outokumpu
sustainable stainless steel

Sanicro® 35 – Bridging the gap between stainless and Ni-based alloys

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).

Sanicro® 35 is an alloy combining the best features of a high performance austenitic stainless steel and nickel based alloys. This grade is our latest addition to the Ultra range, it has excellent corrosion resistance in combination with a high mechanical strength.

Sanicro® 35 in a nutshell:

- Excellent resistance to pitting and crevice corrosion
- Excellent resistance to stress corrosion cracking (SCC)
- High resistance to uniform corrosion in acid and caustic environments
- High resistance to erosion-corrosion
- Very high mechanical strength
- Good weldability using nickel based alloy consumables
- Good fabricability, i.e. machining and forming

Chemical composition

Table 1

Alloy 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
Sanicro® 35 [2]	–	–	N08935	52	40	425	A	0.02	27.0	35.5	6.4	0.27	Cu
For comparison													
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	20.0	18.0	6.1	0.20	Cu
Ultra Alloy 825	2.4858 [3]	–	N08825	33	30 [4]	241 [4]	A	0.01	23.0	39.0	3.2	–	Cu, Ti, Al
Forta SDX 2507	1.4410	–	S32750	43	20	550	D	0.02	25.0	7.0	4.0	0.27	–
Alloy 625 [5]	–	–	N06625	51	30 [6]	414 [6]	A	0.01	20–23	>58	8–10	–	Nb+Ta
Alloy C-276 [5]	2.4819 [3]	–	N10276	69	40 [7]	283 [7]	A	0.01	14.5–16.5	Base	15–17	–	W, Co

Grade family: A = austenitic, D = duplex. [1] Elongation reference varies between different standards, for coil the standard typically uses A_{80} – otherwise see footnote for specific grade. [2] Min. values hot-rolled and cold-rolled ≤ 6.35 mm acc. to ASTM B625. [3] Grade designation according to DIN17750. [4] Min values hot rolled and cold rolled acc. to ASTM B424. [5] Not produced by Outokumpu. [6] Values acc. to ASTM B443. [7] Min values hot rolled and cold rolled acc. to ASTM B575.

Sanicro® 35 is a trademark owned by Alleima AB and produced as plate and sheet by Outokumpu under a license agreement.

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 forms at **steelfinder.outokumpu.com**

Applications

Due to its extremely good pitting and crevice corrosion properties, Sanicro® 35 is particularly suitable for applications where seawater is used for cooling or heating. Sanicro® 35 also has a high resistance to uniform corrosion in acid environments, making it suitable for a variety of applications. It is an attractive material of choice for applications within the oil and gas industry where H_2S may be present, thanks to its high resistance to stress corrosion cracking.

Corrosion resistance

Uniform corrosion

Thanks to the combination of high contents of nickel, chromium and molybdenum, Sanicro® 35 has good resistance to many commonly found acids, such as sulfuric acid, nitric acid, phosphoric acid and organic acids.

Sanicro® 35 has better resistance in hydrochloric acid compared to stainless steels with a lower chromium and molybdenum content and can be useful in environments where moderate levels of hydrochloric acid is present. See Figure 1.

In low to intermediate concentrations of sulfuric acid, the resistance of Sanicro® 35 is better than Ultra 904L, see Figure 2. In chloride contaminated sulfuric acid, Sanicro® 35 can be expected to offer significantly better resistance than Ultra 904L and Ultra 254 SMO, see Table 2.

The high chromium content in Sanicro® 35 causes complete passivity in a wide range of environments, maintaining negligible corrosion rates in conditions where even Ni-based grades may corrode actively, as shown in Table 2. Once passivity can no longer be maintained (i.e. above the isocorrosion line), corrosion rates may be higher.

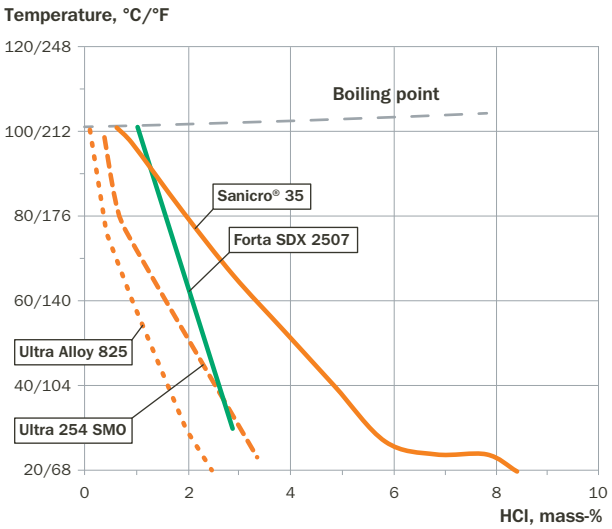

Fig. 1. Isocorrosion diagram for Sanicro® 35 in hydrochloric acid. The line represents a limit, below which the corrosion rate is expected to be lower than 0.1 mm/year. Other grades are included for comparison.

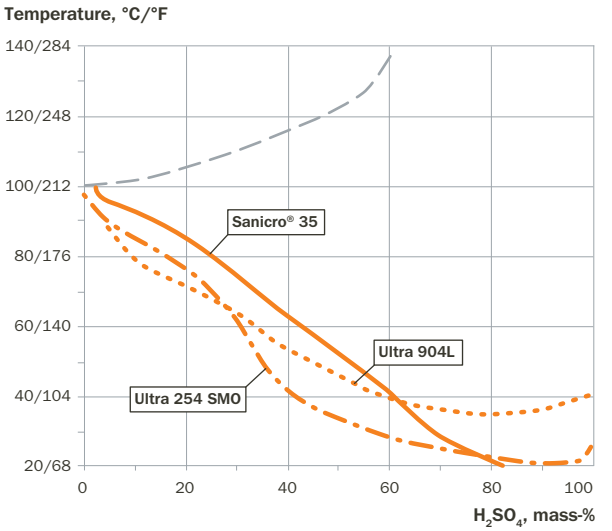

Fig. 2. Isocorrosion diagram for Sanicro® 35 in sulfuric acid. The line represents a limit, below which the corrosion rate is expected to be lower than 0.1 mm/year. Other grades are included for comparison.

Uniform corrosion rates (mm/year) after testing in 20 weight% sulfuric acid according to ISO 18069.

Table 2

Alloy designation	0 ppm chlorides			200 ppm chlorides		2,000 ppm chlorides
	60 °C	80 °C	100 °C	60 °C	80 °C	60 °C
Sanicro® 35	–	**0.00**	**1.92**	–	**0.00**	**0.00**
Ultra 904L	0.05	1.16	–	0.44	0.42	0.48
Ultra 254 SMO	0.15	1.40	–	0.59	2.34	0.84
Ultra Alloy 825	0.06	0.17	0.15	0.24	0.66	0.30
Alloy 625	0.05	0.30	0.33	0.17	0.12	0.97
Alloy C-276	0.19	0.25	0.20	0.20	0.21	0.13

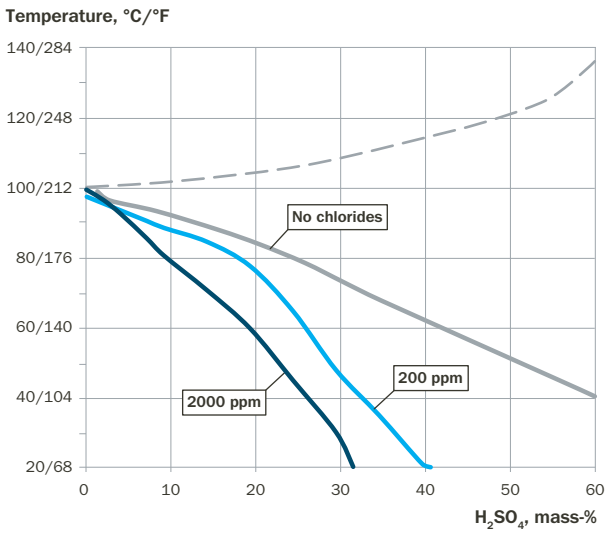

Fig. 3. Performance comparison of Sanicro® 35 in sulfuric acid with and without chloride addition. The line represents a limit, below which the corrosion rate is expected to be lower than 0.1 mm/year.

Uniform corrosion rates (mm/year) after testing in 50 weight% formic acid, with and without addition of chlorides, according to ISO 18069.

Table 3

Alloy designation	0 ppm chlorides		1,000 ppm chlorides	
	100 °C	Boiling	100 °C	Boiling
Sanicro® 35	**0.03**	**0.10**	**0.02**	**0.58**
Ultra 904L	0.15	0.15	1.19	
Ultra 254 SMO	0.03	0.24	0.09	1.36
Forta SDX 2507	0.00	0.24	0.00	0.43
Ultra Alloy 825	0.54	0.07	1.05	
Alloy 625	0.12	0.03	0.48	1.11
Alloy C-276	0.27	0.05	0.26	0.34

PRE, CPT and CCT data, typical values.

Table 4

Alloy designation	PRE	CPT [°C]		CCT [°C]
		ASTM G150 [1]	ASTM G48 E [2]	ASTM G48 F [2]
Sanicro® 35	**52**	**>90**	**85**	**45**
Ultra 904L	34	58 ± 3	40	10
Ultra 254 SMO	43	87 ± 3	65	35
Ultra Alloy 825	33	56 ± 3	25	5
Alloy 625	51	>90	90	25
Alloy C-276	69	>90	>BP	50

[1] Wet ground surfaces, P320 grit.
[2] Dry ground surfaces, P120 grit.

90-day corrosion tests in natural and chlorinated seawater at various temperatures.

Table 5

Test condition	Sanicro® 35		Alloy 625	
	Pitting	Crevice	Pitting	Crevice
30 °C Natural	No	No	No	Yes
45 °C Chlorinated 0.5 ppm Cl_2	No	No	No	No
80 °C Chlorinated 0.5 ppm Cl_2	No	–	No	–

Figure 3 shows the effect of chloride addition on the isocorrosion curves in sulfuric acid.

Sanicro® 35 performs well in oxidizing acids, where the high chromium content is beneficial.

In organic acids, such as formic acid, Sanicro® 35 generally performs better than stainless steel alternatives and can also be an attractive alternative to higher-alloyed Ni-base grades. Table 3 shows uniform corrosion data in 50% formic acid, highlighting its high resistance even in the presence of chlorides.

Sanicro® 35 also has good resistance to uniform corrosion in alkaline environments, such as sodium and potassium hydroxide solutions. Tests performed at 120 °C showed corrosion rates below 0.1 mm/year in sodium hydroxide concentrations between 40 and 70%.

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.

Although the PRE typically exhibits good agreement with practical performance, it is only a theoretical approximation. A more reliable means to rank the alloys, based on laboratory testing, is by critical pitting temperatures (CPT) and critical crevice corrosion temperatures (CCT) of the material.

PRE, CPT and CCT data according to commonly used methods are listed in Table 4. The CPT value for Sanicro® 35 indicates a pitting resistance significantly higher than Ultra 254 SMO, and on a similar level as Alloy 625. Sanicro® 35 is resistant up to the maximum tested temperatures of 90°C in ASTM G150 and has a CPT of 85°C in ASTM G48 method E.

Sanicro® 35 offers higher crevice corrosion resistance than stainless steel alternatives and similar or better resistance compared to Ni-based materials such as Alloy 625 and Alloy C-276.

Table 5 shows the results from 90-day corrosion tests in natural and chlorinated seawater at various temperatures. The results show that Sanicro® 35 has excellent resistance to both pitting and crevice corrosion in seawater, even at elevated temperatures and chlorinated conditions.

Stress corrosion cracking

Due to its high nickel content, Sanicro® 35 exhibits excellent resistance to chloride induced stress corrosion cracking (SCC). Resistance to cracking can be expected in many environments where type 316L and similar grades would be susceptible to SCC. Cracking may occur in the most extreme conditions, such as in the boiling 45% $MgCl_2$ U-bend test. Even then, Sanicro® 35 exhibits higher resistance than 6Mo grades such as Ultra 254 SMO. See Table 6.

The grade complies with NACE MR0175/ISO 15156-3 as a type 4a and 4c material, with significantly higher environmental limits than 6Mo grades like Ultra 254 SMO. Additionally, cold worked Sanicro® 35 (965 and 1,240 MPa) has been tested in a NACE MR0175/ISO 15156 Test Level VI environment according to NACE TM0198 with no indication of SCC.

Number of cracked U-bend samples after testing in 45% $MgCl_2$ at boiling conditions for 24 hours. Table 6

Alloy designation	Cracked samples
Sanicro® 35	1/3
Ultra 254 SMO	3/3

Mechanical Properties

Table 7 shows the mechanical properties at room temperature for flat rolled products, data according to ASTM B625, EN 10088, ASTM B443 and ASTM B575 when applicable. Table 8 indicates the mechanical values at elevated temperatures.

Mechanical properties at 20 °C

Table 7

Alloy designation	Product form	Min. yield strength $R_{p0.2}$ [MPa]	Min. yield strength $R_{p1.0}$ [MPa]	Tensile strength R_m [MPa]	Min. elongation A [%]
Sanicro® 35 [1]	Sheet	425	–	750	40
	Plate < 6.35 mm	425	–	750	40
	Plate ≥ 6.35 mm	350	–	700	40
Ultra 254 SMO [2]	Cold rolled	320	350	650–850	35
	Hot rolled	300	340	650–850	35
	Plate	300	340	650–850	40
Alloy 625 [3]	Cold rolled sheet /strip	414	–	827	30
	Cold rolled plate ≤ 9.5 mm	379	–	758	30
	Hot rolled sheet and plate ≤ 70 mm	379	–	758	30
Alloy C-276 [4]	Plate	283	–	690	40
	Sheet	283	–	690	40
	Strip	283	–	690	40

Values according to [1] ASTM B625, [2] EN 10088-2, [3] ASTM B443 (Grade 1 not produced by Outokumpu) and [4] ASTM B575

Mechanical properties at elevated temperatures

Table 8

Temperature [°C]	Thickness [mm]	$R_{p0.2}$ [MPa]	$R_{p1.0}$ [MPa]
100	< 6.35	350	375
	6.35 ≤ t ≤ 50	250	280
200	< 6.35	300	325
	6.35 ≤ t ≤ 50	215	250
300	< 6.35	275	300
	6.35 ≤ t ≤ 50	200	240
400	< 6.35	250	275
	6.35 ≤ t ≤ 50	170	210
450	< 6.35	250	275
	6.35 ≤ t ≤ 50	160	200

Physical properties

Table 9

Temperature °C	Density [kg/dm³]	Modulus of elasticity [GPa]	Coefficient of thermal expansion 30-T °C [10^{-6}/K]	Thermal conductivity [W/(m x K)]	Thermal capacity [J/(kg x K)]	Electrical resistivity [Ω x mm²/m]	Magnetizable
20	8.1	190	–	10.0	450	1.0	No
100	–	185	14.0	12.0	470	–	–
200	–	180	14.5	13.5	500	–	–
300	–	175	15.0	15.5	510	–	–
400	–	170	15.5	17.0	530	–	–

Fabrication

Forming

Sanicro® 35 has a very good formability making it suitable for all sheet and plate forming processes as indicated by the high elongation value. Despite its high strength, Sanicro® 35 retains a very high fracture strain in comparison to other stainless steel and Ni-base alloys. However, the higher yield stress must be considered e.g. in terms of higher forces during forming and increased spring back after forming. Also, a higher demand on the tool material and lubricant should be taken into account. Both of these effects can be reduced, if down gauging is possible due to the increased strength.

The excellent forming properties of Sanicro® 35 can be quantified in several formability metrics. The r-value describes a material's tendency towards thinning in a certain forming direction, with higher values indicating lower tendency towards thinning. With values close to 1 in three tensile directions Sanicro® 35 is not only resilient to thinning but also shows almost isotropic behavior (see Figure 4) and therefore little to no earing.

The limiting factor for most sheet metal forming operations is the formability in plane strain condition. As indicated in Figure 5, Sanicro® 35 shows equal or slightly better formability when compared with Alloy 625 and Ultra 254 SMO. This is also the case for other formability metrics like the limiting dome height (LDH), which measures the ability of a material to withstand stretch forming. Here, Sanicro® 35 outperforms Alloy 625 by more than 10% and behaves similar to Ultra 254 SMO. The same can be said for the hole expansion ratio (HER), which determines the edge stretching ability of sheet metal, an attribute needed e.g. for the crimping of edges. For this metric an even stronger outperformance of more than 30% can be observed for Sanicro® 35 when compared to Alloy 625.

Welding

The weldability of Sanicro® 35 is good and welding is suitable using TIG (GTAW), MIG/MAG (GMAW), MMA (SMAW). For multi pass welding it is recommended to use TIG welding for the root pass. Welding should be undertaken with low heat input, maximum 1.2 kJ/mm, and an interpass temperature of maximum 100 °C.

Nickel based alloy UNS N06059 (ERNiCrMo-13, NiCr23Mo16) e.g. Avesta P16 is recommended as filler material. Use of filler material is recommended for this material. In addition Alloy 686 (ERNiCrMo-14) and C-22 (ERNiCrMo-10) can be utilized as an alternative to achieve matching strength and corrosion resistance. Autogenous welding should typically be avoided but if necessary, followed by appropriate and qualified post weld heat treatment.

Argon is recommended as shielding gas and backing/purging gas with TIG welding to achieve the best combination of mechanical properties and corrosion resistance of the welded joints.

For MIG/MAG welding Ar + 20–40% He + 1–3% CO_2 is recommended as shielding gas for optimal corrosion resistance and arc stability. Pure Ar can also be utilized.

Preheating and post-weld heat treatment are not necessary under normal circumstances. To maintain full corrosion resistance of the welded joint, welding must be followed by thorough cleaning to ensure the removal of all oxides and heat tint.

Welding of fully austenitic stainless steels and nickel based alloys often involves the risk of hot cracking in the welded joints if the weldment is under restraint. Due to the low level of impurities in Sanicro® 35, the risk of hot cracking is lower than for most nickel based alloys.

Joint type selection should be made according to recommendation for high alloyed austenitic stainless steels and nickel based alloys.

For more detailed information on welding procedures contact Outokumpu.

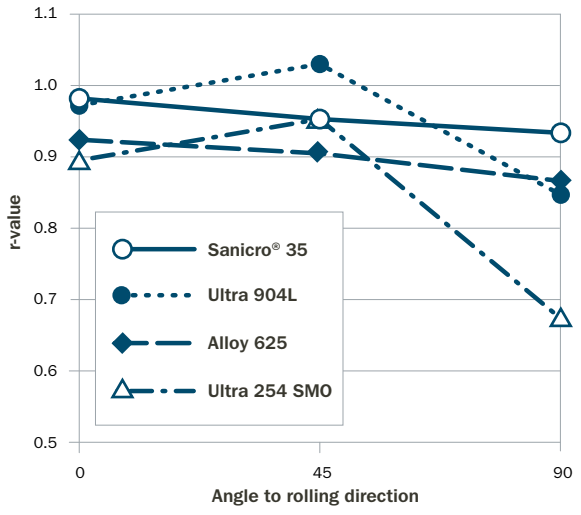

Fig. 4. r-values for some high performance alloys.

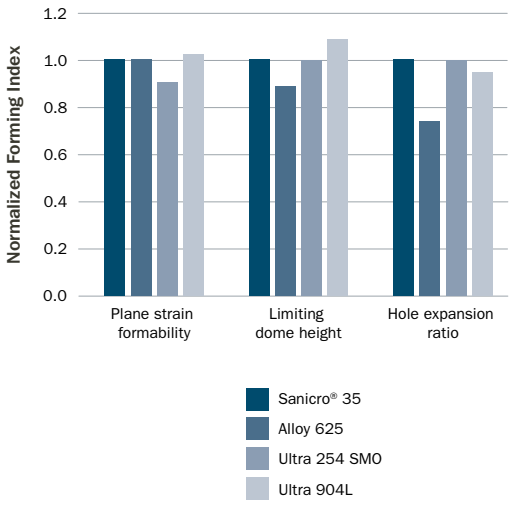

Fig. 5. Formability ranking of some high performance alloys.

Machining

High performance grades such as austenitic stainless steels and nickel-base alloys are generally perceived as challenging to machine due to their high work-hardening rate and toughness as well as their tendency towards built-up edge. This is especially the case for Sanicro® 35 due to its increased proof strength. However, with the right tools and setup Sanicro® 35 can be successfully machined.

The machinability of a certain grade can be described by the tool life, that is a function of the cutting speed. High cutting speeds typically corresponding to lower tool life, tested through varying the cutting speed until a preset tool life is achieved, this enables machinability comparison of different grades. In Figure 6 Sanicro® 35 is compared to Alloy 625 in terms of face milling and indexable drilling. For both processes Sanicro® 35 shows a superior machinability with roughly 20 % higher cutting speeds for 5 (V5) and 10 minutes of tool life (V10) in face milling and more than 50 % higher cutting speed for 20 minutes of tool life (V20) in indexable drilling. This enables either a higher productivity or a reduction in tooling costs when machining Sanicro® 35 as opposed to Alloy 625.

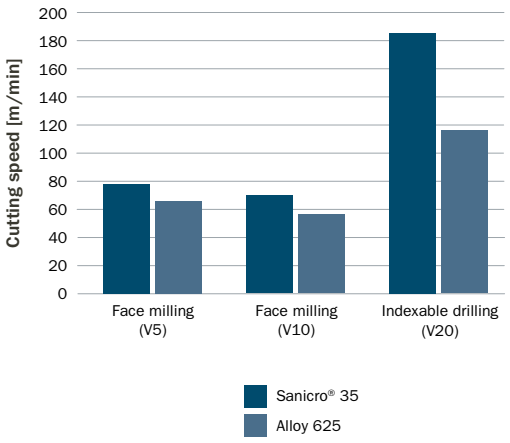

Fig. 6. Machinability index comparing Sanicro® 35 with Ni-base Alloy 625.

Products

Sanicro® 35 is available as cold rolled sheet and plate in thicknesses of 0.4–5.5 mm with a width of up to 1,350 mm.

Sanicro® 35 is available as hot rolled plate in thicknesses of 10–50 mm with a width of up to 2,000 mm.

Standards and Approvals

Sanicro® 35 as sheet and plate is included in ASTM B625 as UNS N08935.

Sheet, plate, bar and seamless tube and pipe are covered by the ASME Code Case 2982-2, Boiler and Pressure Vessel Code, Section VIII, Division I and II.

Compliance with NACE MR0175/ISO 15156-3:2015, (Petroleum, Petrochemical, and Natural Gas Industries - Materials for Use in H_2S-Containing Environments in Oil and Gas Production - Part 3: Cracking-Resistant CRAs (Corrosion-Resistant Alloys) and Other Alloys) for type 4a and type 4c materials. Compliance with ANSI/ NACE MR0103/ISO 17495-1:2016, (Petroleum, petrochemical and natural gas industries-Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments) for highly alloyed austenitic stainless steels and nickel alloys.

A pre-approval for Particular Material Appraisal (PMA), TÜV is available, Pre-PMA no:1326W232560.

Seamless tube and pipe are included in ASTM B163 and ASTM B677. Sanicro® 35 as bar and wire products are included in ASTM B649.

Contacts and enquiries

Contact us

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

www.outokumpu.com/contact

Notes

Working towards a world that lasts 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	Superior machinability	Special surfaces

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