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Stainless steels for extremely corrosive environments

Outokumpu Ultra range datasheet

General characteristics

The Ultra range contains 8 stainless steel products meant for extremely corrosive environments (PRE of more than 27).

Key products

Outokumpu name	Typical applications	Product forms
Ultra 904L A high-nickel and molybdenum 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	C, H, P, B, R, S, T
Ultra 254 SMO 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 • Maritime exhaust gas cleaning (EGC) • Bleaching equipment in the pulp and paper industry • Flanges and valves	C, H, P, B, R, S, T

Other Ultra range alloys

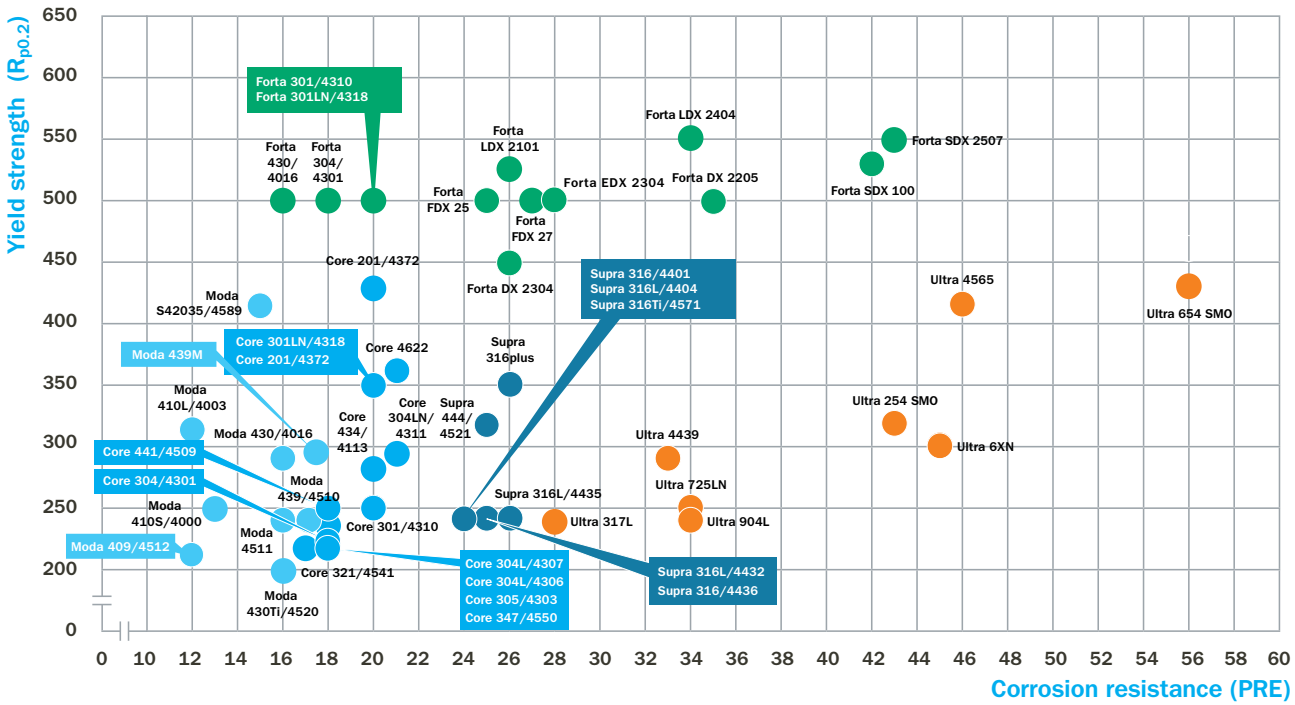
Outokumpu name	Typical applications	Product forms
Ultra 317L A molybdenum-alloyed austenitic stainless steel with higher corrosion resistance than Supra 316L/4404 – mainly used in the USA and Asia.	• Chemical processing industry	C, P, B, R, S, T
Ultra 4439 A molybdenum and nitrogen-alloyed austenitic stainless steel with significantly higher corrosion resistance than Supra 316L/4404. Also known as 317LMN.	• Chemical processing industry • Flue gas cleaning • Flanges and valves	C, H, P, S, T

Outokumpu name	Typical applications	Product forms
Ultra 725LN Ultra 725LN is a type 310 material (high chrome 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 to Ultra 904L.	• Urea applications	P
Ultra 6XN 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	C, H, P, S
Ultra 4565 A 4.5% molybdenum, very high nitrogen alloyed austenitic stainless steel with excellent corrosion resistance and high mechanical strength.	• Flue gas desulfurization applications	C, H, P, S, T
Ultra 654 SMO 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 • Plate heat exchangers • Flue gas cleaning applications	C, P, S, T

Product forms:
C = Cold rolled coil and sheet, H = Hot rolled coil and sheet, P = Quarto plate, B = Bar, R = Wire rod, S = Semifinished (bloom, billet, ingot & slab), T = Pipe

Product performance comparison

Yield strength vs. corrosion resistance

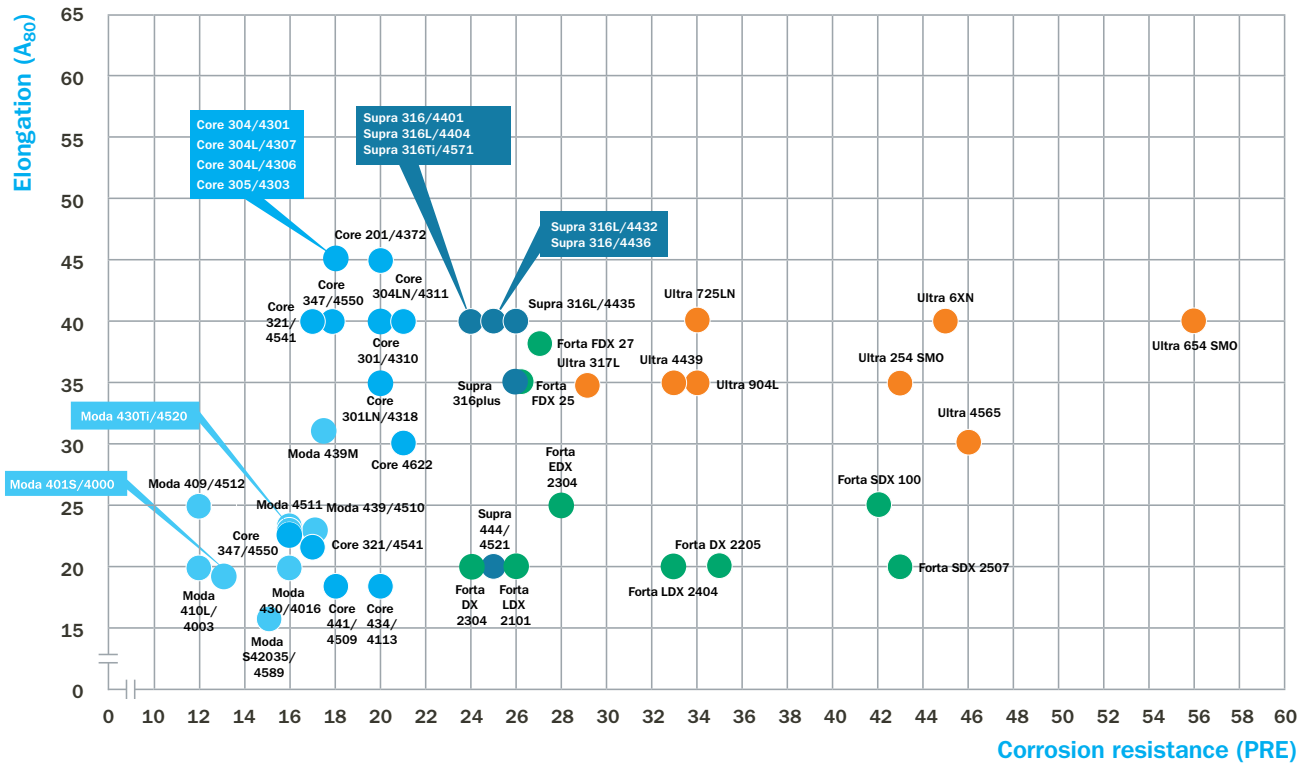


- Moda – Mildly corrosive environments (PRE to 17)
- Core – Corrosive environments (PRE 17 to 22)
- Supra – Highly corrosive environments (PRE 22 to 27)
- Forta – Duplex & other high strength
- Ultra – Extremely corrosive environments (PRE > 27)

PRE calculation = %Cr + 3.3 x % Mo + 16 x %N

Note: PRE values shown are Outokumpu typical values. Yield strength ($R_{p0.2}$) according to EN 10088-2 minimum values for cold rolled strip. For more values by product, please see **steelfinder.outokumpu.com**

Elongation vs. corrosion resistance



- Moda – Mildly corrosive environments (PRE up to 17)
- Core – Corrosive environments (PRE 17 to 22)
- Supra – Highly corrosive environments (PRE 22 to 27)
- Forta – Duplex and other high strength (PRE 18 to 43)
- Ultra – Extremely corrosive environments (PRE > 27)

PRE calculation = %Cr + 3.3 x % Mo + 16 x %N

Note: PRE values shown are Outokumpu typical values. Elongation (A_{80}) according to EN 10088-2 minimum values for cold rolled strip. For more values by product, please see **steelfinder.outokumpu.com**

Products and dimensions

To find the minimum and maximum thickness and width by surface finish for a specific Ultra range product, please visit **steelfinder.outokumpu.com**

Chemical composition

The chemical composition is given as % by mass.

Ouotkumpu name	C	Cr	Ni	Mo	N	Others	Family
Ultra 904L	0.01	19.8	24.2	4.3	–	Cu	A
Ultra 254 SMO	0.01	20	18	6.1	0.20	Cu	A
Ultra 317L	0.02	18.2	13.7	3.1	–	–	A
Ultra 4439	0.02	17.3	13.7	4.1	0.14	–	A
Ultra 725LN	0.01	25	22.3	2.1	0.12	–	A
Ultra 6XN	0.01	20.5	24.8	6.5	0.20	Cu	A
Ultra 4565	0.02	24	17	4.5	0.45	5.5Mn	A
Ultra 654 SMO	0.01	24	22	7.3	0.50	3.5Mn. Cu	A

Table uses Outokumpu typical values. The required standard will be fully met as specified in the order.

For the chemical composition list for different standards by stainless steel product, see **steelfinder.outokumpu.com**

Corrosion resistance

Outokumpu name	PRE	CCT	CPT
Ultra 904L	34	10	62±3
Ultra 254 SMO	43	35	87±3
Ultra 317L	28	<0	33±3
Ultra 4439	33	10	50±3
Ultra 725LN	34	–	–
Ultra 6XN	45	35	>90
Ultra 4565	46	40	>90
Ultra 654 SMO	56	60	>90

PRE (Pitting Resistance Equivalent) is calculated using the following formula:
PRE = %Cr + 3.3 x %Mo + 16 x %N

CPT (Critical Pitting corrosion Temperature) is measured in an Avesta Cell (ASTM G 150), in a 1M sodium chloride solution (35,000 ppm or mg/l chloride ions).

CCT (Critical Crevice corrosion Temperature) is obtained by laboratory tests according to ASTM G 48 Method F.

Higher additions of alloy elements such as nickel, molybdenum, chrome, and nitrogen give a higher wet corrosion resistance that is not always reflected in PRE values.

Contact an Outokumpu representative to discuss what product is the most appropriate for your application.

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Corrosion resistance of Ultra range products

In general, a high content of alloying elements gives the Ultra range exceptionally good resistance to uniform corrosion. As an example, Ultra 904L is one of the few stainless steels that at temperatures of up to 35 °C/95 °F provides full resistance in dilute sulfuric acid environments within the entire range of concentration, from 0 to 100%.

For acids and acid solutions containing halide ions – such as hydrochloric acid, hydrofluoric acid, chloride-contaminated sulfuric acid, phosphoric acid produced according to the wet process (WPA) at elevated temperatures, and pickling acid based on nitric acid and hydrofluoric acid mixtures – Ultra 254 SMO and Ultra 4565 are preferable.

Pitting and crevice corrosion

Resistance to pitting and crevice corrosion is primarily determined by the chromium, molybdenum, and nitrogen content of the material. For example, Ultra 4565 and Ultra 654 SMO have such good resistance to pitting that common test methods are not sufficiently aggressive to initiate any corrosion.

In narrow crevices the passive film may more easily be damaged, and in unfavorable 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. Crevice corrosion occurs in the same environments as pitting. Higher chromium, molybdenum, or nitrogen content enhances the corrosion resistance of the steel.

Stress corrosion cracking

Conventional stainless steels such as Core 304L/4307 and Supra 316L/4404 are sensitive to stress corrosion cracking (SCC) under certain conditions – i.e. a special environment in combination with tensile stress in the material and often also an elevated temperature. Resistance to SCC increases with higher nickel and molybdenum content. For this reason, Ultra range stainless steels such as Ultra 904L, Ultra 254 SMO, Ultra 654 SMO, Ultra 317L, and Ultra 4565 have very good resistance to SCC.

Seawater

The Ultra range products Ultra 254 SMO, Ultra 6XN, Ultra 4565, and especially Ultra 654 SMO are excellent materials for applications involving exposure to seawater. Natural seawater contains living organisms that 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 water temperature of their local habitat, and their activity varies between the different seas around the world. In cold seas natural water is most aggressive at 25–30 °C/77–86°F, while the corresponding value in tropical seas is just above 30 °C/86 °F. Biological activity ceases at temperatures higher than this. 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 strongly oxidizing agents and they cause the corrosion potential of the steel surface to exceed the norm for non-chlorinated seawater. This in turn results in an increased risk of corrosion. In chlorinated seawater aggressiveness increases with temperature. 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/110 °F. Ultra 654 SMO should be use for flange joints, or the surfaces of, for example, Ultra 254 SMO flanges should be overlay welded, for example, using an ISO Ni Cr 25 Mo16 type filler, if the temperature exceeds 30 °C/85 °F. Higher chlorine content can be permitted if chlorination is intermittent.

Tests have indicated that Ultra 654 SMO can be used in plate heat exchangers that use chlorinated seawater as a cooling medium at temperatures up to at least 60 °C/140 °F. The risk of crevice corrosion in non-chlorinated seawater is considerably lower. Ultra 254 SMO has successfully been used in some 50 installations for desalination of seawater according to the reverse osmosis process. Ultra 654 SMO is resistant to pitting in boiling seawater.

Sulfide-induced stress corrosion cracking

Hydrogen sulfide can sometimes cause embrittlement of ferritic steel and even of cold formed duplex and austenitic steels. 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. NACE MR0175/ISO 15156-3 provides requirements and recommendations for the 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.

Ultra 904L, Ultra 254 SMO, Ultra 6XN, Ultra 4565, 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, Ultra 4565, and Ultra 654 SMO are acceptable for use for any component or equipment up to 60 °C/ 140 °F in sour environments, if the partial pressure of hydrogen sulfide (pH_2S) does not exceed 1 bar/15 psi, or without temperature and pH_2S restrictions if the chloride concentration does not exceed
50 ppm.

Intergranular corrosion

Ultra range products have such a low carbon content that the risk of conventional intergranular corrosion caused by chromium carbide precipitates resulting from welding is minimal. This means that welding can be performed without risk of intergranular corrosion.

Erosion corrosion

Unlike copper alloys, Ultra range stainless steels generally offer very good resistance to impingement attack, and there are no motives for limiting the velocity of water in, for example, piping systems that convey seawater. Further, stainless steel is not sensitive to seawater that has been contaminated by sulfur compounds or ammonia.

For further information on corrosion resistance, please refer to the corrosion tables in the Outokumpu Corrosion Handbook, available from our sales offices.

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Mechanical properties

The strength and elongation properties of Ultra 317L, Ultra 4439, and Ultra 904L are similar to those of conventional austenitic stainless steels. The addition of nitrogen to Ultra 254 SMO, Ultra 6XN, Ultra 4565, and Ultra 654 SMO gives higher yield and tensile strength. Despite the greater strength of these steels, they offer very good possibilities for cold as well as hot forming.

Outokumpu name	Product form	Yield strength $R_{p0.2}$ (MPa)	Yield strength $R_{p1.0}$ (MPa)	Tensile strength R_m (MPa)	Elongation A (%)	Elongation A_{80} (%)
Ultra 904L	C	240	270	530–730	35	35
	H	240	270	530–730	35	35
	P	220	260	520–720	35	35
	R*	260	300	600	50	–
	B*	400	–	600	20	–
Ultra 254 SMO	C	320	350	650–850	35	35
	H	320	350	650–850	35	35
	P	300	340	650–850	40	40
	R*	340	380	680	50	–
	B*	–	–	–	–	–
Ultra 317L	P	220	260	520–720	40	40
	R*	260	280	580	50	–
Ultra 4439	C	290	320	580–780	35	35
	P	270	310	580–780	40	40
Ultra 725LN	P	250	–	540–740	40	40
Ultra 6XN	P	300	340	650–850	40	40
Ultra 4565	C	420	460	800–950	30	30
	P	420	460	800–950	30	30
Ultra 654 SMO	P	430	470	750–1000	40	40

Note: figures according to EN 10088-2 minimum values unless marked otherwise. In general, cold roiled coil and sheet have higher strength values than plate.

*Outokumpu typical value.

A_{80} initial length = 80 mm, A initial length = $5.65\sqrt{S0}$

Product forms: cold rolled coil and sheet (C), hot rolled coil and sheet (H), Quarto plate (P), wire rod (R), cold drawn bar, $10 < d \leq 16$mm (B). More product forms may be available than are shown in the table.

For more information, please see **steelfinder.outokumpu.com**

Outokumpu name	Product form	Yield strength $R_{p0.2}$ (ksi)	Yield strength $R_{p1.0}$ (ksi)	Tensile strength R_m (ksi)	Elongation A_{50} (%)
Ultra 904L	C	32	–	71	35
	H	32	–	71	35
	P	32	–	71	35
	R*	38	44	87	–
Ultra 254 SMO	C	45	–	100	35
	H	45	–	100	35
	P	45	–	95	35
	R*	49	55	99	–
Ultra 317L	C	30	–	75	40
	H	30	–	75	40
	P	30	–	75	40
	R*	38	41	84	–
Ultra 4439	C	35	–	80	40
	H	35	–	80	40
	P	35	–	80	40
Ultra 725LN	C	37	–	78	25
	H	37	–	78	25
	P	37	–	78	25
Ultra 6XN	C	45	–	100	30
	H	45	–	95	30
	P	45	–	94	30
Ultra 4565	C	60	–	115	35
	H	60	–	115	35
	P	60	–	115	35
Ultra 654 SMO	C	62	–	109	40

Note: Figures according to ASTM A240 unless marked with a *

*Outokumpu typical value

A_{50} initial length = 50 mm

Product forms: cold rolled coil and sheet (C), hot rolled coil and sheet (H), Quarto plate (P), wire rod (R). More product forms may be available than are shown in the table.

Physical properties

Metric						
Outokumpu name	Density kg/dm³	Modulus of elasticity GPa at 20 °C	Coefficient of thermal expansion 20–100 °C	Thermal conductivity (W/m °C) at 20 °C	Thermal capacity (J/kg °C) at 20 °C	Electrical resistivity (µΩm) at 20 °C
Ultra 904L	8	195	15.8	12	450	1
Ultra 254 SMO	8	195	16.5	14	500	0.85
Ultra 317L	8	200	16	14	500	0.85
Ultra 4439	8	200	16	14	500	0.85
Ultra 725LN	8	195	15.7	14	500	0.8
Ultra 6XN	8.1	195	15.8	12	450	1
Ultra 4565	8	190	14.5	12	450	0.92
Ultra 654 SMO	8	190	15	11	500	0.78

Imperial						
Outokumpu name	Density lb/in³	Modulus of elasticity (10^6) psi	Coefficient of thermal expansion 68-212 °F	Thermal conductivity (10^3) Btu/ft hr °F	Thermal capacity Btu/lb °F	Electrical resistivity µΩ-inch
Ultra 904L	0.289	28	8.8	69	0.107	3.9
Ultra 254 SMO	0.289	28	9.2	81	0.119	3.3
Ultra 317L	0.289	29	8.9	81	0.119	3.3
Ultra 4439	0.289	29	8.9	81	0.119	3.3
Ultra 725LN	0.289	28	8.7	81	0.119	3.2
Ultra 6XN	0.293	28	8.8	69	0.107	3.9
Ultra 4565	0.289	27.5	8.1	69	0.107	3.6
Ultra 654 SMO	0.289	27.5	8.3	64	0.119	3

Fabrication

Formability

Ultra range products have very good formability and are suitable for the full range of forming processes for stainless steel. The somewhat higher yield strength – and in some cases lower fracture elongation compared to the most common standard austenitic steel grades – can result in small differences in forming behavior depending on the chosen forming process, such as an increased springback. However, this can be compensated for, especially if the forming process can be designed for the specific product being used.

Moreover, an excellent interplay between the high yield strength, work hardening rate, and elongation mean that the high nitrogen containing products Ultra 4565 and Ultra 654 SMO are perfectly suited to lightweight and cost-effective applications with complex shapes.

The impact of high strength varies according to the forming technique. For all Ultra range products the estimated forming forces will be higher than for standard austenitic stainless steel products. This effect will be reduced if down-gauging is possible. In addition, the high yield strength of high-strength steels may result in higher demands on tools and lubricants, so down-gauging should be considered.

Cold forming

The high strength of the high nitrogen containing products Ultra 4565 and Ultra 654 SMO is clearly demonstrated when the stress-strain curves of high-performance austenitic stainless steel products are compared with the standard austenitic product Supra 316L/4404. The deformation-hardening rate is very similar for all austenitic products. The formability of Ultra range products can be characterized in several ways. The 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 has excellent R-values.

Hot forming

Higher temperatures cause deterioration in ductility and increased oxide formation (scaling). Normally, hot forming should be followed by solution annealing and quenching but, for Ultra 904L, if the hot forming is discontinued at a temperature above 1100 °C/2010 °F and the material is quenched directly thereafter, it may be used without subsequent heat treatment. It is important that the entire piece being formed is quenched from temperatures above 1100 °C/2010 °F. In the case of partial heating or partial cooling below 1100 °C/2010 °F, or if the cooling has been too slow, hot forming should always be followed by solution annealing and quenching. Ultra 254 SMO, Ultra 4565, and Ultra 654 SMO should be quenched at a temperature of at least 1150 °C/2100 °F after hot forming to remove intermetallic phases formed during the hot forming process. These phases can also recur if the subsequent cooling process is too slow, resulting in impaired corrosion resistance.

Machining

Austenitic stainless steels work harden quickly. Together with their high toughness, this means that they are often perceived as problematic from a machining perspective, for example in operations such as turning, milling, and drilling. This applies to an even greater extent to most highly alloyed steels, especially those with a high nitrogen content – i.e. Ultra 254 SMO, Ultra 6XN, Ultra 4565, and Ultra 654 SMO. However, with the right choice of tools, tool settings, and cutting speeds, these products can be successfully machined.

Welding

Ultra range steels are well suited for welding, and the methods used for welding conventional austenitic steels can also be used on these products. However, due to their stable austenitic structure, they are somewhat more sensitive to hot cracking in connection with welding, so in general 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. Solidification after partial remelting, for example by welding, causes redistribution of elements such as molybdenum, chromium, and nickel. These variation remain in the cast structure of the weld and can impair corrosion resistance in certain environments. Segregation tendency is less evident in Ultra 904L, and this product is normally welded using a filler of the same composition as the base material. It can even be welded without filler.

For Ultra 254 SMO, Ultra 6XN, Ultra 4565, and Ultra 654 SMO, the variation for molybdenum in particular is so great that it must be compensated for by using fillers with a higher molybdenum content.

Outokumpu name	Welding consumables	
	Covered electrodes ISO 3581 ISO 14172	Wires ISO 14343 ISO 18274
Ultra 4439	19 13 4 NL or 20 25 5 CuL	19 13 4 NL or 20 25 5 CuL
Ultra 904L	20 25 CuL	20 25 CuL
Ultra 254 SMO Ultra 4565 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

* Avesta Welding designation. For use in certain oxidizing environments, e.g. chlorine dioxide stage in pulp bleaching plants, when welding Ultra 254 SMO or Ultra 4565.

Contacts and enquiries

Contact us

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

outokumpu.com/contacts

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	
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	Heat-resisting 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

Standards	
ASTM/ASME delivery standards	
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
Other common specification standards	
NACE MR0175	Sulfide stress cracking resistant material for oil field equipment
Norsok M-CR-630	Material data sheets for 6Mo stainless steel
VdTÜV WB 473	Austenitischer Stahl X 1 CrNiMoCuN 20 18 7 Werkstoff-Nr. 1.4547
VdTÜV WB 537	Stickstofflegierter austenitischer Stahl X2CrNiMnMoN 25-18-6-5 Werkstoff-Nr 1.4565

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**

outokumpu classic | outokumpu pro

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

outokumpu
high performance stainless steel

outokumpu.com

1563EN-GB:1. May 2015. Erweko, Finland.