Duplex stainless steels

Outokumpu Forta range datasheet

General characteristics

Forta is associated with strength. This range covers the strongest stainless steels in our portfolio. It also brings together three product groups:

- **Forta Duplex** products for high strength, high to very high corrosion resistance, and enhanced resistance to stress corrosion cracking
- **Forta H-Series** fully austenitic products for high strength and high ductility
- **Forta Temper rolled** products for high strength and high hardness

The charts and diagrams in this datasheet show how this strength fits in with other stainless steel grades. Examples of where the products are typically used are given throughout the datasheet. The Forta range contains duplex and other high strength stainless steels, with a yield strength of typically minimum 400 MPa, that enable thinner structures and weight reduction. Table 1 shows the entire range with the three parts.

Grades

Table 1

Forta — Duplex and other high strength steels (proof strength $R_{p0.2}$ > 400 MPa), PRE 16 to 43. — Outokumpu Pro family

Steel designations		ASTM		Performance				Typical chemical composition, % by mass					
Outokumpu name	EN	Type	UNS	PRE	A [1] %	$R_{p0.2}$ MPa	Grade family	C	Cr	Ni	Mo	N	Others
Duplex, high strength, high corrosion resistance and enhanced resistance to stress corrosion cracking													
Forta DX 2205	1.4462	–	S32205 [2]	35	20	500	D	0.02	22.4	5.7	3.1	0.17	–
Forta LDX 2101	1.4162	–	S32101	26	20	530	D	0.03	21.5	1.5	0.3	0.22	5Mn Cu
Forta DX 2304	1.4362	–	S32304	26	20	450	D	0.02	23	4.8	0.3	0.1	Cu
Forta EDX 2304	1.4362	–	S32304	28	25 [3]	500 [3]	D	0.02	23.8	4.3	0.5	0.18	Cu
Forta LDX 2404	1.4662	–	S82441	34	20	550	D	0.02	24	3.6	1.6	0.27	3Mn Cu
Forta SDX 100	1.4501	–	S32760	42	25 [4]	530 [4]	D	0.02	25.4	6.9	3.8	0.27	W Cu
Forta SDX 2507	1.4410	–	S32750	43	20	550	D	0.02	25	7	4	0.27	–
For comparison													
Core 304L/4307	1.4307	304L	S30403	18	45	220	A	0.02	18.1	8.1	–	–	–
Supra 316L/4404	1.4404	316L	S31603	24	40	240	A	0.02	17.2	10.1	2.1	–	–
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

Grade family: D = duplex, A = austenitic, F = ferritic. [1] Min. values acc. to ASTM A240, for strip t ≤ 5 mm. Elongation reference varies between different standards, information referenced here denotes A_{80} – otherwise see footnote for specific grade or inquire to reference alternative standard. [2] Also available in S31803.
[3] Outokumpu MDS-D35 for EDX 2304. [4] Min. values for plate acc. to EN 10088-2.

Duplex characteristic properties

- Good to very good resistance to uniform corrosion
- Good to very good resistance to pitting and crevice corrosion
- High resistance to stress corrosion cracking and corrosion fatigue
- High mechanical strength
- Good abrasion and erosion resistance
- Good fatigue resistance
- High energy absorption
- Low thermal expansion
- Good weldability

When it comes to costs, all parties seek stability. In large-scale construction projects, the right material choices can multiply savings. Outokumpu Forta Duplex stainless steel has excellent strength. This often means the same structure can be built with less material: for example, tank walls can be considerably thinner. Compared to other grades with comparable corrosion resistance, the nickel content of Outokumpu Forta Duplex is very low. This means greater price stability and easier budgeting.

The Forta Duplex range with typical applications and the products we supply

Table 2

Outokumpu designation	Typical applications	Product forms
Forta DX 2205 (EN 1.4462/UNS S32205) The most popular duplex product on the market. Offers very good resistance to uniform and localized corrosion and stress corrosion cracking in combination with high mechanical strength.	• Cargo tanks in chemical tankers • Pulp and paper industry applications such as digesters and process tanks • Oil and gas industry, typically tubular products, flanges, fittings and valves • Structural components in bridges	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Forta LDX 2101 (EN 1.4162/UNS S32101) A lean-alloyed duplex product with good resistance to localized and uniform corrosion, as well as stress corrosion cracking, making it a good substitute for coated carbon steel in e.g. structural components and storage tanks. Forta LDX 2101 also offers high mechanical strength.	• Storage tanks • Domestic water heaters • Structural components for floodgates and bridges • Rebar for concrete structures • Pulp and paper industry applications such as digesters and components for paper machines • Flanges and valves	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Rebar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Forta DX 2304 (EN 1.4362/UNS S32304) A duplex product with a leaner alloying composition than Forta DX 2205. It has good resistance to localized and uniform corrosion, as well as stress corrosion cracking, combined with high mechanical strength.	• Pulp and paper industry applications • Blast walls on oil platforms • Storage tanks	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Rebar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Forta EDX 2304 (EN 1.4362/UNS S32304) An enhanced version of Forta DX 2304 with better corrosion resistance and higher mechanical strength.	• Offshore topside structural components • Storage tanks	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate

Table 2, continued

Outokumpu name	Typical applications	Product forms
Forta LDX 2404 (EN 1.4662/UNS S82441) A low-nickel, high-nitrogen duplex product with higher mechanical strength than Forta DX 2205. Offers very good resistance to localized and uniform corrosion, as well as stress corrosion cracking.	• Storage tanks • Structural components for flood and sluice gates • Mining industry applications	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Forta SDX 100 (EN 1.4501/UNS S32760) A super duplex product with higher corrosion resistance and mechanical strength than Forta DX 2205. Often used in extremely corrosive environments such as desalination, chemical, or offshore subsea applications.	• Desalination plants • Industrial piping • Scrubbers • Oil and gas industry, typically tubular products, flanges, fittings and valves • Deep-sea pipelines	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Forta SDX 2507 (EN 1.4410/UNS S32750) A super duplex product with higher corrosion resistance and mechanical strength than Forta DX 2205. Often used in extremely corrosive environments such as desalination, chemical, or offshore subsea applications.	• Desalination plants • Industrial piping • Scrubbers • Oil and gas industry, typically tubular products, flanges, fittings and valves • Deep-sea pipelines	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Bar • Wire rod • Semi-finished (bloom, billet, ingot & slab)
Forta FDX 27 (EN 1.4637/UNS S82031) A duplex stainless steel with improved formability and good resistance to uniform and localized corrosion, as well as stress corrosion cracking. Forta FDX 27 has high strength and excellent forming properties. Forta FDX 27 is used in applications where the use of standard duplex is restricted due to its formability limitations.	• Plate heat exchangers • Deep drawing applications for corrosive environments • Pump components	• Cold rolled coil and sheet • Hot rolled coil and sheet

Performance

Strength vs. corrosion resistance

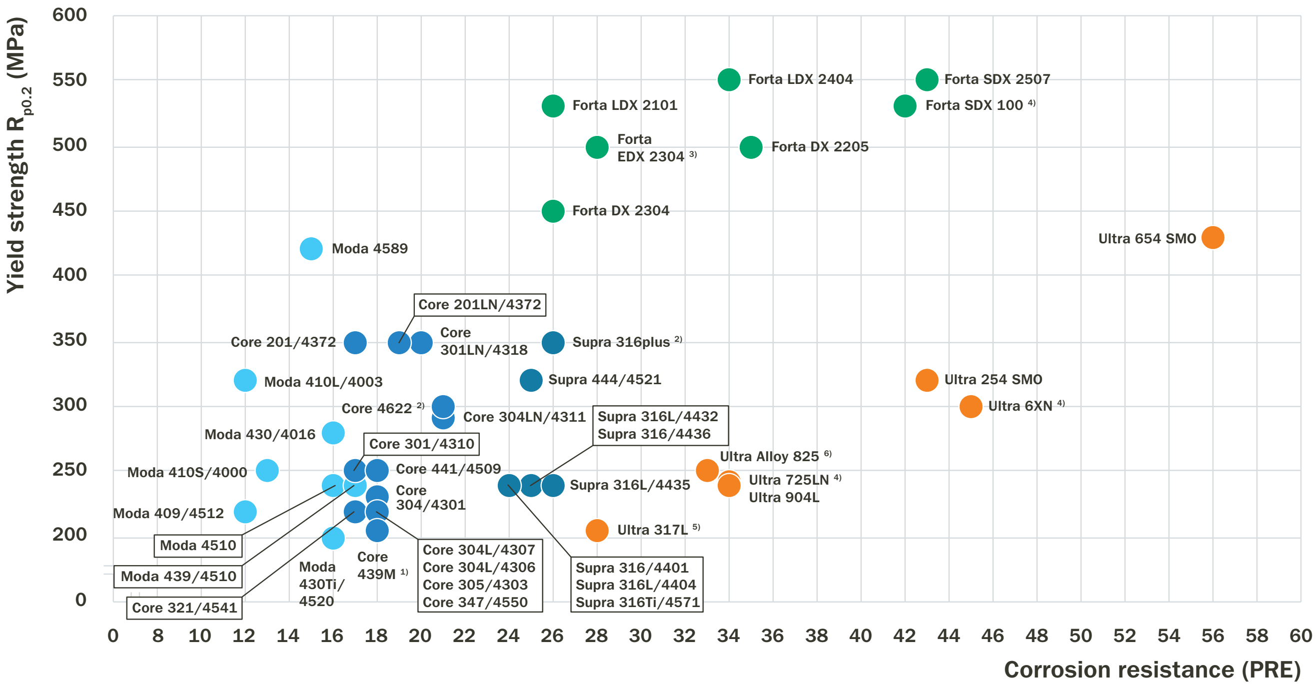

Fig. 1. Strength vs. corrosion resistance.

Elongation vs. corrosion resistance

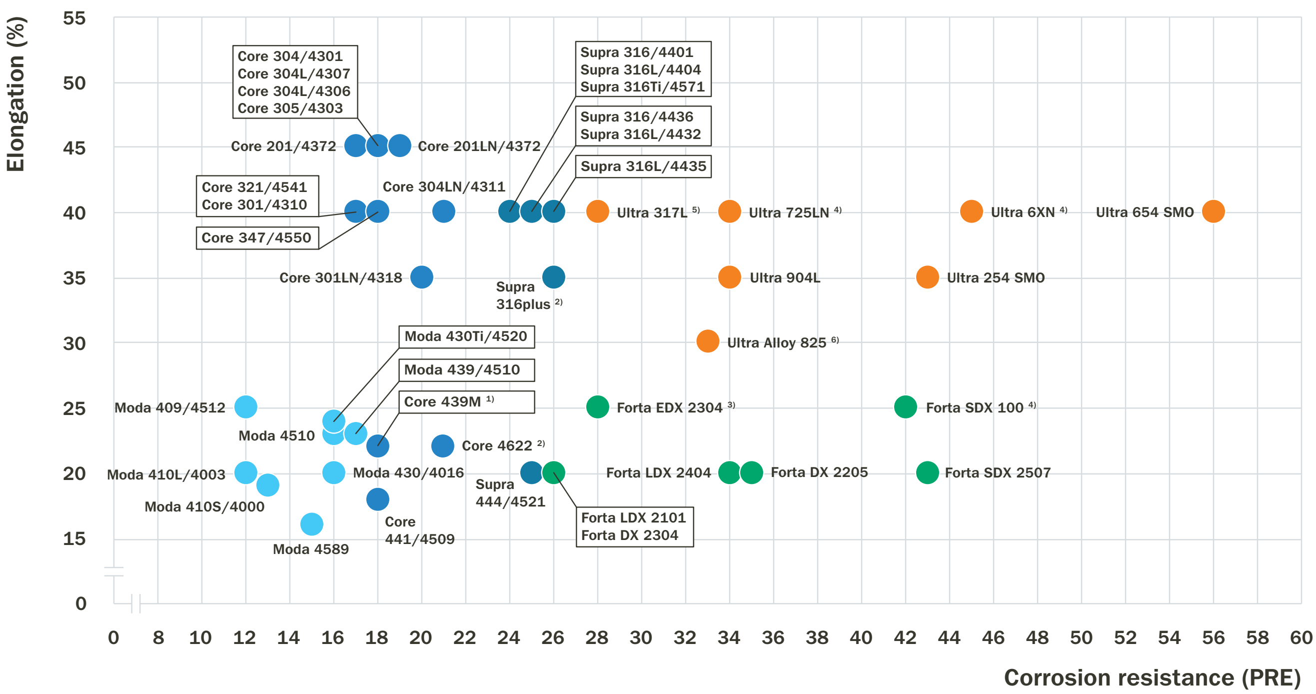

Fig. 2. Elongation vs. corrosion resistance.

- 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

Outokumpu Forta Duplex steels provide a wide range of corrosion resistance in various environments. For a more detailed description of their resistance, see the Outokumpu Corrosion Handbook. A brief description is shown below regarding their corrosion resistance in different types of environments.

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.

Due to their high chromium content, Outokumpu Forta Duplex steels offer excellent corrosion resistance in many environments.

Forta LDX 2101 has, in most cases, a better resistance to uniform corrosion than Core 304L/4307 and in some cases as good as Supra 316L/4404. Forta DX 2304 is in most cases equivalent to Supra 316L/4404 and Forta EDX 2304. Forta SDX 100 is typically comparable to Forta SDX 2507.

Sulfuric acid

The isocorrosion diagram in sulfuric acid is shown in Figure 3. The duplex grades have generally good resistance in dilute sulfuric acid. In sulfuric acid contaminated by chloride ions, Forta DX 2205 shows much better resistance than Supra 316L/4404 and a similar resistance to that of Ultra 904L, Figure 4.

Hydrochloric acid

Stainless steel grades such as Core 304L/4307 and Supra 316L/4404 have very limited use in contact with hydrochloric acid because of the risk of uniform and localised corrosion. High-alloyed duplex steels such as Forta SDX 2507 and to some extent also Forta DX 2205 can be used in dilute

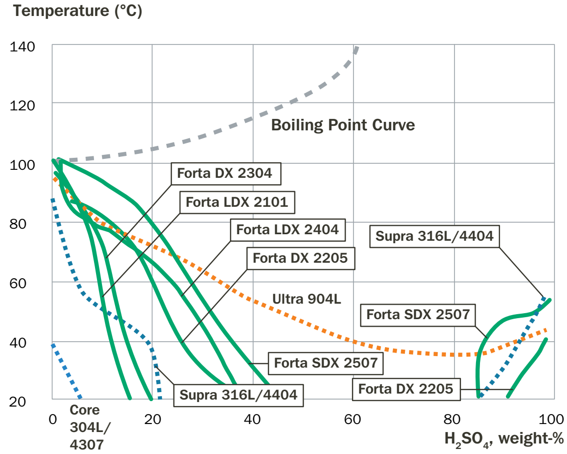

Fig. 3. Isocorrosion curves, 0.1 mm/year, in sulfuric acid.

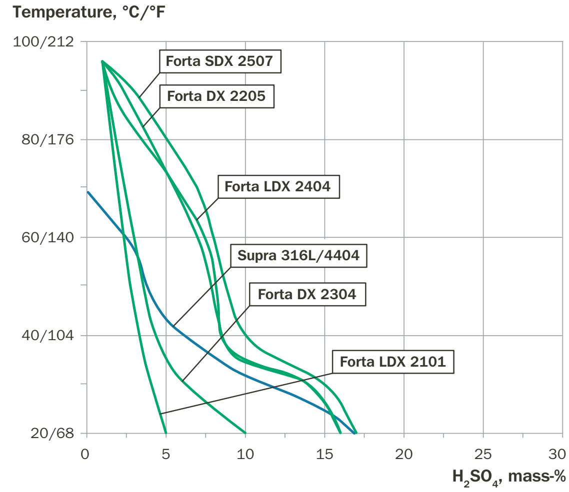

Fig. 4. Isocorrosion diagram, 0.1 mm/year, for duplex stainless steels in naturally aerated sulphuric acid of chemical purity with an addition of 2000 ppm chloride.

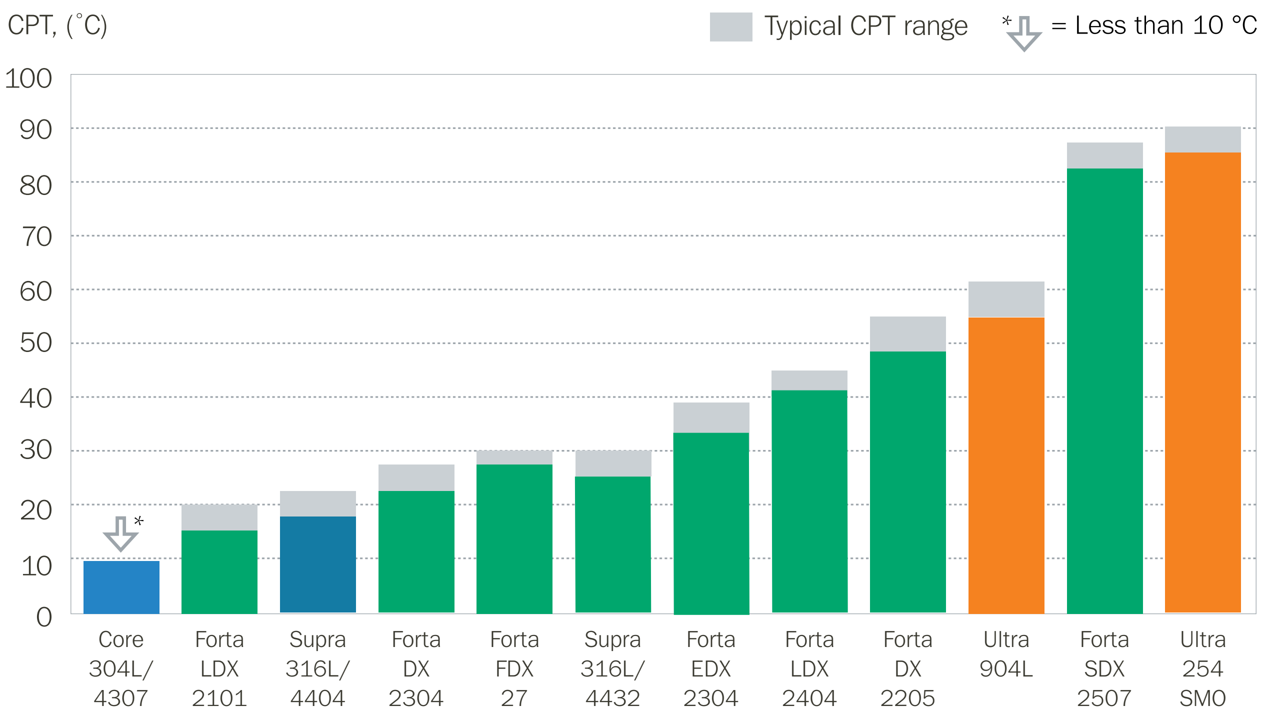

Fig. 5. Typical critical pitting corrosion temperatures (CPT) in 1M NaCl measured according to ASTM G150 using the Avesta Cell. Test surfaces wet ground to P320 grit. CPT varies with product form and surface finish.

hydrochloric acid as shown in Figure 6. Localized corrosion around crevices can in some cases be a risk, even below the boundary line in the isocorrosion diagram.

Nitric acid

Because nitric acid is a strongly oxidizing acid, non-molybdenum alloyed steels are often more resistant than the molybdenum alloyed grades. Forta LDX 2101 and Forta DX 2304 are good alternatives because of their high chromium content in combination with a low molybdenum content.

Alkaline environments

Duplex stainless steels generally have excellent corrosion resistance in alkaline environments. They are commonly used in the pulp and paper industry due to their superior resistance to alkaline liquors compared to materials such as carbon steel, austenitic stainless steels and nickel base alloys. Field tests in operating digesters and liquor heaters have shown that the corrosion resistance increases as the chromium content in the stainless steel increases, while molybdenum is not as beneficial as it is in pH-neutral, or slightly acidic chloride containing environments. In fact, molybdenum has been found to be detrimental in hot alkaline solutions.

Grades like Forta LDX 2101 and Forta DX 2304 generally perform better than both standard austenitic and higher-alloyed grades, while offering a significant cost saving compared to many of the alternatives.

Pitting and crevice corrosion

The resistance to pitting and crevice corrosion increases with the content of chromium, molybdenum and nitrogen in the steel. This is often illustrated by the pitting resistance equivalent (PRE) for the material, which can be calculated by using the formula:
PRE = %Cr + 3.3 x %Mo + 16 x %N. PRE values calculated for different grades are presented in Table 3. The PRE value should only be used for a rough comparison between different materials. A much more reliable way of ranking the pitting resistance of steels is according to the critical pitting temperature (CPT). There are several methods available to measure CPT.

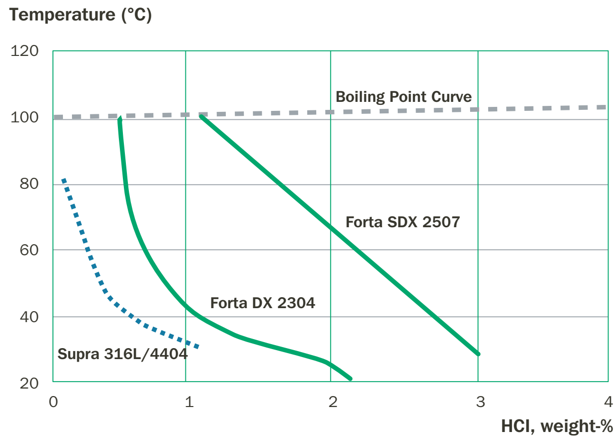

Fig. 6. Isocorrosion curves 0.1 mm/year, in hydrochloric acid.

PRE values for Forta Duplex grades and some austenitic grades

Table 3

Steel designations				PRE
		ASTM		
Outokumpu name	EN	Type	UNS	
Duplex, high strength, high corrosion resistance and enhanced resistance to stress corrosion cracking				
Forta DX 2205	1.4462	–	S32205 *)	35
Forta LDX 2101	1.4162	–	S32101	26
Forta DX 2304	1.4362	–	S32304	26
Forta EDX 2304	1.4362	–	S32304	28
Forta LDX 2404	1.4662	–	S82441	34
Forta SDX 100	1.4501	–	S32760	42
Forta SDX 2507	1.4410	–	S32750	43
For comparison				
Core 304L/4307	1.4307	304L	S30403	18
Supra 316L/4404	1.4404	316L	S31603	24
Ultra 904L	1.4539	904L	N08904	34
Ultra 254 SMO	1.4547	–	S31254	43

*) Also available in S31803.

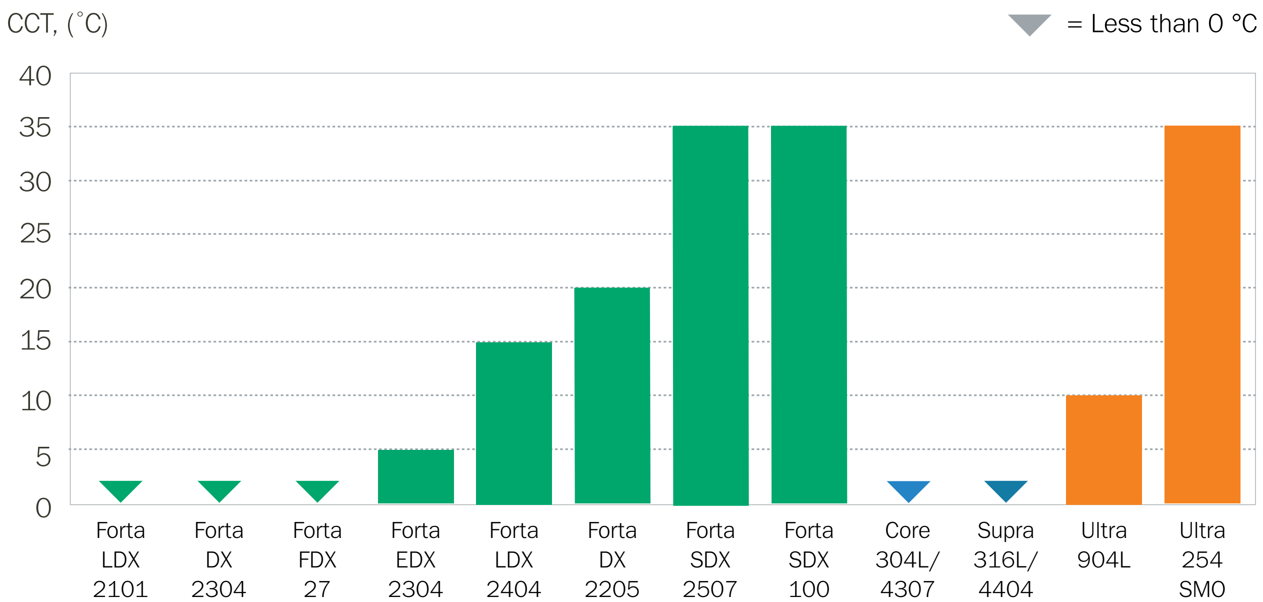

Fig. 7. Typical critical crevice corrosion temperature (CCT) according to ASTM G 48 Method F. Test surfaces dry ground to P120 grit. CCT varies with product form and surface finish.

ASTM G150 is an electrochemical method used by Outokumpu making it possible to measure the resistance to pitting initiation without interference from crevice corrosion. The results are given as the critical pitting temperature, CPT, at which pitting is initiated. The pitting corrosion resistance of the steels in a wet ground (P320 grit) condition is shown in Figure 5. The actual value of the as delivered surface may however differ between product forms.

When ranking the resistance to crevice corrosion, it is common to measure a critical temperature at which corrosion is initiated in a well-defined solution. The typical critical crevice corrosion temperatures (CCT) measured in 6% FeCL +1% HCl according to ASTM G48 Method F is presented in Figure 7. Different products and different surface finishes, e.g. mill finish surfaces, may show CCT values that differ from the values given in the Figure 7. Due to their different alloying levels, duplex steels show considerable differences in the resistance to pitting and crevice corrosion. Outokumpu Forta LDX 2101 has a resistance in-between Core 304L/4307 and Supra 316L/4404, Forta DX 2304 is on a level with conventional molybdenum-alloyed steels of the Supra 316L/4404 type, while Forta LDX 2404 and Forta DX 2205 are equivalent.

Stress corrosion cracking

Stainless steel can be affected by stress corrosion cracking (SCC) in chloride containing environments at elevated temperatures. Conventional austenitic stainless steels such as Core 304L/4307 and Supra 316L/4404 are is particularly vulnerable to stress corrosion cracking. Duplex stainless steels are less susceptible to this type of corrosion.

Different methods are used to rank stainless steel grades with regard to their resistance to stress corrosion cracking and results may vary depending on the test method as well as test environment. In Table 4 a comparison is given of the stress corrosion cracking resistance of conventional and high alloyed austenitic stainless steels and duplex stainless steels for some immersion tests carried out in various chloride solutions.

The results show that duplex stainless steels are not immune under very harsh conditions, such as boiling concentrated magnesium chloride. However they withstand stress corrosion cracking under many conditions where conventional austenitic grades are expected to fail.

Sulfide induced stress corrosion cracking

In the presence of hydrogen sulfide and chlorides the risk of stress corrosion cracking, especially at low temperatures, increases. Such environments can exist, for example, in boreholes for oil and gas wells. Duplex grades, such as Forta DX 2205 and Forta SDX 2507 have demonstrated good resistance, while 13% chromium steels have shown a tendency towards stress corrosion cracking. However, caution should be taken regarding conditions with high partial pressure of hydrogen sulfide and where the steel is subjected to high internal stress.

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 H2S environments. It identifies materials that are resistant to cracking in a defined H2S containing environment, but does not guarantee that the material selected using the standard will be immune from cracking under all service conditions.

Duplex stainless steels Forta DX 2205, Forta SDX 100 and Forta SDX 2507 are included in ISO 15156-3 (NACE MR0175). In accordance with ISO 15156-3 (NACE MR0175) solution annealed and rapidly cooled Forta DX 2205 is acceptable for use for any component or equipment up to 232 °C (450 °F) in sour environments, if the partial pressure of hydrogen sulfide does not exceed 0.1 bar (1.5 psi). Forta SDX 100 and Forta SDX 2507 are acceptable for use up to 232 °C (450 °F) if the partial pressure of hydrogen sulfide does not exceed 0.2 bar (3 psi).

Corrosion fatigue

The combination of high mechanical strength and very good resistance to corrosion gives duplex steels a high corrosion fatigue strength. S-N curves for Forta DX 2205 and Supra 316L/4404 in synthetic seawater are shown in Figure 8. The corrosion fatigue strength of Forta DX 2205 is considerably higher than that of Supra 316L/4404.

Intergranular corrosion

Due to the duplex microstructure and low carbon content, the duplex steels have very good resistance to intergranular corrosion. The composition of the steel ensures that austenite is reformed in the heat-affected zone after welding. The risk of undesirable precipitation of carbides and nitrides in the grain boundaries is thus minimised.

Erosion corrosion

Stainless steel in general offers good resistance to erosion corrosion. Duplex grades are especially good thanks to their combination of high surface hardness and good corrosion resistance. Examples of applications where this is beneficial include systems subjected to particles that cause hard wearing e.g. pipe systems containing water and sand or salt crystals.

Galvanic corrosion

Galvanic corrosion can occur when two dissimilar metals are in contact. The noblest material is protected while the less noble material is more severely attacked. As long as the duplex stainless steels are passive they are, in most environments, nobler than other metallic construction materials. This means that the stainless steel is protected while the corrosion rate of e.g. carbon steel is increased. Galvanic corrosion does not occur between different grades of stainless steels as long as both grades remain passive.

Results from stress corrosion cracking immersion tests in chloride solutions

Table 4

Outokumpu name	ASTM G123 25% NaCl, pH 1.5, 106°C (b.p.), 1,000 h U-bend samples	40% $CaCl_2$, 100°C, 500 h 4-PB samples (90% of $R_{p0.2}$)	ASTM G36 45% $MgCl_2$, 155°C (b.p.), 24 h U-bend samples
Duplex, high strength, high corrosion resistance and enhanced resistance to stress corrosion cracking			
Forta DX 2205	No SCC	No SCC	SCC
Forta LDX 2101	No SCC	No SCC	SCC
Forta DX 2304	No SCC	No SCC	SCC
Forta EDX 2304	No SCC	No SCC	SCC
Forta LDX 2404	No SCC	No SCC	SCC
Forta SDX 100	No SCC	No SCC	SCC
Forta SDX 2507	No SCC	No SCC	SCC
Forta FDX 27	No SCC	No SCC	SCC
For comparison			
Core 304L/4307	SCC	SCC	SCC
Supra 316L/4404	SCC	SCC	SCC
Ultra 904L	No SCC	No SCC	No SCC
Ultra 254 SMO	No SCC	No SCC	SCC

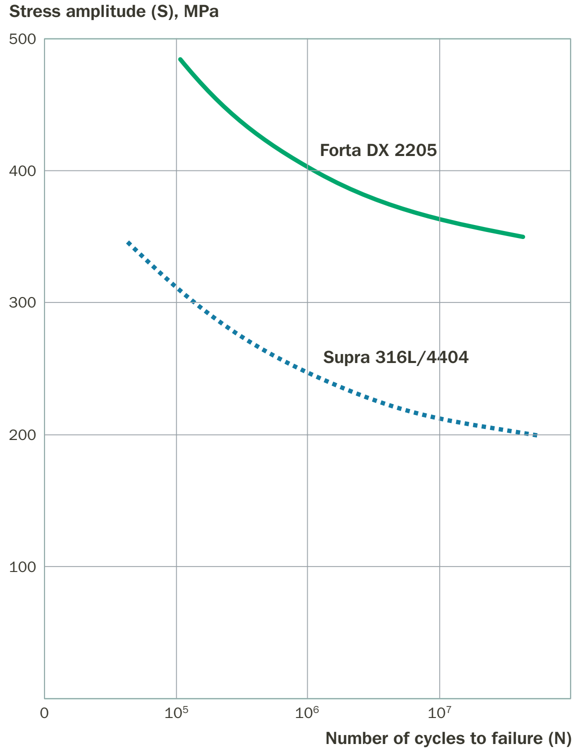

Fig. 8. Corrosion fatigue of stainless steel in synthetic seawater. Rotating bending test, 1500 r/min, with smooth specimens from 15 mm plate.

Mechanical properties

Tables 5, 7 and 8 show the mechanical properties for flat rolled products, data according to EN 10088 and EN 10028 when applicable. The allowable design values may vary between product forms. The appropriate values are given in the relevant specifications. Table 6 shows mechanical properties for flat rolled products according to ASTM A240.

Mechanical properties, metric

Table 5

Outokumpu name	EN	ASTM UNS	Product form	Yield strength $R_{p0.2}$ [MPa]	Tensile strength R_m [MPa]	Elongation A [%]	Elongation A_{80} [%]
Forta DX 2205	1.4462	S32205	Cold rolled coil (C)	500	700–950	20	20
			Hot rolled coil (H)	460	700–950	25	25
			Quarto plate (P)	460	640–840	25	25
			Wire rod [1)]	510	750	35	–
			Bar	450	650–880	25	–
Forta LDX 2101	1.4162	S32101	Cold rolled coil (C)	530	700–900	30	20
			Hot rolled coil (H)	480	680–900	30	30
			Quarto plate (P)	450	650–850	30	30
			Wire rod [1)]	480	700	38	–
			Bar	400	650–900	25	–
Forta DX 2304	1.4362	S32304	Cold rolled coil (C)	450	650–850	20	20
			Hot rolled coil (H)	400	650–850	20	20
			Quarto plate (P)	400	630–800	25	25
			Wire rod [1)]	500	700	35	–
			Bar	400	600–830	25	–
Forta EDX 2304	1.4362	S32304	Cold rolled coil (C) [2)]	500	690	25	–
			Hot rolled coil (H) [2)]	500	690	25	–
Forta LDX 2404	1.4662	S82441	Cold rolled coil (C)	550	750–900	25	20
			Hot rolled coil (H)	550	750–900	25	–
			Quarto plate (P)	480	680–900	25	–
			Bar	450	650–900	25	–
Forta SDX 100	1.4501	S32760	Cold rolled coil (C)	550	750–1000	20	20
			Hot rolled coil (H)	530	750–1000	25	25
			Quarto plate (P)	530	730–930	25	25
Forta SDX 2507	1.4410	S32750	Cold rolled coil (C)	550	750–1000	20	20
			Hot rolled coil (H)	530	750–1000	20	20
			Quarto plate (P)	530	730–930	20	20
			Bar	530	730–930	25	–
Forta FDX 27	1.4637 [3)]	S82031	Cold rolled coil (C) [4)]	500	700	–	35 [5)]

Note: Values according to EN 10088-2 / EN 10088-3 minimum values unless marked otherwise.

[1)] Outokumpu typical values.
[2)] Values according to Outokumpu MDS-D35.
[3)] Designation included in Stahl-Eisen-Liste.
[4)] Values according to ASTM A240.
[5)] A_{50} initial length = 50 mm.

A_{80} initial length = 80 mm, A initial length = $5.65\sqrt{S_0}$ (A_5)

More product forms may be available than shown in table.

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

Mechanical properties, imperial

Table 6

Outokumpu name	EN	ASTM UNS	Product form	Yield strength $R_{p0.2}$ [ksi]	Tensile strength R_m [ksi]	Elongation A_{50} [%]
Forta DX 2205	1.4462	S32205	Cold rolled coil (C)	65	95	25
			Hot rolled coil (H)	65	95	25
			Quarto plate (P)	65	95	25
			Wire rod [1]	74	109	–
Forta LDX 2101	1.4162	S32101	Cold rolled coil (C)	77	101	30
			Hot rolled coil (H)	65	94	30
			Quarto plate (P)	65	94	30
			Wire rod [1]	70	102	–
Forta DX 2304	1.4362	S32304	Cold rolled coil (C)	58	87	25
			Hot rolled coil (H)	58	87	25
			Quarto plate (P)	58	87	25
			Wire rod [1]	73	102	–
Forta EDX 2304	1.4362	S32304	Cold rolled coil (C) [2]	73	100	25 [3]
			Hot rolled coil (H) [2]	73	100	25 [3]
Forta LDX 2404	1.4662	S82441	Cold rolled coil (C)	78	107	25
			Hot rolled coil (H)	78	107	25
			Quarto plate (P)	70	99	25
Forta SDX 100	1.4501	S32760	Cold rolled coil (C)	80	108	25
			Hot rolled coil (H)	80	108	25
			Quarto plate (P)	80	108	25
Forta SDX 2507	1.4410	S32750	Cold rolled coil (C)	80	116	15
			Hot rolled coil (H)	80	116	15
			Quarto plate (P)	80	116	15
Forta FDX 27	1.4637 [4]	S82031	Cold rolled coil (C)	73	102	35

Note: Values according to ASTM A240 minimum values unless marked otherwise.

[1] Outokumpu typical values
[2] Values according to Outokumpu MDS-D35
[3] A_5
[4] Designation included in Stahl-Eisen-Liste.

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.

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

Impact toughness. Minimum values according to EN 10028, transverse direction, plate / cold rolled and hot rolled coil, [J]

Table 7

	Forta LDX 2101	Forta DX 2304 *)	Forta LDX 2404	Forta DX 2205	Forta SDX 100	Forta SDX 2507
20°C	40 / 80	90 / 90	60 / 80	100 / 100	90 / 90	90 / 90
-40°C	27 / 50	40 / 40	40 / 40	40 / 40	40 / 40	40 / 40

*) Also valid for Forta EDX 2304 since they have the same EN number.

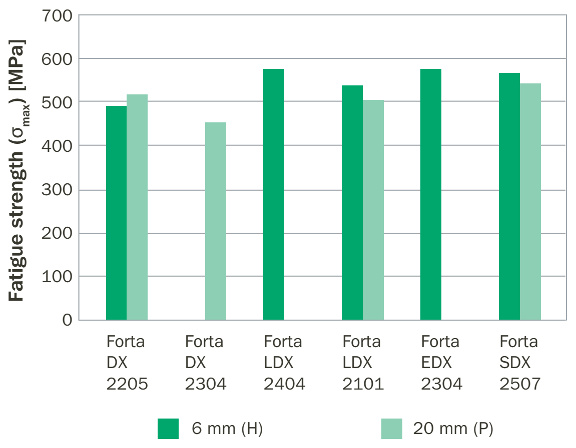

Fig 9. Fatigue strength, 50% probability of failure at 2 million cycles, tested with R = 0.1, F = 20 Hz.

Fatigue

The high tensile strength of duplex steels also implies high fatigue strength. Forta range Duplex grades have fatigue strength in the same order as the 0.2% yield strength. The fatigue strength for 2 million cycles tested with R= $\sigma_{min}/\sigma_{max}$= 0.1 in air at room temperature at 20 Hz are shown in Figure 9.

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

Table 8

Outokumpu name	EN	ASTM UNS	Product form	Yield strength $R_{p0.2}$ [MPa/ksi]	Yield strength $R_{p1.0}$ [MPa/ksi]	Tensile strength R_m [MPa/ksi]	Elongation A [%]	Hardness
Forta DX 2205	1.4462	S32205	Cold rolled coil (C)	690/100	740/107	880/127	26 *)	101 HRBW
			Hot rolled coil (H)	630/91	725/105	840/121	30	250 HBW
			Quarto plate (P)	510/74	–	750/109	35	230 HBW
Forta LDX 2101	1.4162	S32101	Cold rolled coil (C)	610/88	660/95	810/117	29 *)	99 HRBW
			Hot rolled coil (H)	560/81	630/91	755/109	35	235 HBW
			Quarto plate (P)	500/72	–	700/101	38	225 HBW
Forta DX 2304	1.4362	S32304	Cold rolled coil (C)	620/90	660/95	790/114	26 *)	99 HRBW
			Hot rolled coil (H)	600/87	670/97	765/111	30	235 HBW
			Quarto plate (P)	450/65	–	670/97	40	210 HBW
Forta EDX 2304	1.4362	S32304	Cold rolled coil (C)	600/87	–	770/111	30 *)	–
			Hot rolled coil (H)	600/87	–	750/109	30	–
Forta LDX 2404	1.4662	S82441	Cold rolled coil (C)	640/93	–	850/123	24 *)	–
			Hot rolled coil (H)	645/93	720/104	825/119	30	250 HBW
			Quarto plate (P)	520/75	–	750/109	33	230 HB
Forta SDX 100			Quarto plate (P)	580/84	–	830/120	35	260 HBW
Forta SDX 2507	1.4410	S32750	Cold rolled coil (C)	730/106	790/114	970/140	24 *)	103 HRBW
			Hot rolled coil (H)	700/101	785/114	905/131	30	270 HBW
			Quarto plate (P)	580/84	–	830/120	35	250 HBW
Forta FDX 27	1.4637	S82031	Cold rolled coil (C)	650/94	647/94	850/123	36 *)	–

*) A_{80} initial length = 80 mm.

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 yield strength according to EN 10028-7

Table 9

Outokumpu name	Strength		100 °C/212 °F	150 °C/302 °F	200 °C/392 °F	250 °C/482 °F
Forta DX 2205	Yield strength	$R_{p0.2}$ [MPa/ksi]	360/52	335/48	315/45	300/43
	Tensile strength	R_m [MPa/ksi]	590/85	570/82	550/79	540/78
Forta LDX 2101	Yield strength	$R_{p0.2}$ [MPa/ksi]	380/55	350/50	330/47	320/46
	Tensile strength	R_m [MPa/ksi]	590/85	560/81	540/78	540/78
Forta DX 2304 [1)]	Yield strength	$R_{p0.2}$ [MPa/ksi]	330/47	300/43	280/40	265/38
	Tensile strength	R_m [MPa/ksi]	540/78	520/75	500/72	490/71
Forta LDX 2404	Yield strength	$R_{p0.2}$ [MPa/ksi]	385/55	345/50	325/47	315/45
Forta SDX 100	Yield strength	$R_{p0.2}$ [MPa/ksi]	450/65	420/60	400/58	380/55
	Tensile strength	R_m [MPa/ksi]	680/98	660/95	640/92	630/91
Forta SDX 2507	Tensile strength	R_m [MPa/ksi]	680/98	660/95	640/92	630/91
Forta FDX 27 [2)]	Yield strength	$R_{p0.2}$ [MPa/ksi]	400/58	360/52	340/49	330/48
	Tensile strength	R_m [MPa/ksi]	600/87	570/83	560/81	550/80

[1)] Also valid for Forta EDX 2304 since they have the same EN number. However, typical values are higher for Forta EDX 2304 compared to Forta DX 2304. Contact Outokumpu for more details.
[2)] Values from internal standard, AM 641.

Physical properties

In Tables 10 and 11 physical properties are given for Forta duplex grades.

Values according to EN 10088-1

Table 10

Metric									
Outokumpu name	EN	ASTM Type	UNS	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]
Forta DX 2205	1.4462	–	S32205	7.8	200	13.0	15	500	0.8
Forta LDX 2101	1.4162	–	S32101	7.7	205	13.0	15	500	0.75
Forta DX 2304	1.4362	–	S32304	7.8	200	13.0	15	500	0.8
Forta EDX 2304	1.4362	–	S32304	7.8	200	13.0	15	500	0.8
Forta LDX 2404	1.4662	–	S82441	7.7	205	13.0	15	500	0.8
Forta SDX 100	1.4501	–	S32760	7.8	200	13.0	15	500	0.8
Forta SDX 2507	1.4410	–	S32750	7.8	200	13.0	15	500	0.8
Forta FDX 27	1.4637*	–	S82031	7.7	205	12.5	14.5	500	0.8

*) Designation included in Stahl-Eisen-Liste, own data. Note: Values according to EN 10088-1.

Values according to EN 10088-1

Table 11

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]
Forta DX 2205	0.282	29×10^6	7.2	8.7	0.119	31.50
Forta LDX 2101	0.278	30×10^6	7.2	8.7	0.119	29.53
Forta DX 2304	0.282	29×10^6	7.2	8.7	0.119	31.50
Forta EDX 2304	0.282	29×10^6	7.2	8.7	0.119	31.50
Forta LDX 2404	0.278	30×10^6	7.2	8.7	0.119	31.50
Forta SDX 100	0.282	29×10^6	7.2	8.7	0.119	31.50
Forta SDX 2507	0.282	29×10^6	7.2	8.7	0.119	31.50
Forta FDX 27	0.278	30×10^6	6.9	8.3	0.119	31.50

Typical values *)

Table 12

		20 °C	100 °C	200 °C	300 °C
Density	g/cm³	7.8	–	–	–
Modulus of elasticity	GPa	200	194	186	180
Poissons ratio	–	0.3	–	–	–
Linear expansion at (RT → T)°C	x 10^{-6}/°C	–	13.0	13.5	14.0
Thermal conductivity	W/m °C	15	16	17	18
Thermal capacity	J/kg °C	500	530	560	590
Electric resistivity	µΩm	0.80	0.85	0.90	1.00

*) Values may differ slightly between the different duplex grades. RT=Room temperature.

Fabrication

Cold forming

Outokumpu Forta Duplex stainless steel is suitable for all forming processes available for stainless steel. The high yield strength compared to austenitic and ferritic stainless steel can however give differences in forming behavior. Depending on the chosen forming technique there could be consequences, such as increased springback. This point is particularly relevant to the forming of any high strength steel. Moreover, an excellent interplay between high yield strength, work hardening rate and elongation promote the duplex grades for light weight and cost-efficient applications with complex shapes.

The impact of the high strength varies for different forming techniques. Common for all is that the estimated forming forces will be higher than for the corresponding austenitic and ferritic stainless steel grades. This effect will usually be lower than expected from just the increase in strength since the choice of duplex stainless steel is often associated with gauge reduction. It is important to consider that duplex stainless steel may also be more demanding on the tools and on the lubricant. This should also be noted when looking to down gauge.

In Figures 10 and 11, representative stress strain curves for selected Forta grades are compared with austenitic grades with corresponding corrosion resistance. The high strength of the duplex grades is clearly demonstrated as well as the lower elongation compared to the austenitic grades. Note the superior elongation for Forta FDX 27 making this grade suitable for forming intensive applications.

Figure 12 gives a relative comparison of the formability in plane strain condition between Forta grades and corresponding austenitic grades. The ranking represents the most critical failure mode in sheet forming, especially in forming operations dominated by thinning (stretching). Note also here the excellent formability of Forta FDX 27. In pure drawing, the duplex grades are comparable to austenitic grades in that about the same limiting drawing ratio can be achieved.

Some basic fabrication advice is presented in Table 14.

For more information, see the Outokumpu Sheet Metal Forming Handbook, available from our sales offices.

outokumpu.com/contacts

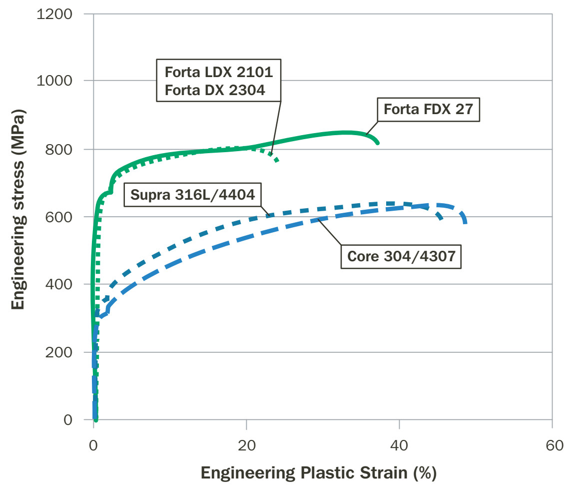

Fig. 10. Stress-strain curves for duplex and austenitic grades with corresponding corrosion resistance. Valid for coil product, 1 mm thickness.

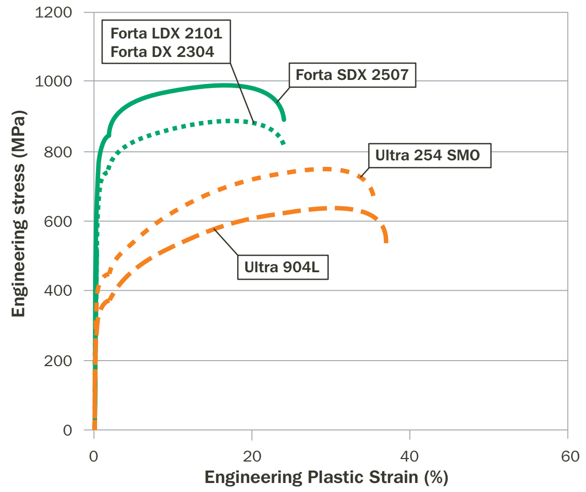

Fig. 11. Stress-strain curves for duplex and austenitic grades with corresponding corrosion resistance. Valid for coil product, 1 mm thickness.

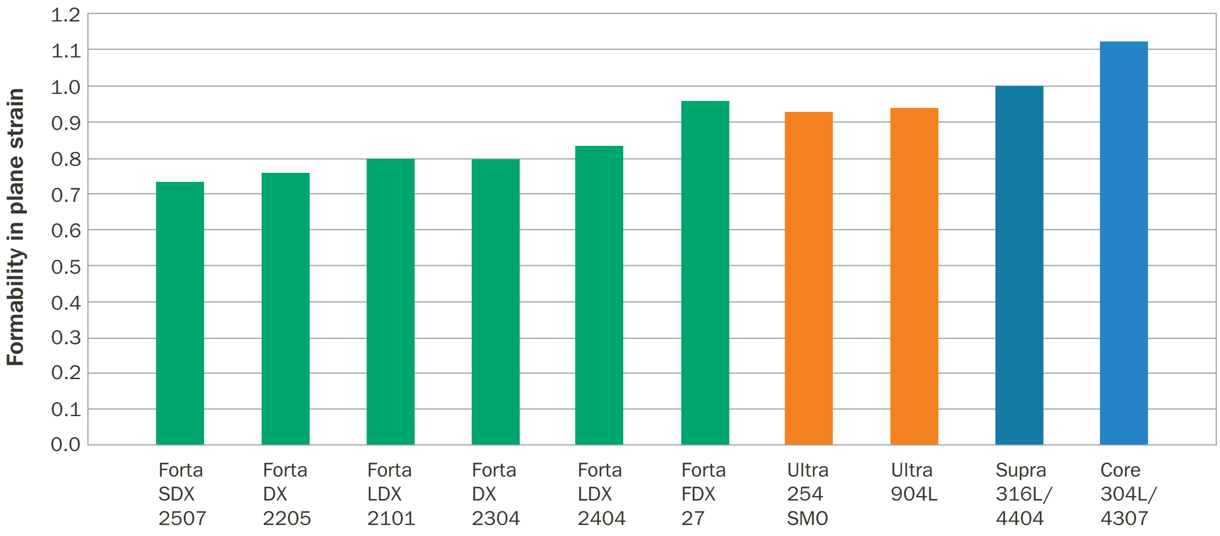

Fig 12. Formability ranking of some duplex and austenitic grades in relation to grade Supra 316L/4404.

Typical temperatures, °C

Table 13

	Forta LDX 2101	Forta DX 2304, Forta EDX 2304	Forta FDX 27	Forta LDX 2404	Forta DX 2205	Forta SDX 100	Forta SDX 2507
Hot forming	1100–900	1100–900	1100–900	1120–900	1150–950	1200–1025	1200–1025
Quench annealing	1020–1080	950–1050	1020–1080	1000–1120	1020–1100	1040–1120	1040–1120
Stress relief annealing	1020–1080	950–1050	1020–1080	1000–1120	1020–1100	1040–1120	1040–1120

Hot forming

Hot forming is performed at the temperatures illustrated in Table 13. It should, however, be observed that the strength of the duplex material is low at high temperatures and components require support during fabrication. Hot forming should normally be followed by quench annealing.

Basic fabrication advice

Table 14

Fabrication advice	
Cutting, shearing	Maximum thickness for shearing and punching is 80-85% of that of austenitic steel.
Roll bending	More bending force will be needed compared to other stainless steels. Through the downgauging, this effect will however be smaller than anticipated. The springback due to the higher strength is large when roll bending.
Break bending	Avoid sharp bending radius. Minimum ratio between inner radius to sheet thickness should not be less than 2.
Deep drawing	If drawing is dominant, formability is comparable to austenitic stainless steel. If stretching is dominant, formability is closer to ferritic steels.
Roll forming	The high strength of the sheet has to be considered in the design of the rolls. If properly designed there are no problems in roll forming duplex.
Tooling use	Strong, durable tools (hardness, HRC larger than 60).
Lubrication	Because of the high strength of duplex and extreme pressure needed, additives are useful in complex forming operations.

Heat treatment

Temperatures suitable for heat treatment are presented in Table 13. The heat treatment should be followed by subsequent rapid cooling in water or air. This treatment applies for both solution annealing and stress relieving. The latter can in special cases be done at 500-550 °C. Further information concerning these operations is available from Outokumpu.

Microstructure

The chemical composition of Outokumpu Forta Duplex steels is balanced to give approximately equal amounts of ferrite and austenite in solution-annealed condition. The higher the annealing temperature the higher the ferrite content.

Outokumpu Forta Duplex steels are more prone to precipitation of sigma phase, nitrides and carbides than corresponding austenitic steels, causing embrittlement and reduced corrosion resistance. The formation of intermetallic phases such as sigma phase occurs in the temperature range 600-1000 °C and decomposition of ferrite occurs in the range 350-500 °C (475°C embrittlement).

Exposures at these temperatures should therefore be avoided. In proper welding and heat-treatment operations the risk of embrittlement is low. However, certain risks exist, for example at heat treatment of thick sections, especially if the cooling is slow. Figure 13 illustrates the relation between time and temperature that leads to a reduction of the impact toughness with 50%.

Due to the risk of embrittlement, the duplex steels should only carefully be used at temperatures above 250–325°C. The maximum temperature depends on the grade and the design rule being used as well as on the actual temperature/time exploitation of the final product in combination with what degree of influence on the properties that can be accepted for the specific final use. Contact Outokumpu for more information.

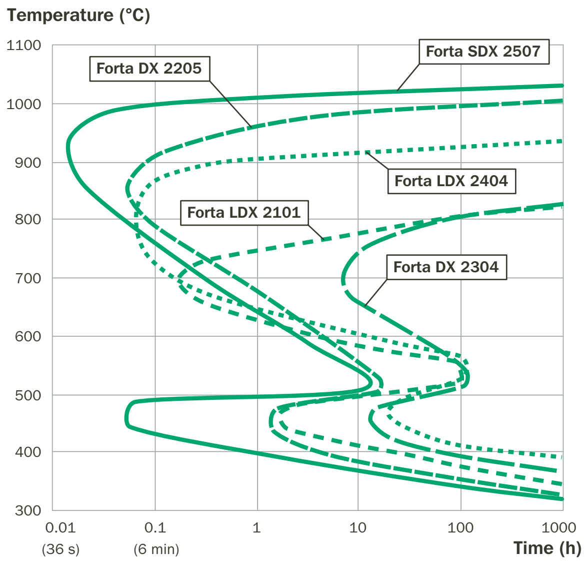

Fig. 13. TTT diagrams illustrating the time and temperature leading to 50% reduction of impact toughness.

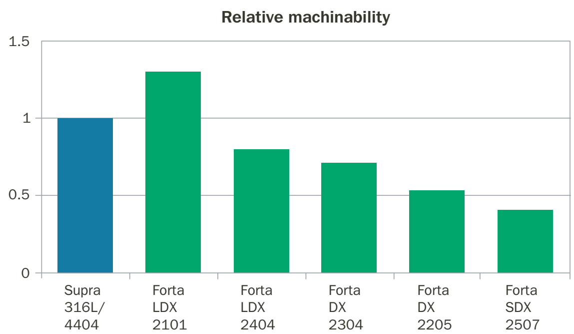

Fig. 14. Machinability index comparing Forta duplex and Supra 316L/4404. Data for Forta LDX 2101 indicates a level possible with machining parameters adjusted to the grade.

Machining

Duplex steels are generally more demanding to machine than conventional austenitic stainless steel such as Supra 316L/4404, due to the higher hardness.

The machinability can be illustrated by a machinability index, as illustrated in Figure 14. This index, which increases with improved machinability, is based on a combination of test data from several different machining operations. It provides a good description of machinability in relation to Supra 316L/4404. For further information, see our Machining Guidelines available for all duplex grades, or contact Outokumpu.

Due to the higher strength, the cutting forces will be higher, which increases the risk of vibrations. The trick is to have a stable setup. Use the shortest possible tool extension plus good and rigid clamping

Use cutting tools with a positive geometry. Duplex stainless steels are prone to work hardening. Non-sharp tools will generate a hard surface and decrease the tool life.

The swarf generated during machining can stick to tools. Problems especially occur when the cutting speed is too low. The main difference between carbon steel and stainless steels when machining is that problems are faced in the event of slow running. The result will be poor surface finish and short tool life. The problem is simply solved by increasing the cutting speed.

The lean duplex product Forta LDX 2101 has superior machinability compared with other duplex stainless steels. Even compared with low-alloyed standard austenitic stainless steel, Forta LDX 2101 is often easier to machine provided that the machining parameters are adjusted for Forta LDX 2101.

Welding consumables

Table 15

Outokumpu name	EN	ASTM		Consumable ISO designation
		Type	UNS	
Duplex, high strength, high corrosion resistance and enhanced resistance to stress corrosion cracking				
Forta DX 2205	1.4462	–	S32205	22 9 3 NL
Forta LDX 2101	1.4162	–	S32101	23 7 NL, 22 9 3 NL
Forta DX 2304	1.4362	–	S32304	23 7 NL, 22 9 3 NL
Forta EDX 2304	1.4362	–	S32304	22 9 3 NL
Forta LDX 2404	1.4662	–	S82441	22 9 3 NL
Forta SDX 100	1.4501	–	S32760	25 9 4 NL
Forta SDX 2507	1.4410	–	S32750	25 9 4 NL
Forta FDX 27	1.4637 *)	–	S82031	22 9 3 NL

*) Designation included in Stahl-Eisen-Liste.

Welding

Duplex stainless steels can be welded with most of the methods used for austenitic stainless steel such as:

- Shielded metal arc welding (SMAW)
- Gas tungsten arc welding (GTAW, TIG)
- Gas metal arc welding (GMAW, MIG)
- Flux-cored arc welding (FCAW)
- Plasma arc welding (PAW)
- Submerged arc welding (SAW)
- Laser beam welding (LBW)
- Others: Resistance and high frequency (HF) welding

In general, the main challenge when welding Outokumpu Forta range duplex products is maintaining the phase balance in the heat-affected zone (HAZ) without precipitation. The chemical composition balances the microstructure. Therefore, it is important to use the correct welding consumable and procedure.
The following general instructions should be followed when welding Forta range duplex products:

1. Weld without preheating.
2. Allow the material to cool between passes, preferably to below 150 °C/300 °F (for Forta SDX 2507 and Forta SDX 100 100 °C/210 °F).
3. Duplex filler material is required and recommended with the exception of Forta LDX 2101, which can be welded without filler material in some cases.
4. The recommended arc energy should be kept within specified limits.
5. The heat input should be adapted to the product and adjusted to the thickness of the welded material.
6. The edge preparation angle should be about 10° greater and the land should be somewhat smaller than when welding standard austenitics.
7. If welded with filler, post-weld annealing is normally not necessary.
8. For GTAW and PAW methods, the addition of nitrogen (1–2%) to the shielding/purging gas is recommended.

Further information concerning these operations is available from Outokumpu.

Welding to other steels, including carbon steels

Outokumpu Forta range duplex stainless steels are readily weldable to other steels, including carbon steels. The filler type should be duplex. When duplex steels are welded to carbon steels, one alternative is to use a 23Cr13Ni2Mo type filler. In most cases duplex fillers offer more strength and better corrosion resistance. When welding duplex to super austenitic steels, please contact Outokumpu for assistance.

Post-weld treatment

In order to restore the stainless steel surface and achieve good corrosion resistance, it is necessary to perform a post-weld treatment. There are both mechanical methods (for example, brushing, blasting, and grinding) and chemical methods (for example, pick- ling) available. The most appropriate method depends on the type of imperfections to be removed, as well as corrosion resistance, hygiene, and aesthetic requirements.

Products and dimensions

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

Products and dimensions

Table 16

Product group	Quarto plate	Hot rolled coil, strip and sheet	Cold rolled coil, strip and sheet	Precision strip
Forta Duplex	✓	✓	✓	✓

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**

Product standards

Table 17

Standards	
Flat products	
EN ISO 18286	Hot-rolled stainless steel plates – Tolerances on dimensions and shape
EN 10051	Hot-rolled steel strip tolerances
EN 10088-1	Stainless steels – Part 1: List of Stainless steels
ISO 15510	Stainless steels – chemical composition
EN ISO 9445	Cold-rolled stainless narrow strip, wide strip, plate/sheet and cut lengths tolerances
ASTM A 480	General requirements for flat-rolled stainless and heat resisting steel
ASTM A 959	Harmonized standard grade compositions for wrought stainless
ASME II-D	Materials – Physical properties tables
Flat and long products	
EN 10028-7	Flat products for pressure purposes – Stainless steels
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 10088-4	Technical delivery conditions for sheet/plate and strip
EN 10088-5	Technical delivery conditions for bars, rods wire, sections and bright products of corrosion resisting steels for construction purposes
EN 10095	Heat resisting steels and nickel alloys
EN 10151	Stainless steel strip for springs
EN 10302	Creep resisting steels, nickel and cobalt alloys
ASTM A 167	Stainless and heat-resisting Cr-Ni steel plate, sheet, and strip
ASTM A 176	Stainless and heat-resisting Cr steel plate, sheet, and strip
ASTM A 240	Cr and Cr-Ni stainless steel plate, sheet and strip for pressure vessels
ASTM A276	Stainless steel and heat resisting steel bars and shapes
ASTM A479/479M	Stainless steel bars for boilers/pressure vessels
ASTM A493	Stainless steel and heat-resisting steel rod and wire for cold heading and forging
ASTM A555	General requirements for stainless and heat resistant steel wire and wire rod
ASTM A 666	Austenitic stainless steel sheet, strip, plate, bar for structural and architectural applications
ASME II-A	Materials. Part A – Ferrous Material Specifications

Duplex pressure vessel approvals

Forta DX 2205, Forta LDX 2101, Forta DX 2304, Forta EDX 2304, Forta LDX 2404, Forta SDX 100 and Forta SDX 2507 are listed in EN 10028-7:2016.

In ASME II-A 2015, Forta DX 2205 (S31803 and S32205), Forta LDX 2101 (S32101), Forta DX 2304 (S32304), Forta EDX 2304 (S32304), Forta LDX 2404 (S82441), Forta SDX 100 (S32760) and Forta SDX 2507 (S32750) are listed for general use in the temperature range -30 – 316 °C. Data for Forta FDX 27 can be found in ASME code case 2860 and 2861, valid up to and including 5 mm thickness.

Certificates and approvals

Outokumpu meets the most common certifications and approvals including:

- 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 full list of certificates and approvals by mill, see **outokumpu.com/certificates**

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

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Working towards forever.

We work with our customers and partners to create long lasting solutions for the tools of modern life and the world's most critical problems: clean energy, clean water, and efficient infrastructure. Because we believe in a world that lasts forever.

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

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