

Standard Cr-Ni-Mo Stainless Steels

Steel grades

Outokumpu	EN	ASTM
4401	1.4401	316
4404	1.4404	316L
4436	1.4436	316
4432	1.4432	316L
4406	1.4406	316LN
4429	1.4429	S31653
4571	1.4571	316Ti
4435	1.4435	316L

Characteristic properties

- All-purpose grades
- Enhanced corrosion resistance compared to standard Cr-Ni grades
- Excellent formability
- Excellent weldability
- Excellent impact strength

Chemical composition

The chemical composition of specific steel grades may vary slightly between different national standards.

The required standard will be fully met as specified on the order.

General characteristics

These grades are molybdenum-containing austenitic stainless steels intended to provide improved corrosion resistance relative to the standard Cr-Ni steel grades used in corrosive process environments.

The addition of molybdenum provides improved resistance to pitting and crevice corrosion in environments containing chlorides or other halides.

These grades are used in applications for handling the wide range of chemicals used by process industries, e.g. pulp and paper, textile, food and beverages, pharmaceutical, medical, and in the manufacture of other chemical processing equipment. These grades are supplied with a wide range of functional and aesthetic surfaces.

Modern stainless steels are today easily produced with low carbon contents and the risk of chromium carbide precipitation has thereby decreased significantly. Intergranular corrosion caused by chromium carbides is therefore rarely an issue nowadays, but stabilised grades, often type 1.4571, are still specified. Non-titanium-stabilised grades generally have a better surface finish than titanium-stabilised grades.

Given their fully austenitic structure, all these grades are non-magnetic in the annealed condition but may become slightly magnetic as a result of phase transformation due to cold working or welding. The high nitrogen grades, i.e. 1.4406 and 1.4429 have except from an increased mechanical strength also a more stable austenitic structure leading to a lower permeability in comparison to the other standard Cr-Ni-Mo stainless steel grades.

Chemical composition

Table 1

Outokumpu steel name	International steel no.		Typical composition, %						National steel designations, superseded by EN			
	EN	ASTM	C	N	Cr	Ni	Mo	Others	BS	DIN	NF	SS
4401	1.4401	316	0.04	–	17.2	10.2	2.1	–	316S31	1.4401	Z7 CND 17-11-022	2347
4404	1.4404	316L	0.02	–	17.2	10.1	2.1	–	316S11	1.4404	Z3 CND 17-11-02	2348
4436	1.4436	316	0.04	–	16.9	10.7	2.6	–	316S33	1.4436	Z7 CND 18-12-03	2343
4432	1.4432	316L	0.02	–	16.9	10.7	2.6	–	316S13	–	Z3 CND 17-12-03	2353
4406	1.4406	316LN	0.02	0.14	17.2	10.3	2.1	–	316S61	1.4406	Z3 CND 17-11 Az	–
4429	1.4429	S31653	0.02	0.14	17.3	12.5	2.6	–	316S63	1.4429	Z3 CND 17-12 Az	2375
4571	1.4571	316Ti	0.04	–	16.8	10.9	2.1	Ti	320S31	1.4571	Z6 CNDT 17-12	2350
4435	1.4435	316L	0.02	–	17.3	12.6	2.6	–	316S13	1.4435	Z3 CND 18-14-03	2353
4301	1.4301	304	0.04	–	18.1	8.3	–	–	304S31	1.4301	Z7 CN 18-09	2333
904L	1.4539	904L	0.01	–	20	25	4.3	1.5 Cu	904S13	1.4539	Z2 NCDU 25-20	2562
254 SMO®	1.4547	S31254	0.01	0.20	20	18	6.1	Cu	–	1.4547	–	2378
LDX 2101®	1.4162	S32101	0.03	0.22	21.5	1.5	0.3	5 Mn	–	–	–	–
2304	1.4362	S32304	0.02	0.10	23	4.8	0.3	–	–	1.4362	Z3 CN 23-04 Az	2327
2205	1.4462	S32205*	0.02	0.17	22	5.7	3.1	–	318S13	1.4462	Z3 CND 22-05 Az	2377

* Also available as S31803

Mechanical properties

Outokumpu Stainless uses the European Standard EN10088 where applicable. The permitted design values may vary between product forms, see the specification in question for the correct value.

The values in Table 2 and 3 refer to hot rolled plate/cold rolled strip and sheet. For hot rolled strip, the proof strength corresponds to that of hot rolled plate, and the tensile strength and elongation to that of cold rolled strip.

Mechanical properties. Hot rolled plate/cold rolled strip and sheet, minimum values at 20°C

Table 2

Steel grade	Proof strength		Tensile strength	Elongation	Impact value
	R _{p0.2} MPa	R _{p1.0} MPa	R _m MPa	A ₅ %	KV J
4401	220/240	260/270	520/530	45/40	60
4404	220/240	260/270	520/530	45/40	60
4436	220/240	260/270	530/550	40/40	60
4432	220/240	260/270	520/550	45/40	60
4406	280/300	320/330	580/580	40/40	60
4429	280/300	320/330	580/580	40/35	60
4571	220/240	260/270	520/540	40/40	60
4435	220/240	260/270	520/550	45/40	60

Mechanical properties. Hot rolled plate/cold rolled strip and sheet, typical values at 20°C

Table 3

Steel grade	Proof strength		Tensile strength	Elongation	Hardness
	R _{p0.2} MPa	R _{p1.0} MPa	R _m MPa	A ₅ %	HB
4401	280/290	320/320	570/590	55/55	160
4404	280/290	320/320	570/590	55/55	165
4436	300/300	340/340	590/600	50/55	165
4432	280/300	320/330	570/600	50/55	165
4406	320/	360/	620/	50/	
4429	350/350	390/390	670/670	45/45	180
4571	270/270	310/310	570/590	50/55	165
4435	270/300	310/340	570/600	55/55	150

Tensile properties at elevated temperatures.

Proof strength R_{p0.2}, MPa, minimum values

Table 4a

Steel grade	Temperature, °C				
	100	200	300	400	500
4401	166	137	118	108	100
4404	177	147	127	115	110
4436	166	137	118	108	100
4432	177	147	127	115	110
4406	211	167	145	135	128
4429	211	167	145	135	129
4571	185	167	145	135	129
4435	165	137	119	108	100

Tensile properties at elevated temperatures.

Proof strength R_{p1.0}, MPa, minimum values

Table 4b

Steel grade	Temperature, °C				
	100	200	300	400	500
4401	199	167	145	135	128
4404	211	117	156	144	139
4436	199	167	145	135	128
4432	211	177	156	144	139
4406	246	198	175	164	158
4429	246	198	175	164	158
4571	218	196	175	164	158
4435	200	165	145	135	128

Tensile properties at elevated temperatures.

Proof strength R_m, MPa, minimum values

Table 4c

Steel grade	Temperature, °C				
	100	200	300	400	500
4401	430	390	380	380	360
4404	430	390	380	-	-
4436	430	390	380	380	360
4432	460	420	410	410	390
4406	520	460	440	-	-
4429	520	460	440	435	430
4571	440	390	375	375	360
4435	420	380	370	-	-

Mechanical properties at low temperatures.

Proof strength R_m, MPa, minimum values

Table 5

Steel grade	Temp °C	R _{p0.2} MPa	R _{p1.0} MPa	R _m MPa	A ₅ %
4404*	-80	275	355	840	40
4404*	-196	350	450	1200	35
4406**	-80	380	450	800	35
4406**	-196	600	700	1150	30

Values from EN 10028-7

* 4401, 4571, 4432, 4436 and 4435 have approximately the same values as 4404.

** 4429 has approximately the same values as 4406.

Physical properties

The physical properties are the same for all steel grades in this group.

Data according to EN 10088.

Physical properties, typical values at 20°C Table 6

Density	kg/dm ³	8.0
Modulus of elasticity	GPa	200
Poissons ratio		0.3
Thermal conductivity	W/m°C	15
Heat capacity	J/kg°C	500
Electrical resistivity	μΩm	0.75

Physical properties at elevated temperatures.

Linear expansion (RT→T) x 10⁻⁶/°C Table 7a

Steel grade	Temperature, °C				
	100	200	300	400	500
4571	16.5	17.5	18.0	18.5	19.0
Non-Ti-stabilised grades	16.0	16.5	17.0	17.5	18.0

Physical properties at elevated temperatures.

Modulus of elasticity, GPa Table 7b

Steel grade	Temperature, °C				
	100	200	300	400	500
All grades	194	186	179	172	165

Corrosion Resistance

The Cr-Ni-Mo standard stainless steels have a versatile corrosion resistance and are suitable for a wide range of applications. The grades with molybdenum content of 2.6 per cent (4432, 4436, 4435, 4429) have somewhat enhanced corrosion resistance compared to the grades with molybdenum content of 2.1 per cent (4404, 4401, 4406, 4571). A brief description of their resistance to different types of corrosion follows below. For a more detailed description of their corrosion resistance properties in different environments, please refer to our Corrosion Handbook.

Uniform corrosion

Uniform corrosion is characterised by a uniform attack on the steel surface that has come into contact with a corrosive medium. The corrosion resistance is generally considered good if the corrosion rate is less than 0.1 mm/year.

This group of Cr-Ni-Mo grades have a good resistance in many organic and inorganic chemicals. An example of an isocorrosion diagram is shown in figure 1.

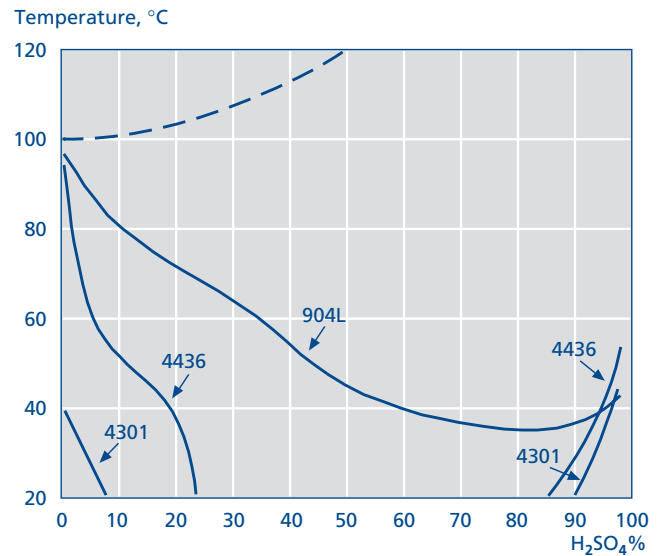


Fig. 1. Isocorrosion diagram for 4301, 4436 and 904L in stagnant sulphuric acid. The curves represent a corrosion rate of 0.1 mm/y. The dashed line represents the boiling point.

Pitting and crevice corrosion

The resistance to pitting and crevice corrosion can be enhanced by increasing the content of chromium, molybdenum and nitrogen. These grades have a significantly better resistance to these types of localised corrosion than the standard Cr-Ni grades.

For better resistance, higher alloyed grades such as 2205 and 254 SMO are recommended (see Figure 2).

Figure 3 shows up to which approximate temperatures stainless steel can be used in oxygen-saturated solutions of varying chloride content. There is an additional risk for stress corrosion cracking at temperatures above 50°C.

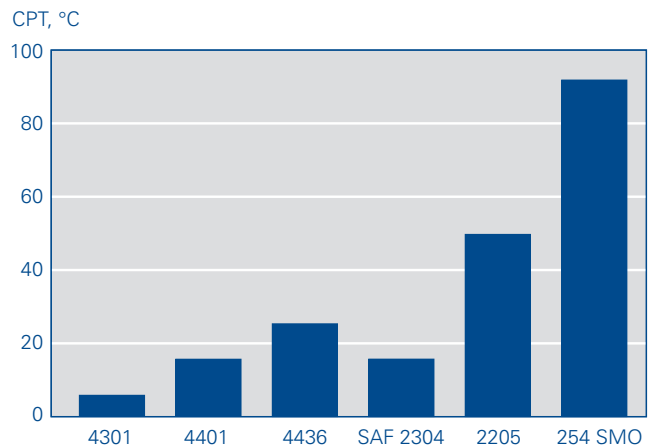


Fig. 2. Critical pitting temperatures (CPT) in 1M NaCl according to ASTM G 150 using the Avesta Cell. Typical values.

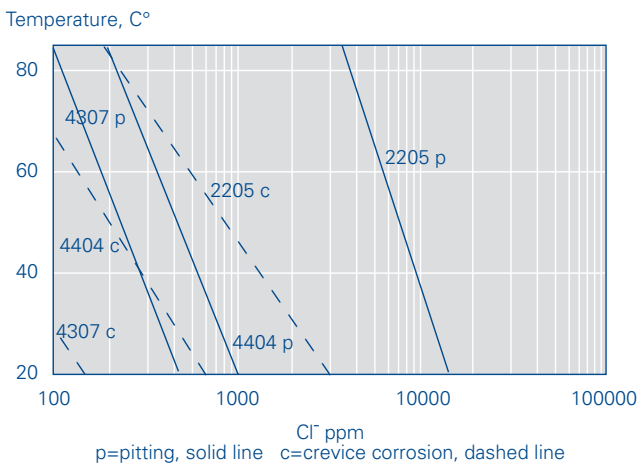


Fig. 3. Risk of pitting and crevice corrosion on conventional stainless steel in water of different chloride content or temperature.

Stress corrosion cracking

These austenitic grades – like the standard Cr-Ni steels – are susceptible to stress corrosion cracking (SCC).

Critical service conditions, i.e. applications subjected to combinations of tensile stresses, temperatures above about 50°C and certain solutions, especially those containing chlorides, should be avoided.

For applications demanding high resistance to SCC, the duplex grades 2205, 2304, and LDX 2101 are more suitable.

Stress corrosion cracking may also occur in hot alkaline solutions (above 110°C).

Intergranular corrosion

Intergranular corrosion is not a common problem for modern stainless steels since the carbon content is generally kept at a low level.

Operations that increase the risk for intergranular corrosion are welding of heavy gauges, heat treatment operations within the critical temperature interval (550 – 850°C) and slow cooling after heat treatment or hot forming. Ti-stabilised steels and steels with low carbon content (0.02%) have better resistance towards intergranular corrosion after such operation conditions.

Fabrication

Hot forming

Hot working can be carried out in the 850 – 1150°C range. For maximum corrosion resistance, forgings should be annealed at 1070°C and rapidly cooled in air or water after hot working operations.

Cold forming

These grades can be readily formed and fabricated by a full range of cold working operations. They can be used in heading, drawing and bending. Any cold working operations

will increase the strength and hardness of the material (see Figure 4) and may leave it slightly magnetic. For more information on deep drawing, contact Avesta Research Centre.

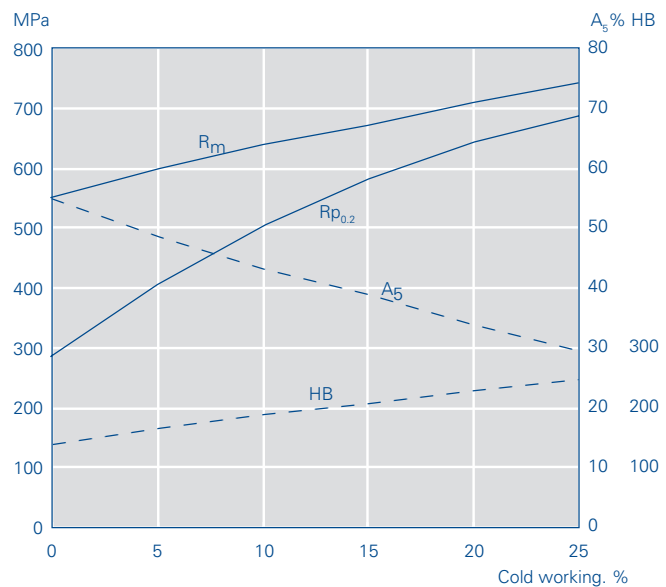


Fig. 4. 4404 work-hardening at cold working.

Heat treatment

Annealing

Quench annealing should be performed at 1030 – 1110°C and followed by rapid cooling in water or air.

For Ti-stabilised grades, annealing temperatures above 1070°C may impair the resistance to intergranular corrosion.

Ti-stabilised grades may also be given a stabilising treatment at lower temperatures. However, temperatures below 980°C should only be used after due consideration of the intended service environment.

In applications where high residual stresses cannot be accepted, stress relief treatment may be necessary.

This can be performed by annealing as outlined above, but may also be performed at lower temperatures.

Please contact Outokumpu Stainless for further information.

Hardening

These grades cannot be hardened by heat treatment. However, they can be hardened by cold working.

Machining

These austenitic grades are more difficult to machine than ordinary carbon steels but are still comparatively easy to machine compared to more highly alloyed stainless grades. Unless modified for improved machinability, they require higher cutting forces than carbon steels, show resistance to chip breaking and a high tendency to built-up edge formation. The best machining results are obtained by using high-power equipment, sharp tooling and a rigid set-up.

The machinability of these grades in relation to other stainless steels is indicated by the machinability index in Figure 5.

This index, which rises with increased machinability, is based on a compounded evaluation of test data from several different machining operations. It gives an indication of the machinability of different stainless steel grades in relation to that of grade 4436. It should be noted that it does not describe the relative difficulty of machining with cemented carbide and high speed steel tools. Nitrogen alloyed stainless steels are more difficult to machine.

Better machinability performance is given by PRODEC versions, which have been modified for improved machinability. PRODEC is available as hot rolled plate and bar in 4401, 4404, 4436 and 4432.

For more information, contact Avesta Research Centre.

The following welding filler metals from Avesta Welding are recommended:

Table 8

Steelgrade	Filler
4401	316L/SKR
4404	316L/SKR
4436	316L/SKR
4432	316L/SKR
4406	316L/SKR
4429	316L/SKR
4571	318/SKNb, 316L/SKR
4435	316L/SKR

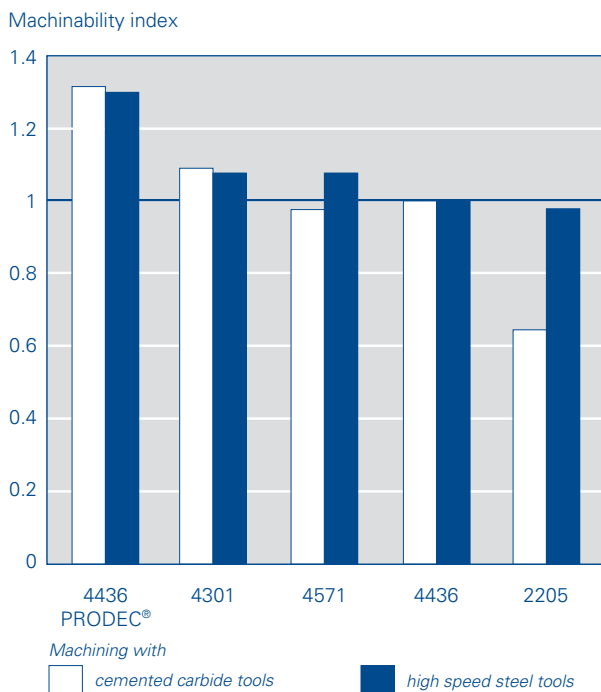


Fig. 5. Relative machinability for some stainless steel grades.

Other filler metals with a molybdenum content higher than that of the base metal may also be used. For further information, contact Avesta Welding or see www.avestawelding.com.

Products

- Hot rolled plate, sheets and strip
- Cold rolled plate, sheet and coil
- Cold rolled narrow strip
- Welded tube and pipe
- Bar
- Rod
- Billet
- Welding consumables

Welding

These grades can be readily welded by a full range of conventional welding methods such as:

- Shielded metal arc welding (SMAW)
- Gas tungsten arc welding, TIG (GTAW)
- Gas metal arc welding, MIG (GMAW)
- Flux-cored arc welding (FCAW)
- Plasma arc welding (PAW)
- Submerged arc welding (SAW)

Material Standards

Table 9

EN 10088-1	Stainless steels – List of stainless steels (Not for ordering)
EN 10088-2	Stainless steels – Sheet/plate and strip for general purposes
EN 10088-3	Stainless steels – Semi-finished products, bars, rods, sections for general purposes
EN 10028-7	Flat products for pressure purposes – Stainless steels
EN 10272	Stainless steel bars for pressure purposes
ASTM A240/ASME SA-240	Heat-resisting Cr and Cr-Ni stainless steel plate, sheet and strip for pressure vessels
ASTM A480	General requirements for flat-rolled stainless and heat resisting steel
ASTM A959	Harmonized standard grade compositions for wrought stainless
ASTM A666/ASME SA-666	Austenitic stainless steel sheet, strip, plate, bar for structural and architectural applications

Information given in this brochure may be subject to alterations without notice. Care has been taken to ensure that the contents of this publication are accurate but Outokumpu Stainless and its affiliated companies do not accept responsibility for errors or for information which is found to be misleading. Suggestions for or descriptions of the end use or application of products or methods of working are for information only and Outokumpu Stainless and its affiliated companies accept no liability in respect thereof. Before using products supplied or manufactured by the company the customer should satisfy himself of their suitability.

Outokumpu is a dynamic metals and technology group with a clear target to become the number one in stainless steel. Customer in a wide range of industries use our metal products, technologies and services worldwide. We are dedicated to helping our customers gain competitive advantage. We call this promise the Outokumpu factor.



Outokumpu Stainless AB, Avesta Research Centre
Box 74, SE-774 22 Avesta, Sweden
Tel. +46 (0)226 810 00, Fax +46 (0)226 810 77