# 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 eisaly produced with low carbon contents and the risk of chromium carbide precipitation has thereby decreased significantly. Intergranular corrosion caused by chromium carbides is therfore rarely an issue nowdays, 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 | | Typical composition, % | | | | | | National steel designations, superseded by EN | | | |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 $R_{p0.2}$ MPa | Proof strength $R_{p1.0}$ MPa | Tensile strength $R_m$ MPa | Elongation $A_5$ % | Impact value 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 $R_{p0.2}$ MPa | Proof strength $R_{p1.0}$ MPa | Tensile strength $R_m$ MPa | Elongation $A_5$ % | Hardness 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/dm³ | 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.

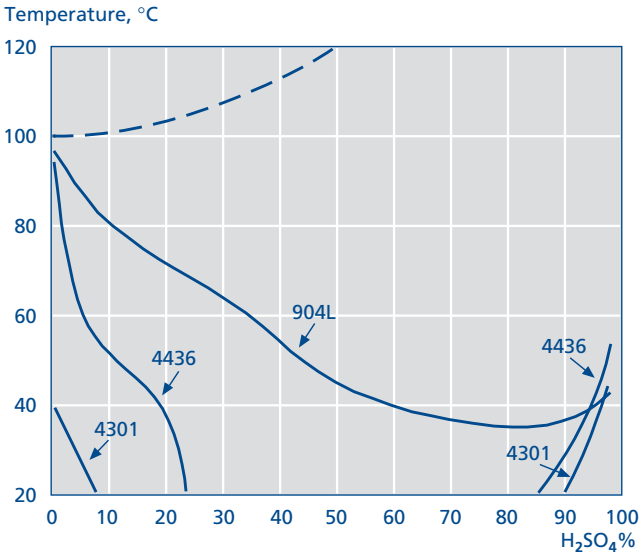


**Fig. 1.** Isocorrosion diagram for 4301, 4436 and 904L in stagnant sulphuric acid. The curves represent a corrosion rate of 0.1 mm/y.
The dashed line represents the boiling point.

### 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.

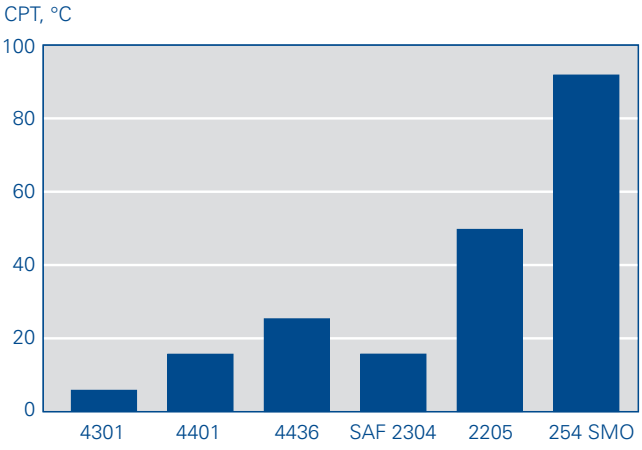


**Fig. 2.** Critical pitting temperatures (CPT) in 1M NaCl according to ASTM G 150 using the Avesta Cell. Typical values.

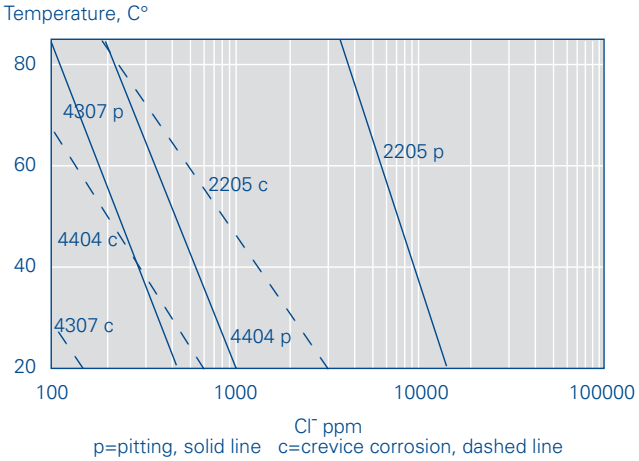


**Fig. 3.** Risk of pitting and crevice corrosion on conventional stainless steel in water of different chloride content or temperature.

### 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.

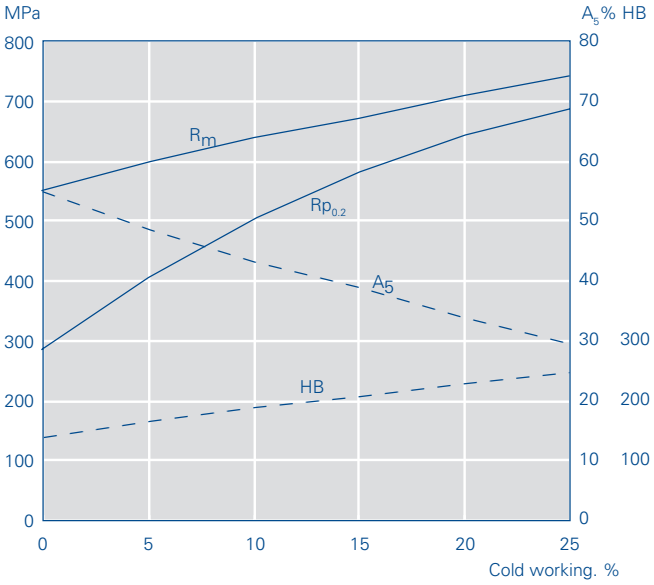


**Fig. 4.** 4404 work-hardening at cold working.

### 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.

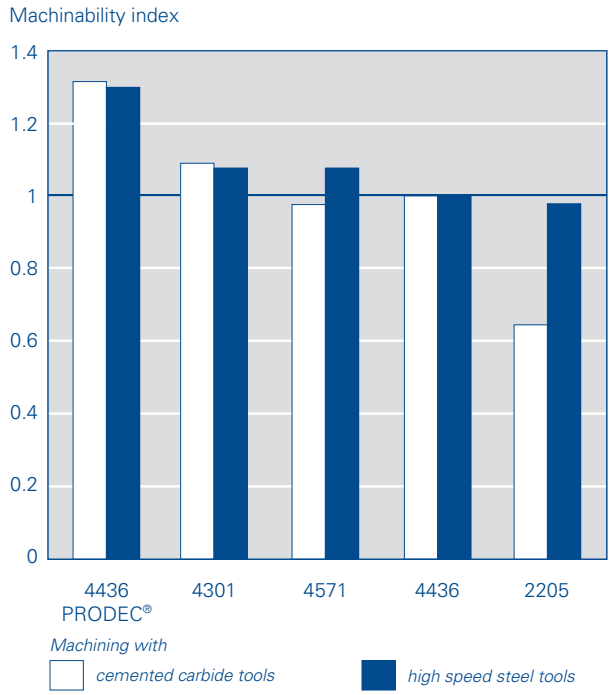


**Fig. 5.** Relative machinability for some stainless steel grades.

### 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)

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 |

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

## 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 |

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*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.*

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