outokumpu

Stainless steels for extremely corrosive environments

Outokumpu Ultra range datasheet

General characteristics and properties

The Ultra range consists of stainless steel and nickel based alloys meant for extremely corrosive environments (PRE > 27).

The Outokumpu Ultra range consists of high performance austenitic stainless steels and nickel based alloys that differ substantially from more conventional grades with regard to resistance to corrosion and, in some cases, also mechanical and physical properties. This is due to the high contents of mainly chromium, nickel, molybdenum and nitrogen. They have a fully austenitic microstructure in the quenched and annealed condition.

Ultra range grades have:

- Very good resistance to uniform corrosion
- Good to exceptionally good resistance to pitting and crevice corrosion
- Very good resistance to various types of stress corrosion cracking
- Very good ductility
- Good weldability
- Excellent formability

Chemical composition

Table 1

Ultra

Steels with PRE > 27,
for extremely corrosive environments.

Outokumpu Pro family

Steel designations				Performance				Typical chemical composition, % by mass					
		ASTM			A [1]	$R_{p0.2}$	Grade						
Outokumpu name	EN	Type	UNS	PRE	%	MPa	family	C	Cr	Ni	Mo	N	Others
Ultra 904L	1.4539	904L	N08904	34	35	240	A	0.01	19.8	24.2	4.3	–	1.4Cu
Ultra 254 SMO	1.4547	–	S31254	43	35	320	A	0.01	20	18	6.1	0.2	Cu
Ultra Alloy 825	2.4858 [2]	–	N08825	33	30 [3]	241 [3]	A	0.01	23	39.5	3.2	–	Cu, Ti
Ultra 317L [4]	(1.4438) [5]	317L	S31703	28	40 [6]	205 [6]	A	0.02	18.2	11.6	3.1	–	–
Ultra 725LN	1.4466	–	S31050	34	40 [7]	250 [7]	A	0.01	25	22.3	2.1	0.12	–
Ultra 6XN	1.4529	–	N08926/ N08367	45	40 [7]	300 [7]	A	0.01	20.5	24.8	6.5	0.2	Cu
Ultra 654 SMO	1.4652	–	S32654	56	40	430	A	0.01	24	22	7.3	0.5	3.5Mn Cu
For comparison													
Supra 316L/4404	1.4404	316L	S31603	24	40	240	A	0.02	17.2	10.1	2.1	–	–
Forta DX 2205	1.4462	–	S32205	35	20	500	D	0.02	22.4	5.7	3.1	0.17	–
Forta SDX 2507	1.441	–	S32750	43	20	550	D	0.02	25	7	4	0.27	–

Grade family: A = austenitic. [1] Elongation reference varies between different standards, for coil the standard typically uses A80 – otherwise see footnote for specific grade. [2] Grade designation according to DIN 17750. [3] Min. values hot-rolled and cold-rolled acc. to ASTM B424. [4] Also available with 11.7% Ni which is not consistent with 1.4438. [5] Quarto plate also available as EN 1.4438. Coil only available as ASTM 317L. [6] Min values acc. to ASTM A-240 [7] Min. values for plate acc. to EN 10088-2.

PRE = %Cr + 3.3 x %Mo + 16 x %N
Values for $R_{p0.2}$ yield strength and the A_{80} for elongation are according to EN 10088-2 min. values for cold rolled strip. Chemical compositions and PRE calculations are based on Outokumpu typical values.
Please see values for other product froms at **steelfinder.outokumpu.com**

Key products

Table 2

Outokumpu name	Typical applications	Product forms
Ultra 904L (EN 1.4539/UNS N08904) A high-nickel and molybdenum-alloyed austenitic stainless steel with very high corrosion resistance. Ultra 904L was originally developed for handling sulfuric acid at ambient temperatures, and is now used in a broad range of chemical industry applications.	• Chemical and petrochemical industry equipment such as pipes, heat exchangers, tanks, and reactor vessels • Sulfuric acid handling • Flanges and valves	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Ultra 254 SMO (EN 1.4547/UNS S31254) A 6 % molybdenum and nitrogen-alloyed austenitic stainless steel with extremely high resistance to both uniform and localized corrosion. This product was developed especially for oil and gas offshore platforms and the pulp and paper industry.	• Applications requiring resistance to chlorinated seawater • Flue gas cleaning applications • Bleaching equipment in the pulp and paper industry • Flanges and valves • Heat exchangers (plate and tubular)	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Ultra Alloy 825 (EN 2.4858/ UNS N08825) Outokumpu Ultra Alloy 825 is a titanium stabilized austenitic nickel base alloy with an addition of copper. It has excellent resistance to stress corrosion cracking and very good resistance in oxidizing and reducing acids.	• Components in sour gas service • Offshore oil and gas piping systems • Equipment in petroleum refineries • Heating coils • Heat exchangers • Tanks • Scrubbers • Chemical processing equipment • Food process equipment • Nuclear industry equipment	• Cold rolled coil, strip and sheet • Hot rolled coil, strip and plate • Wire rod

Other Ultra grades

Table 3

Outokumpu name	Typical applications	Product forms
Ultra 317L (EN 1.4438/UNS S31703) A molybdenum-alloyed austenitic stainless steel with higher corrosion resistance than Supra 316L/4404 – mainly used in the USA and Asia.	• Chemical processing industry equipment	• Cold rolled coil and sheet • Hot rolled coil and sheet *) • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Ultra 725LN (EN 1.4466/UNS S31050) Ultra 725LN is a type 310 material (high chromium and high nickel) that has been developed and optimized specifically for urea applications, which demand extremely high corrosion resistance. It has similar general pitting resistance as Ultra 904L.	• Urea applications	• Quarto plate
Ultra 6XN (EN 1.4529/UNS N08926/UNS N08367) A 6% molybdenum, high-nickel and nitrogen-alloyed austenitic product with extremely high resistance to both uniform and localized corrosion.	• Applications requiring resistance to chlorinated seawater • Flue gas cleaning applications	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Semi-finished (bloom, billet, ingot & slab)
Ultra 654 SMO (EN 1.4652/UNS S32654) "The most corrosion resistant stainless steel in the world." A 7% molybdenum, very high nitrogen-alloyed austenitic product with high mechanical strength. A potentially lean alternative to traditional wet corrosion resistant nickel-based alloys.	• Pressurized and erosive systems handling chlorinated seawater at higher temperatures • Heat exchangers (plate and tubular) • Flue gas cleaning applications	• Cold rolled coil and sheet • Quarto plate • Semi-finished (bloom, billet, ingot & slab)

*) Not available as EN 1.4438

Performance

Strength vs. corrosion resistance

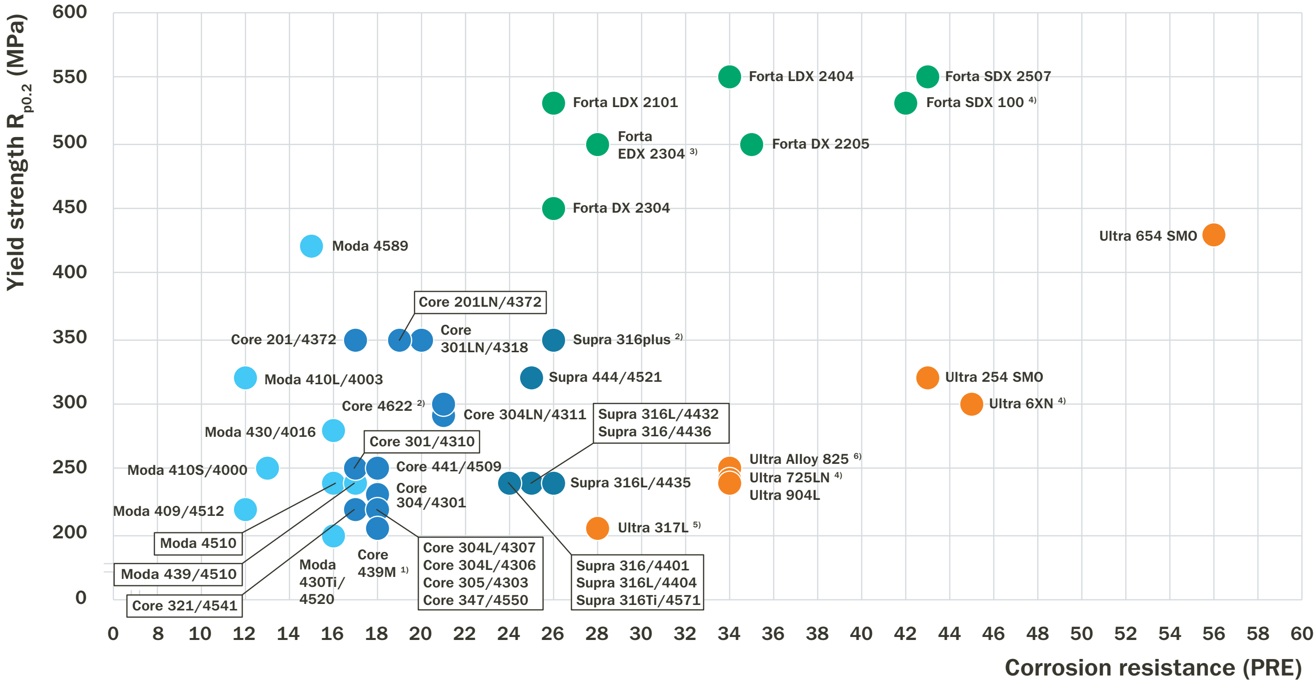

Fig. 1. Strength vs. corrosion resistance.

Elongation vs. corrosion resistance

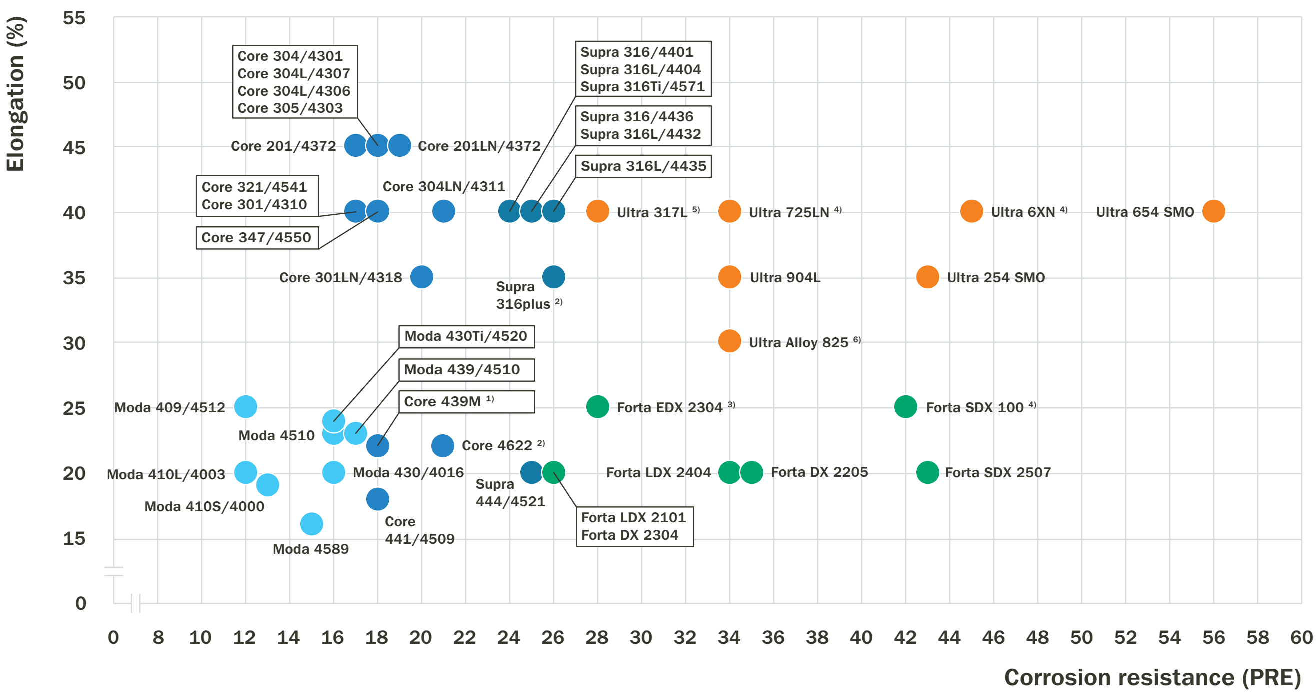

Fig. 2. Elongation vs. corrosion resistance.

- Moda – Steels for mildly corrosive environments (PRE ≤17)
- Core – Steels for corrosive environments (PRE 17–22)
- Supra – Steels for highly corrosive environments (PRE 22–26)
- Forta – Duplex steels (PRE 26–43)
- Ultra – Steels for extremely corrosive environments (PRE > 27)

PRE calculation = %Cr + 3.3 x % Mo + 16 x %N.
Values for $R_{p0.2}$ yield strength and the A_{80} for elongation are according to EN 10088-2 min. values for cold rolled strip. Chemical compositions and PRE calculations are based on Outokumpu typical values.

[1] Elongation reference varies between different standards, for coil the standard typically uses A_{80} – otherwise see footnote for specific grade.
[2] Min. values acc. to EN 10028-7.
[3] Outokumpu MDS-D35 for EDX 2304.
[4] Min. values for plate acc. to EN 10088-2.
[5] Min values acc. to ASTM A-240.
[6] Min. values hot-rolled and cold-rolled acc. to ASTM B424.

Please see values for other product forms at **steelfinder.outokumpu.com**

Corrosion resistance

Uniform corrosion

The high content of alloying elements gives the steels Ultra 317L, Ultra Alloy 825, Ultra 904L, Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO exceptionally good resistance to uniform corrosion.

Ultra 904L was originally developed to withstand environments involving dilute sulfuric acid. It is one of the few stainless steels that, at temperatures of up to 35°C, provides full resistance in such environments within the entire range of concentration, from 0 to 100%, see Fig. 3. Ultra 904L also offers good resistance to a number of other inorganic acids, e.g., phosphoric acid, as well as most organic acids.

Reducing acids and acid solutions containing halide ions can be very aggressive and the corrosion resistance of Ultra 317L and Ultra 904L may be insufficient. Examples of such acids are, hydrochloric acid, hydrofluoric acid, chloride contaminated sulfuric acid, phosphoric acid produced according to the wet process (WPA) at elevated temperatures, and also pickling acid based on nitric acid and hydrofluoric acid mixtures. In these cases Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO are preferable, Figures 4-7 and Tables 4 and 5. In certain cases they are an alternative to other considerably more expensive alloys.

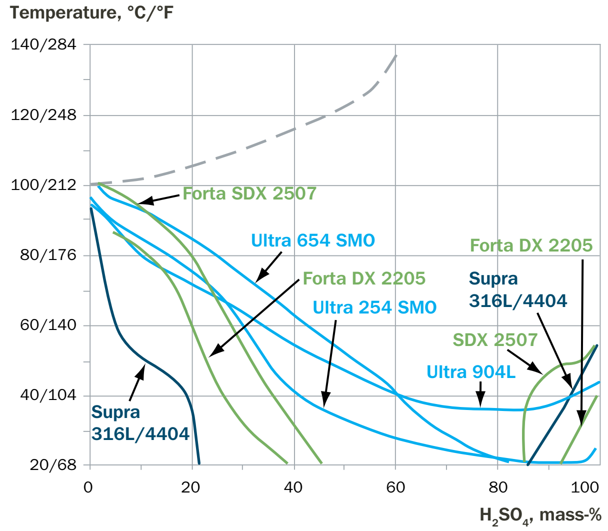

Fig. 3. Isocorrosion curves, 0.1 mm/year, in pure sulfuric acid.

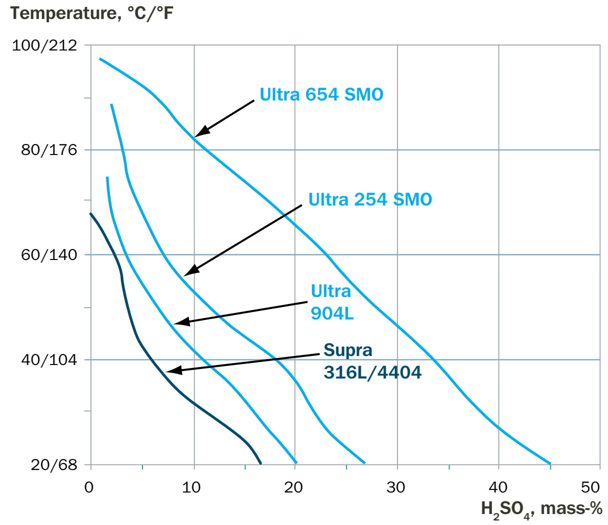

Fig. 4. Isocorrosion curves, 0.1 mm/year, in sulfuric acid containing 2000 ppm chlorides.

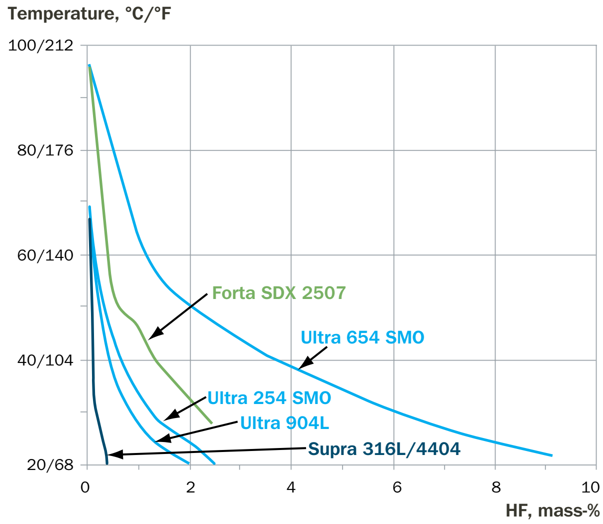

Fig. 5. Isocorrosion curves, 0.1 mm/year, in pure hydrofluoric acid.

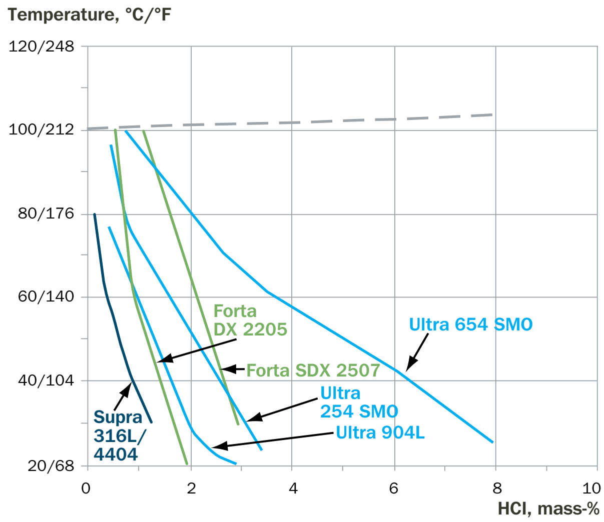

Fig. 6. Isocorrosion curves, 0.1 mm/year, in pure hydrochloric acid.

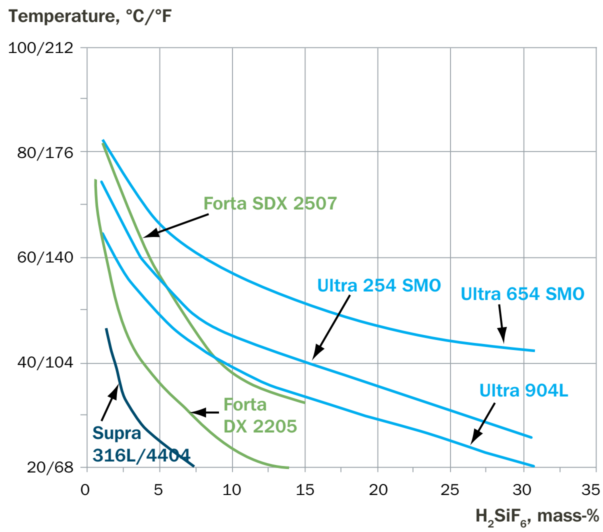

Fig. 7. Isocorrosion curves, 0.1 mm/year, in pure fluosilicic acid.

Uniform corrosion in wet process phosphoric acid *) at 60°C

Table 4

Steel grade	Corrosion rate, mm/year
Ultra 254 SMO	0.05
Ultra 904L	1.2
Supra 316L/4404	>5

*) Composition: 54% P_2O_5, 0.06% HCl, 1.1% HF, 4.0% H_2SO_4, 0.27% Fe_2O_3, 0.17% Al_2O_3, 0.10% SiO_2, 0.20% CaO and 0.70% MgO.

Uniform corrosion in pickling acid *) at 25°C

Table 5

Steel grade	Corrosion rate, mm/year
Ultra 654 SMO	0.06
Ultra 254 SMO	0.27
Ultra 904L	0.47
Supra 316L/4404	>6

*) Composition: 20% HNO_3 + 4% HF.

Fractional distillation of tall oil often needs more corrosion resistant material than the Supra 316L/4404. Table 6 presents the results of exposing test coupons at a Swedish tall oil plant with the object of determining suitable material for woven packings of stainless steel. In this particular case, packings produced from about 20,000 km of 0.16 mm diameter Ultra 254 SMO wire were used.

Corrosion rates in a fatty acid column for the distillation of tall oil at 235°C

Table 6

Steel grade	Corrosion rate, mm/year
Ultra 254 SMO	0.06
Ultra 904L	0.47
Supra 316L/4404	0.88

In hot concentrated caustic solutions the corrosion resistance is mainly determined by the nickel content of the material, and Ultra 904L in particular can be a good alternative to more conventional stainless steels.

For more detailed information concerning the corrosion resistance of the different steels in other environments, see the Outokumpu Corrosion Handbook.

Pitting and crevice corrosion

Resistance to localized corrosion such as pitting and crevice corrosion is determined mainly by the chromium, molybdenum and nitrogen content in the material. This is often illustrated using the pitting resistance equivalent (PRE) for the material, which can be calculated using the formula: PRE = %Cr + 3.3 x %Mo + 16 x %N. PRE values of Ultra range grades are presented in Table 7. The PRE value can be used for rough comparisons of different stainless steels.

A much more reliable means is to rank the steel according to the critical pitting temperature of the material (CPT). There are several different methods available to measure the CPT. Figure 9 shows the CPT, as measured according to ASTM G 150, in a 1 M NaCl solution (35,000 ppm or mg/l chloride ions). The CPT value for mill finish surface may vary between different product forms.

PRE values of the Ultra grades

Table 7

Steel grade	PRE
Key products	
Ultra 904L	34
Ultra 254 SMO	43
Ultra Alloy 825	33
Other Ultra grades	
Ultra 317L	28
Ultra 725LN	34
Ultra 6XN	45
Ultra 654 SMO	56
For comparison	
Supra 316L/4404	24
Forta DX 2205	35
Forta SDX 2507	43

Ultra 6XN, and especially Ultra 654 SMO, have such a good resistance to pitting, that common test methods are not sufficiently aggressive to initiate any corrosion. A better measure of resistance is given by evaluating the results of various crevice corrosion tests (e.g. ASTM G48).

The crevice corrosion resistance of stainless steels can be evaluated by measuring their critical crevice corrosion temperatures (CCT). Typical CCT values according to ASTM G48 Method F can be found in figure 9.

In narrow crevices the passive film may more easily be attacked and in unfavourable circumstances stainless steel can be subjected to crevice corrosion. Examples of such narrow crevices may be under gaskets in flange fittings, under seals in certain types of plate heat exchangers, or under hard adherent deposits.

Guide to material selection

Figure 10 illustrates to which approximate temperatures Ultra 904L and Ultra 254 SMO can be used in aerated waters of varying chloride content. Ultra 317L has slightly higher resistance against pitting and crevice corrosion compared to grade Supra 316L/4404. Ultra 6XN is on the same range as Ultra 254 SMO but Ultra 654 SMO has much higher resistance compared to Ultra 254 SMO.

It should be underlined that the resistance of a material is also influenced by factors other than temperature and chloride content. Examples of such factors are weld defects, presence of oxide from welding, contamination of the steel surface by particles of non-alloyed or low-alloyed steel, microbial activity, pH and chlorination of water. In demanding cases, such as crevices under the seals of plate heat exchangers or inside threaded connections, the lines for crevice corrosion will move to the left, i.e. the limit for chloride content/temperature is lower.

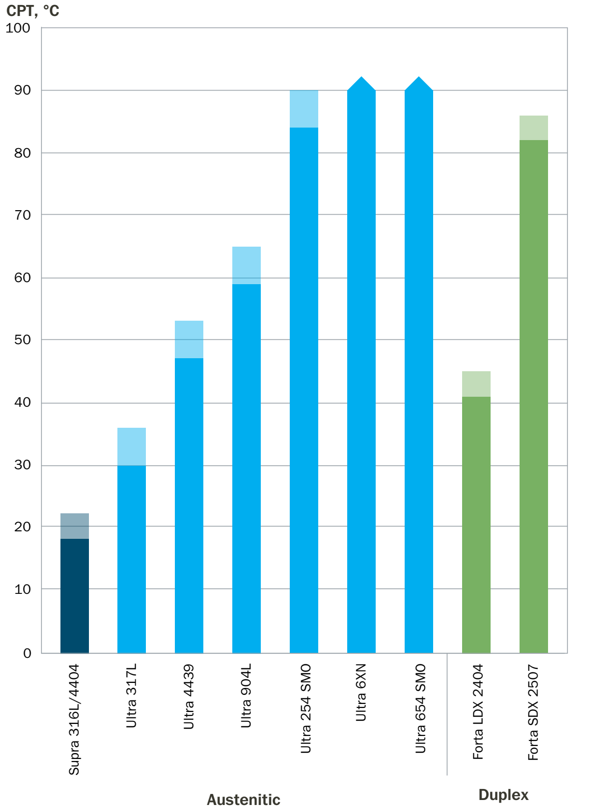

Fig. 8. Typical critical pitting corrosion temperatures (CPT) in 1 M NaCl measured according to ASTM G150 using the Avesta Cell. Test surfaces were wet ground to P320 grit. CPT varies with product form and surface finish.

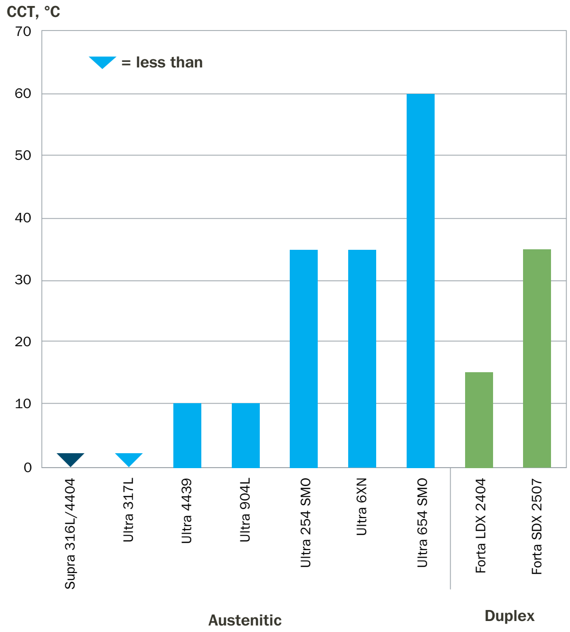

Fig. 9. Typical critical crevice corrosion temperature (CCT) according to ASTM G48 Method F. Test surfaces were dry ground to P120 grit. CCT varies with product form and surface finish.

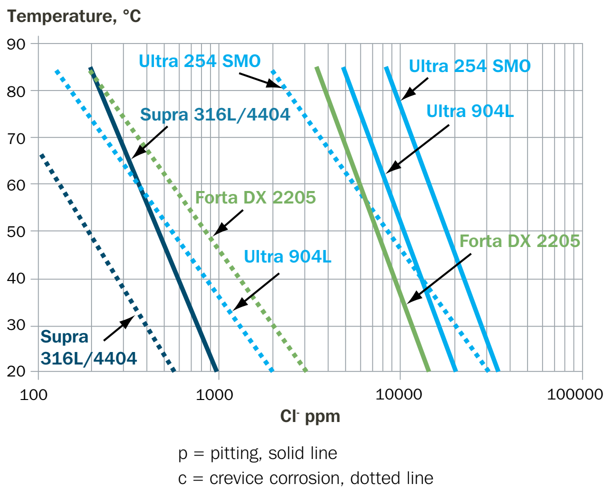

Fig. 10. Engineering diagram indicating the maximum temperature and chloride concentration allowed in slightly chlorinated (< 1 ppm) waters.

Seawater

The high performance austenitic stainless steels Ultra 254 SMO, Ultra 6XN and especially Ultra 654 SMO are excellent materials for seawater service.

Natural seawater contains living organisms, which very quickly form a biofilm on stainless steel. This film increases the corrosion potential of the steel and thus, the risk of pitting and crevice corrosion. The activity of the biofilm is temperature related. Different organisms are adapted to the natural water temperature of their habitat. Their activity varies between the different seas around the world. In cold seas, the natural water is most aggressive at 25-30°C while the corresponding value in tropical seas is just above 30°C. The biological activity ceases at higher temperatures.

In many seawater systems the water is chlorinated with either chlorine or hypochlorite solutions to reduce the risk of fouling. Both chlorine and hypochlorite are strong oxidizing agents and they cause the corrosion potential of the steel surface to exceed what is normal in non-chlorinated seawater, which in turn means increased risk of corrosion. In chlorinated seawater the aggressiveness increases as the temperature rises.

In crevice-free welded constructions Ultra 254 SMO may normally be used in chlorinated seawater with a chlorine content of up to 1 ppm at temperatures up to about 45°C. Ultra 654 SMO should be used for flange joints, or the sealing surfaces should be overlay welded, e.g., using an ISO Ni Cr 25 Mo 16 type filler, if the temperature exceeds 30°C. Higher chlorine content can be permitted if chlorination is intermittent.

Tests have indicated that Ultra 654 SMO can be used in plate heat exchangers with chlorinated seawater as a cooling medium at temperatures up to at least 60°C.

The risk of crevice corrosion in non-chlorinated seawater is considerably lower. Ultra 254 SMO has successfully been used in some fifty installations for desalination of seawater according to the reverse osmosis process. Ultra 654 SMO is resistant to pitting in natural boiling seawater.

Stress corrosion cracking

Stress corrosion cracking (SCC) is caused by the combined effect of mechanical stress and corrosive environment. Standard austenitic stainless steels such as Core 304L/4307 and Supra 316L/4404 are sensitive to stress corrosion cracking in chloride containing environments at elevated temperatures.

One way to improve the resistance to SCC is to increase the content of above all nickel and molybdenum. This means that the high performance austenitic steels Ultra 904L, Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO have very good resistance to SCC.

Different methods are used to rank stainless steel grades with regard to their resistance to SCC. The results can vary depending on testing method and environment. The resistance to stress corrosion cracking in a chloride solution under evaporative conditions can be determined according to the drop evaporation method. Here a 0.1 M NaCl solution is allowed to slowly drip onto a heated specimen being subjected to tensile stress. By this method the threshold value is determined for the maximum relative stress resulting in rupture after 500 hours of testing. The threshold value is usually expressed as a percentage of the proof strength of the steel at 200°C. Figure 11 shows the results of such a test, where high performance austenitic Ultra grades and Forta duplex steels offer considerably better resistance to SCC than Supra 316L/4404.

The resistance to alkaline SCC is more dependent on the nickel content of the material. In this respect high performance austenitic steels are superior to conventional stainless steels. Nickel-based alloys are, however, to be preferred in the most demanding conditions.

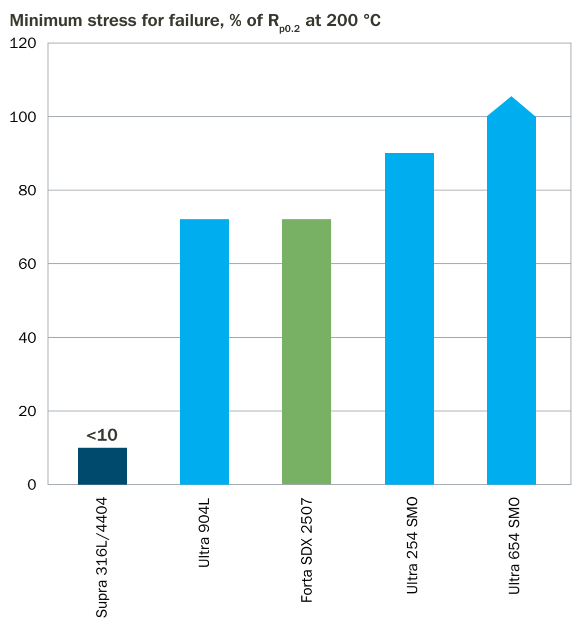

Fig. 11. Typical threshold stresses determined using the drop evaporation test.

Sulfide-induced stress corrosion cracking

Hydrogen sulfide can sometimes cause embrittlement of ferritic steels, and even of cold-worked duplex and austenitic steels. The sensitivity to cracking increases when the environment contains both hydrogen sulfide and chlorides. Such “sour” environments occur for example in the oil and gas industry.

Standard ISO 15156-3 (NACE MR0175) provides requirements and recommendations for selection of corrosion resistant alloys for use in oil and natural gas production in H_2S environments. It identifies materials that are resistant to cracking in a defined H_2S containing environment, but does not guarantee that the material selected using the standard will be immune from cracking under all service conditions.

High performance austenitic stainless steels Ultra 904L, Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO are included in NACE MR0175/ISO 15156-3. In accordance with NACE MR0175/ ISO 15156-3 solution annealed Ultra 904L, Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO are acceptable for use for any component or equipment up to 60°C in sour environments. This is providing that the partial pressure of hydrogen sulfide (pH_2S) does not exceed 1 bar (15 psi), or without restriction on temperature and pH_2S if the chloride concentration does not exceed 50 ppm. Moreover, solution annealed Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO are acceptable for use up to 171°C or pH_2S up to 7 bar (100 psi) if the chloride concentration does not exceed 5000 ppm.

Intergranular corrosion

High performance austenitic steels have such a low carbon content that the risk of conventional intergranular corrosion caused by chromium carbide precipitates in connection with welding is negligible. This means that welding can be performed without risk of intergranular corrosion.

Erosion corrosion

Unlike copper alloys, stainless steel generally offers very good resistance to impingement attack. There are no reasons to limit the velocity of water, e.g. in piping systems that convey seawater. Further, stainless steel is not sensitive to seawater that has been contaminated by sulfur compounds or ammonia.

In systems subjected to particles causing extreme wear, e.g., sand or salt crystals, the higher surface hardness of duplex steels can in some cases be an advantage.

Galvanic corrosion

The high performance austenitic steels Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO are not affected by galvanic corrosion if they are connected to titanium in systems used for conveying seawater. However, the rate of corrosion for copper alloys is increased if they come into contact with most stainless steels (or with titanium). The intensity of corrosion is closely related to the surface area ratio between the stainless steel and the copper alloy, Figure 12. The tests presented have been carried out with Ultra 254 SMO but the relation is the same for other high performance steels. The galvanic effect is reduced somewhat if the seawater is chlorinated.

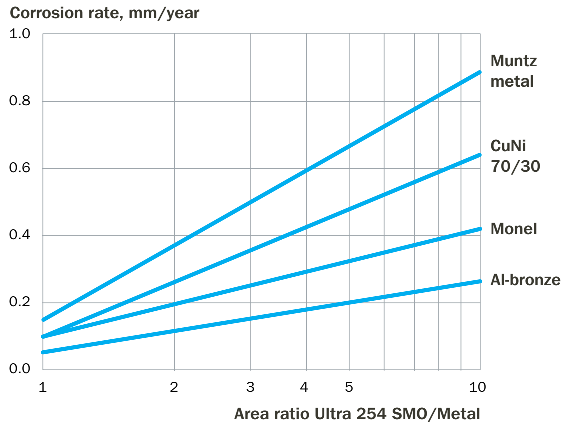

Fig. 12. Galvanic corrosion of copper alloys in contact with Ultra 254 SMO in slow moving seawater at ambient temperature.

Fabrication

Forming

All Outokumpu high performance austenitic grades have very good formability properties and are suitable for all forming processes available for stainless steel. The somewhat higher proof strength, and in some cases, lower fracture elongation compared to the most common standard austenitic steel grades can however impose small differences in forming behaviour. Depending on the chosen forming technique there could be consequences, such as increased springback. This can be compensated for, especially if the forming process can be designed for the specific steel grade. Moreover, an excellent interplay between the high proof strength, work hardening rate and elongation, make the high nitrogen containing grade Ultra 654 SMO well suited for light weight and cost-effective applications with complex shapes.

The impact of a high strength varies for different forming techniques. Common for all high performance austenitic grades is that the estimated forming forces will be higher than for the standard austenitic stainless steel grades. However, this effect will be reduced if down gauging is possible. A common issue for high strength steels is the high yield strength which may result in higher demands on the tool materials and the lubricant. Also in this respect attention should be given to the possibility of down gauging.

For more information, see the Outokumpu Forming Handbook, available from our sales offices.
outokumpu.com/contacts

Cold forming

The high strength of the high nitrogen containing grade Ultra 654 SMO is clearly demonstrated when the stress-strain curves of high performance austenitic Ultra grades are compared with the standard austenitic grade Supra 316L/4404, Figure 13. The deformation hardening rate is similar for all the austenitic grades presented in Figure 13.

The formability of Outokumpu's Ultra grades can be characterized in several ways. A sheet material's ability to withstand thinning during forming is demonstrated by the r-value in different tensile directions. The higher the r-value the better. Ultra 654 SMO shows excellent r-values as illustrated in Figure 14.

Figure 15 gives a relative comparison of the formability in plane strain condition between Ultra grades and the standard grade Supra 316L/4404. The ranking represents the most critical failure mode in sheet forming, especially in forming operations dominated by thinning (stretching). In pure drawing, all austenitic grades are comparable in that about the same limiting drawing ratio can be shown.

Hot forming

Suitable temperatures for hot forming of Ultra grades are shown in Table 8. Higher temperatures cause a deterioration in ductility and an increase in the formation of oxides (scaling). Normally hot working should be followed by solution annealing and quenching. However for Ultra 904L, if the hot forming is discontinued at a temperature above 1100°C and the material is quenched directly thereafter, the material may be used without subsequent heat treatment. It is important that the entire workpiece has been quenched from temperatures above 1100°C. In the case of partial heating or partial cooling below 1100°C or if cooling has been too slow, hot working should always be followed by solution annealing and quenching.

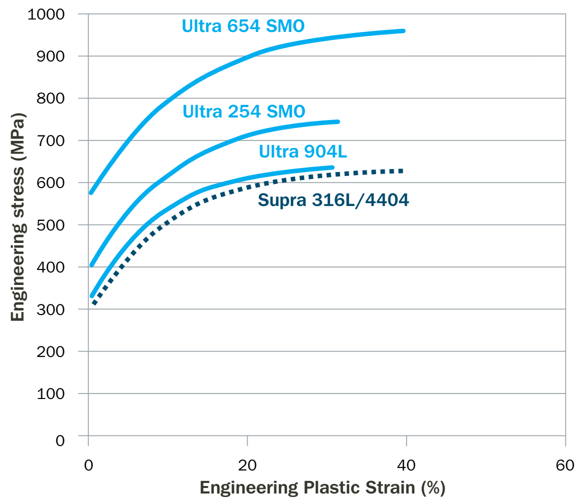

Fig. 13. Engineering stress-strain curves for high performance austenitic grades and standard austenitic grade Supra 316L/4404 (1.0 mm thick cold rolled).

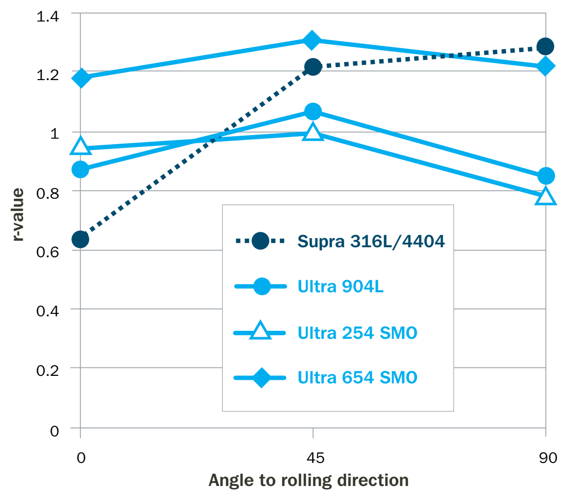

Fig. 14. r-values for high performance austenitic grades and standard austenitic grade Supra 316L/4404.

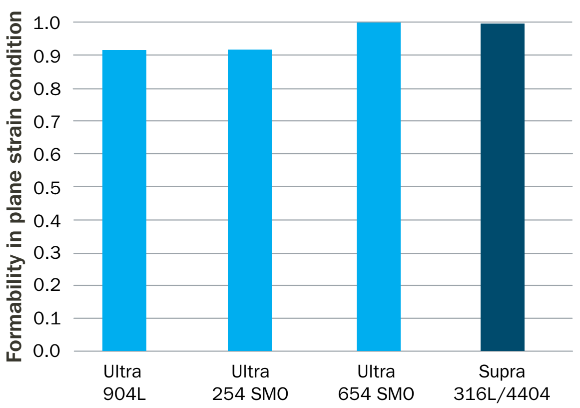

Fig. 15. Formability ranking of high performance austenitic grades in relation to standard austenitic grade Supra 316L/4404.

Typical temperatures, °C

Table 8

	Hot forming [1]	Solution annealing [1]	Pressure vessel approval
Ultra 904L	1150–850	1060–1140	-196 – +400
Ultra 254 SMO	1200–1000	1150–1200 [2]	-196 – +400
Ultra Alloy 825	1150–850	1070–1150	-196 – +475
Ultra 317L	–	–	–
Ultra 725LN	1150–850	1120–1180	-196 – +400
Ultra 6XN	1200–1000	1150–1200	RT – +427 [3]

[1] According to EN 10088-2.
[2] Quenching with water at a thickness above 2 mm, below 2 mm an annealing temperature of 1120-1150°C and cooling with air/water can be used.
[3] ASME Code Case 2195-1.

Ultra 254 SMO and Ultra 654 SMO should be quenched at a temperature of at least 1150°C after hot working to remove intermetallic phases formed during the hot working operation. These phases can also reoccur if the subsequent cooling process is too slow, resulting in reduced corrosion resistance.

Machining

Austenitic stainless steels work-harden quickly. This, together with their high toughness, means that they are often perceived as challenging from a machining perspective in operations such as turning, milling and drilling. This applies to an even greater extent to most highly alloyed steels and especially those that have a high nitrogen content, i.e. Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO.

However, with the right choice of tools, tool settings and cutting speeds, these materials can be successfully machined. For further information see the Outokumpu Machining Guidelines for these grades.

Welding

All Ultra grades are well suited for welding and the methods used for welding conventional austenitic steels can also be used on the Ultra range. However, due to their stable austenitic structure, they are somewhat more sensitive to hot cracking in connection with welding and generally welding should be performed using a low heat input.

On delivery, sheet, plate and other processed products have a homogeneous austenitic structure with an even distribution of alloying elements in the material. Solidification after partial smelting, e.g. by welding, causes redistribution of certain elements such as molybdenum, chromium and nickel. Segregation could remain in the cast structure of the weld which could impair the corrosion resistance in certain environments.

Segregation tendency is less evident in Ultra 904L and this steel is normally welded using a filler of the same composition as the base material and it can even be welded without filler. For Ultra 254 SMO, Ultra 6XN and Ultra 654 SMO, the variation for molybdenum in particular is so great that it must be compensated for by using fillers which have a higher content of molybdenum. EN ISO Ni Cr 21 Mo Fe Nb type of filler is normally used for welding Ultra 254 SMO and Ultra 6XN. ISO Ni Cr 25 Mo 16 type filler is recommended for the welding of Ultra 654 SMO.

The effect of segregation after welding can also be reduced by subsequent heat treatment and quench annealing, but such action is normally limited to uncomplicated geometries, e.g., pipes, pipe fittings and end pieces.

In the case of multi-run welding, the workpiece should be allowed to cool to 100°C before welding the next run. This is the case for all Ultra grades.

In order to restore the stainless steel surface and achieve good corrosion resistance after welding, it is often necessary to perform a post fabrication treatment.

There are different methods available. Both mechanical methods such as brushing, blasting and grinding and chemical methods, e.g. pickling. Which method to apply depends on not only what consequences the fabrication caused, i.e. what type of imperfections are to be removed, but also on requirements with regard to corrosion resistance, hygiene and aesthetic appearance.

For more information, see the Outokumpu Welding Handbook, available from our sales offices.
outokumpu.com/contacts

Welding consumables

Table 9

Steel grade	Welding consumables	
	Covered electrodes ISO 3581 ISO 14172	Wires ISO 14343 ISO 18274
Ultra 904L	20 25 CuL	20 25 CuL
Ultra 254 SMO	Ni Cr 21 Mo Fe Nb or Ni Cr 25 Mo 16 or P54 [*)]	Ni Cr 22 Mo 9 Nb
Ultra 317L	317L	317L
Ultra 725LN	25 22 2 N L	25 22 2 N L
Ultra 6XN	Ni Cr 21 Mo Fe Nb or Ni Cr 25 Mo 16 or P54 [*)]	Ni Cr 22 Mo 9 Nb
Ultra 654 SMO	Ni Cr 25 Mo 16	Ni Cr 25 Mo 16

[*)] voestalpine Böhler Welding designation. For use in certain oxidizing environments, e.g. chlorine dioxide stage in pulp bleaching plants, when welding Ultra 254 SMO and Ultra 6XN.

Mechanical properties

Mechanical properties at 20 °C, values according to EN 10088-2

Table 10

Metric						
Outokumpu name	**Product form**	**Min. yield strength $R_{p0.2}$ [MPa]**	**Min. yield strength $R_{p1.0}$ [MPa]**	**Tensile strength R_m [MPa]**	**Min. elongation A [%] [1)]**	**Hardness**
Ultra 904L	Cold rolled	240	270	530–730	35	–
	Hot rolled	220	260	530–730	35	–
	Plate	220	260	520–720	35	–
Ultra 254 SMO	Cold rolled	320	350	650–850	35	–
	Hot rolled	300	340	650–850	35	–
	Plate	300	340	650–850	40	–
Ultra Alloy 825	Cold rolled	–	–	–	–	–
	Hot rolled	–	–	–	–	–
	Plate	–	–	–	–	–
Ultra 317L	Cold rolled	240	270	–	35	–
	Hot rolled	220	260	–	35	–
	Plate	220	260	520–720	40	–
Ultra 725LN	Cold rolled	–	–	–	–	–
	Hot rolled	–	–	–	–	–
	Plate	250	290	540–740	40	–
Ultra 6XN	Cold rolled	–	–	–	–	–
	Hot rolled	–	–	–	–	–
	Plate	300	340	650–850	40	–
Ultra 654 SMO	Cold rolled	430	470	750–1000	40	–
	Hot rolled	430	470	750–1000	40	–
	Plate	430	470	750–1000	40	–

[1)] Thickness < 3 mm: A_{80}, initial length = 80 mm Thickness ≥ 3 mm: A, initial length = $5.65\sqrt{S_0}$

Mechanical properties, values according to ASTM A240

Table 11

Imperial						
Outokumpu name	**Product form**	**Min. yield strength $R_{p0.2}$ [ksi]**	**Min. yield strength $R_{p1.0}$ [ksi]**	**Min. tensile strength R_m [ksi]**	**Min. elongation A_{50} [%] [*)]**	**Max. hardness**
Ultra 904L	Cold rolled	31	–	71	35	90 HRBW
	Hot rolled	31	–	71	35	90 HRBW
	Plate	31	–	71	35	90 HRBW
Ultra 254 SMO	Cold rolled	45	–	100	35	96 HRBW
	Hot rolled	45	–	95	35	96 HRBW
	Plate	45	–	95	35	96 HRBW
Ultra Alloy 825	Cold rolled	–	–	–	–	–
	Hot rolled	–	–	–	–	–
	Plate	–	–	–	–	–
Ultra 317L	Cold rolled	30	–	75	40	95 HRBW
	Hot rolled	30	–	75	40	95 HRBW
	Plate	30	–	75	40	95 HRBW
Ultra 725LN	Cold rolled	39	–	84	25	95 HRBW
	Hot rolled	37	–	78	25	95 HRBW
	Plate	37	–	78	25	95 HRBW
Ultra 6XN	Cold rolled	45	–	100	30	100 HRBW
	Hot rolled	45	–	95	30	241 HBW
	Plate	45	–	95	30	241 HBW
Ultra 654 SMO	Cold rolled	62	–	109	40	250 HBW
	Hot rolled	62	–	109	40	250 HBW
	Plate	62	–	109	40	250 HBW

[*)] Initial length = 2 in. or 50 mm.

Mechanical properties at 20 °C/68 °F, typical values

Table 12

Metric/Imperial

Outokumpu name	Product form	Yield strength $R_{p0.2}$ [MPa/ksi]	Yield strength $R_{p1.0}$ [MPa/ksi]	Tensile strength R_m [MPa/ksi]	Elongation A/A_{80} [%]	Hardness
Ultra 904L	Cold rolled (1 mm)	340/49	375/54	655/95	38 [1)]	82 HRBW [2)]
	Hot rolled (4 mm)	280/41	330/48	600/87	45	150 HBW
	Plate (15 mm)	260/38	285/41	600/87	50	155 HBW
Ultra 254 SMO	Cold rolled (1 mm)	375/54	415/60	735/107	41 [1)]	87 HRBW [2)]
	Hot rolled (4 mm)	390/57	440/64	740/107	45	190 HBW
	Plate (15 mm)	320/46	350/51	680/99	50	160 HBW
Ultra 317L	Cold rolled (1 mm)	–	–	–	–	–
	Hot rolled (4 mm)	–	–	–	–	–
	Plate (15 mm)	300/44	340/49	610/88	50	–
Ultra 725LN	Cold rolled (1 mm)	–	–	–	–	–
	Hot rolled (4 mm)	–	–	–	–	–
	Plate (15 mm)	280	300	630	55	–
Ultra 6XN	Cold rolled (1 mm)	[2)]	[2)]	[2)]	[2)]	[2)]
	Hot rolled (4 mm)	–	–	–	–	–
	Plate (15 mm)	320/46	340/49	700/102	50	180 HBW
Ultra 654 SMO	Cold rolled (1 mm)	520/75	590/86	950/138	59	226 HBW
	Hot rolled (4 mm)	–	–	–	–	–
	Plate (15 mm)	460/67	490/71	860/125	60	200 HBW

1) A_{80} initial length = 80 mm, A initial length = $5.65\sqrt{S_0}$
2) New product, typical values under establishment.

More product forms may be available than are shown in the table. For more information, please see **steelfinder.outokumpu.com**

Mechanical properties at elevated temperatures, minimum values according to EN 10088-2

Table 13

Metric/Imperial

Outokumpu name	Mechanical properties [MPa/ksi]		100°C/212°F	200°C/392°F	300°C/572°F	400°C/752°F	500°C/932°F
Ultra 904L	Proof strength	$R_{p0.2}$	205/30	175/25	145/21	125/18	110/16
	Proof strength	$R_{p1.0}$	235/34	205/30	175/25	155/22	140/20
	Tensile strength	R_m	500/73	460/67	440/64	–	–
Ultra 254 SMO	Proof strength	$R_{p0.2}$	230/33	190/28	170/25	160/23	148/21
	Proof strength	$R_{p1.0}$	270/39	225/33	200/29	190/28	180/26
	Tensile strength	R_m	615/89	560/81	525/76	510/74	495/72
Ultra 317L	Proof strength	$R_{p0.2}$	172/25	147/21	127/18	115/17	110/16
	Proof strength	$R_{p1.0}$	206/30	177/26	156/23	144/21	138/20
	Tensile strength	R_m	430/62	390/57	380/55	–	–
Ultra 725LN	Proof strength	$R_{p0.2}$	–	–	–	–	–
	Proof strength	$R_{p1.0}$	–	–	–	–	–
	Tensile strength	R_m	–	–	–	–	–
Ultra 6XN	Proof strength	$R_{p0.2}$	230/33	190/28	170/25	160/23	–
	Proof strength	$R_{p1.0}$	270/39	225/33	205/30	190/28	–
	Tensile strength	R_m	550/80	520/75	480/70	–	–
Ultra 654 SMO	Proof strength	$R_{p0.2}$	350/51	315/46	300/44	295/43	280/41
	Proof strength	$R_{p1.0}$	390/57	355/51	335/49	330/48	310/45
	Tensile strength	R_m	680/99	620/90	585/85	560/81	–

Physical properties

In Tables 14-15 physical properties are given for Ultra range grades.

Values according to EN 10088-1

Table 14

Metric							
Outokumpu name	Density [kg/dm³]	Modulus of elasticity at 20 °C [GPa]	Coefficient of thermal expansion 20–100 °C [10^{-6}/K]	Thermal conductivity at 20 °C [W/(m x K)]	Thermal capacity at 20 °C [J/(kg x K)]	Electrical resistivity at 20 °C [Ω x mm²/m]	Magnetizable
Ultra 904L	8.0	195	15.8	12	450	1.00	No
Ultra 254 SMO	8.0	195	16.5	14	500	0.85	No
Ultra Alloy 825	8.0	195	14.1	10.5	440	1.12	No
Ultra 317L	8.0	200	16.0	14	500	0.85	No
Ultra 725LN	8.0	195	15.7	14	500	0.80	No
Ultra 6XN	8.1	195	15.8	12	450	1.00	No
Ultra 654 SMO	8.0	190	15.0	11 *)	500	0.78	No

*) Value measured by Outokumpu.

Values according to EN 10088-1

Table 15

Imperial							
Outokumpu name	Density [lbm/in³]	Modulus of elasticity [psi]	Coefficient of thermal expansion 68–212 °F [µin / (in x °F)]	Thermal conductivity [Btu/(hr x ft x °F)]	Thermal capacity [Btu/(lbm x °F)]	Electrical resistivity [µΩ x in]	Magnetizable
Ultra 904L	0.289	28 x 10^6	8.8	6.9	0.108	39.37	No
Ultra 254 SMO	0.289	28 x 10^6	9.2	8.1	0.120	33.46	No
Ultra Alloy 825	0.289	28 x 10^6	7.8	6.1	0.105	44.09	No
Ultra 317L	0.289	29 x 10^6	8.9	8.1	0.120	33.46	No
Ultra 725LN	0.289	28 x 10^6	8.7	8.1	0.120	31.50	No
Ultra 6XN	0.292	28 x 10^6	8.8	6.9	0.108	39.37	No
Ultra 654 SMO	0.289	28 x 10^6	8.3	6.4 *)	0.120	30.71	No

*) Value measured by Outokumpu.

Product forms

Table 16

Product	Hot rolled quarto plate	Hot rolled coil and sheet	Cold rolled coil and sheet	Rod coil	Bars	Semi-finished [bloom, billet, ingot, slab]
Ultra 904L	✓	✓	✓	✓	✓	✓
Ultra 254 SMO	✓	✓	✓	✓	✓	✓
Ultra Alloy 825	✓	✓	✓	–	–	–
Ultra 317L	✓*)	✓	✓	✓	✓	✓
Ultra 725LN	✓	–	–	–	–	–
Ultra 6XN	✓	✓	✓	–	–	–
Ultra 654 SMO	✓	–	✓	–	–	✓

*) Available with 11.7% Ni which is not consistent with 1.4438. See also outokumpu.com.

Standards and approvals

The most commonly used international product standards are given in the table below. For a full list of standards by product, see **steelfinder.outokumpu.com**

Standards

Table 17a

Standards	
European delivery standards	
EN 10028-7	Flat products for pressure purposes – Stainless steels
EN 10088-2	Stainless steels – Corrosion resisting sheet/plate/strip for general and construction purposes
EN 10088-3	Stainless steels – Corrosion resisting semi-finished products/bars/rods/wire/sections for general and construction purposes
EN 10088-4	Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for construction purposes
EN 10088-5	Technical delivery conditions for bars, rods, wire, sections and bright products of corrosion resistant steels for construction purposes
EN 10272	Stainless steel bars for pressure purposes
EN 10283	Corrosion resistant steel castings
ASTM/ASME delivery standards	
ASTM A 193 / ASME SA-193	Alloy and stainless steel bolts and nuts for high pressure and high temperature service
ASTM A 240 / ASME SA-240	Cr and Cr-Ni stainless steel plate/sheet/strip for pressure purposes
ASTM A 276	Stainless and heat-resisting steel bars/shapes
ASTM A 312 / ASME SA-312	Seamless and welded austenitic stainless steel pipe
ASTM A 351 / ASME SA-351	Steel castings, austenitic, duplex for pressure containing parts
ASTM A 358 / ASME SA-358	Electric fusion-welded austenitic Cr-Ni alloy steel pipe for high temperature
ASTM A 409 / ASME SA-409	Welded large diameter austenitic pipe for corrosive or high-temperature service
ASTM A 473	Stainless steel forgings for general use
ASTM A 479 / ASME SA-479	Stainless steel bars for boilers and other pressure vessels
ASTM A 743	Castings, Fe-Cr-Ni, corrosion resistant for general application
ASTM A 744	Castings, Fe-Cr-Ni, corrosion resistant for severe service
ASTM B 649 / ASME SB-649	Bar and wire
ASTM B424	Standard specification for Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) plate, sheet and strip
ASTM B906	Standard specification for General Requirements for Flat-Rolled Nickel and Nickel Alloys plate, sheet and strip
ASME Boiler & Pressure Vessel Code, Sections I, IID, III, IX + Code cases 1936 and N-188-1	ASME boiler & pressure vessel design

Table 17b

Standards	
Other common specification standards	
DIN 17744 + 17750	Plate, sheet and strip
ISO 6208	Nickel and nickel alloy plate, sheet and strip
ISO 9722	Nickel and nickel alloys – Composition and forms of wrought products
ISO 15156 (NACE MR 0175)	Petroleum and natural gas industries – Materials for use in H2Scontaining environments in oil and gas production – Part: 3 Crackingresistant CRA's (corrosion resistant alloys) and other alloys
ISO 17945 (NACE MR0103)	Petroleum, petrochemical and natural gas industries -- Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments
NACE MR0175	Sulfide stress cracking resistant material for oil field equipment
Norsok M-CR-630	Material data sheets for 6Mo stainless steel
VDT V 432	
VdTÜV WB 473	Austenitischer Stahl X 1 CrNiMoCuN 20 18 7 Werkstoff-Nr. 1.4547

Certificates and approvals

- AD 2000 Merkblatt
- Approval of Material Manufacturers
- Factory Production Control Certificate
- ISO 9001
- ISO 14001
- ISO 50001
- ISO/TS 16949
- NORSOK
- OHSAS 18001
- Pressure Equipment Directive (PED)

For the list of certificates and approvals by mill, see **outokumpu.com/certificates**

Contacts and enquiries

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Our experts are ready to help you choose the best stainless steel product for your next project.

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Moda	Core	Supra	Forta	Ultra	Dura	Therma	Prodec	Deco
Mildly corrosive environments	Corrosive environments	Highly corrosive environments	Duplex & other high strength	Extremely corrosive environments	High hardness	High service temperatures	Improved machinability	Special surfaces

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