled with good high temperature strength make Alleima® 6R35 a suitable material for applications as tubes in heating furnaces and heat exchangers in sulfurization and hydro-treating plants. In the petrochemical industry the steel is used in cracking furnaces for the production of ethylene and vinyl chloride. It is also frequently used for heat exchangers and piping in the chemical and petrochemical industries.

Corrosion resistance

General corrosion

Alleima® 6R35 has with some limitations (nitric acid) the same resistance as the unstabilized steel ASTM 304. Consequently, the grades have good resistance to

- Organic acids at moderate temperatures
- Salt solutions, e.g. sulfates, sulfides and sulfites
- Caustic environments at moderate temperatures

Intergranular corrosion

The stabilization with titanium gives Alleima 6R35 improved resistance to intergranular corrosion.

Pitting and crevice corrosion

Pitting and crevice corrosion may occur even in solutions of relatively low chloride content. However, the stabilization with titanium results in a somewhat better resistance than that of ASTM 304.

Stress corrosion cracking

Austenitic steels, like Alleima® 6R35 are susceptible to stress corrosion cracking. This may occur at temperatures above about 60°C (140°F), if the material is subjected to tensile stresses and at the same time comes into contact with certain solutions, particularly those containing chlorides. Such service conditions should therefore be avoided. Conditions when plants are shut down must also be considered as the condensates which are then formed can develop a chloride content that leads to both stress corrosion cracking and pitting.

In applications demanding high resistance to stress corrosion cracking we recommend the austenitic-ferritic steel SAF™ 2304.

Gas corrosion

Alleima® 6R35 can be used in:

- Air up to 850°C (1560°F)
- Steam up to 750°C (1380°F)
- Synthesis gas (ammonia synthesis) up to about 550°C (1020°F)

Creep should also be taken into account when using the steel in the creep range.

In flue gases containing sulfur, the corrosion resistance is reduced. in such environments this steel can be used at temperatures up to 600-750°C (1110-1380°F) depending on service conditions. Factors to consider are whether the atmosphere is oxidizing or reducing, i.e. the oxygen content, and whether impurities such as sodium and vanadium are present.

Bending

Annealing after cold bending is not normally necessary, but this point must be decided with regard to the degree of bending and the operating conditions. Heat treatment, if any, should take the form of stress-relieving or solution annealing.

Hot bending is carried out at 1100-850°C (2010-1560°F) and should be followed by solution annealing.

Forms of supply

Seamless tube and pipe-Finishes and dimensions

Seamless tube and pipe in Alleima® 6R35 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.

Hollow bar

Hollow bars are supplied solution-annealed and white-pickled.

Sizes in stock

Seamless tube and pipe
Seamless tube and pipe are stocked in a wide range of sizes according to ISO and ANSI both in hot extruded as well as in the cold finished and annealed condition. Details of our manufacturing and stock programme are given in catalogue S-110-ENG.

Hollow bar
Hollow bar is stocked in large number of sizes. Our standard size range for stock comprises 32-250 mm (1.3-9.8 in.) O.D. See catalogue S-110-ENG.

Heat treatment

The tubes are normally delivered as described above. If additional heat treatment is needed after further processing the following is recommended.

Solution annealing

Tp 321

1040-1100 °C (1905-2010 °F), 2-5 min, rapid cooling in air or water.

Tp321H

Stabilization treatment: 1040-1100 °C (1920-2010 °F), 2-5 min rapid cooling in air or water. However, annealing above 1100°C (2010 °F) may be required in order to meet grain size requirements. This treatment should be followed by a stabilization treatment.

Stress relieving

850-950 °C (1560-1740 °F), 10-15 minutes, cooling in air.

Mechanical properties

At 20°C (68°F)

Proof strength	Tensile strength	Elong.	Hardness

$R_{p0.2}$ [a)]		$R_{p1.0}$ [a)]		R_m		A[b)]	HRB
MPa	ksi	MPa	ksi	MPa	ksi	%	
≥210	≥30	≥240	≥35	515-690	75-100	≥35[c)]	≤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-section area.
c) NFA 49-117 and NFA 49–217 with min 45% can be fulfilled.

Impact strength

Due to its austenitic microstructure, Alleima® 6R35 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.

At high temperatures

Metric units

Temperature	Proof strength [c)]	
	$R_{p0.2}$	$R_{p1.0}$
°C	MPa	MPa
	min	min
50	195	230
100	180	210
150	170	195
200	160	185
250	150	180
300	140	175
350	135	170
400	130	165
450	130	165
500	125	160
550	125	160
600	120	155

Imperial units

Temperature	Proof strength [c)]

	$R_{p0.2}$	$R_{p1.0}$
°F	ksi	ksi
	min	min
200	26.0	30.5
400	22.5	26.5
600	19.5	25.0
800	18.5	23.5
1000	17.5	23.0
1100	17.0	22.0

c) For extruded tube and pipe with wall thickness greater than 10 mm (0.4 in.) the proof strength may fall short of the stated value by 20 MPa (2.9 ksi) at 100°C (200°F) and by 10 MPa (1.4 ksi) in the temperature range 200-600°C (400-1100°F).

Creep rupture strength

Temperature		10 000 h		100 000 h	
°C	°F	MPa	ksi	MPa	ksi
		approx.	approx.	approx.	approx.
550	1020	234	34.0	184	26.7
575	1065	175	25.4	126	18.3
600	1110	143	20.7	94	13.6
625	1155	110	16.0	75	10.9
650	1200	90	13.1	58	8.4
675	1245	76	11.0	48	7.0
700	1290	59	8.6	39	5.7
750	1380	29	4.2	16	2.3

Physical properties

Density: 7.9 g/cm^3, 0.29 lb/in^3

Thermal conductivity

Temperature, °C	W/m °C	Temperature, °F	Btu/ft h °F
20	14	68	8
100	15	200	8.5
200	17	400	10

300	19	600	11
400	21	800	12
500	22	1000	13
600	24	1200	14
700	25	1400	15
800	26	1600	16
900	28	1800	16.5
1000	29	2000	17.5
1100	30		

Specific heat capacity

Temperature, °C	J/kg °C	Temperature, °F	Btu/lb °F
20	465	68	0.11
100	490	200	0.12
200	515	400	0.12
300	540	600	0.13
400	560	800	0.14
500	580	1000	0.14
600	595	1200	0.14
700	610	1400	0.15
800	625	1600	0.15
900	640	1800	0.16
1000	650	2000	0.16
1100	665		

Thermal expansion [1)]

Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	17.5	86-200	9.5
30-200	17.5	86-400	10
30-300	18	86-600	10
30-400	18	86-800	10
30-500	18.5	86-1000	10.5

30-600	18.5	86-1200	10.5
30-700	19	86-1300	10.5

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

Modulus of elasticity [1)]

Temperature, °C	MPa	Temperature, °F	ksi
20	200	68	29.0
100	194	200	28.2
200	186	400	26.9
300	179	600	25.8
400	172	800	24.7
500	165	1000	23.5

1) (x10^{3})

Welding

Welding

The weldability of Alleima® 6R35 is good. Welding must be carried out without preheating and subsequent heat treatment is normally not required. 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 Alleima® 6R35, heat input of <1.5 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 19 9 Nb / AWS A5.9 ER347 (e.g. Exaton 19.9.Nb)

MMA/SMAW welding

ISO 3581 E 19 9 Nb R / AWS A5.4 E347-17(e.g. Exaton 19.9.NbR)

ISO 14343 S 19 9 Nb / AWS A5.9 ER347 (e.g. Exaton 19.9.LNb) 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 Alleima 6R35, is required.

Machining

Alleima® 6R35 has good machining properties. Please contact Alleima for detailed recommendations on the choice of tools and cutting data.

Alleima

Alleima® 3R12
Tube and pipe, seamless
Datasheet

Alleima® 3R12 is an austenitic stainless chromium-nickel steel with a low carbon content.

Standards

- ASTM: TP304L, TP304
- UNS: S30403, S30400
- EN Number: 1.4306, 1.4301
- W.Nr.: 1.4306*, 1.4301*
- DIN: X 2 CrNi 19 11*, X 5 CrNi 18 10*
- SS: 2352*, 2333*
- AFNOR: Z 2 CN 18.10*
- BS: 304S31*, 304S11*
- JIS: SUS304L, SUS304LTB, SUS304TP

Product standards

- ASTM A213, A269 and A312
- JIS G3459
- JIS G3463
- EN 10216-5
- BS 3605, 3606*
- DIN 17456, 17458*
- NFA 49-117, 49-217
- SS 14 23 52, 14 23 33*

* Obsolete. Replaced by EN.

Approval
JIS approval for Stainless Steel Tubes

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni
≤0.030	0.5	1.3	≤0.030	≤0.015	18.5	10

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Subject to agreement, material with extra low Co content can be supplied.

Applications

Alleima® 3R12 is used for a wide range of industrial applications. Typical examples are: heat exchangers, condensers, pipelines, cooling and heating coils in the chemical, petrochemical, fertilizer, pulp and paper and nuclear power industries, as well as in the production of pharmaceuticals, foods and beverages.

Corrosion resistance

General corrosion

Alleima® 3R12 has good resistance in

- Organic acids at moderate temperatures
- Salt solutions, e.g. sulfates, sulfides and sulfites
- Caustic solutions at moderate temperatures

Alleima® 3R12 has better resistance than normal type ASTM TP304 to oxidizing agents, such as nitric acid. Figure 2 shows isocorrosion in nitric acid for Alleima® 3R12.

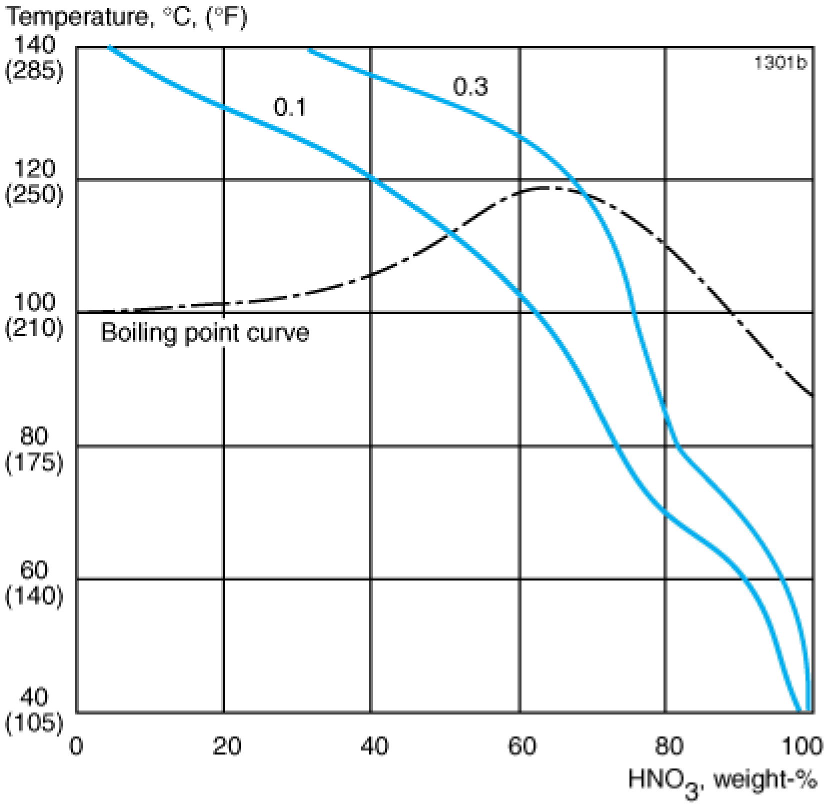

Figure 2. Diagram showing isocorrosion in nitric acid for Alleima 3R12 at the corrosion rates of 0.1 mm/year (4mpy) and 0.3 mm/year (12 mpy).

Intergranular corrosion

Alleima® 3R12 has a low carbon content and therefore better resistance to intergranular corrosion than steels of type ASTM TP304.

The TTC-diagram, Figure 3, which shows the result of testing for 24 h in boiling Strauss solution (12% sulfuric acid, 6% copper sulfate) confirms the superior resistance of Alleima 3R12. This is an advantage in complicated welding operations.

The good resistance against intergranular attack of Alleima 3R12 is also demonstrated in the Huey test (boiling in 65% nitric acid for 5x48 h). A maximum corrosion rate of 0.40 mm/year in the annealed condition and 0.60 mm/year in the sensitized (675°C (1275°F)) condition can be met.

Alleima® 3R12 with its controlled and low impurity level, shows better results than ordinary ASTM TP304L or TP321.

Figure 3. TTC-diagram for Alleima 3R12 (AISI 304L) and AISI 304.

Pitting and crevice corrosion

The steel may be sensitive to pitting and crevice corrosion even in solutions of relatively low chloride content. Molybdenum-alloyed steels have better resistance improves with increasing molybdenum content.

Stress corrosion cracking

Austenitic steels are susceptible to stress corrosion cracking (SCC). This may occur at temperatures above about 60°C (140°F) if the steel is subjected to tensile stresses and at the same time comes into contact with certain solutions, particularly those containing chlorides. Such service conditions should therefore be avoided. Conditions when plants are shut down must also be considered, as the condensates which are then formed can develop conditions that leads to both stress corrosion cracking (SCC) and pitting.

In applications demanding high resistance to stress corrosion cracking (SCC) we recommend the duplex (austenitic-ferritic) steel SAF 2304.

Gas corrosion

Alleima 3R12 can be used in:

- Air up to 850°C (1560°F)
- Steam up to 750°C (1380°F)
- Synthesis gas (ammonia synthesis) up to about 550°C (1020°F).

Creep behavior should also be taken into account when using the Alleima 3R12 in the creep range.

In flue gases containing sulfur, the corrosion resistance is reduced. In such environments the steel can be used at temperatures up to 600-750°C (1110-1380°F) depending on service conditions. Factors to consider are whether the atmosphere is oxidizing or reducing, i.e. the oxygen content, and whether impurities such as sodium and vanadium are present.

Bending

Annealing after cold bending is not normally necessary, but this point must be decided with regard to the degree of bending and the operating conditions. Heat treatment, if any, should take the form of stress relieving or solution annealing, see under 'Heat treatment'.

Hot bending is carried out at 1100-850°C (2010-1560°F) and should be followed by solution annealing.

Forms of supply

Seamless tube and pipe in Alleima® 3R12 is supplied in dimensions up to 260 mm (10.2 in.) outside diameter in the solution-annealed and white-pickled condition or solution annealed by a bright-annealing process. U-bent tubes can be supplied on request.

Heat treatment

Tubes in Alleima® 3R12 are normally delivered in heat treated condition. If additional heat treatment is needed after

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further processing the following is recommended.

Stress relieving

850-950°C (1560-1740°F), cooling in air.

Solution annealing

1000-1100°C (1830-2010°F), rapid cooling in air or water.

Mechanical properties

For tube and pipe with wall thickness greater than 10 mm (0.4 in.) the proof strength may fall short of the stated value by about 10 MPa (1.4 ksi).

Metric units, at 20°C

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	$A_{2"}$	HRB
MPa	MPa	MPa	%	%	
≥210	≥240	515-680	≥45	≥35	≤90

Imperial units, at 68°F

Proof strength		Tensile strength	Elong.		Hardness
$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	$A_{2"}$	HRB
ksi	ksi	ksi	%	%	
≥30	≥35	75-99	≥44	≥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 $L_0 = 5.65 \sqrt{S_0}$ where L_0 is the original gauge length and S_0 the original cross-section area.

Impact strength

Due to its austenitic microstructure, Alleima® 3R12 has very good impact strength, both at room temperature and at cryogenic temperatures.

Tests have demonstrated that the grade 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 - metric units

Temperature	Proof strength	
	$R_{p0.2}$	$R_{p1.0}$
°C	MPa	MPa
50	≥190	≥215

100	≥165	≥190
150	≥150	≥175
200	≥140	≥165
250	≥130	≥155
300	≥125	≥150
350	≥120	≥145
400	≥115	≥140
450	≥110	≥135
500	≥105	≥130
550	≥100	≥125

At high temperatures - imperial units

Temperature	Proof strength	
	$R_{p0.2}$	$R_{p1.0}$
°F	ksi	ksi
200	≥24	≥28
400	≥20	≥24
600	≥18	≥22
800	≥16	≥20
1000	≥15	≥18

Creep-rupture strength (ISO-values)

Temperature		10 000 h		100 000 h	
°C	°F	MPa	ksi	MPa	ksi
550	1020	≈195	≈28.3	≈115	≈16.6
575	1065	≈147	≈21.3	≈93	≈13.5
600	1110	≈122	≈17.6	≈74	≈10.7
625	1155	≈100	≈14.5	≈58	≈8.4
650	1200	≈79	≈11.5	≈45	≈6.5
675	1245	≈64	≈9.2	≈33	≈4.8
700	1290	≈48	≈7.0	≈23	≈3.3

Physical properties

Density: 7.9 g/cm³, 0.29 lb/in³

Thermal conductivity

Temperature, °C	W/m °C	Temperature, °F	Btu/ft h °F
20	15	68	8.5
100	16	200	9.5
200	18	400	10.5
300	20	600	12
400	22	800	13
500	23	1000	14
600	25	1200	15
700	26	1300	15

Specific heat capacity

Temperature, °C	J/kg °C	Temperature, °F	Btu/lb °F
20	475	68	0.11
100	500	200	0.12
200	530	400	0.13
300	560	600	0.13
400	580	800	0.14
500	600	1000	0.14
600	615	1200	0.15
700	625	1300	0.15

Thermal expansion[1)]

Temperature, °C	Per °C	Temperature, °F	Per °F
30-100	16.5	86-200	9
30-200	17	86-400	9.5
30-300	17.5	86-600	10
30-400	18	86-800	10
30-500	18.5	86-1000	10
30-600	18.5	86-1200	10.5
30-700	19	86-1400	10.5

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

Modulus of elasticity[1)]

Temperature, °C	MPa	Temperature, °F	ksi
20	200	68	29.0
100	194	200	28.2
200	186	400	26.9
300	179	600	25.8
400	172	800	24.7
500	165	1000	23.5

1) Modulus of elasticity, (x10^{3})

Welding

The weldability of Alleima® 3R12 is good. Welding must be carried out without preheating and subsequent heat treatment is normally not required. 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 Alleima® 3R12, heat input of <2.0 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 14343 S 19 9 L / AWS A5.9 ER308L (e.g. Exaton 19.9.L)

MMA/SMAW welding

ISO 3581 E 19 9 L R / AWS A5.4 E308L-17(e.g. Exaton 19.9.LR)

ISO 14343 S 19 9 L / AWS A5.9 ER308L (e.g. Exaton 19.9.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 Alleima® 3R12, is required.

Sizes in stock

Seamless tube and pipe

Alleima® 3R12 is stocked in a wide range of sizes according to ISO and ANSI. Heat exchanger tubes are also stocked in a number of sizes as BWG-sizes. Hollow bar is stocked in a large number of sizes as SANMAC 304L (see data sheet S-1824-ENG) but on request hollow bar in 3R12 can also be supplied.
Details of our manufacturing and stock programme are given in catalogue S-110-ENG.

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
- 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

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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 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.

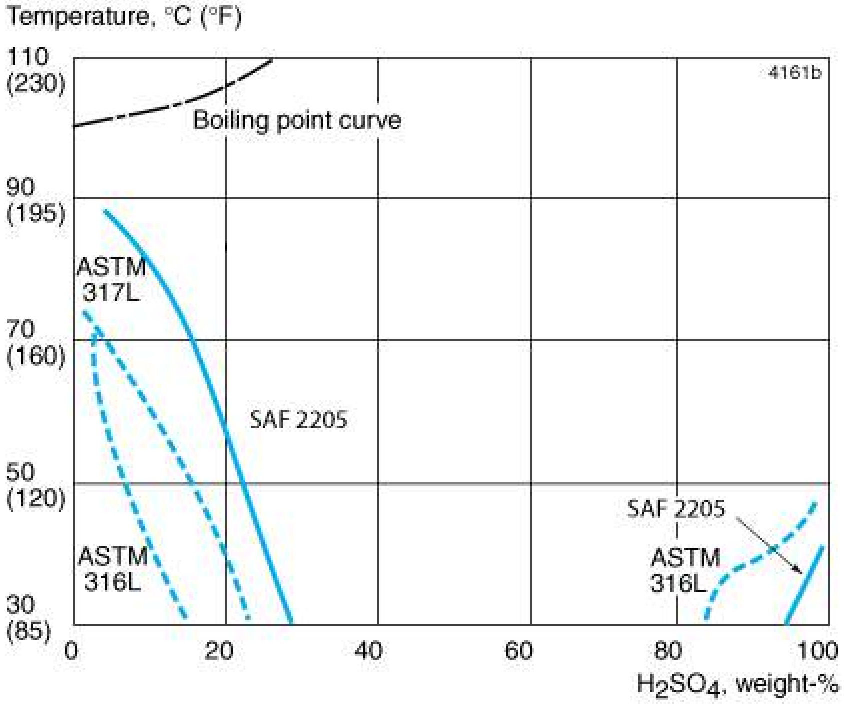

Figure 3. Iso- corrosion diagram for SAF™ 2205, ASTM TP316L and ASTM TP317L in sulphuric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in a natural aerated stagnant test solution.

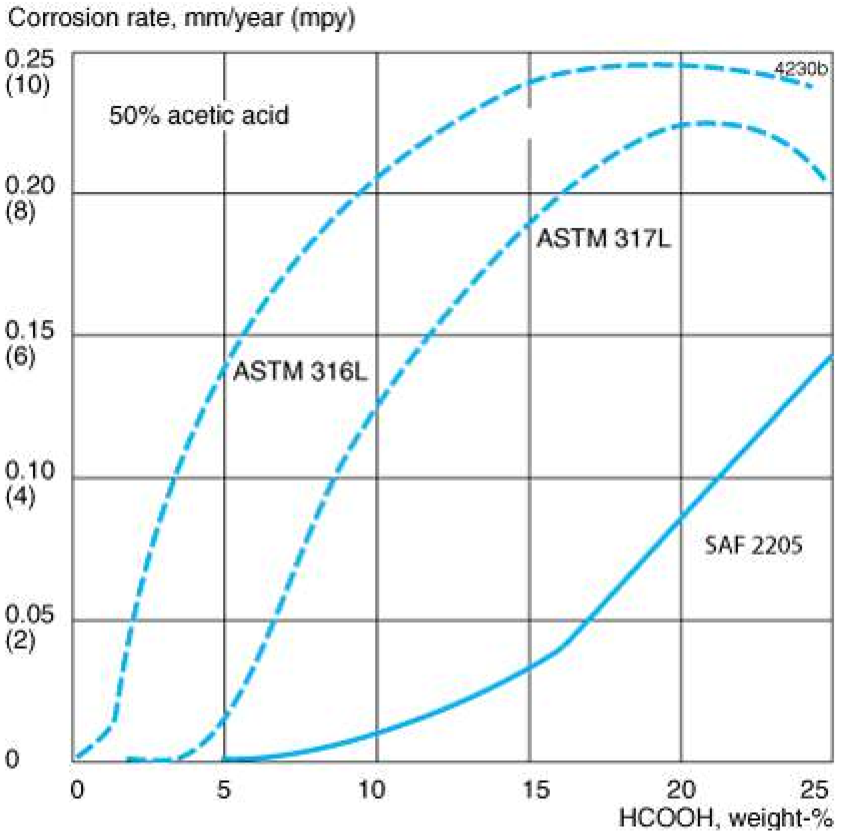

Figure 4. Corrosion rate of SAF™ 2205, ASTM TP316L and ASTM TP317L in boiling mixtures of 50% acetic acid and varying proportions of formic acid. Test time 1+3+3 days.

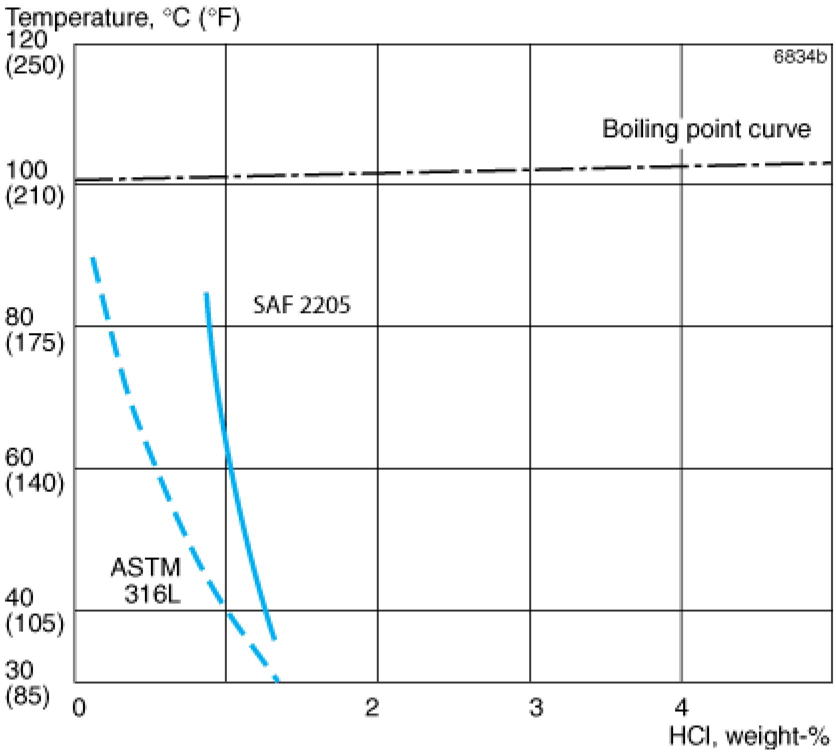

Figure 5. Iso- corrosion diagram in naturally aerated hydrochloric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

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.

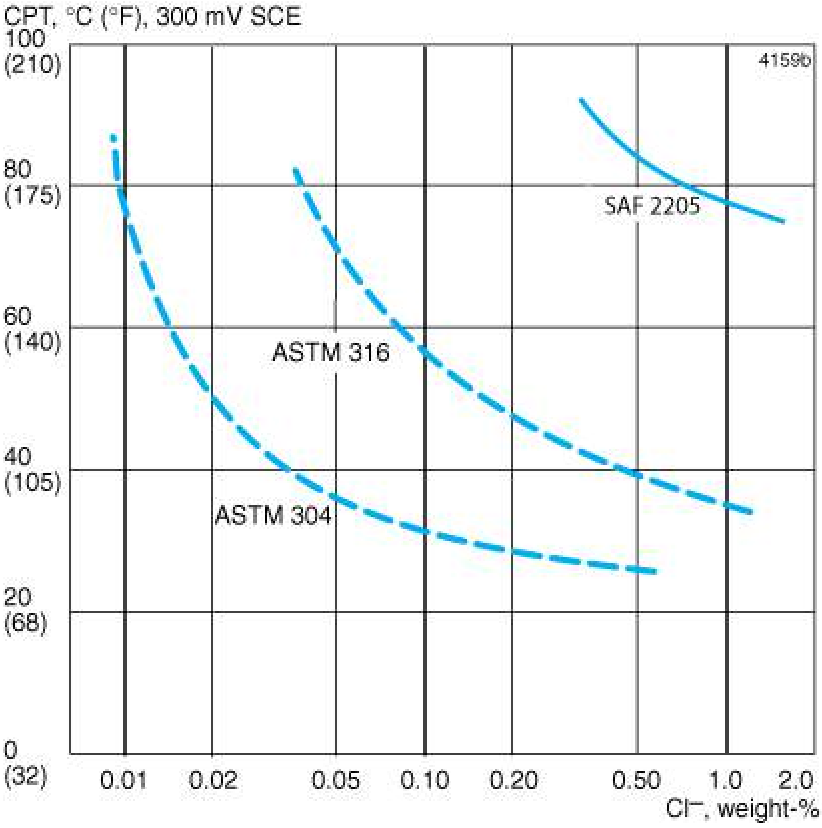

Figure 6. Critical pitting temperatures (CPT) for SAF™ 2205, ASTM TP304 and ASTM TP316 at varying concentrations of sodium chloride (potentiostatic determination at +300 mV SCE), pH6.0

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).

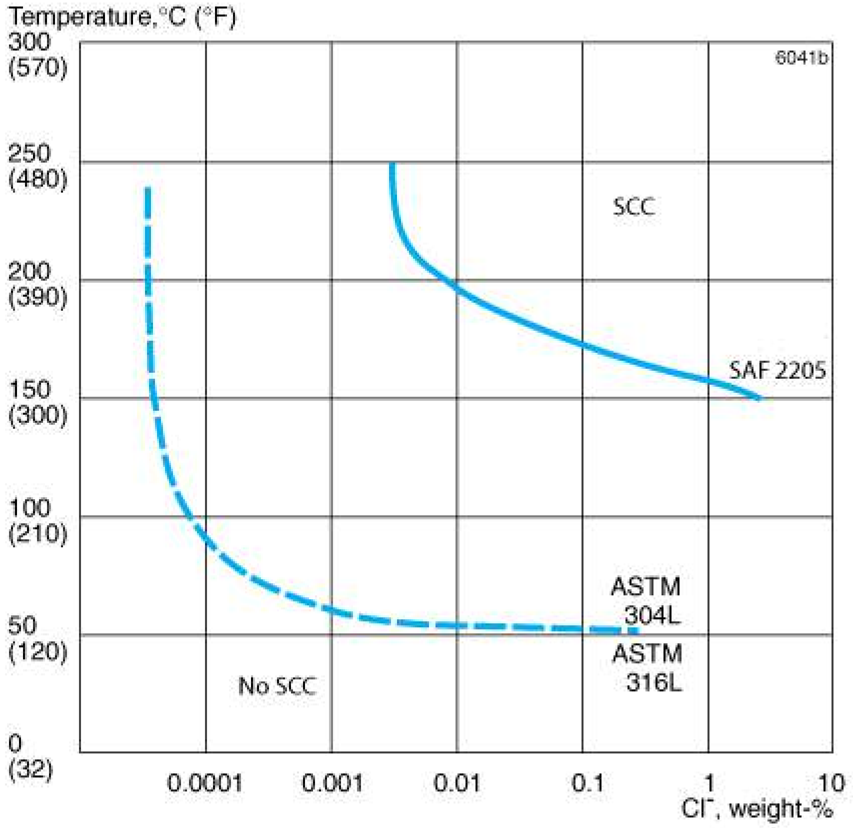

Figure Figure 7. Resistance to stress corrosion cracking (SCC) in neutral chloride solutions with an oxygen content of about 8 ppm. Laboratory results for SAF™ 2205 of constant load specimens loaded to the proof strength at the test temperature.

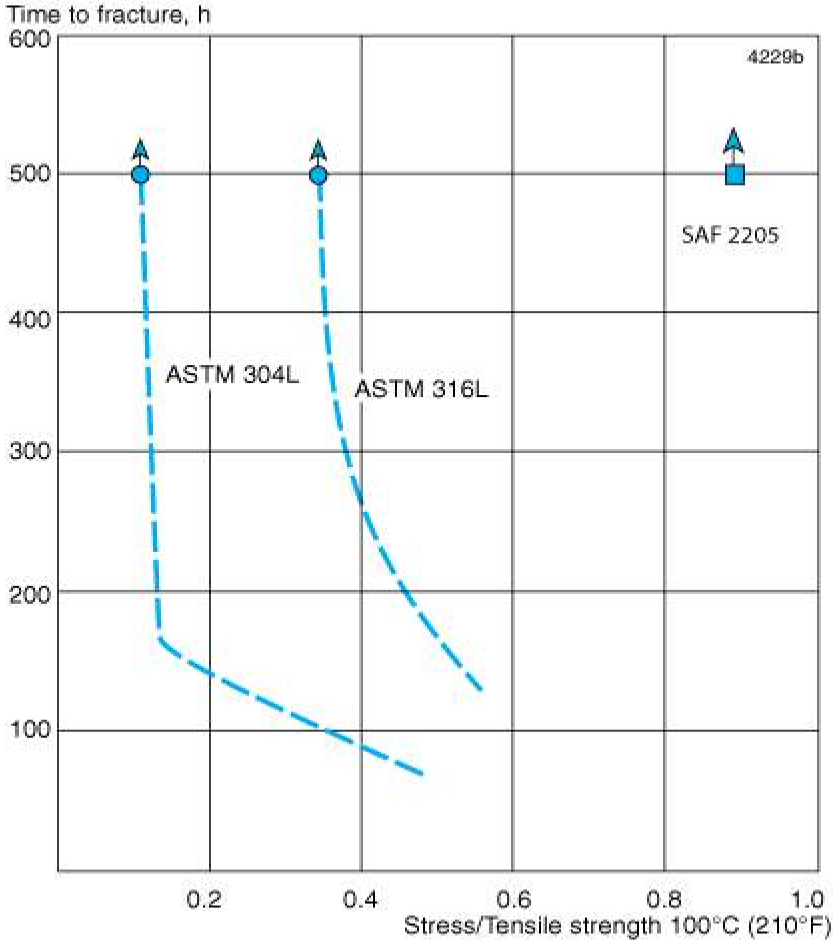

Figure 8. Results of stress corrosion cracking (SCC) tests on SAF™ 2205, ASTM TP304L and ASTM TP316L in 40% $CaCl_2$, pH 6.5, at 100°C (210°F) with aerated test solution.

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.

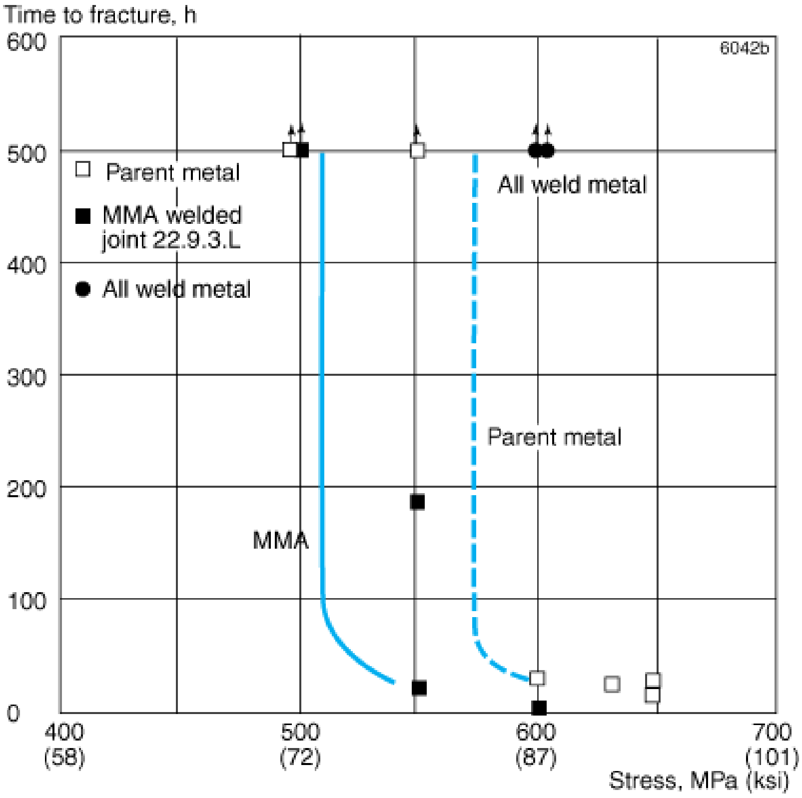

Figure 9. Results of tests according to NACE TM 0177 test solution A of SAF 2205™ in welded and unwelded condition.

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 (Strauś 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

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.

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
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)

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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.

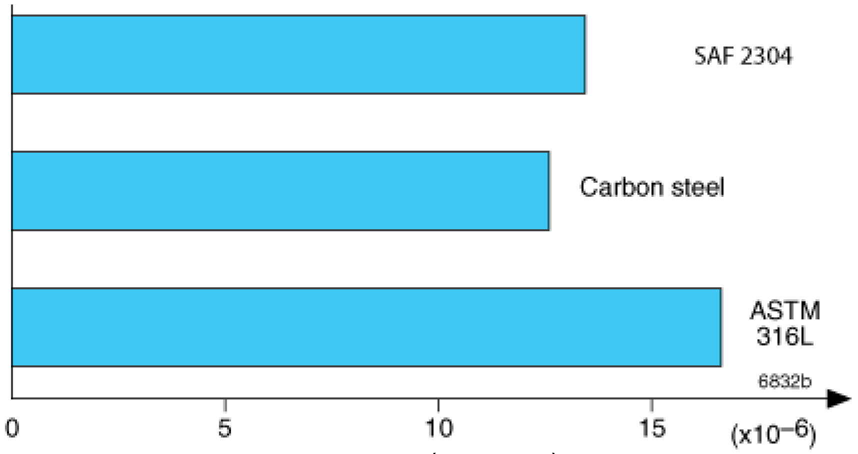

Figure 2. Thermal expansion per °C (30-100°C).

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.

SAF™ 2507
Tube and pipe, seamless
Datasheet

SAF™ 2507 is a super-duplex (austenitic-ferritic) stainless steel for service in highly corrosive conditions. The grade is characterized by:

- Excellent resistance to stress corrosion cracking (SCC) in chloride-bearing environments
- Excellent resistance to pitting and crevice corrosion
- High resistance to general corrosion
- Very high mechanical strength
- Physical properties that offer design advantages
- High resistance to erosion corrosion and corrosion fatigue
- Good weldability

Standards

- UNS: S32750
- EN Number: 1.4410
- EN Name: X 2 CrNiMoN 25-7-4
- SS: 2328

Product standards

- Seamless tube and pipe: EN 10216-5
- Seamless and welded tube and pipe: ASTM A789; A790
- Flanges: ASTM A182
- Fittings: ASTM A182; (ASTM A815 applied for)
- Plate, sheet and strip: ASTM A240, EN 10088-2
- Bar steel: ASTM A479, EN 10088-3
- Forged billets: EN 10088-3

Approvals

- Approved by the American Society of Mechanical Engineers (ASME) for use in accordance with ASME Boiler and Pressure Vessel Code, Section VIII, div. 1. There is no approval for UNS S32750 in the form of plate. However, according to ASME paragraph UG-15, the design values for seamless tube according to ASME Section VIII, div. 1 are also allowed to be used for plate.
- ASME B31.3 Chemical Plant and Petroleum Refinery piping
- VdTÜV-Werkstoffblatt 508

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- 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)

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo	N
≤0.030	≤0.8	≤1.2	≤0.025	≤0.015	25	7	4	0.3

Corrosion resistance

General corrosion

SAF 2507™ is highly resistant to corrosion by organic acids, e.g. experience less than 0.05 mm/year in 10% formic and 50% acetic acid where ASTM 316L has corrosion rate higher than 0.2 mm/year. Pure formic acid see Figure 4. Also in contaminated acid SAF 2507™ remains resistant.

Figure 5 and Figure 6 show results from tests of SAF™ 2507 and various stainless steels and nickel alloys in acetic acid contaminated with chlorides which in practice are frequently present in processes.

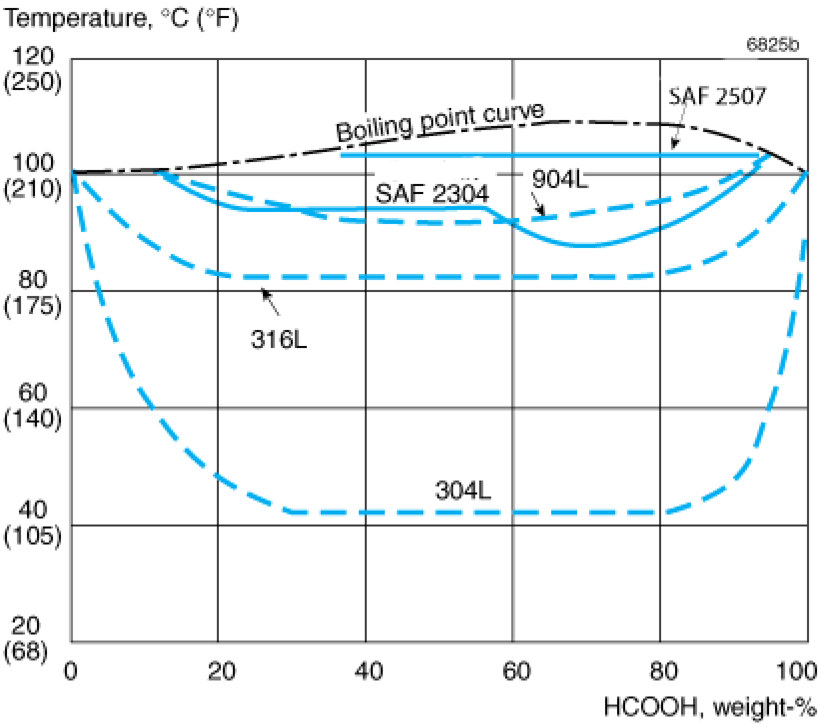

Figure 4. Isocorrosion diagram in formic acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

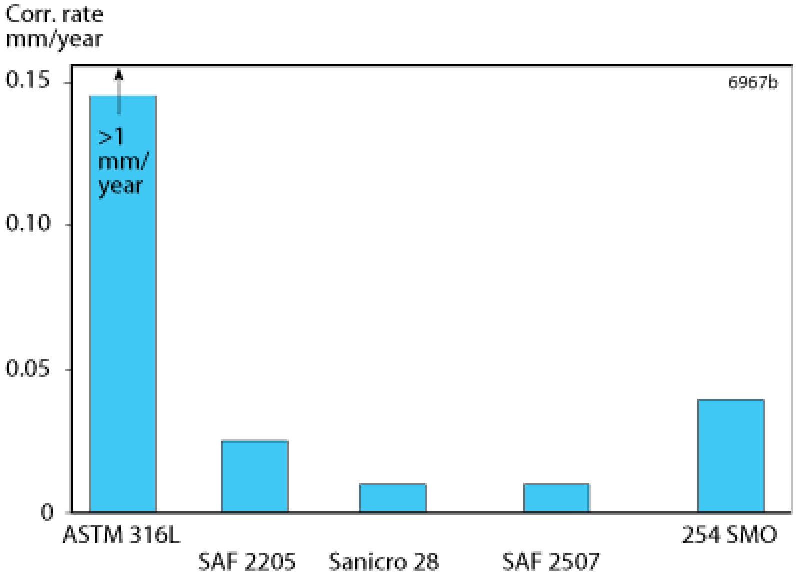

Figure 5. Corrosion rate of various alloys in 80% acetic acid with 2000 ppm chloride ions at 90°C.

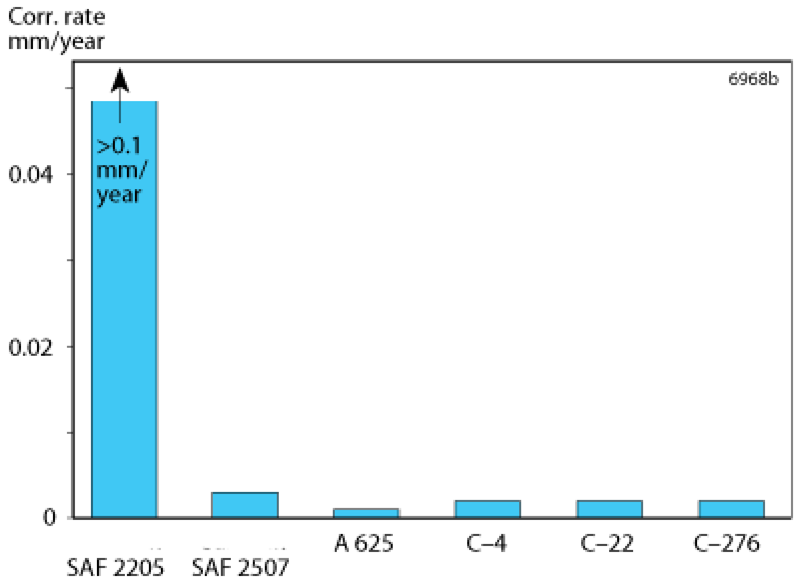

Figure 6. Corrosion rate of various alloys in concentrated acetic acid with 200 ppm chloride ions.

Practical experience with SAF™ 2507 in organic acids, e.g. in terephthalic acid plants, has shown that this alloy is highly resistant to this type of environment. The alloy is therefore a competitive alternative to high alloyed austenitics and nickel alloys in applications where standard austenitic stainless steels corrode at a high rate.

Resistance to inorganic acids is comparable to, or even better than that of high alloy austenitic stainless steels in certain concentration ranges. Figures 7 to 9 show isocorrosion diagrams for sulfuric acid, sulfuric acid contaminated with 2000 ppm chloride ions, and hydrochloric acid, respectively.

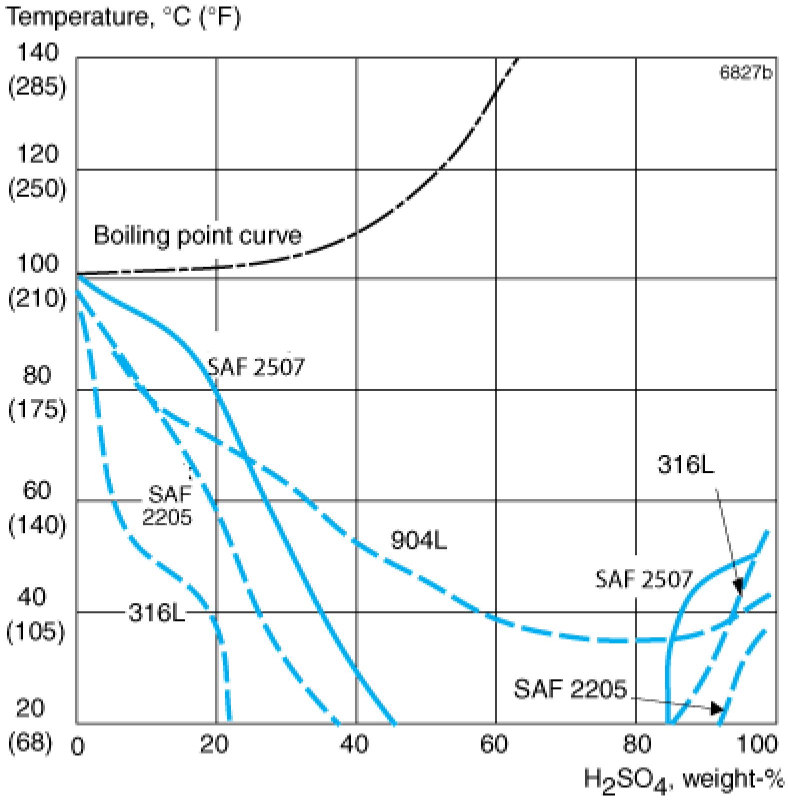

Figure 7. Isocorrosion diagram in naturally aerated sulfuric acid. The curves represent a corrosion rate of 0.1 mm/ year (4 mpy) in a stagnant test solution.

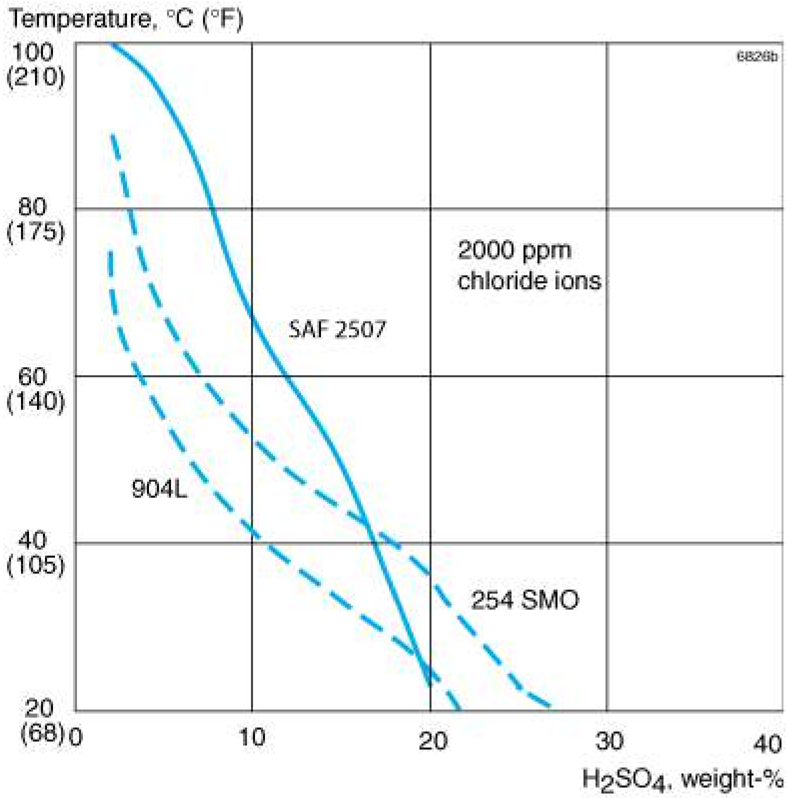

Figure 8. Isocorrosion diagram, 0.1 mm/year (4 mpy) in a naturally aerated sulfuric acid containing 2000 ppm chloride ions.

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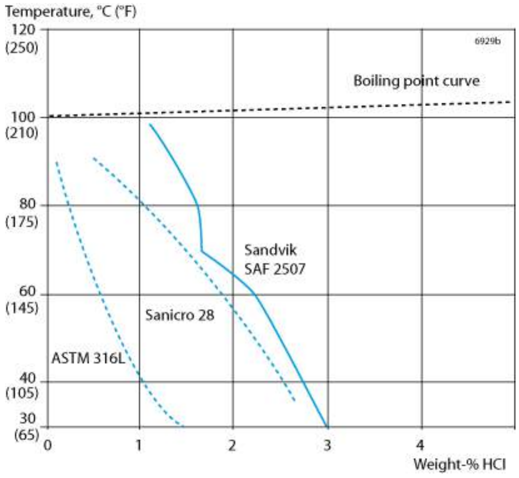

Figure 9. Isocorrosion diagram in hydrochloric acid. The curves represent a corrosion rate of 0.1 mm/year (4 mpy) in stagnant test solution.

Pitting and crevice corrosion

The pitting and crevice corrosion resistance of stainless steel is primarily determined by the content of chromium, molybdenum and nitrogen. The manufacturing and fabrication practices, e.g. welding, are also of vital importance for the actual performance in service.

A parameter for comparing the resistance to pitting in chloride environments is the PRE number (Pitting Resistance Equivalent).
The PRE is defined as, in weight-%
PRE = %Cr + 3.3 x %Mo + 16 x %N

For duplex stainless steels the pitting corrosion resistance is dependent on the PRE value in both the ferrite phase and the austenite phase, so that the phase with the lowest PRE value will be limiting for the actual pitting corrosion resistance. In SAF™ 2507 the PRE value is equal in both phases, which has been achieved by a careful balance of the elements.

The minimum PRE value for SAF™ 2507 seamless tubes is 42.5. This is significantly higher than e.g. the PRE values for other duplex stainless steels of the 25Cr type which are not super-duplex. As an example, UNS S31260 25Cr3Mo0.2N has a minimum PRE-value of 33.

One of the most severe pitting and crevice corrosion tests applied to stainless steel is ASTM G48, i.e. exposure to 6% $FeCl_3$ with and without crevices (method A and B respectively). In a modified version of the ASTM G48 A test, the sample is exposed for periods of 24 hours. When pits are detected together with a substantial weight loss (>5 mg), the test is interrupted. Otherwise, the temperature is increased by 5 °C (9 °F) and the test is continued with the same sample. Figure 11 shows critical pitting and crevice temperatures (CPT and CCT) from the test.

Potentiostatic tests in solutions with different chloride contents are presented in Figure 11. Figure 12 shows the effect of increased acidity. In both cases the applied potential is 600 mV vs SCE, a very high value compared with that normally associated with natural unchlorinated seawater, thus resulting in lower critical temperatures compared with most practical service conditions.

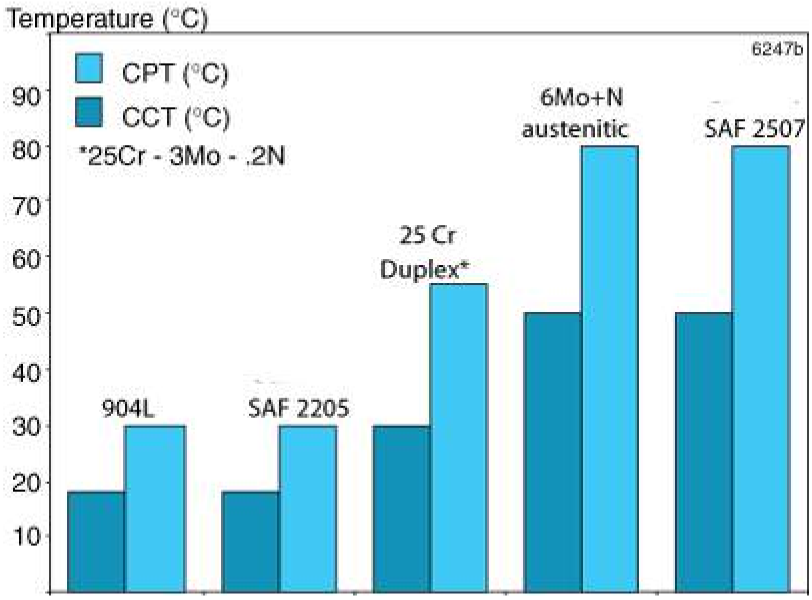

Figure 10. Critical pitting and crevice temperatures in 6% $FeCl_3$, 24h (similar to ASTM G48).

The scatter band for SAF™ 2507 and 6Mo+N illustrates the fact that both alloys have similar resistance to pitting, and CPT-values are within the range shown in the figure.

Tests were performed in natural seawater to determine the critical crevice corrosion temperature of samples with an applied potential of 150 mV vs SCE. The temperature was raised by 4°C (7°F) steps every 24 hours until crevice corrosion occurred. The results are shown in the table below.

Alloy	**CCT (°C)**
SAF 2507	64
6Mo+N	61

In these tests the propagation rates of initiated crevice corrosion attacks, at 15-50°C (59-122°F) and an applied potential of 150 mV vs SCE were also determined. These were found to be around ten times lower for SAF™ 2507 than for the 6Mo+N alloy.

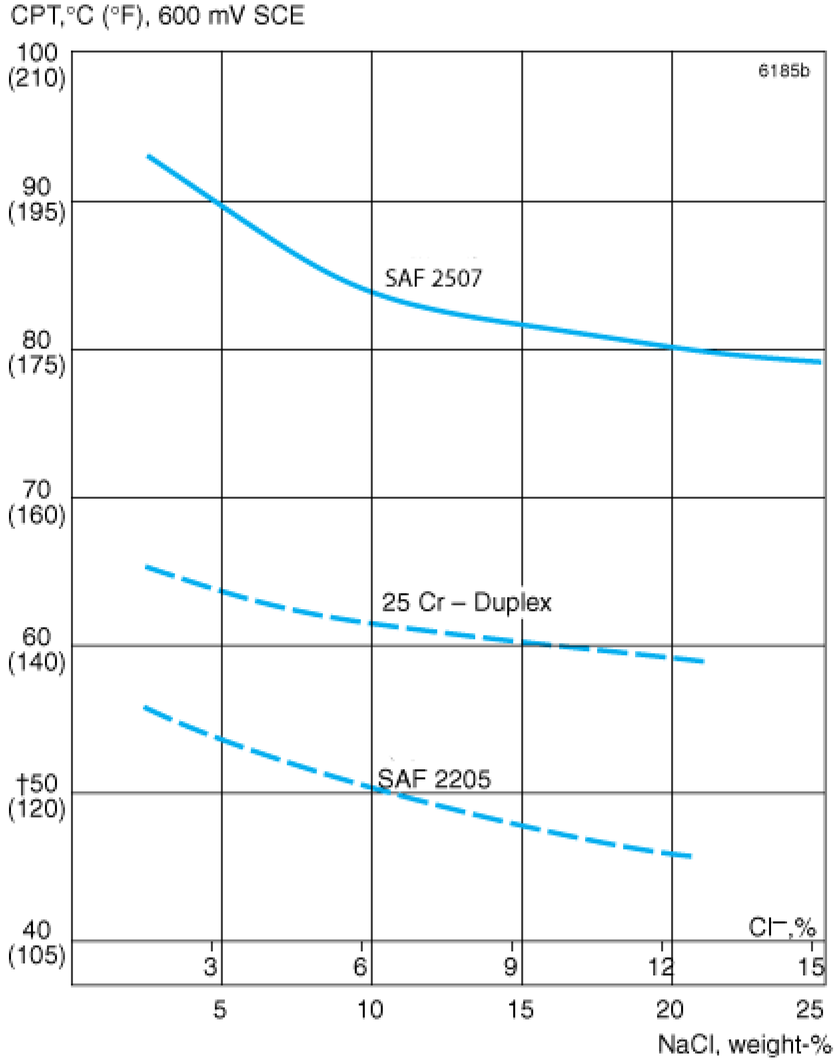

Figure 11. Critical pitting temperatures (CPT) at varying concentrations of sodium chloride, from 3 to 25% (potentiostatic determination at +600 mV SCE with surface ground with 600 grit paper).

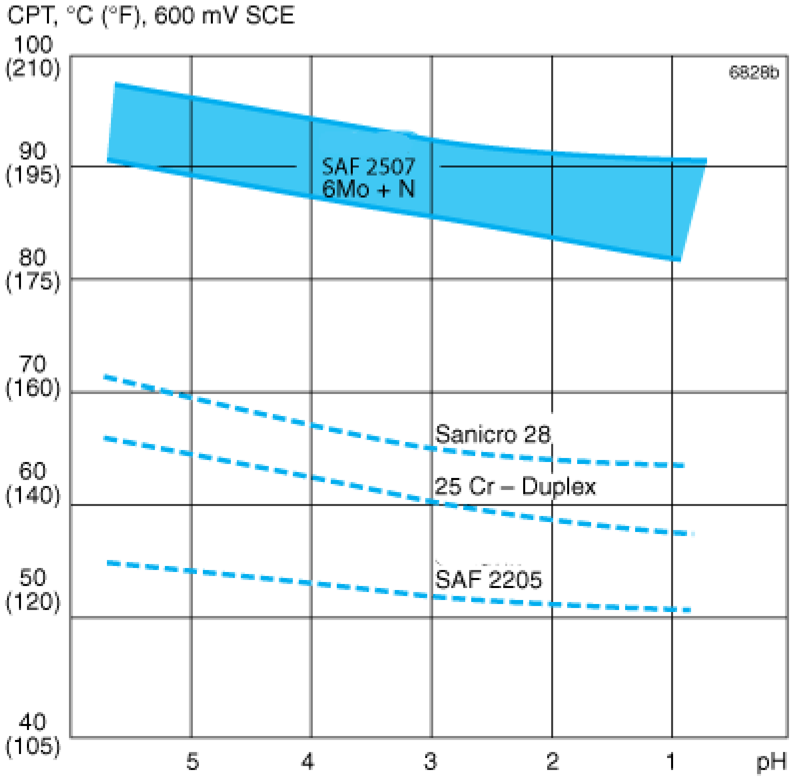

Figure 12. Critical pitting temperatures (CPT) in 3% NaCl with varying pH (potentiostatic determination at +600 mV SCE with surface ground with 600 grit paper).

The corrosion resistance of SAF™ 2507 in oxidizing chloride solutions is illustrated by critical pitting temperatures (CPT) determined in a 'Green death' -solution (1% $FeCl_3$ + 1% $CuCl_2$ +11% H_2SO_4 + 1.2% HCl) and in a 'Yellow death' -solution (0.1 % $Fe_2(SO_4)_3$ + 4% NaCl + 0.01 M HCl). The table below shows CPT-values for different alloys in these solutions. It is clear that the values for SAF™ 2507 are on the same level as those for the nickel alloy UNS N06625. The tests demonstrate a good correlation with the ranking of alloys for use as reheater tubes in flue gas desulfurization systems.

Critical pitting temperature (CPT) determined in different test solutions.

Alloy	Critical pitting temperature (CPT), °C 'Green death'	'Yellow death'
SAF™ 2507	72.5	>90
6Mo+N	70	>90
UNS N06625	67.5	>90
ASTM 316	<25	20

Stress corrosion cracking

SAF™ 2507 has excellent resistance to chloride induced stress corrosion cracking (SCC).

The SCC resistance of SAF™ 2507 in chloride solutions at high temperatures is illustrated in Figure 13. There were no signs of SCC up to 1000 ppm Cl^-/300°C and 10000 ppm Cl^-/250°C.

SAF™ 2507 U-bend specimens exposed for 1000 hours in hot brine (108°C, 226°F, 25% NaCl) showed no cracking.

The threshold stress for SAF 2507® in 40% $CaCl_2$ at 100 °C (210 °F) and pH = 6.5 is above 90% of the tensile strength for both parent metal and welded joints (TIG-welded with Alleima® 25.10.4.L or MMA-welded with Alleima® 25.10.4.LR).

Figure 14 shows the result of testing in 40% $CaCl_2$ at 100 °C (210 °F) acidified to pH = 1.5. Acidifying of the standard test solution to pH = 1.5 lowers the threshold stress for SAF™ 2205, but not for SAF™ 2507. This applies to both parent metal and welded joints.

The threshold stress for both parent metal and welded joints of SAF™ 2507 in boiling 45% $MgCl_2$, 155°C (311°F) (ASTM G36), is approximately 50% of the proof strength.

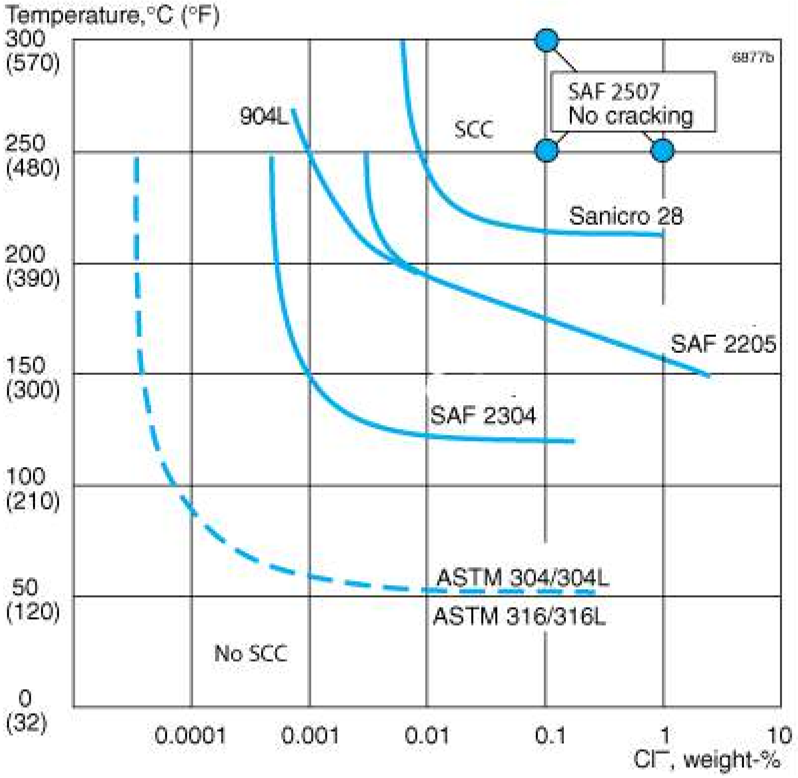

Figure 13. SCC resistance in oxygen-bearing (abt. 8 ppm) neutral chloride solutions. Testing time 1000 hours. Applied stress equal to proof strength at testing temperature.

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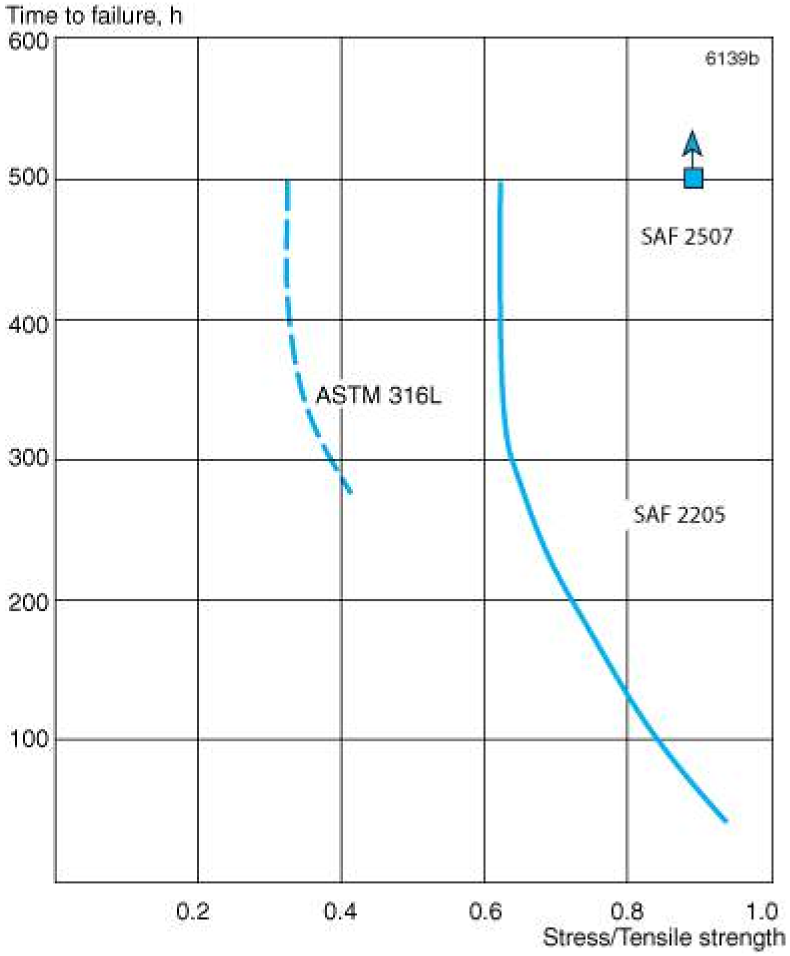

Figure 14. Results of SCC tests with constant load in 40% $CaCl_2$, pH=1.5, at 100 °C (210°F) with aerated test solution.

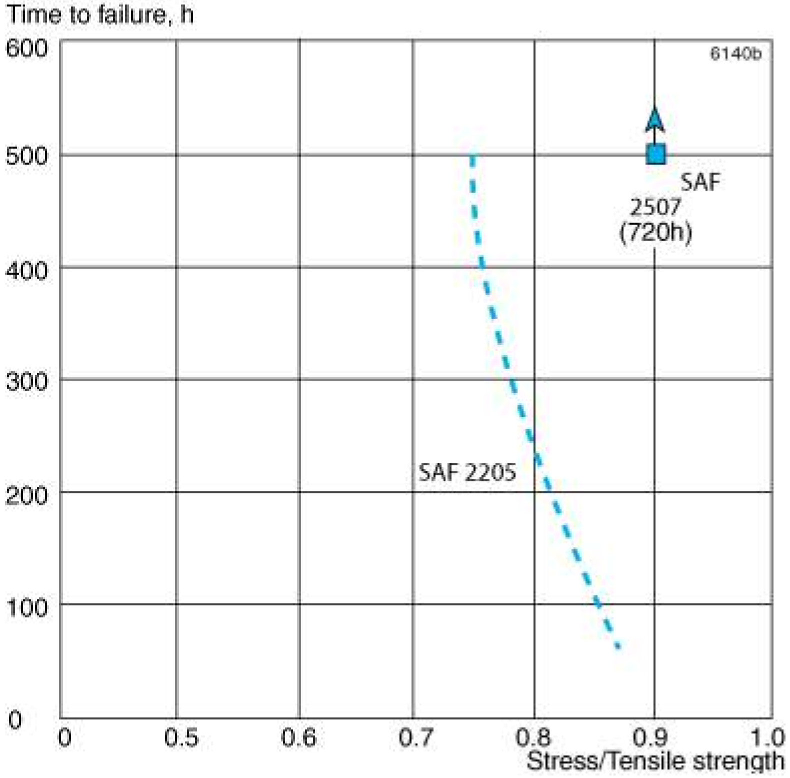

Figure 15. Constant load SCC tests in NACE solution at room temperature (NACE TM 0177).

Figure 15 shows the results of SCC tests at room temperature in NACE TM0177 Test solution A (5% sodium chloride and 0.5% acetic acid saturated with hydrogen sulfide). No cracking occurred on SAF™ 2507, irrespective of the applied stress.

In aqueous solutions containing hydrogen sulfide 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 the case with ordinary chloride-induced stress corrosion cracking, ferritic stainless steels are more sensitive to this type of stress corrosion cracking than austenitic steels.

In accordance with ISO 15156/NACE MR 0175 solution annealed and rapid cooled wrought SAF™ 2507 is suitable for use at temperatures up to 450 °F (232 °C) in sour environments in oil and gas production, if the partial pressure of hydrogen sulphide does not exceed 3 psi (0.20 bar).

SAF™ 2507, with a maximum hardness of 32 HRC, solution annealed and rapidly cooled, according to NACE MR0103, is suitable for use in sour petroleum refining.

Hydrogen Induced Stress Cracking (HISC)

Hydrogen Induced Stress Cracking (HISC) is an embrittlement phenomenon that may occur in cathodically protected subsea steel constructions in the presence of high tensile stresses. When connected to cathodically protected carbon steels, super duplex stainless steels will also be cathodically protected even though this is not necessary. At the prevalent low electrochemical potentials, atomic hydrogen will be generated on the steel surfaces by the reduction of sea water. Embrittlement due to HISC may occur when hydrogen diffuses into the metal.

Hydrogen diffuses much faster in the ferrite phase than in the austenite phase. Therefore, ferritic steels and ferrite containing steels, e.g. super duplex stainless steels, are more susceptible to HISC than austenitic stainless steels. A high mechanical stress increases the risk of HISC by increasing the hydrogen diffusion rate, crack initiation and propagation in the material.

In super duplex stainless steels, cracks tend to propagate in the embrittled ferrite phase and arrest at ferrite-austenite phase boundaries. Susceptibility to HISC significantly increases with increasing austenite spacing. Coarse-grained microstructures are therefore more susceptible. A testing program performed at Alleima Materials Technology has confirmed that tendency to HISC is reduced when austenite spacing is less than 30 µm, as recommended by DNV RP-F112. Cold pilgered and solution annealed tubes with austenite spacing between 5-15 µm have shown very good resistance to HISC under applied stress up to 130% of the yield strength without cracking.

The acceptable stress without HISC occurring for products with different austenite spacing is illustrated in figure 16.

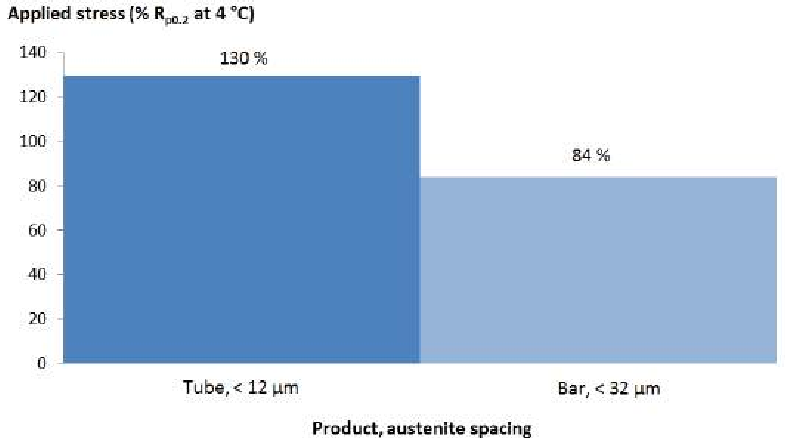

Figure 16. Tolerable stress as a percentage of the actual yield strength at 4°C without HISC occurring is schematically shown for tube and bar products with different austenite spacing. SAF™ 2507 (UNS S32750) has been tested on hydrogen pre-charged tensile specimens, using constant load with a dead weight, with an applied potential of -1050 mV/SCE in a electrochemical cell with 3% NaCl solution at 4°C, 500 hours. [NACE paper no. 07498]

Intergranular corrosion

SAF™ 2507 is a member of the family of modern duplex stainless steels whose chemical composition is balanced to give quick reformation of austenite in the high temperature heat affected zone of a weld. This results in a microstructure that provides the material with good resistance to intergranular corrosion. SAF™ 2507 passes testing to ASTM A262 Practice E (Strauss test) without reservation.

Erosion corrosion

The mechanical properties combined with corrosion resistance give SAF™ 2507 a good resistance to erosion corrosion. Testing in sand containing media has shown that SAF™ 2507 has an erosion corrosion resistance better than corresponding austenitic stainless steels. Figure 17 below shows the relative mass loss rate of the duplex SAF™ 2507, SAF™ 2205 and an austenitic 6Mo+N type steel after exposure to synthetic seawater (ASTM D-1141) containing 0.025-0.25% silica sand at a velocity of 8.9-29.3 m/s (average of all tests is shown).

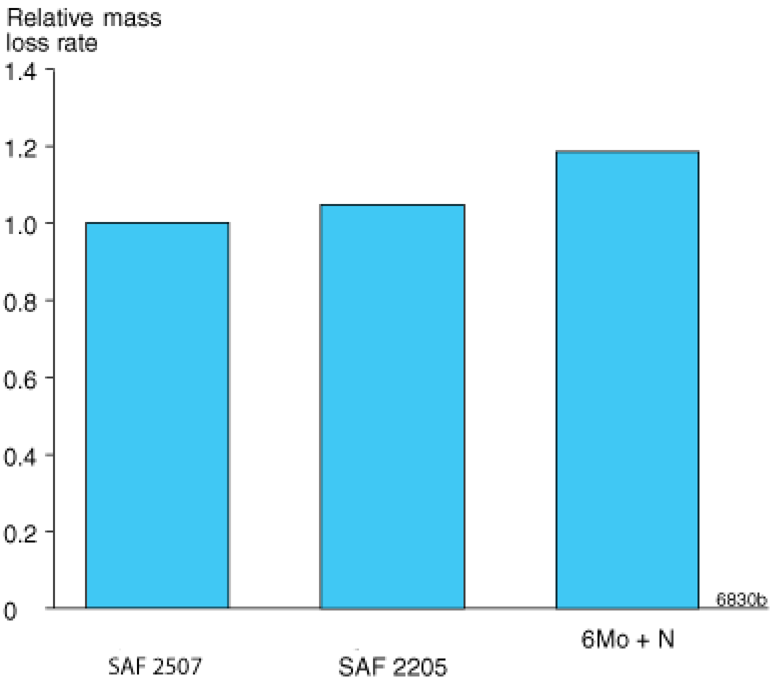

Figure 17. Relative mass loss rate after testing of the resistance against erosion corrosion.

Corrosion fatigue

Duplex stainless steels which have a high tensile strength usually have a high fatigue limit and high resistance to both fatigue and corrosion fatigue.

The high fatigue strength of SAF™ 2507 can be explained by its good mechanical properties, while its high resistance to corrosion fatigue has been proven by fatigue testing in corrosive media.

Applications

SAF™ 2507 is a duplex stainless steel especially designed for service in aggressive chloride-containing environments. Typical applications are:

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Typical applications for SAF™ 2507

Oil and gas exploration and production	Chloride-containing environments such as seawater handling and process systems. Hydraulic and process fluid tubes in umbilicals
Seawater cooling	Tubing for heat exchangers in refineries, chemical industries, process industries and other industries using seawater or chlorinated seawater as coolant
Salt evaporation	Evaporator tubing for production of corrosive salts, e.g. chlorides, sulfates and carbonates
Desalination plants	Pressure vessels for reverse osmosis units, tube and pipe for seawater transport, heat exchanger tubing
Geothermal wells	Heat exchangers in geothermal exploitation units, systems exposed to geothermal or high salinity brines, tubing and casing for production
Oil refining and petrochemical and gas processing	Tubes and pipes where the process environment contains a high amount of chlorides, or is contaminated with hydrochloric acid
Pulp and paper production	Material for chloride-containing bleaching environments
Chemical processing	Organic acid plants, also when process solutions are contaminated with e.g. chlorides
Mechanical components requiring high strength	Propeller shafts and other products subjected to high mechanical load in seawater and other chloride-containing environments
Desulfurization units	As reheater tubes in flue gas desulfurization systems. The good mechanical and corrosion properties make SAF™ 2507 an economical choice in many applications by reducing the life cycle cost of equipment.

Fabrication

Bending

The starting force needed for bending is slightly higher for SAF™ 2507 than for standard austenitic stainless steels (ASTM 304L and 316L).

If the service conditions are on the limit of the stress corrosion resistance of SAF™ 2507 heat treatment is recommended after cold bending. For pressure vessel applications in Germany and the Nordic countries, heat treatment may be required after cold deformation in accordance with VdTÜV-Wb 508 and NGS 1609. Heat treatment should be carried out by solution annealing (See under Heat treatment) or resistance annealing.

Hot bending is carried out at 1125-1025°C (2060-1880°F) and should be followed by solution annealing.

Expanding

Compared to austenitic stainless steels, SAF™ 2507 has a higher proof and tensile strength. This must be kept in mind when expanding tubes into tubesheets. Normal expanding methods can be used, but the expansion requires higher initial force and should be undertaken in one operation. As a general rule, tube to tubesheet joints should be welded if the service conditions include a high chloride concentration, thus limiting the risk of crevice

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corrosion.

Machining

Being a two-phase material (austenitic-ferritic) SAF™ 2507 will present a different tool wear profile from that of single-phase steels of type ASTM 304L. The cutting speed must therefore be lower than that recommended for ASTM 304L. It is recommended that a tougher insert grade is used than when machining austenitic stainless steels, e.g. ASTM 304L.

Forms of supply

Seamless tube and pipe– finishes and dimensions

Seamless tube and pipe in SAF™ 2507 is supplied in dimensions up to 260 mm outside diameter. The delivery condition is solution annealed and either white pickled, or bright annealed.

Other forms of supply:

- Welded tube and pipe
- Fittings and flanges
- Plate, sheet and wide strip
- Bar steel
- Forged products
- Cast products

Heat treatment

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

Solution annealing

1050-1125°C (1920-2060°F), rapid cooling in air or water.

Mechanical properties

The following figures apply to material in the solution annealed condition. Tube and pipe with wall thickness above 20 mm (0.787 in.) may have slightly lower values. For seamless tubes with a wall thickness <4 mm we guarantee proof strength ($R_{p0.2}$) values that are 50 MPa higher than those listed below at 20°C (68°F) as well as those listed at higher temperatures. More detailed information can be supplied on request.

At 20°C (68°F)

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

Metric units

Proof strength, MPa		Tensile strength, MPa	Elongation, %		Hardness, HRC
$R_{p0.2}$ [a)]	$R_{p1.0}$ [a)]	R_m	A [b)]	$A_{2"}$	
≥550	≥640	800-1000	≥25	≥15	≤32

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Imperial units

Proof strength, ksi		Tensile strength, ksi	Elongation, %		Hardness, HRC
$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	$A_{2"}$	HRC
≥80	≥93	116-145	≥25	≥15	≤32

1 MPa = 1 N/mm²
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.

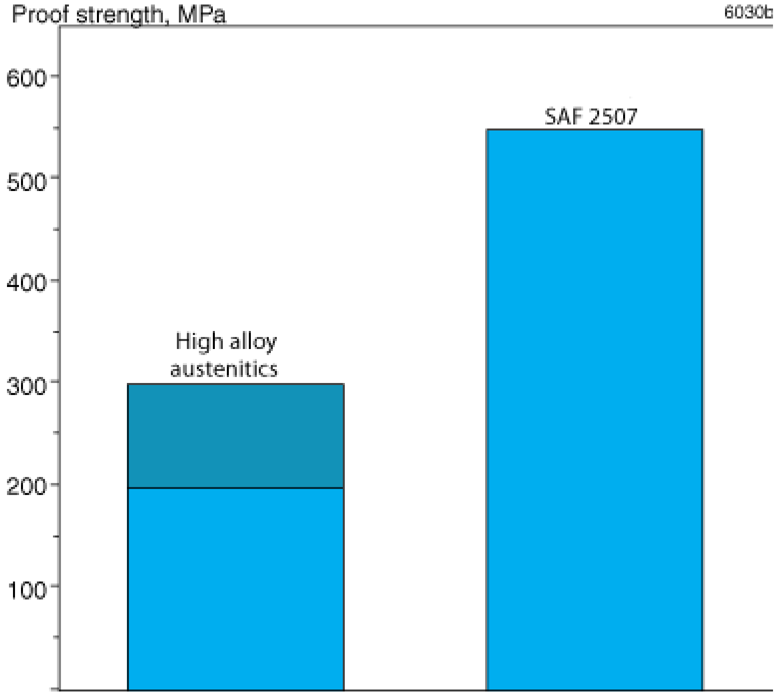

Figure 1. Comparison of minimum proof strength, 0.2% offset, of SAF™ 2507 and high alloy austenitic grades, for material in the solution annealed condition.

At high temperatures

If SAF™ 2507 is exposed to temperatures exceeding 250°C (480°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, 250°C (480°F) is required as a maximum, according to VdTÜV-Wb 508 and NGS 1609.

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

Metric units

Temperature, °C	Proof strength $R_{p0.2}$, MPa
	min.
50	530

100	480
150	445
200	420
250	405
300	395

Imperial units

Temperature, °F	Proof strength $R_{p0.2}$, ksi
	min.
120	77.0
200	70.5
300	64.5
400	61.0
500	58.5
600	57.0

Seamless tube and pipe in the cold-worked condition

Proof strength		Tensile strength		Elong.	Hardness, HRC
$R_{p0.2}$		R_m		A2"	
MPa	ksi	MPa	ksi	%	
862 - 1034	125-150	≥ 896	≥ 130	≥ 10	≤ 37
965 - 1103	140-160	≥1000	≥ 145	≥ 9	≤ 38

Impact strength

SAF™ 2507 possesses good impact strength. The ductile brittle transition temperature is below -50°C (-58°F). The impact strength of welded SAF™ 2507 is also good, although the values are lower than the base metal. The impact strength, if gas shielded arc weldments, is a minimum of 27 J (20 ft lb) at a temperature of -50°C (-58°F).

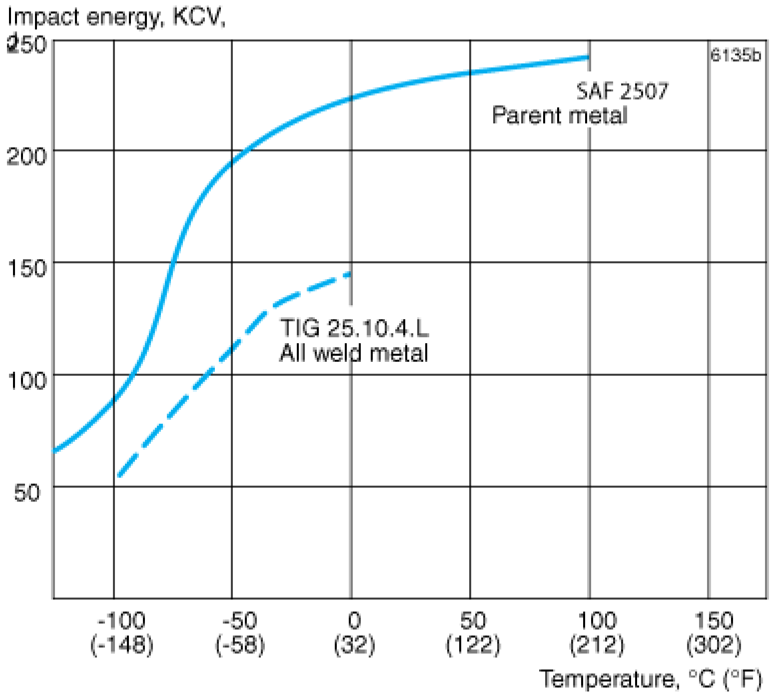

Figure 2. Typical impact energy curves for SAF™ 2507 using standard Charpy V specimens (average of 3 at each temp.). Parent metal samples taken in the longitudinal direction from 260 x 12 mm hot extruded and solution annealed (1075°C / 1965°F) tube. All weld metal samples from Alleima® 25.10.4.L TIG wire.

According to ASME B31.3 the following design values are recommended for UNS S32750 (SAF™ 2507):

Temperature		Stress	
°F	°C	ksi	MPa
100	38	38.7	267
200	93	38.5	265
300	149	36.4	251
400	204	35.4	244
500	260	34.5	238
600	316	34.3	236

Physical properties

Density: 7.8 g/cm^3, 0.28 lb/in.^{3}

Specific heat capacity

Metric units Imperial units

Temperature, °C	J/(kg °C)	Temperature, °F	Btu/(lb °F)

20	490	68	0.12
100	505	200	0.12
200	520	400	0.12
300	550	600	0.13
400	585	800	0.14

Thermal conductivity
Metric units, W/(m °C)

Temperature, °C	20	100	200	300	400
SAF 2507	14	15	17	18	20
ASTM 316L	14	15	17	18	20

Imperial units, Btu/(ft h °F)

Temperature, °F	68	200	400	600	800
SAF™ 2507	8	9	10	11	12
ASTM 316L	8	9	10	10	12

Thermal expansion
SAF™ 2507 has a coefficient of thermal expansion close to that of carbon steel. This gives SAF™ 2507 definite design advantages over austenitic stainless steels in equipment comprising of both carbon steel and stainless steel. The values given below are average values in the temperature ranges.

Metric units, x10^{-6}/°C

Temperature, °C	30-100	30-200	30-300	30-400
SAF™ 2507	13.5	14.0	14.0	14.5
Carbon steel	12.5	13.0	13.5	14.0
ASTM 316L	16.5	17.0	17.5	18

Imperial units, x10^{-6}/°F

Temperature, °F	86-200	86-400	86-600	86-800
SAF™ 2507	7.5	7.5	8.0	8.0
Carbon steel	6.8	7.0	7.5	7.8
ASTM 316L	9.0	9.5	10.0	10.0

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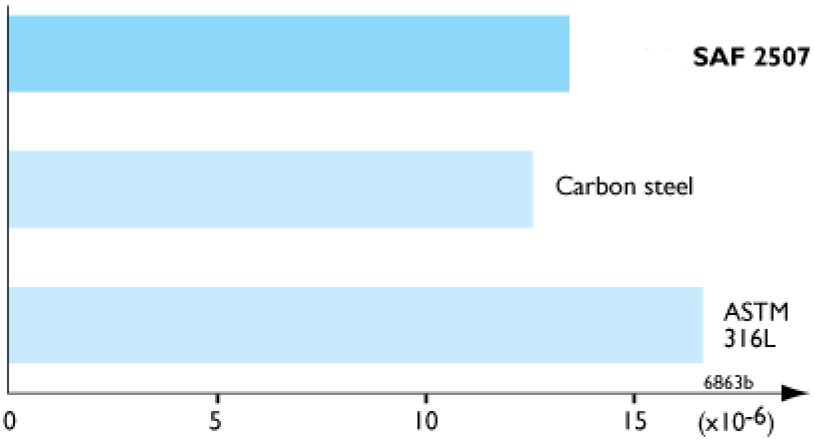

Figure 3. Thermal expansion, per °C (30-100°C, 86-210°F).

Resistivity

Temperature, °C	μΩm	Temperature, °F	μΩin.
20	0.83	68	32.7
100	0.89	200	34.9
200	0.96	400	37.9
300	1.03	600	40.7
400	1.08	800	43.2

Modulus of elasticity, (x10^3)

Metric units and imperial units

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

Welding

Welding

The weldability of SAF™ 2507 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™ 2507, heat input of 0.2-1.5 kJ/mm and interpass temperature of <150°C (300°F) are recommended.

Recommended filler metals

GTAW/TIG welding

ISO 14343 S 25 9 4 N L / AWS A5.9 ER2594 (e.g. Exaton 25.10.4.L)

MMA/SMAW welding

ISO 3581 E 25 9 4 N L R / AWS A5.4 E2594-16 (e.g. Exaton 25.10.4.LR)

ISO 3581 E 25 9 4 N L B / AWS A5.4 E2594-15 (e.g. Exaton 25.10.4.LB)

Overlay welding

ISO 14343 S 25 9 4 N L / AWS A5.9 ER2594 (e.g. Exaton 25.10.4.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 2507®, is required.

Alleima

Sanicro® 625
Tube and pipe, seamless
Datasheet

Sanicro® 625 is an austenitic nickel-chromium alloy characterized by:

- Extremely good corrosion resistance in widely varying acidic and chloride containing environments
- High strength
- Excellent fabrication properties.

Sanicro® 625 can be used in a wide range of temperatures from -196°C to 815°C (-321°F to 1500°F). Typical uses include hydraulic and instrumentation systems, heat-exchangers and high-temperature applications. However, it should be noted that prolonged exposure to temperatures above 600°C (1100°F) may lead to embrittlement.

Standards

- UNS: N06625
- ISO: NW6625

Product standards

ASTM B444, Grade 1 and Grade 2
ASME SB444, Grade 1 and Grade 2
ISO 6207

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo	Fe	Nb
0.025	0.2	0.15	≤0.015	≤0.015	21.5	61	8.7	4	3.5

Applications

Sanicro® 625 is an extremely versatile nickel alloy, suitable for use in both oxidizing and reducing acidic environments, such as:

- Hydrochloric acid
- Nitric acid
- Phosphoric acid

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- Chloride containing environments

The grade can also be used for a wide range of temperatures from -196°C to 815°C (-321°F to 1500°F). Typical areas of use include hydraulic systems, heat-exchangers and high-temperature applications.

Some industrial examples are:

- High temperature aerospace
- Chemical process industry
- Power industry

Corrosion resistance

Wet corrosion

Sanicro® 625 shows very good resistance to pitting corrosion, intergranular corrosion and is virtually immune to stress corrosion cracking in chloride-containing environments. The grade is able to withstand general corrosion in both severe oxidizing and non-oxidizing acids.

Resistance in chloride environments is also extremely good owing to the high PRE number, ≥48.

Pitting Resistance Equivalent, PRE
PRE = %Cr + 3.3 x %Mo + 16 x %N

High temperature corrosion

In addition to its excellent wet corrosion resistance, Sanicro® 625 is also able to resist oxidation and scaling at high temperature.

Forms of supply

Sanicro® 625 seamless nickel alloy tubing is supplied bright annealed in the outside diameter range 6 - 42 mm (0.25" - 1.625") and wall-thickness 0.89 - 5.0 mm (0.035" - 0.197"). Some dimensions may be supplied annealed and white pickled.

Tubing is supplied as:

- Annealed (Grade 1)
- Solution annealed (Grade 2)

Tolerances

Sanicro® 625, OD 6-42 mm EN 10305-1

Size OD, mm	Tolerances OD, mm	Wall thickness %
6-30	+/-0.08	+/-10
32-40	+/-0.15	+/-10
42	+/-0.20	+/-10

Mechanical properties

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At 20°C, metric units

Condition	Proof strength	Tensile strength	Elongation
	$R_{p0.2}$ 1)	R_m	$A_{2"}$
	MPa	MPa	%
Grade 1 2)	≥415	≥827	≥30
Grade 2 3)	≥276	≥690	≥30

At 68°F, imperial units

Condition	Proof strength	Tensile strength	Elongation
	$R_{p0.2}$ 1)	R_m	$A_{2"}$
	ksi	ksi	%
Grade 1 2)	≥60	≥120	≥30
Grade 2 3)	≥40	≥100	≥30

1) Corresponds to 0.2% offset yield strength

2) Annealed at 871°C (1600°F) minimum

3) Solution annealed at 1093°C (2000°F) minimum

Physical properties

Density: 8.36 g/cm^3, 0.30 lb/in^3

Welding

The weldability of Sanicro® 625 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.

For Sanicro® 625, heat-input of <1.5 kJ/mm and interpass temperature of <100°C (210°F) are recommended. A string bead welding technique should be used.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 18274 S Ni 6625/AWS A5.14 ERNiCrMo-3 (e.g. Exaton Ni60)

MMA/SMAW welding

ISO 14172 E Ni 6625/AWS A5.11 ENiCrMo-3 (e.g. Exaton Ni60) in technical data without notice. This datasheet is only valid for Alleima materials.

Alleima® Alloy 400
Tube and pipe, seamless
Datasheet

Alleima® Alloy 400 is a copper-nickel alloy with the following characteristics:

- High strength and toughness
- Good bendability
- Excellent corrosion resistance in many environments

Standards

- UNS: N04400
- W.Nr.: 2.4360

Product standards

- ASTM B163, ASTM B165-05

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	S	Ni
≤0.3	≤0.5	≤2	≤0.024	≥63

Others
Cu=30
Fe<2.5

Applications

Alleima® Alloy 400 is used in a wide variety of applications in the chemical, nuclear and oil and gas industries, including heat-exchangers, pumps and valves, reboiler tubes and control lines.

Forms of supply

Alleima® Alloy 400 tubing is supplied in the annealed condition in lengths of 6 m.

Mechanical properties

At 20°C (68°F)

Proof strength	Tensile strength	Elong.

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$R_{p0.2}$ 1)		R_m		A 2)
MPa	ksi	MPa	ksi	%
≥195	≥28	≥480	≥70	≥40

1 MPa = N/mm^2
1) $R_{p0.2}$ and $R_{p1.0}$ correspond to 0.2% offset and 1.0% offset yield strength, respectively.
2) 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.

Physical properties

Density

8.83 g/cm^3, 0.32 lb/in^3

Thermal conductivity

21.8 W.m -1.°K-1

Specific heat capacity

427 J.kg-1.°K-1

Thermal expansion

13.9 mm/m/°C

Modulus of elasticity

173 GPa

Electrical Resistivity

5.47 µΩ/cm

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Alleima® 254 SMO
Tube and pipe, seamless
Datasheet

Alleima® 254 SMO is a high-alloy austenitic stainless steel developed for use in seawater and other aggressive chloride-bearing media. The steel is characterized by the following properties:

- Excellent resistance to pitting and crevice corrosion, PRE = ≥42.5*
- High resistance to general corrosion
- High resistance to stress corrosion cracking
- Higher strength than conventional austenitic stainless steels
- Good weldability

*The PRE is defined as, in weight-%, PRE = %Cr + 3.3 x %Mo + 16 x %N

Trademark information: 254 SMO is a trademark owned by Outokumpu OY.

Standards

- UNS: S31254
- EN Number: 1.4547
- EN Name: X1CrNiMoCuN20-18-7
- W.Nr.: 1.4529**
- AFNOR: Z1 CNDU 20.18.06AZ*

* Obsolete. Replaced by EN.
** Nearest equivalent grade.

Product standards

- Seamless tube and pipe: ASTM A269, A213, A312, NFA 49-217, EN 10216-5
- Norsok MDS R11/R18, IOGP S-563 MDS IR111/111S/IR118/IR118S
- Welded tube and pipe: ASTM A249, A269 , A312, A358, A409
- Fittings: ASTM A182
- Bar: ASTM A276, A479, EN 10088-3
- Forged products: ASTM A473

Approvals

- UNS S31254 (Alleima® 254 SMO) in the form of seamless pipe has been approved by the American Society of

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Mechanical Engineers (ASME) for use according to ASME Boiler and Pressure Vessel Code section VIII, div. 1. However, there is no approval for UNS S31254 in the form of seamless tube, but according to the ASME paragraph UG-15 it is allowed to use the design values for seamless pipe according to ASME section VIII, div. 1 also for seamless tube.
- NACE MR 0175 (sulphide stress cracking resistant material for oil field equipment).

Chemical composition (nominal)

Chemical composition (nominal) %

C	Si	Mn	P	S	Cr	Ni	Mo	N	Cu
≤0.020	≤0.80	≤1.00	≤0.030	≤0.010	20	18	6.1	0.20	0.7

Applications

Alleima 254 SMO is used in the following applications:

- Equipment for handling of seawater, such as seawater cooling, cooling water pipes, ballast water systems, firefighting systems etc.
- Hydraulic and instrumentation tubing
- Equipment in pulp bleaching plants
- Components in gas cleaning systems
- Tanks and pipelines for chemicals with high halide contents

Trademark information: 254 SMO is a trademark owned by Outokumpu OY.

Corrosion resistance

In solutions containing halides such as chloride and bromide ions, conventional stainless steels can be readily attacked by local corrosion in the form of pitting corrosion, crevice corrosion or stress corrosion cracking (SCC). In acid environments, the presence of halides also accelerates general corrosion.

General corrosion

In pure sulphuric acid, Alleima 254 SMO is much more resistant than ASTM TP316, and in naturally aerated sulphuric acid containing chloride ions Alleima 254 SMO exhibits higher resistance than '904L', see Figure 2.

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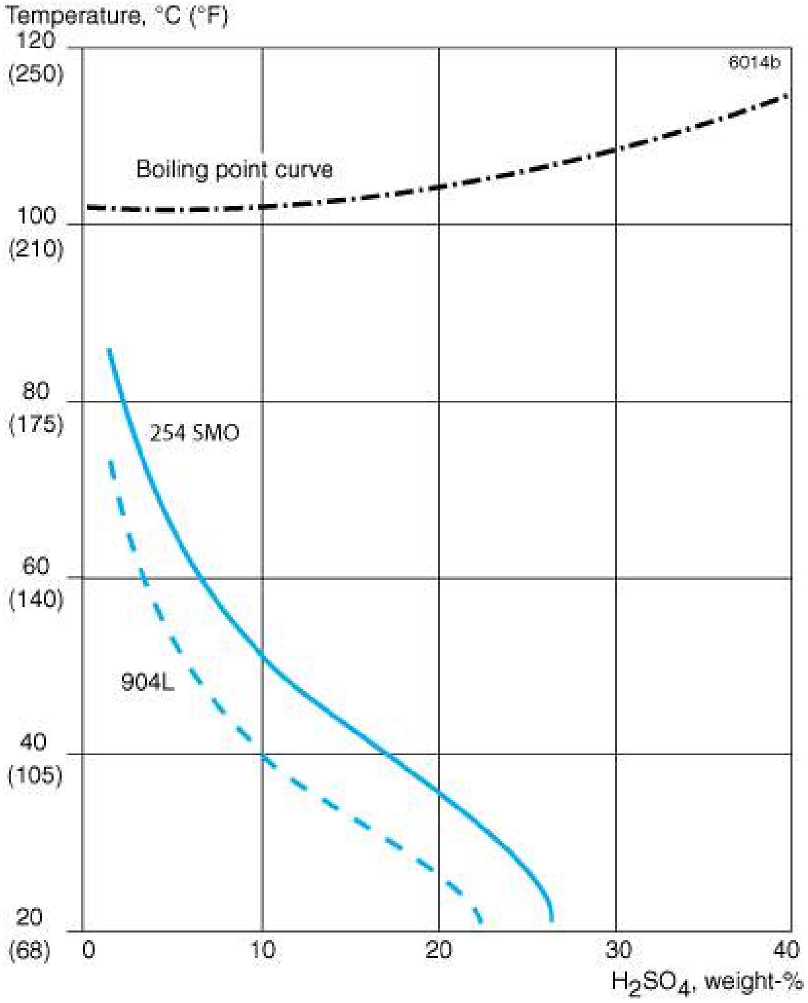

Figure 2. Isocorosion diagram 0.1 mm/year (4mpy) in naturally aerated sulphuric acid containing 2000 ppm chloride ions.

Stress corrosion cracking (SCC)

Ordinary austenitic steels of the ASTM TP304 and TP316 type are prone to stress corrosion cracking (SCC) in chloride-containing solutions at temperatures exceeding about 60°C (140°F). For the austenitic steels, resistance to SCC increases with higher nickel and molybdenum contents. The tables below show the results of two accelerated tests, clearly demonstrating that Alleima 254 SMO has a very good resistance to SCC.

Stress corrosion cracking tests in boiling 25% NaCl solution, pH=1.5. U-bend specimens.

Grade	Time to failure	Remark
ASTM TP316	<150 h	Pitting
'904L'	No failure (1000 h)	Crevice corrosion
Sandvik 254 SMO	No failure (1000 h)	No attack

Stress corrosion cracking tests. Drop evaporation method*. Stress: 0.9x$R_{p0.2}$

Grade	Time to failure hours
ASTM TP316	105

'904L'	225
Sandvik 254 SMO	425

* A 0.1 M NaCl solution is allowed to drop slowly onto an electrically heated tensile test specimen at 300 °C (570 °F).

Intergranular corrosion

Alleima 254 SMO has a very low carbon content. This means that there is very little risk of carbide precipitation during heating, for example when welding. The steel passes the Strauss test (ASTM A262, practice E) even after sensitizing for one hour at 600–1000°C (1110–1830°F).

However, due to the high alloying content of the steel, inter-metallic phases can precipitate at the grain boundaries in the temperature range 600–1000°C (1110–1830°F). These precipitations do not involve any risk of intergranular corrosion in the environments in which the steel is intended to be used. Thus, welding can be carried out without any risk of intergranular corrosion.

Pitting corrosion

The pitting and crevice corrosion resistance of stainless steel is primarily determined by the content of chromium, molybdenum and nitrogen. Manufacture and fabrication, e.g. welding, are also of vital importance for the actual performance in service. A parameter for comparing the resistance to pitting in chloride environments is the PRE number (Pitting Resistance Equivalent). The PRE is defined as, in weight-%, PRE = %Cr + 3.3 x %Mo + 16 x %N

PRE-value for Alleima 254 SMO = ≥42,5.

The results of laboratory determination of the critical pitting temperature (CPT) in 3 % NaCl are shown in Figure 3, where it can be seen that Alleima 254 SMO possesses very good resistance in water containing chlorides. Alleima 254 SMO is, therefore, a suitable material for use in seawater.

Crevice corrosion

The weak point of conventional stainless steels is their limited resistance to crevice corrosion. In seawater, for example, there is a considerably greater risk of crevice corrosion under gaskets, deposits or fouling. Tests in natural seawater at 60°C (140°F) have shown that Alleima 254 SMO can be exposed for prolonged periods without suffering crevice corrosion. Figure 4 shows the results of accelerated crevice corrosion tests.

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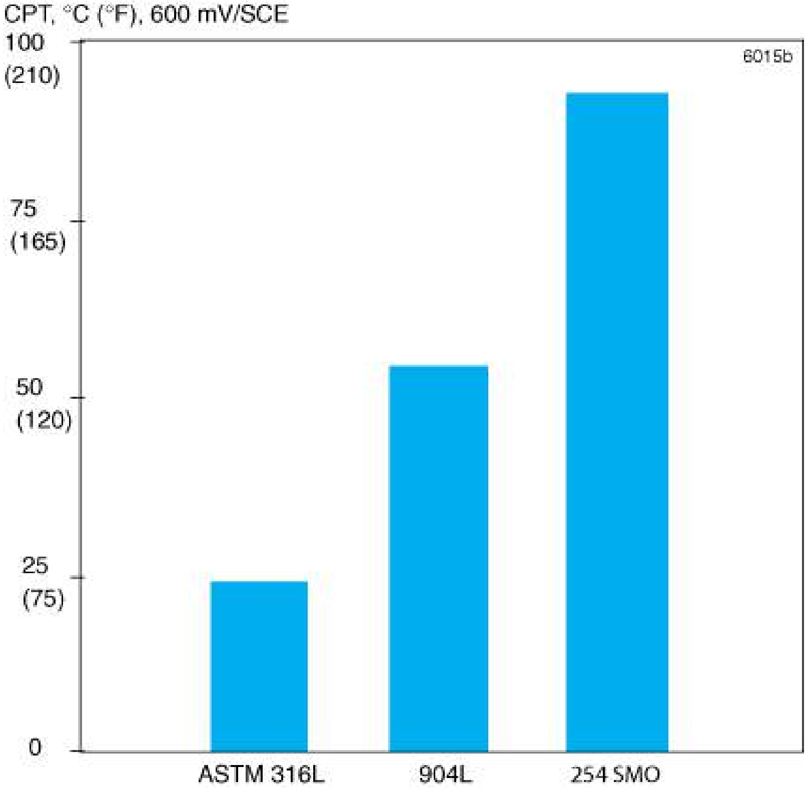

Figure 3. Critical pitting temperature (CPT) in 3% NaCl, 600 mV/SCE.

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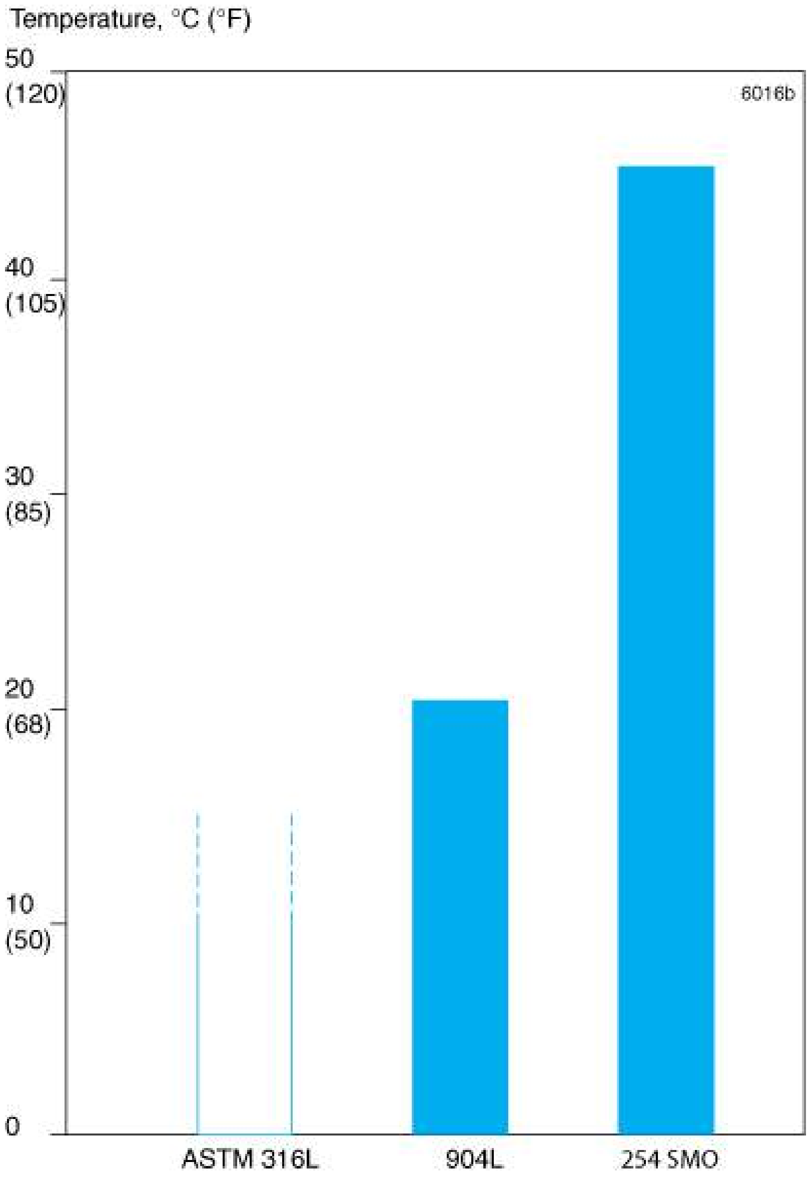

Figure 4. Critical crevice corrosion temperature in $FeCl_3$ for Sandvik 254 SMO, AISI 316L and 904L. According to ASTM G-48.

Fabrication

Avoid abrasion against copper/copper alloys or other similar metals which, if present in metallic form, can cause cracks during subsequent welding, hot processing or heat treatment.

Bending

The excellent formability of Alleima 254 SMO permits cold bending to very tight bending radii. Annealing is not normally necessary after cold bending.

Machining

Alleima 254 SMO is a high alloyed austenitic stainless steel and thus tougher inserts in metal cutting are needed than is the case for lower alloyed austenitic grades. When machining Alleima 254 SMO considerably lower cutting speeds are recommended compared to the grades Sanmac 304/304L and Sanmac 316/316L, which have improved machinability.

Forms of supply

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Seamless tube and pipe are supplied in dimensions up to 230 mm (9.06 in.) outside diameter. The delivery condition is either solution annealed and white pickled, or solution annealed in a bright annealing process.

Other forms of supply

- Welded tube and pipe
- Fittings and flanges
- Bar steel
- Forged products
- Cast products

Heat treatment

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

Solution annealing

1150–1200°C (2100–2190°F), quenching in water. Thin-walled tubes min. 1130°C (2060°F), quenching in air/water.

Mechanical properties

The following figures apply to solution annealed condition seamless tube and pipe.

Metric units, at 20°C

Wall thickness	Proof strength		Tensile strength	Elong.		Hardness
	$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	$A_{2"}$	HRB
mm	MPa	MPa	MPa	%	%	
<5	≥310	≥340	675-850	≥35	≥35	≤96
>5	≥310	≥340	655-850	≥35	≥35	≤96

1 MPa = 1 N/mm^2

Imperial units, at 68°F

Wall thickness	Proof strength		Tensile strength	Elong.		Hardness
	$R_{p0.2}$ a)	$R_{p1.0}$ a)	R_m	A b)	$A_{2"}$	HRB
inch	ksi	ksi	ksi	%	%	
<0.187	≥45	≥49	98-123	≥35	≥35	≤96
>0.187	≥45	≥49	98-123	≥35	≥35	≤96

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.

Impact strength

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Due to its austenitic microstructure, Alleima 254 SMO 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.

At high temperatures

Intermetallic phases are precipitated within the temperature range of 600–1000°C (1110–1830°F). Therefore, the steel should not be exposed to these temperatures for prolonged periods.

Metric units

Temperature
Proof strength
°C
R
p0.2
R
p1.0
MPa
MPa
min.
min.
100
230
270
200
190
225
300
170
200
400
160
190
500

148
180

Imperial units

Temperature	Proof strength	
°F	$R_{p0.2}$	$R_{p1.0}$
	ksi	ksi
	min.	min.
200	34	40
400	27	32
600	24	29
700	24	28
900	22	26

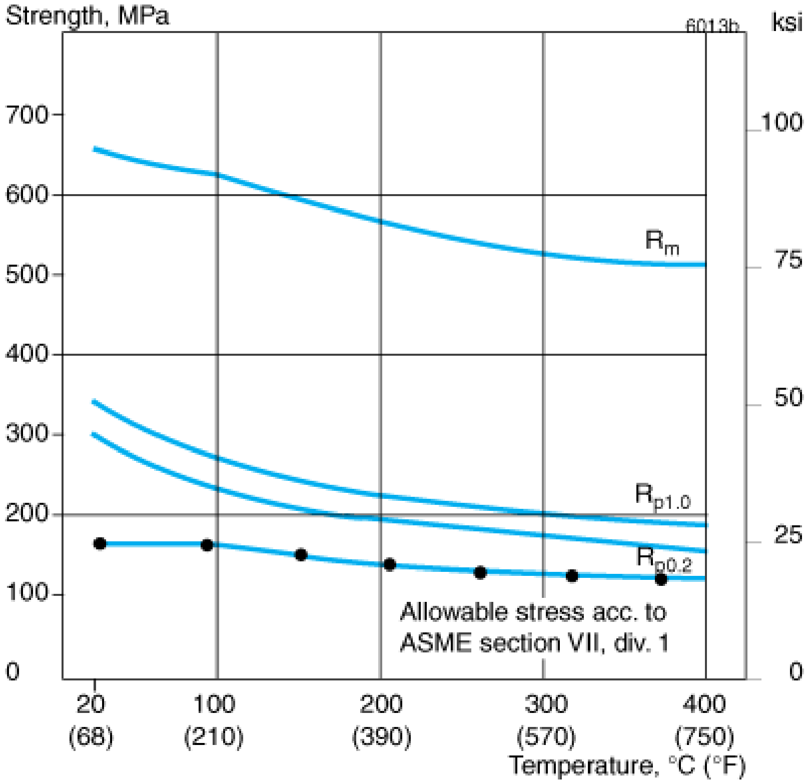

Figure 1. Strength values (min. values) for Sandvik 254SMO and allowable stress according to ASME Boiler and Pressure Vessel Code section VIII, div. 1.

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	10	68	6
100	12	200	7
200	14	400	8
300	16	600	9.5
400	18	800	10.5
500	20	1000	11.5
600	21	1200	12.5
700	23	1300	13

Specific heat capacity

Temperature, °C
J/kg °C
Temperature, °F

Btu/ft h °F
20
485
68
0.12
100
510
200
0.12
200
535
400
0.13
300
565
600
0.14
400
585
800
0.14
500
600
1000
0.14
600
615
1200
0.15
700
625

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1400	
0.15	

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

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

Modulus of elasticity, ($x10^3$)

Temperature, °C	MPa	Temperature, °F	ksi
20	195	68	28.3
100	190	200	27.6
200	182	400	27.5
300	174	600	25.1
400	166	800	23.8
500	158	1000	22.5

Welding

The weldability of Alleima 254 SMO 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, Alleima 254 SMO 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 Alleima 254 SMO, heat-input of <1.5 kJ/mm and interpass temperature of <100°C (210°F) are recommended. A string bead welding technique should be used.

Nickel alloys with high molybdenum and chromium must be used as filler metals to have good corrosion resistance in the as-welded condition.

Recommended filler metals

TIG/GTAW or MIG/GMAW welding

ISO 18274 S Ni 6625/AWS A5.14 ERNiCrMo-3 (e.g. Exaton Ni60)

ISO 18274 S Ni 6059/AWS A5.14 ERNiCrMo-13 (e.g. Exaton Ni59)

MMA/SMAW welding

ISO 14172 E Ni 6625/AWS A5.11 ENiCrMo-3 (e.g. Exaton Ni60)

ISO 14172 E Ni 6059/AWS A5.11 ENiCrMo-13 (e.g. Exaton Ni59)

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