outokumpu
high performance stainless steel

Forta FDX – Formable Duplex Stainless Steel

Steel grades

Table 1

Outokumpu	EN	UNS
Forta FDX 27	1.4637*	S82031

*) Designation according to Stahl Eisen Liste (Register of European Steels).

General characteristics

Ferritic-austenitic stainless steels, also referred to as duplex stainless steels, combine many of the beneficial properties of ferritic and austenitic steels. Due to the relatively high content of chromium and nitrogen, these steels offer good resistance to localized and uniform corrosion.

The new Forta FDX 27 exhibits a unique combination of high strength and substantially improved formability utilizing Transformation Induced Plasticity (TRIP). Characteristic properties are:

- Increased formability compared to other duplex grades
- High mechanical strength
- Good resistance to uniform corrosion
- Good resistance to pitting and crevice corrosion
- High resistance to stress corrosion cracking and corrosion fatigue
- Good abrasion and erosion resistance
- Good fatigue resistance
- High energy absorption
- Low thermal expansion
- Good weldability

Applications

The Forta FDX 27 provides a totally new stainless steel solution for applications where the formability of other duplex grades is not sufficient or limits the design capability. Examples of potential applications are given below:

- Plate heat exchangers
- Flexible pipes
- Pump components
- Components for automotive and transportation industry (high pressure, lightweight)
- Components for structural design
- Domestic heating boilers
- Forming intensive components
- Domestic water heaters

Chemical composition

The range in chemical composition according to Stahl Eisen Liste (Register of European Steels) and ASTM A240 of Forta FDX 27 is shown in Table 2.

Chemical composition

Table 2

Outokumpu Steel name	EN	ASTM/UNS	Typical chemical composition, % by mass[1]					
			C	Cr	Ni	Mo	N	Others
Forta FDX 27	1.4637	S82031	≤ 0.04	19.0-22.0	2.0-4.0	0.6-1.4	0.14-0.24	≤ 2.5Mn
Forta LDX 2101	1.4162	S32101	0.03	21.5	1.5	0.3	0.22	5Mn Cu
Forta DX 2304 [2]	1.4362	S32304	0.02	23.0	4.8	0.3	0.10	Cu
Core 304L/4307	1.4307	304L	0.02	18.1	8.1	–	–	–
Supra 316L/4404	1.4404	316L	0.02	17.2	10.1	2.1	–	–

[1] For Forta FDX 27 the range in chemical composition is given.
[2] Also available as Forta EDX 2304 with modified composition for enhanced properties.

Mechanical properties, room temperature

Table 3

Outokumpu Steel name	Typical values (1 mm)					Minimum values [1)]		
	$R_{p0.2}$ MPa	R_m MPa	A_{50} %	A_{80} %	Ag %	$R_{p0.2}$ MPa	R_m MPa	A_{50} %
Forta FDX 27	650	850	40	36	34	500	700	35
Forta LDX 2101	620	825	31	28	19	530	700	30
Forta DX 2304	620	800	28	26	19	400	600	25
Core 304L/4307	280	630	62	58	52	170	485	40
Supra 316L/4404	285	610	60	56	47	170	485	40

Source: Forming handbook for 1 mm sheet thickness. [1)] Minimum values according to ASTM A240, t < 5mm.

Microstructure

The chemical composition of duplex stainless steels is generally balanced to give approximately equal amounts of ferrite and austenite in solution-annealed condition. For the Forta FDX 27 the composition is balanced to give an optimal austenite stability leading to a controlled transformation of austenite to martensite during cold forming operations (so-called TRIP). Typically, the austenite content in the solution annealed condition is slightly higher for the Forta FDX grade than for other duplex grades.

The Forta FDX alloy is not sensitive to sigma phase formation. However, like all duplex grades it is more prone to precipitation of nitrides and carbides than the corresponding austenitic steels. Due to the risk of 475 °C embrittlement that occurs for the duplex grades, the Forta FDX alloy should be used with caution at temperatures above 250 °C.

Mechanical properties

Table 3 shows the mechanical properties for flat cold rolled products. Typical values are given for Outokumpu material in 1mm thickness, minimum values are according to ASTM A240.

Fatigue

The fatigue strength for 50% probability of failure at 2 million cycles tested in air at room temperature and 20 Hz is shown in Table 4. The high yield and tensile strength of the formable duplex stainless steels also implies high fatigue strength. As shown by the table the fatigue strength of the formable duplex steels corresponds approximately to the yield strength of the material.

Fatigue strength, cold rolled sheet.

Table 4

	Forta FDX 27
$R_{p0.2}$ [MPa]	577
R_m [MPa]	806
Fatigue strength σ_{max}, 50% probability [MPa]	549

Test conditions: 2 million cycles, R = 0.1, f = 20 Hz, in air at room temperature.

Temper rolled condition

Temper rolling is a technique used to increase the strength of a material by cold working through precise cold rolling reduction. By this it is possible to obtain defined strength levels for specific thicknesses.

Due to higher elongation values on cold rolled condition than regular duplex, Forta FDX 27 can be temper rolled to reach higher yield and tensile strength and still keep an acceptable formability (elongation) level and corrosion resistance (see Figure 1).

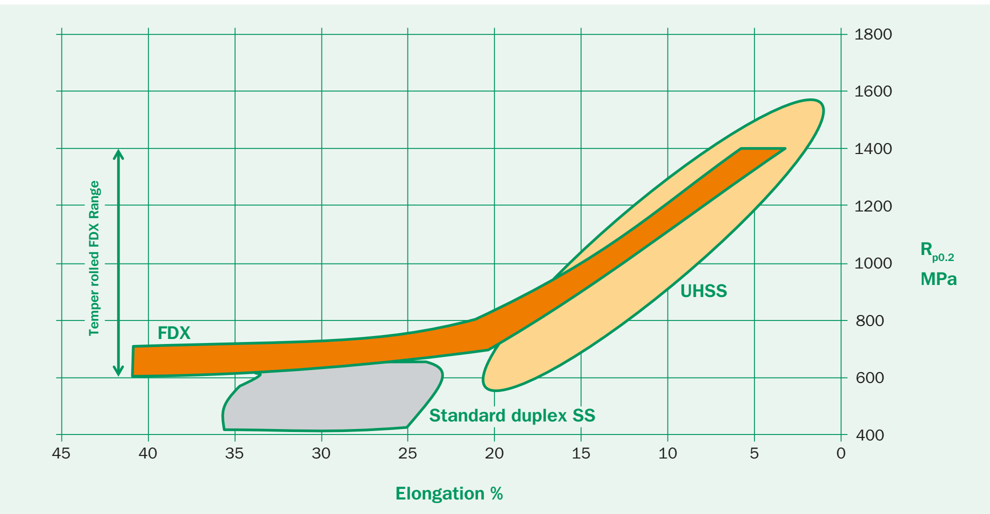

Figure 1. Yield strength and elongation of Forta FDX 27 grades after different levels of cold working compared to standard duplex stainless steels and ultra high strength steels (UHSS).

Fabrication

Cold forming

The high yield strength of duplex stainless steel compared to austenitic and ferritic stainless steel can impose some differences in forming behaviour depending on chosen forming technique. 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 down gauging.

Forta FDX 27 have excellent formability properties in comparison to other duplex stainless steels such as Forta LDX 2101 and Forta DX 2304 and close to standard austenitic stainless steels such as Core 304L/4307 and Supra 316L/4404. The TRIP effect offers a balanced work hardening rate resulting in an enhanced uniform elongation and higher work hardening ratio at large (plastic) deformations in comparison to other duplex grades. These remarkable mechanical properties make Forta FDX 27 more suitable for manufacturing of components with stretch forming as the primary forming operation. As for most of the duplex stainless steels, the Lankford values (r-values) are less than 1.0 in transversal direction but always larger than 0.4.

Figure 2 shows the elongation versus the yield strength for different types of stainless steels illustrating that Forta FDX 27 has a unique combination of properties.

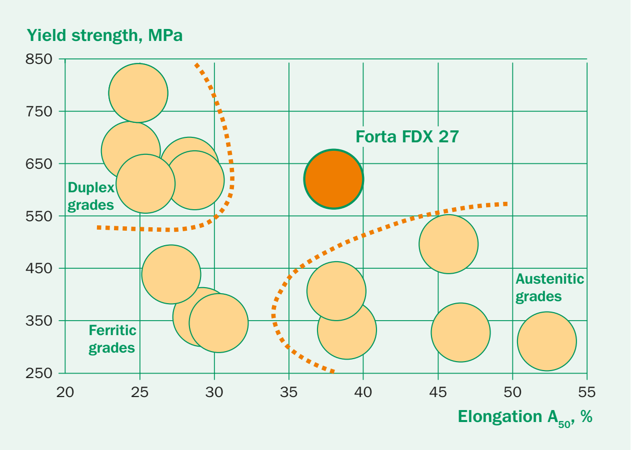

Figure 2. Elongation versus yield strength for different types of stainless steels. Typical values for cold rolled coil and sheet.

The key advantage of Forta FDX 27 compared to other duplex grades is that it is more adaptable to various forming processes since it has far better formability. For example, components to be formed predominantly by deep drawing can almost be designed as those made in standard austenitic stainless steels with good results. Moreover, physical try-outs verify that Forta FDX 27 is suitable for forming intensive components such as heat exchanger plates. For special cases, Outokumpu Avesta Research Centre can support customers in detailed computer analyses of the impact on the forming process of the Forta FDX grade.

Welding

Trials, qualified welders and procedures are natural parts of professional welding. With this in place duplex stainless steels are readily weldable using most of the welding methods used for austenitic stainless steels, Forta FDX 27 is no exception. The TRIP effect in Forta FDX 27 will be present but to a lower degree when welding autogenously and the effect will not be present when welding with a filler material. The general welding recommendations for duplex grades should be followed, e.g. the use of nitrogen based shielding gas which will enhance the properties of the joint. Suitable welding consumables are listed in Table 5.

Welding consumables

Table 5

Steel grade	Consumable ISO Designation	Typical composition, % by mass				
		C	Cr	Ni	Mo	N
Forta FDX 27	22 9 3 NL	0.02	22.5	8.5	3.0	0.15

Post fabrication treatment

In order to restore the stainless steel surface and achieve good corrosion resistance after fabrication it is often necessary to perform a post fabrication treatment. There are many different methods available. Both mechanical methods such as brushing, blasting and grinding, and chemical methods, e.g. pickling. Which method to apply depends on what consequences the fabrication caused, i.e. what type of imperfections to be removed, but also on requirements with regard to corrosion resistance, hygienic demands and aesthetic appearance. Vigorous mechanical cleaning like heavy grinding and shot blasting should be avoided for Forta FDX 27, as this can affect the corrosion resistance negatively. Chemical cleaning is always preferred for optimal corrosion resistance.

Corrosion resistance

The duplex grades provide in general a wide range of corrosion resistance in various environments. Corrosion results presented in this data sheet are from non-deformed flat specimens, unless stated otherwise. However, as the increased formability of Forta FDX 27 is based on the transformation induced plasticity, it is of interest to investigate whether deformation and deformation induced martensite affects the corrosion resistance of the grade. Results from performed studies [1] have shown that there is no significant detrimental effect of tensile deformation (up to 30%) on the corrosion properties of the new formable duplex stainless steel. With regards to pitting corrosion the Figure 3 shows that there is no pronounced effect of tensile deformation on the measured critical pitting temperature.

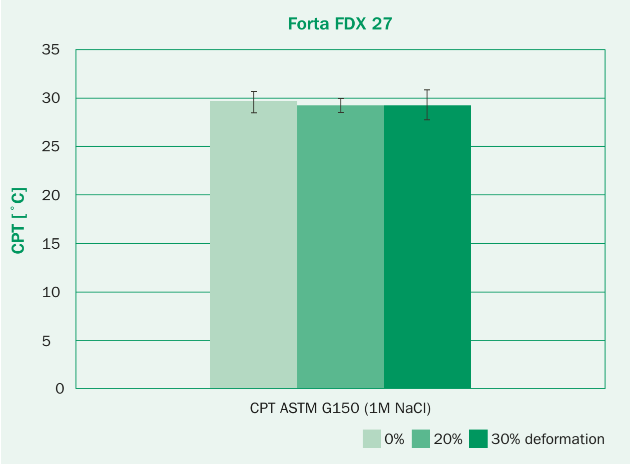

Figure 3. The effect of tensile deformation on the critical pitting temperature (CPT) for Forta FDX 27. Tests were carried out according to ASTM G150 in 1M NaCl. The error bars indicate the standard deviation [1].

Critical temperatures in solutions prescribed by MTI-1 and five additional solutions that reflect practical situations

Table 6a

Test solution	HCl	HCl	HCl + $FeCl_3$	H_2SO_4	H_2SO_4 + NaCl, °C	H_2SO_4	H_2SO_4	H_3PO_4	H_3PO_4 + HF	WPA 1	WPA 2
Conc. %wt	**0.2**	**1.0**	**1.0 + 0.3**	**10**	**10 + 0.33**	**60**	**96**	**85**	**83 + 2**	***See Table 7***	
Forta FDX 27	>bp	65	35	45	25	<20	20	85	35	60p*	<20
Forta LDX 2101	>bp	55	20	75	40	<15	30	100	40	60	<25
Forta DX 2304	>bp	70	35	70	<10	<15	35	90	35	60	35
Forta EDX 2304	>bp	75	40	75	<20	<20	40	90	N.T.	55	N.T.
Forta LDX 2404	>bp	95p	50	75	35	<15	40	100	45	55	55
Forta DX 2205	>bp	85	45p	60	35	<15	25	90	50	45	60
Core 304L/4307	>bp	30p*	20p	25	N.T.	<15	15	80	45	<10	<10
Supra 316L/4404	>bp	30	25	40	25	<20	45	95	45	<10	<20
Supra 316L/4432	>bp	40	30	40	25	<15	45	95	40	<10	<10

*) Pitting attack may occur at lower temperature than the critical. bp = boiling point. N.T. = not tested.

Table 6b

Test solution	HNO_3	HNO_3	HNO_3 + HCl	CH_3COOH	$CH_3COOH + (CH_3CO)_2O$	HCOOH	NaOH
Conc. %wt	**10**	**65**	**60 + 2**	**80**	**50 + 50**	**50**	**50**
Forta FDX 27	>bp	95	>60	>bp	110	75	80
Forta LDX 2101	>bp	105	>60	>bp	105	95	85
Forta DX 2304	>bp	90	>60	>bp	95	85	100
Forta EDX 2304	>bp	95	>60	>bp	95	90	105
Forta LDX 2404	>bp	100	>60	>bp	90	85	100
Forta DX 2205	>bp	105	>60	>bp	100	90	90
Core 304L/4307	>bp	100	>60	100p	>bp	<10	85
Supra 316L/4404	>bp	100	>60	>bp	120	40	90
Supra 316L/4432	>bp	95	>60	>bp	120	40	90

*) Pitting attack may occur at lower temperature than the critical. bp = boiling point.

Chemical composition of simulated wet process phosphoric acid (WPA)

Table 7

	Chemical composition, % by weight.								
	H_3PO_4	Cl-	F-	H_2SO_4	Fe_2O_3	Al_2O_3	SiO_2	CaO	MgO
WPA 1	75	0.2	0.5	4.0	0.3	0.2	0.1	0.2	0.7
WPA 2	75	0.02	2.0	4.0	0.3	0.2	0.1	0.2	0.7

Uniform corrosion

Uniform corrosion is characterized by a uniform attack on the steel surface in contact with a corrosive medium. Uniform corrosion data in various solutions based on the MTI-1 procedure are shown in Tables 6a and 6b. The results are presented as the critical temperature (°C) where the corrosion rate exceeds 0.127 mm/year in the test solution.

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 for different grades are presented in Table 8. The PRE value can be used for a rough comparison between different materials.

A much more reliable way of ranking steels is according to the critical pitting temperature (CPT). Typical critical pitting corrosion temperature data (CPT) in 1M NaCl is presented in Figure 4.

Stress corrosion cracking

Stainless steel can be affected by stress corrosion cracking (SCC) in chloride containing environments at elevated temperatures. Standard austenitic stainless steels (from our Core and Supra ranges) are particularly vulnerable to stress corrosion cracking while stainless steels of the duplex type 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 9 a comparison is given of the stress corrosion cracking resistance of standard austenitic stainless steels and duplex stainless steels.

Duplex stainless steels withstand stress corrosion cracking under many conditions where standard austenitic grades are expected to fail.

Products

Thickness

- Cold rolled coil and sheet 0.2 – 3.7 mm.

Width

- Slitted strip from 10 mm up to full coil 1524 mm.

Finish

- < 0.4 mm, 2R finish (cold rolled, bright annealed).
- 0.4 – 3.7 mm, 2E finish (cold rolled, heat treated, mechanically descaled, pickled).

Product specifications and approvals

The FDX grade is included in ASTM A240 and work is in progress for EN standardization.

PRE values for some duplex and austenitic grades

Table 8

Outokumpu steel name	PRE
Forta FDX 27	27
Forta LDX 2101	26
Forta DX 2304	26
Core 304L/4307	18
Supra 316L/4404	24

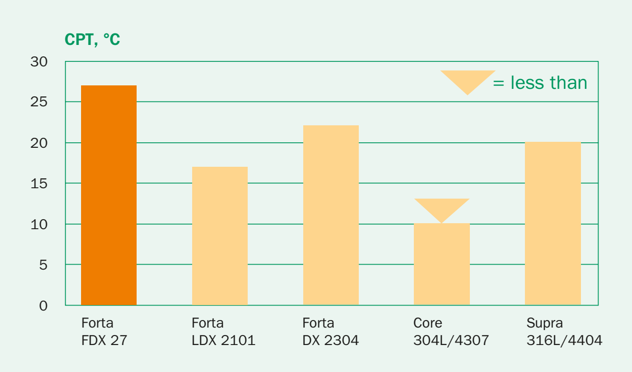

Figure 4. Typical critical pitting corrosion temperatures (CPT) in 1M NaCl measured according to ASTM G150 by using the Avesta Cell. Test surfaces wet ground to P320 mesh. CPT varies with product form and surface finish.

Comparative stress corrosion cracking resistance in accelerated laboratory tests

Table 9

Outokumpu steel name	ASTM G36 45% $MgCl_2$ 155 °C (b.p.) U-bend	ASTM G123 25% NaCl, pH 1.5 106 °C (b.p.) U-bend	40% $CaCl_2$ 100 °C 0.9 x $R_{p0.2}$ Four-point bend
Forta FDX 27	Expected	Not anticipated	Not anticipated
Forta LDX 2101	Expected	Not anticipated	Not anticipated
Forta DX 2304	Expected	Not anticipated	Not anticipated
Core 304L/4307	Expected	Expected	Expected
Supra 316L/4404	Expected	Expected	Possible

Expected = SCC is expected to occur. Not anticipated = SCC is not expected to occur. Possible = SCC may occur. b.p. = boiling point.

References

[1] M. Schönning, L. Wegrelius, E. Stark. Influence of Deformation on Corrosion Resistance of the New Duplex Transformation Induced Plasticity (TRIP) Stainless Steels UNS S82012 and UNS S82031. (Dallas, NACE 2015), Paper no. 5724.

Own notes

1521EN-US:4. August 2017.

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