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STAINLESS STEEL TECHNICAL HANDBOOK

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Welding of stainless steel requires knowledge about the material as well as welding methods and products to maintain the material's stainless properties. This technical handbook provides both. If you have any further questions regarding welding methods and products, ask our technical support. You will find your nearest Elga contact at www.elga.se.

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BRIEF HISTORY OF STAINLESS STEELS

221-206 BC The Chinese Qin dynasty uses chromium to strengthen weapons and protect them from corrosion.

1778 Molybdenum is discovered by another Swede; Carl Vilhelm von Scheele.

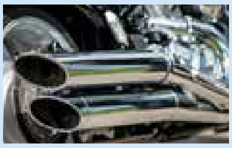
1871 First patent on “weather resistant steel” by John T Wood and John Clark.

1911 Philip Monnartz reports on the relationship between chromium content and corrosion resistance.

221 BC — 1751 — 1778 — 1797 — 1871 — 1910 — 1911 — 1912

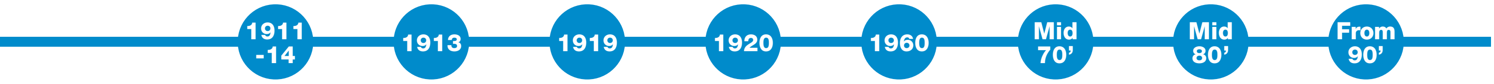
1751 Nickel is discovered by Swedish scientist Axel Fredrik Cronstedt.

1797 Nicolas Louis Vauquelin discovers Chrome.



1910 First patent on stainless steel in Germany by Philip Monnartz and William Borchers.

1912, Krupp engineers Benno Strauss and Eduard Maurer patent austenitic stainless steel as ThyssenKrupp Nirosta.



1911-14 Several ferritic stainless steels are discovered.

1913 Harry Brearley of the Brown-Firth research laboratory in Sheffield, England, while seeking a corrosion-resistant alloy for gun barrels, discovers and subsequently industrialized a martensitic stainless steel alloy.

1919 Elwood Haynes patents a martensitic stainless steel.

1920 First duplex stainless steel was produced
Avesta 453S (26Cr, 5Ni, 1.5Mo)
Avesta 453E (26Cr, 4Ni).

1960- Modern Duplex SS (Nitrogen alloying is possible) Sandvik 3R60 (18.5Cr, 5Ni, 2.7Mo).

Mid 70'
2205 (22Cr,5.5Ni, 3Mo,0,17N). This DSS still has highest annual tonnage.

Mid 80'
The oil industry drives the development of much more highly alloyed materials such as super duplex steels (e.g. SAF 2507/UNS S32750) with PREN values above 40, and super austenitic steels such as 254SMO (UNS S31254) and 654SMO (UNS S32654).

From 90' – present day
2205 continues to gain momentum in various industries. In some cases the extraordinary corrosion resistance is higher than necessary. This had led to the development of numerous lean duplex grades, such as LDX 2101® and Duplex 2304. These new stainless steels contain fewer alloying elements than 2205 and are designed for applications where they can replace grades like 304 and even 316. Source: ISSF.

STRUCTURE OF STAINLESS STEELS

Stainless steel is not a specific material, but a common term for a group of corrosion-resistant steel types. Stainless steels are steels which normally have a chromium content of at least 10.5%.

They can also contain nickel, molybdenum, nitrogen, copper, manganese, tungsten, titanium, niobium, cerium and other substances in varying degrees. Interest in nitrogen as an alloying element is increasing and many stainless steels, both austenitic and duplex with significant nitrogen levels have been in commercial use for the last ten years. It is well demonstrated that nitrogen in combination with molybdenum significantly increases resistance to pitting corrosion. The nitrogen also increases yield strength by solid solution strengthening of austenite.

Since the mechanical properties and the usefulness of each type of steel is dependent on its composition, it is important to take into account the different qualities of each type before choosing the steel and welding consumable for the application concerned.

Metallurgy

Alloying elements are usually divided into two groups – austenite stabilizers and ferrite stabilizers – as shown in table 1. Some alloying elements used in stainless steels are described in table 2.

Stainless steels are divided into four subgroups:

- Ferritic stainless steel
- Martensitic stainless steel
- Austenitic stainless steel
- Duplex stainless steel

Atmospheric corrosion resistance as a function of chromium content

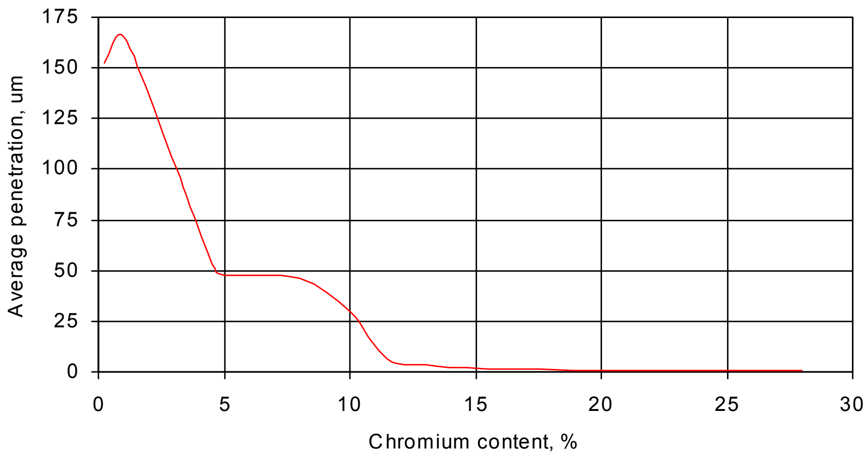


Figure 1. Chromium steels exposed in moderate marine atmosphere for 8 years.

Austenite stabilizers	Ni, Mn, C, N, Co, Cu
Ferrite stabilizers	Cr, Mo, Si, Ti, Nb, V, Al

Table 1.

Increasing the amount of austenite stabilizing elements or decreasing the amount of ferrite stabilizing elements will therefore promote a fully austenitic structure. In the same way, an increase in ferrite stabilizing elements or a decrease in austenite stabilizing elements would promote the ferritic phase.

Consider the phase diagram for Iron-Chromium-Nickel as shown in figure 2. Note that if we follow the composition 22% Cr-10% Ni (A) during cooling from liquid to room temperature, the first phase formed is delta. This is a ferritic phase also called delta-ferrite. At about 1400 °C, the melt is fully solidified and the phase present is delta-ferrite. Below this temperature, some of the delta-ferrite will be transformed to the gamma phase. Gamma is an austenitic phase which, compared to delta-ferrite, is non-magnetic.

If the composition of the melt had been 17% Cr-15% Ni (B) instead, the gamma phase would have formed initially. Below 1400 °C, the only existing phase is gamma and the steel is fully austenitic. By adding elements shown in table 2, it is possible to control which phase is formed and in which amount it is present.

For welding applications, it is often desirable to have a small amount of delta-ferrite in the weld metal. The reason for this is that ferrite has a higher solubility for sulphur and phosphorous than austenite. Primary austenite solidification causes rejection of sulphur and phosphorus to the remaining liquid. A low melting point segregates results, which become trapped between growing dendrites (austenite grains) causing cracks along grain boundaries. Primary ferrite solidification does not cause sulphur and phosphorus rejection, thus preventing solidification cracking.

Sometimes, however, it is not desirable to have any delta ferrite at all. This is the case in high temperature applications, where delta ferrite during service will transform to the very brittle sigma-phase causing weld metal embrittlement. Type 310 fully austenitic steel is often used in such applications.

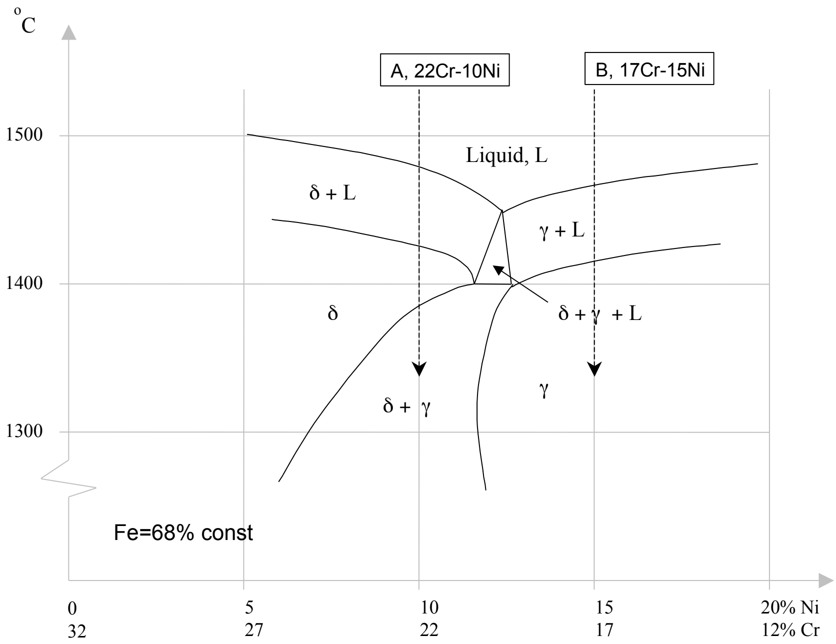


Figure 2. Cr-Ni-Fe diagram. ϒ = austenite, δ = ferrite

Alloying elements	Role	Effects Duplex S.S Metallurgy
Nickel (Ni)	Austenite stabilizer	• DSS/SDSS* contains an intermediate amount of Ni such as 4-7% • Prevents formation of detrimental intermetallic phases in austenitic SS • Increases Charpy-V toughness I of austenitic SS • Balances the austenite/ferritic ratio
Nitrogen (N)	Austenite stabilizer	• N is added to offset the effects of Cr and Mo contents to form sigma phase • Increases resistance to pitting and crevice corrosion • Substantially increases strength (mech. prop.) and toughness • Most effective strengthening element (solid solution) • Delays formation of intermetallic phases during welding and fabrication
Manganese (Mn)	Austenite stabilizer	• Increases N solubility and to some extent stabilizes austenitic phase (directly or indirectly). Negative effect decreases resistance to pitting corrosion.
Copper (Cu)	Austenite stabilizer	• Max 2% • Cavitation erosion • In standard SS it is a harmful alloy
Chromium (Cr)	Ferrite stabilizer	• Increases corrosion resistance • Duplex more corrosion resistant than ferritic and 304/316 steels
Molybdenum (Mo)	Ferrite stabilizer	• Improves chloride resistance together with Cr • Typically restricted to 4% in duplex stainless steels • Approx. three times as effective as Cr against pitting and crevice corrosion (Cr 18%) in environments containing chloride.
Silicon (Si)	Ferrite stabilizer	• Added to stainless steels to improve resistance to oxidation at high temperature
Tungsten (W)		• Increases PRE_W**
Titanium& Niobium (Ti&Nb)	Ferrite stabilizer	• Binds C and forms carbide, stops chrome from forming harmful chrome carbide
Sulphur (S) (US = Sulfur)	Impurity	• Used to improve machining properties • Among the detrimental alloying elements, sulphur is likely to have the worst effect. S is generally combined with Mn or several oxides to form precipitates. The worst case is a large oxide inclusion surrounded by sulphur species. Locally, the passive film is unable to resist and severe local corrosion may start.

Table 2. *DSS = Duplex Stainless Steel, SDSS = Super Duplex Stainless Steel
**(PRE_N = Pitting Resistance Equivalent (%Cr+3.3x%Mo+16x%N) (PRE_W = Cr%+3,3x(Mo%+0,5W)+16%N)

Corrosion resistance

A characteristic common to all stainless steels is that they contain chromium (min 10.5%), which inhibits corrosion. This excellent resistance results from the naturally occurring, chromium-rich oxide layer which always exists on the surface of stainless steel. This oxide layer has the unique property of self-healing, which cannot be achieved with layers applied by other means.

If the oxide layer is removed or damaged by abrasion, or if the raw metal surface is exposed when the steel is cut, a new layer is immediately formed by reaction between the steel and the atmosphere or other sources of oxygen. Because protection is re-established immediately, it is possible to choose steel that is not affected even in aggressive marine environments, or by many acids, alkalis and other chemicals.

Strength and formability

Stainless steel is sometimes cold stretched to increase strength, mainly for pressure vessels. Also in the embodiment, the tensile strength of the original stainless steel exceeds that of carbon steel. Similarly, hardness also varies from relatively soft annealed austenitic stainless steel to extremely hard martensitic materials, particularly for razor blades and ball bearings.

In general, ductility is inversely proportional to strength. Soft austenitic steels have outstanding ductility with an elongation exceeding 50%. Austenitic stainless steels can be cold worked to form a large number of semi-finished and finished products. Cold working can be optimized so that the final product achieves the best combination of strength and hardness. Ferritic stainless steels offer good strength and ductility, but without the outstanding formability of the austenitic variants. Martensitic steels can be formed in the annealed condition and subsequently heat treated to achieve the required strength and hardness.

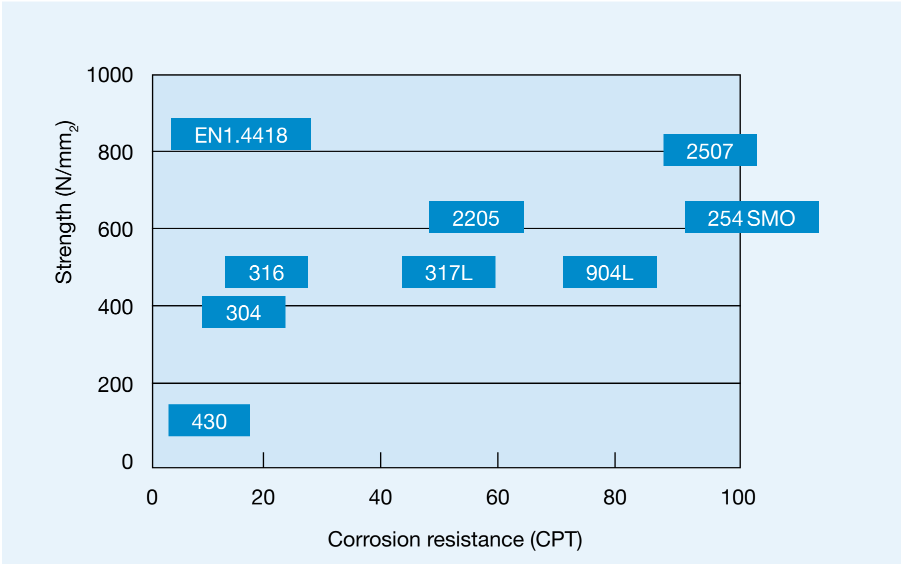


Figure 3. CPT= Critical Pitting Temperature, read more on page 15.

Temperature spectrum

Stainless steel discolours if heated to very high temperatures, but this does not lead to scaling as in ordinary carbon steel and it retains much of its strength when heated. Consequently it is used in industry for many applications where durability at high temperatures is vital.

Strength decreases when steel is heated. The extent of the reduction is dependent on many factors, one of the most important being the actual alloy composition. Compared with carbon steel, stainless steel retains its strength when heated. Therefore, it is used in high-temperature environments in industry for its so-called creep strength and is chosen by many designers thanks to this characteristic.

High-temperature corrosion (scaling) must be avoided, although heat-resistant stainless steels are superior in this regard, because they are stable in contact with air and most of the products of combustion in temperatures up to +1100 °C. A lot of industrial processes are performed at very low temperatures, down to -196 °C (or even lower), and at such temperatures many materials lose their ductility and toughness and fail by brittle fracture. In such applications, specific austenitic stainless steels or nickel alloyed steel are ideally suited.

	Material		Composition weight %							
	AISI	EN-number	C	Mn	Cr	Ni	Si	P	S	Other
Austenitic	201	1.4372	0.15	5.5-7.5	16.0-18.0	3.0-5.5	1.00	0.06	0.03	0.25 N
	202	1.4373	0.15	7.5-10.0	17.0-19.0	4.0-60.	1.00	0.06	0.03	0.25 N
	301	1.4310	0.15	2.00	16.0-18.0	6.0-8.0	1.00	0.045	0.03	
	302		0.15	2.00	17.0-19.0	8.0-10.0	1.00	0.045	0.03	
	302B		0.15	2.00	17.0-19.0	8.0-10.0	2.0-3.0	0.045	0.03	
	303	1.4305	0.15	2.00	17.0-19.0	8.0-10.0	1.00	0.20	>0.15	0-0.6 Mo
	303Se		0.15	2.00	17.0-19.0	8.0-10.0	1.00	0.20	0.06	0.15 Se min
	304	1.4301	0.08	2.00	18.0-20.0	8.0-10.5	1.00	0.045	0.03	
	304L	1.4306	0.03	2.00	18.0-20.0	8.0-12.0	1.00	0.045	0.03	
	305	1.4303	0.12	2.00	17.0-19.0	10.5-13.0	1.00	0.045	0.03	
	308		0.08	2.00	19.0-21.0	10.0-12.0	1.00	0.045	0.03	
	309	1.4828	0.20	2.00	22.0-24.0	12.0-15.0	1.00	0.045	0.03	
	309S	1.4833	0.08	2.00	22.0-24.0	12.0-15.0	1.00	0.045	0.03	
	310		0.25	2.00	24.0-26.0	19.0-22.0	1.00	0.045	0.03	
	310S	1.4845	0.08	2.00	24.0-26.0	19.0-22.0	1.00	0.045	0.03	
	314	1.4841	0.25	2.00	23.0-26.0	19.0-22.0	1.5-3.0	0.045	0.03	
	316	1.4401/36	0.08	2.00	16.0-18.0	10.0-14.0	1.00	0.045	0.03	2.0-3.0 Mo
	316L	1.4404/35/32	0.03	2.00	16.0-18.0	10.0-14.0	1.00	0.045	0.03	2.0-3.0 Mo
	317		0.08	2.00	18.0-20.0	11.0-15.0	1.00	0.045	0.03	3.0-4.0 Mo
	317L	1.4438	0.03	2.00	18.0-20.0	11.0-15.0	1.00	0.045	0.03	3.0-4.0 Mo
	321	1.4541	0.08	2.00	17.0-19.0	9.0-12.0	1.00	0.045	0.03	5 X %C Ti min
	329	1.4460	0.10	2.00	25.0-30.0	3.0-6.0	1.00	0.045	0.03	1.0-2.0 Mo
	330	1.4864	0.08	2.00	17.0-20.0	34.0-37.0	0.75-1.5	0.04	0.03	
	347	1.4550	0.08	2.00	17.0-19.0	9.0-13.0	1.00	0.045	0.03	10 X %C Nb(Cb) +Ta
	348		0.08	2.00	17.0-19.0	9.0-13.0	1.00	0.045	0.03	0.2 Cu.;10 X %C Nb(Cb) +Ta
	384		0.08	2.00	15.0-17.0	17.0-19.0	1.00	0.045	0.03	
Martensitic	403		0.15	1.00	11.5-13.0	---	0.50	0.04	0.03	
	410	1.4006	0.15	1.00	11.5-13.0	---	1.00	0.04	0.03	
	414		0.15	1.00	11.5-13.0	1.25-2.50	1.00	0.04	0.03	
	416	1.4005	0.15	1.25	12.0-14.0	---	1.00	0.04	0.03	
	420	1.4021/28/	>0.15	1.00	12.0-14.0	---	1.00	0.04	0.03	
	422		0.20-0.25	1.00	11.0-13.0	0.5-1.0	0.75	0.25	0.025	0.75-1.25 Mo; 0.75-1.25 W; 0.15-0.3 V
	431	1.4057	0.20	1.00	15.0-17.0	1.25-2.50	1.00	0.04	0.03	
	440A	1.4109	0.60-0.75	1.00	16.0-18.0	---	1.00	0.04	0.03	0.75 Mo
	440B	1.4112	0.75-0.95	1.00	16.0-18.0	---	1.00	0.04	0.03	0.75 Mo
	440C	1.4125	0.95-1.20	1.00	16.0-18.0	---	1.00	0.04	0.03	0.75 Mo
Ferritic	405	1.4002	0.08	1.00	11.5-14.5	---	1.00	0.04	0.03	0.10-0.30 Al
	409	1.4512	0.08	1.00	10.5-11.75	---	1.00	0.045	0.045	6X %C Ti min
	429		0.12	1.00	14.0-16.0	---	1.00	0.04	0.03	
	430	1.4016	0.12	1.00	16.0-18.0	---	1.00	0.04	0.03	
	434	1.4113	0.12	1.00	16.0-18.0	---	1.00	0.04	0.03	0.75-1.25 Mo
	436		0.12	1.00	16.0-18.0	---	1.00	0.04	0.03	0.75-1.25 Mo; 5X %C Nb(Cb) +Ta
	442		0.20	1.00	18.0-23.0	---	1.00	0.04	0.03	
	444		0.025	1.00	17.5-19.5	1.00	1.00	0.04	0.03	1.75-2.5 Mo; 0.015 N; 0.2 Cu; 0.2-1.0 Ti

Table 3.

Several austenitic steels in table 3 contain about 18% Cr and 8% Ni and are often known by the popular term 18-8 stainless steels. Types 304 and 304L are very common grades and differ only in carbon content.

The 'L' grades are designed to avoid sensitization (Cr depletion close to grain boundaries due to chromium carbide formation) which can result from the heating cycle during welding. 316 and 316L contain additional molybdenum, which improves strength at high temperatures but most of all reduces the risk for intergranular corrosion.

The 347 type is known as stabilized stainless steel. This steel is used for elevated temperature applications, where a higher carbon content than that found in 304L and 308L is necessary to achieve good creep resistance. To avoid problems with chromium depletion as mentioned above, steel has to be stabilized. This is done by the addition of niobium (or columbium) and tantalum, which are strong carbide formers (stronger than chromium).

GENERAL PROPERTIES OF STAINLESS STEELS

Ferritic

The main alloy is Cr (~10-30%) and ferritic steels are therefore called chrome steels. They do not normally contain any Ni. They are divided into two groups:

Semi-ferritic

Not ferritic all the way to melting point. (PHT 200-300 °C and PWHT 700-800 °C)

Fully ferritic

Ferritic all the way to melting point. (PHT 20 °C, PWHT not necessary). Use small electrodes and low amperage.

There are a few important differences compared to austenitic steels.

- Cheaper to manufacture
- Higher yield strength
- Lower elongation
- Better thermal conductivity
- Not sensitive to restraint cracks
- Not the same weldability as austenitic
- Good machining

Weldability of ferritic stainless steel varies depending upon the composition. Modern grades are reasonably weldable. However, all ferritic stainless steels suffer from grain growth in the HAZ resulting in loss of toughness. Consequently, interpass temperature and heat input must be limited.

Consumables for welding ferritic stainless steels can match parent metal composition or be austenitic.

Martensitic

Main alloys are Cr 11-17%, Ni up to 5% and C up to 0,4%. Martensitic steels are used for tools, but do not have the same hardness or durability as CMn/low-alloy steels used for tools or wear parts.

- May need both PHT and PWHT
- Mostly used as austenitic filler metal
- Hardens in air
- High mechanical properties

Martensitic stainless steels weldability is comparatively poor, and becomes worse with increasing carbon content. It normally requires preheating, well controlled interpass and cooling, as there is a significant risk of cold cracking in HAZ.

Matching-composition martensitic consumables are used when weld metal properties must match parent material. However, to decrease the risk of cracking, austenitic consumables may be used.

Austenitic

For welding applications, it is often desirable to have a small amount of delta-ferrite in the weld metal (3-10%). These steels do not normally need any post-weld-heat treatment (PWHT). They have about 50% higher thermal expansion compared to ferritic and duplex stainless steels.

Mechanical properties such as yield strength are lower than for ferritic steels.

- Expensive because of alloying element (Ni)
- Good resistance against corrosion (PRE)
- High thermal expansion
- Sensitive to hot cracks
- Good weldability
- Cold hardens when machined

Austenitic stainless steels are the most common and in most cases have really good weldability. Austenitic stainless steels are welded with consumables with a similar or over-alloyed chemical composition compared to the parent metal. Over-alloying is required in the more highly alloyed grades to optimize corrosion resistance.

In some cases there are requirements on fully austenitic weld structures e.g. for higher temperatures.

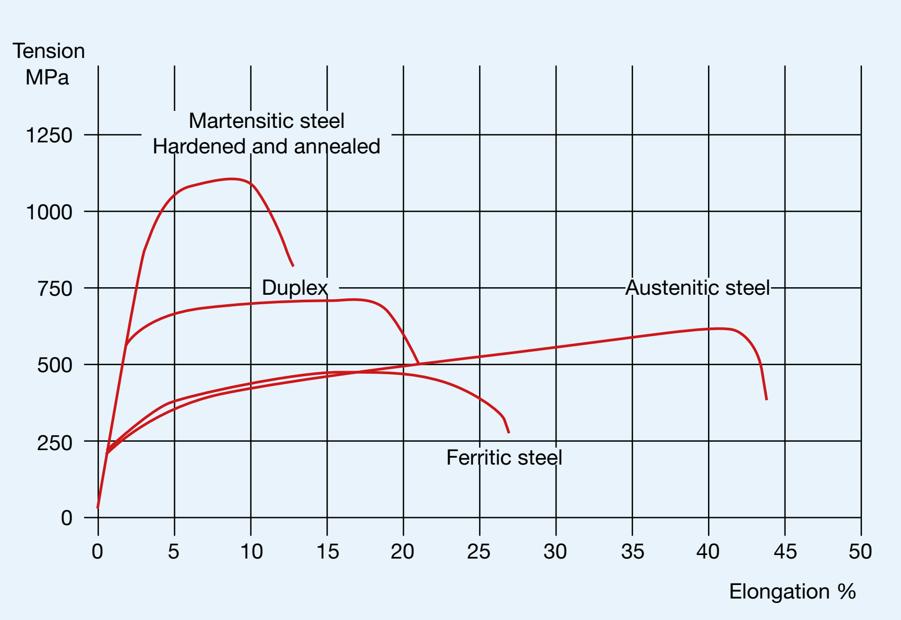


Figure 4.

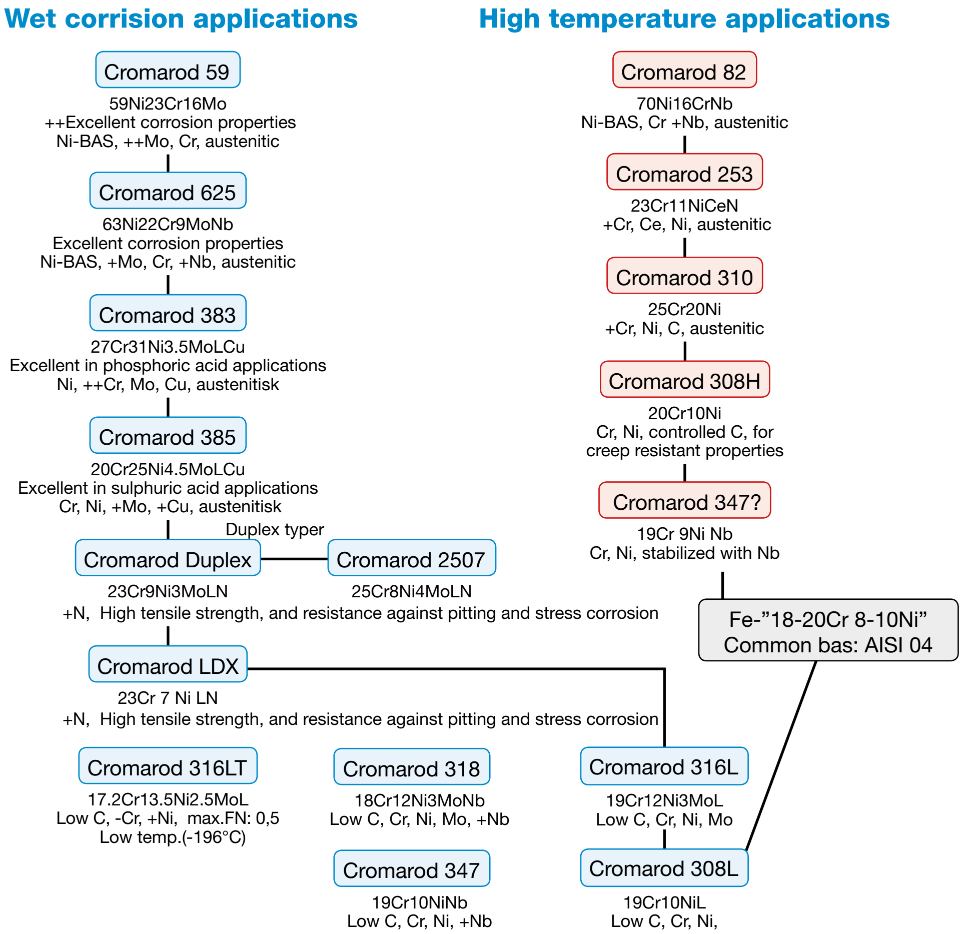
Duplex

Welding metallurgy has played a key role in the alloy development of duplex stainless steels. In terms of a common engineering material, modern duplex stainless steels are now well established as an alternative to other more general types of stainless steels and for certain applications, even nickel base alloys.

Structure	Weldability	PHT	EN:no.	Hydrogen cracks	Hot cracks	Sigma phase formation (475°embrittlement)
Martensitic	-	200-400 °C	1.4006	Very sensitive	No	No
Ferritic	+	200-300 °C	1.4016	Sensitive	No	Yes
Duplex	++	RT	1.4462	Sensitive	Small risk	Small risk
			1.4410	No	Small risk	Small risk
Austenitic	+++	RT	1.4432	No	Small risk	No
Fully austenitic	++	RT	1.4539	No	Yes	No
			1.4845	No	Big risk	No
C Mn (unalloyed)	+++	RT (depending of thickness)	C-Steel CMn-Steel	Yes (high strength steels)	Small risk	No

Table 4. Relative positions of different steel groups depending on the amounts of nickel and chromium.

Duplex grades are readily weldable by all commonly used processes such as SMAW, FCAW, GTAW, BMAW, SAW and a large variety of joint designs. When planning welding operations, it is therefore of paramount importance to carefully consider the choice of welding processes and consumables, the establishment of comprehensive welding procedures and the need for proper control when storing consumables. During production, it is also important to understand the problems associated with storage, handling and fabrication of stainless steel plates and pipes.



The DSS can be divided into 3 groups; based on their, *PREN-values:

Group 1: PRE ~25 23Cr4Ni0.1N (Mo-free) (Lean Duplex)	S32003 (1.4162); S32304 (1.4362); S82441 (1.4662)
Group 2: PRE ~ 35 22Cr5.5Ni3Mo 0.14N (Duplex)	S32205/S31803 (1.4462)
Group 3: PRE ~41 25Cr7Ni4Mo 0.25N, (Super Duplex)	S32750 (1.4410)

Table 5.

Typical properties for DSS, grade 1.4462 compared to other stainless steel types: As can be seen in table 6, the duplex 1.4462 is 50% more expensive compared to the standard 304L grade in terms of price/kg, but less expensive if we compare Price/PRE and Price/Yield strength, valuable design and service life factors.

Steel Grade	Analysis Typical	Rp0.2 N/mm²	Rm N/mm²	*PRE -Value	Price P Index	P/PRE Index	P/Rp0.2 Index
304L	18Cr10Ni	210	520	18	1.0	1.00	1.00
316L	17Cr12Ni2.5Mo	220	520	25	1.3	0.93	1.23
316LN	17Cr12Ni2.5Mo0.18N	300	600	28	1.4	0.89	0.98
317L	18Cr13Ni3.3Mo	250	550	29	1.6	0.98	1.33
1.4462	22Cr6NiMo0.14N	450	700	35	1.5	0.79	0.69

Table 6. March-95, Pitting Resistance Equivalent, *PREN = %Cr+3.3* %Mo+16* %N.

The greatest benefit of molybdenum and nitrogen in stainless steels is the improved resistance to pitting and crevice corrosion, especially in environments containing chloride. One way of measuring this benefit is by determining the critical pitting temperature. Higher PRE means better corrosion resistance. This is normally established with the ASTM G48 test. The critical pitting temperature – CPT – is the point at which pitting corrosion starts in a test specimen immersed in a ferric chloride solution.

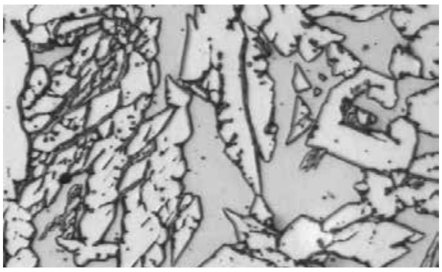
CONSUMABLES
SELECTION GUIDE

Cromarod	AWS Class	EN ISO 3541-A	Special features
308L	A5.4 E308L-17	E 19 9 L R 12	Rutile coating. excellent all positional operability
308LP	A5.4 E308L-17	E 19 9 L R 11	Thin coated. excellent fully positional operability
308L-140	A5.4 E308L-17	E 19 9 L R 53	140% high recovery version
308H	A5.4 E308H-17	E 19 9 R 12	Controlled carbon. for creep at high temperature applications
B308L	A5.4 E 308L-15	E 19 9 L B 42	Basic covered electrod for Cryogenitic applikations down to -196°C
347	A5.4 ~E347-17	E 19 9 Nb R 12	Low carbon+Nb-stabilised. Intended primarily for resistance to intergranular corrosion
B347	A5.4 E 347-15	E 19 9 Nb B 42	For higher demands on welds.
316L	A5.4 E316L-17	E 19 12 3 L R 12	Rutile coating. excellent all positional operability
316LP	A5.4 E316L-17	E 19 12 3 L R 11	Thin coated. excellent fully positional operability
316LV	A5.4 E316L-17	E 19 12 3 L R 15	Vertical down version
316L-140	A5.4 E316L-17	E 19 12 3 L R 53	140% high recovery version
316LT	A5.4 ~E316L-17	~E 19 12 3 L R 12	Good CVN toughness down to -196°C. FN max 0.5. Urea applications
B316L	A5.4 E 316L-15	E 19 12 3 L B 42	Basic covered electrod for Cryogenitic applications down to -196°C
318	A5.4 ~E318-17	E 19 12 3 Nb R 12	Low carbon+Nb-stabilised. Intended primarily for resistance to intergranular corrosion
309L	A5.4 E309L-17	E 23 12 L R 12	Dissimilar joints
309LP	A5.4 E309L-17	E 23 12 L R 11	Thin coated LP version of 309L. excellent fully positional operability
B309L	A5.4 E 309L-15	E 23 12 L B 42	Dissimilar parent materials with higher demands
B309LNb	A5.4 E 309NbL-15	E 23 12Nb B 42	Dissimilar parent materials with higher demands.
309MoL	A5.4 E309MoL-17	E 23 12 2 L R 32	Rutile coating. exellent all positional operability
309MoLP	A5.4 E309MoL-17	E 23 12 2 L R 11	Thin coated LP version of 309MoL. excellent fully positional operability
309MoL-150	A5.4 E309MoL-17	E 23 12 2 L R 53	150% high recovery version
307B	A5.4 ~E307-15	E 18 8 Mn B 12	Basic version of 307 DIN 18 8 Mn - type
310	A5.4 ~E310-17	~E 25 20 R 12	For corrosion and oxidation resistance at high temperatures. 1150°C in air
312	A5.4 ~E312-17	E 29 9 R 32	For difficult-to-weld steels and dissimilar joints. Ferrite = FN 50
317L	A5.4 E317L-17	~E 19 13 4 L R 12	Higher pitting corrosion resistance than 316L
317LP	A5.4 E317L-17	E 19 13 4 L R 11	Thin coated. excellent fully positional operability
317L-140	A5.4 E317L-17	~E 19 13 4 L R 53	140% high recovery version
LDX		E 23 7 N L R 12	Matching for Lean Duplex parent material (ex. LDX 2101)
Duplex	A5.4 ~E2209-17	E 22 9 3 N L R 12	Excellent pitting corrosion resistance. high strength
Duplex LP	A5.4 E2209-17	E 22 9 3 N L R 12	Thin coated. excellent fully positional operability
Duplex-140	A5.4 ~E2209-17	E 22 9 3 N L R 53	140% high recovery version
Duplex B	A5.4 E 2209-15	E 22 9 3 N L B 42	Basic covered electrod for higher demands on welds.
2507R	A5.4 ~E2594-17	E 25 9 4 N L R 12	Super Duplex grade. higher PRE than Duplex
2507B	A5.4 ~E2594-15	E 25 9 4 N L B 12	Basic coating. higher toughness down to -50°C
410NiMo	A5.4 E410NiMo-25	E 13 4 B 12	Synthetic type. basic coating. martensitic deposit. improved toughness
383	A5.4 E383-17	E 27 31 4 Cu L R 12	Highly corrosion resistant grade. phosphoric acid
385	A5.4 ~E385-17	E 20 25 5 Cu N L R 12	Highly corrosion resistant grade. sulphuric acid
253	-	~E 22 12 R 12	High temperature use up to 1150°C. Cerium alloyed. for base material 253MA
82	A5.11 ENi Cr Fe-3	EN ISO 14172 Ni Cr 15 Fe 6 Mn B 12	Ni-base electrode for Inconel 600 types. For service at elevated temperatures
625	A5.11 ENi Cr Mo-3	EN ISOI 14172 Ni Cr 22 Mo 9 Nb B 12	Excellent corrosion resistance. For Inconel 625 / 254 SMO steel
625-170	A5.11 ~ENi Cr Mo-3	*EL ~Ni Cr 20 Mo 9 Nb	170% recovery. Ni-base electrode for fillet. butt and overlay welding
59	A5.11 ENi Cr Mo-13	EN ISO 18274: S Ni 6059	Enhanced corrosion resistance. for alloy 59. C276. 254SMO. 654SMO

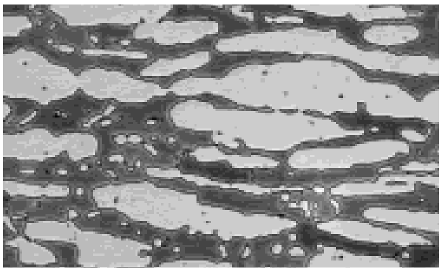
C	Si	Mn	Cr	Ni	Mo	Cu	Nb	N	GMAW Cromamig	GTAW Cromatig	FCAW Cromacore	SAW Cromasaw
0.02	0.8	0.7	19.5	10.4	0.1	0.1	0.05	0.08	X	X	X	X
0.02	0.7	0.6	18.6	9.7	0.1	0.1	0.05	0.08			X	
0.02	0.8	0.7	19.5	10.4	0.1	0.1	0.05	0.08				
0.05	0.7	0.8	19.5	10.0	0.1	0.1	0.05	0.07	X	X	X	
0.03	0.4	1.0	19.0	10.0								
0.02	0.9	0.6	19.0	10.2	0.1	0.1	0.5	0.08	X	X	X	X
0.04	0.4	1.3	19.5	10.2	0.5							
0.02	0.8	0.7	18.5	12.0	2.7	0.1	0.05	0.08	X	X	X	X
0.02	0.7	0.8	18.3	12.2	2.7	0.1	0.05	0.08			X	
0.02	0.7	0.8	18.1	11.8	2.7	0.1	0.05	0.08				
0.02	0.8	0.8	18.4	11.8	2.7	0.1	0.05	0.08				
0.02	0.6	2.3	17.2	14.1	2.5	0.1	0.05	0.08				
0.03	0.4	1.0	18.5	12.0	2.7							
0.02	0.9	0.7	18.0	12.0	2.7	0.1	0.40	0.07	X	X		
0.02	0.8	0.8	23.0	13.0	0.1	0.1	0.05	0.08	X	X	X	X
0.02	0.7	1.1	23.5	12.8	0.1	0.1	0.05	0.08			X	
0.030	0.4	1.0	23.0	12.5								
0.035	0.5	1.0	23.0	12.0	0.8							
0.02	0.8	0.8	22.8	12.8	2.4	0.1	0.05	0.08	X	X	X	X
0.02	0.7	1.0	23.2	13.0	2.5	0.1	0.05	0.08			X	
0.02	0.8	0.7	22.6	13.8	2.8	0.1	0.05	0.08				
0.06	0.3	5.5	18.5	9.5	0.1	0.1	0.05	0.03	X	X		
0.10	0.8	2.3	26.6	21.6	0.1	0.1	0.05	0.06	X	X		
0.10	1.2	0.8	28.8	9.7	0.2	0.1	0.05	0.08	X	X	X	
0.02	0.7	0.8	18.4	13.5	3.7	0.1	0.05	0.08	X	X		X
0.02	0.7	0.8	19.0	12.5	3.3	0.1	0.05	0.08				
0.03	0.8	0.8	18.5	13.5	3.5	0.1	0.05	0.08				
0.03	0.8	0.9	24.5	8.5	0.1			0.14	X	X	X	
0.02	0.8	0.7	23.4	9.5	3.0	0.1	0.05	0.16	X	X	X	X
0.02	0.7	0.7	22.5	9.5	3.0	0.1	0.05	0.16			X	
0.02	0.9	0.7	23.3	9.8	3.1	0.1	0.05	0.13				
0.03	0.6	0.9	23.0	9.0	3.2			0.17	X	X	X	
0.02	0.8	0.7	25.0	9.0	4.0	0.1	0.05	0.23	X	X		X
0.03	0.4	1.3	25.0	8.5	3.7	0.1	0.05	0.23				
0.05	0.5	1.2	12.5	4.5	0.5	0.1	0.05	0.05	X	X		X
0.02	0.7	1.0	27.5	31.5	3.8	1.0	0.05	0.08		X		
0.02	0.8	1.1	20.0	25.5	4.2	1.5	0.05	0.08	X	X		X
0.06	1.5	0.5	22.0	10.5	0.1	0.05	0.05	0.17				
0.03	0.5	6.0	16.0	70.0	0.1	0.05	2.20	0.05	X	X		X
0.03	0.4	0.6	22.0	63.0	9.0	0.05	3.40	0.05	X	X		X
0.04	0.6	0.8	21.0	bal.	9.0	0.05	2.50	0.05				
0.01	0.1	0.3	23.0	59.0	16.0	0.05	0.05	0.05	X	X		

TYPICAL DUPLEX MICROSTRUCTURE

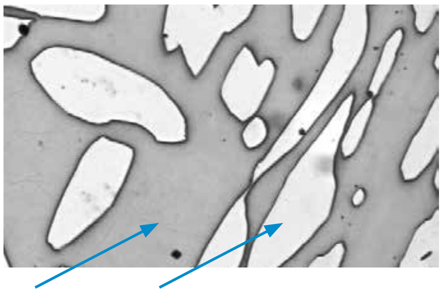
Duplex Weld Metal, 200x



Wrought Duplex, 200x



Cast Duplex, 200x



Normally, the weld metal contains 25-65% ferrite.

Ferrite Austenite

Figure 5.

Duplex is different but not difficult

The weld metal solidifies completely ferritic at 1450°C and the transformation to the final duplex structure takes place in the solid state between 1300°C and 800°C. Typical cooling time between 1200°C and 800°C for a weld metal is 3-25 seconds, depending on heat input and plate thickness – faster cooling rates produce more ferrite. Too slow or too fast cooling rates can result in other ”micro structural problems”, causing reduced corrosion resistance and/or reduced impact strength.

To achieve a proper phase balance, the weld metal has a higher Ni-content than the base material. For a group 2 grade, the weld metal has 9% Ni and the base material 6% Ni, therefore the dilution of base material into the weld metal affects the phase balance. Root runs and high dilution welding methods, i.e. * SAW, tend to give higher ferrite contents due to dilution with the lower Ni-content base material.

Precipitation of secondary austenite in multipass duplex weld metal or HAZ may be possible. These precipitates of austenite may also reduce pitting resistance. This is probably due to a lower content of chromium and molybdenum in this finely dispersed type of austenite. It is also likely that they contain rather low amounts of nitrogen because they have precipitated at low temperatures from an almost nitrogen-free ferrite. The solution to this is to control the ferrite level of the weld through an increased austenite level in the filler metal. Careful recommendations regarding welding parameters, especially for the first 2-3 passes of a multi-pass weld, may also be effective. These problems are not so big when welding group 1 and 2 DSS, but must be considered more carefully when welding the highly alloyed group 3 DSS. To achieve a proper phase balance and avoid precipitation relations, the following parameter ranges are recommended:

Duplex type	**Heat input, kJ/mm	Max. interpass temperature
23Cr4Ni 0.1N	0.5-2.5	No practical limit, max. 250 °C
22Cr5.5Ni3Mo 0.14N	0.5-2.5	No practical limit, max. 250 °C
25Cr7Ni4Mo 0.25N	0.4-1.5	Max. 150 °C

Table 7.

The heat input is chosen to suit the material thickness and the welding process, e.g. for thin-wall tubes (t=1,5 mm) ~ 0.5 kJ/mm is optimum. For heavier wall thickness, a heat input closer to maximum is preferred. In any case the interpass temperature should be kept. Attention must be paid to super duplex steels in wall thickness > 25 mm. As the interpass temperature is measured on the surface of the weld or on the metal close to the weld, the actual temperature will be higher deeper inside the weld metal. This may cause embrittlement and low impact values in the root region.

* (Cromasaw Duplex – 56% ferrite, Cromacore DW 329AP – 35% ferrite).

$$\text{** Heat input} = \frac{\text{current x voltage x 60}}{\text{welding travel speed, in mm, x 1000}}\ \text{kJ/mm}$$

CRYOGENIC APPLICATIONS

Equipment for the transportation and storage of LNG must have good properties at temperatures down to -196°C

The most important material property is good toughness at low temperatures.

Weld metal properties are often the limiting factor.

Weld metal toughness can vary depending on factors such as welding methods, welding procedure and the choice of filler material.

The most common welding methods are TIG, submerged arc and basic coated electrodes.

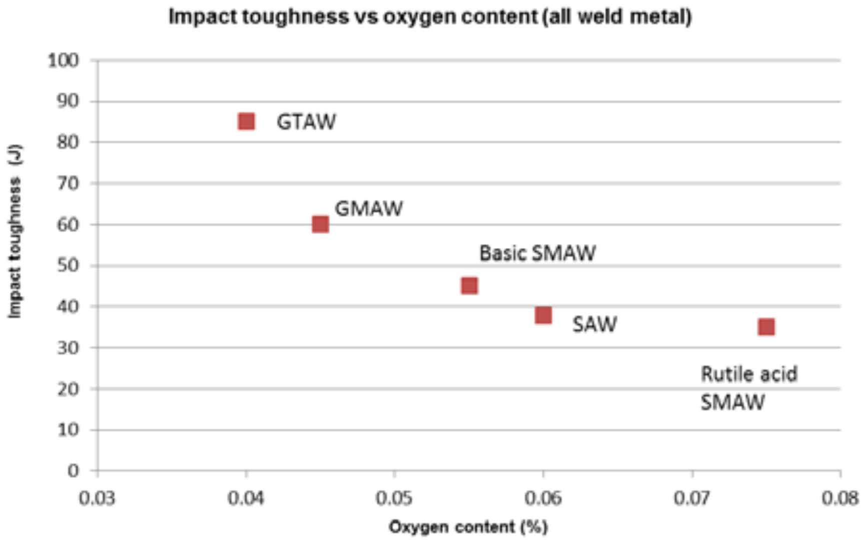


Figure 6.

Elga product range for cryo

Weld Process	Consumable	Rp0,2-MPa	Rm-MPa	IMPACT Charpy V -196°C
MMA	Cromarod B308L	430	570	50J
MMA	Cromarod B316L	470	575	45J
MMA	Cromarod 82	380	630	80J
MMA	Cromarod 625	530	770	60J
FCW	Cromacore 308LT0	407	566	39J
FCW	Cromacore 316LT0	403	580	34J
FCW	Cromacore 625T1	500	790	70J
MIG	Cromamig 308LSi	400	590	50J
MIG	Cromamig 316L	420	600	50J
MIG	Cromamig 82	400	660	80J
MIG	Cromamig 625	480	780	60J
TIG	Cromatig 308L	380	600	60J
TIG	Cromatig 316L	400	600	60J
TIG	Cromatig 82	420	670	100J
TIG	Cromatig 625	480	780	80J
SAW	Hobart SWX 220-308L	390	550	50J
SAW	Hobart SWX 220-316L	400	580	50J
SAW	Hobart SWX 282-82	380	630	100J
SAW	Hobart SWX 282-625	450	720	70J

Table 8.

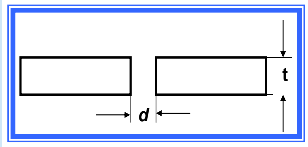

TEGERA

JOINT PREPARATION

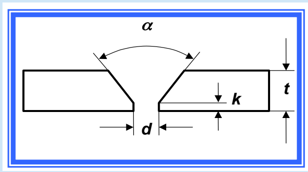
If the plates are prepared with plasma cutting, the oxide layer should be removed by machining or grinding. As a general rule when welding duplex stainless steels, the root gap should be slightly wider than for standard stainless steels.

Typical joint preparation for welding:

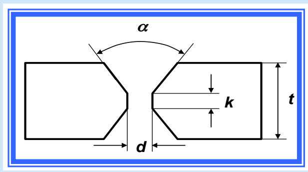
Two-sided butt-groove	t	d
	mm	mm
SMAW	3-4	2-3
GTAW	3-6	2-3
GMAW	3-6	2-3
FCAW	3-8	2-3



V-groove	t	d	k	α
	mm	mm	mm	
SMAW	6-14	2-3	2-3	50-60°
GTAW	6-10	2-3	1-2	50-60°
GMAW	6-12	2-3	2-3	50-60°
FCAW	6-14	2-3	2-3	50-60°
SAW	8-16	0	3-5	80-100°



Double V-groove	t	d	k	α
	mm	mm	mm	
SMAW	14-30	2-3	2-3	50-60°
GTAW	10-16	2-3	1-2	50-60°
GMAW	12-16	2-3	2-3	50-60°
FCAW	12-30	2-3	2-3	50-60°
SAW	12-30	0	3-5	90-100°



Double U-groove	t	d	k	β	r
	mm	mm	mm		mm
SMAW	>30	2-3	2-3	15°	6-8
GTAW	>16	2-3	1-2	15°	6-8
GMAW	>16	2-3	2-3	15°	6-8
FCAW	>30	2-3	2-3	15°	6-8
SAW	>30	0	3-5	15°	6-8

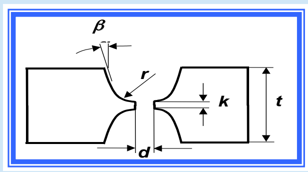


Table 10.

DISSIMILAR
STEELS AND JOINTS

Tools and tricks for dissimilar steels

Requirements	Appearance
Mechanical properties	Yield, tensile strength, elongation
Hardness	Wearing
Impact toughness	Low, high or room temperature
Corrosion	Resistant against different types of corrosion
Microstructure	Ferritic, secondary face, slag, pores
Finish	Hygiene

When welding dissimilar steels, a decision must be taken as to which requirement is most important for the application. The table above shows some requirements for consideration. There are different tools for use in predicting properties and microstructure in weld metal. These charts are very good at predicting the amount of delta ferrite, as can the somewhat different formulas as shown below:

- Schaeffler
  [Nieq= Ni+30C+0.5Mn]
  [Creq= Cr+Mo+1.5Si+0.5Nb+2Ti])
- De Long
  [Nieq= Ni+30C+0.5Mn+20N]
  [Creq= Cr+Mo+1.5Si+0.5Nb])
- WRC-92
  [Nieq= Ni+35C+0.25Cu+20N]
  [Creq= Cr+Mo+0.7Nb]
- Some use a combination of Schaeffler/De Long
  [Nieq= Ni+30C+0.5Mn+30N]
  [Creq= Cr+Mo+1.5Si+0.5Nb+2Ti]

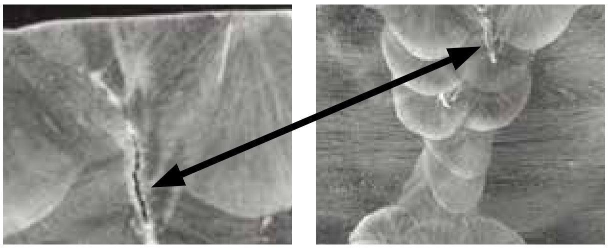
In a too long an arc, nitrogen from the surrounding atmosphere may reduce ferrite content. A ferrite content that is too low increases the risk of hot cracks in the weld metal. As can be seen in the table below, increasing arc length by 5mm gives an increase in N from 0.065 to 0.11. This will affect the ferrite content of weld metal.

Table 11.

Short arc (~3mm) 135A/26V			Long arc (~8mm) 135A/35V		
C	Si	Mn	C	Si	Mn
0.011	1.2	1.1	0.011	1.2	1.1
Cr	Ni	N	Cr	Ni	N
17.5	10.8	0.065	16.6	10.8	0.11

Nickel equivalent = Ni+35C+20N+0.25Cu

Chrome equivalent = Cr+Mo+0.7Nb



Hot cracks due to low ferrite content.

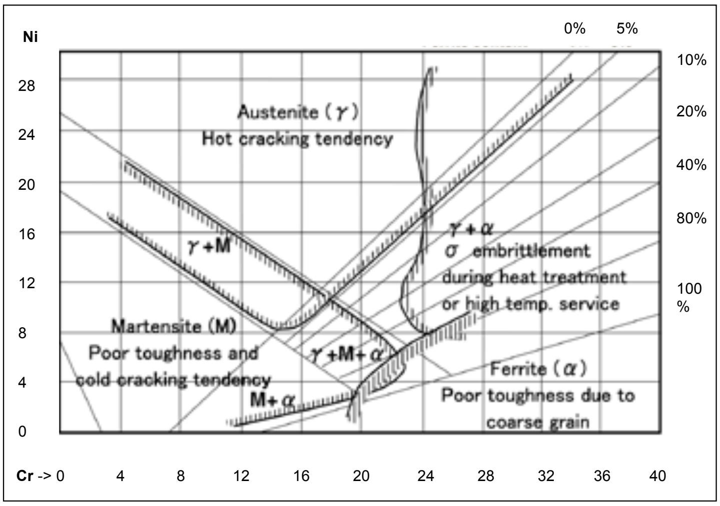


Figure 7.

	Material 1	Material 2	Consum-ables	Weld metal
Name	**304L**	**CMn**	**309MoL**	
Dilution	15%	15%	70%	100%
C	0.040	0.100	0.020	0.035
Si	0	0.300	0.800	0.605
Mn	0	1.000	0.800	0.710
Cr	18.100	0.020	22.800	18.678
Ni	8.100	0.100	12.800	10.190
Mo	0.000	0.050	2.400	1.688
Nb	0	0.005	0	0.001
Ti	0	0	0	0.000
Cu	0	0.100	0	0.015
N	0	0	0	0.000
Cr_{eq}	**18.1**	**1.6**	**26.4**	**21.3**
Ni_{eq}	**9.3**	**3.7**	**13.8**	**11.6**

Table 12.

Predicting weld metal structure

One way of predicting the structure formed in the weld metal is to use a Schaeffler/DeLong diagram in which the ferrite stabilizers are plotted on the horizontal Creq axis and the austenite stabilizers on the vertical Nieq axis. It is possible to see whether the structure is austenitic, martensitic or ferritic or any mixture thereof for given Cr- and Ni equivalents. This is shown in figure 8. The ferrite content is presented as volume percent and calculated in table?.

The Schaeffler De Long diagram in figure 8 is based on table 12, where the dissimilar-metal weld is between stainless steel type 304L (M1 in diagram) and carbon steel (M2). The consumable used (C) is a Cromarod 309MoL, which is normal for this application. Dilutions are set to 15% from each parent metal and rest weld metal. The resulting weld metal (W in diagram) will have a calculated ferrite volume of around 10%. No risk for hot cracking or martensite formation is present.

Ni_{eq}
Ni
C * 30
Mn * 0,5
Cu * 0,5
N * 30

Cr_{eq}
Cr
Si * 1,5
Mo
Nb * 0,5
Ti * 2

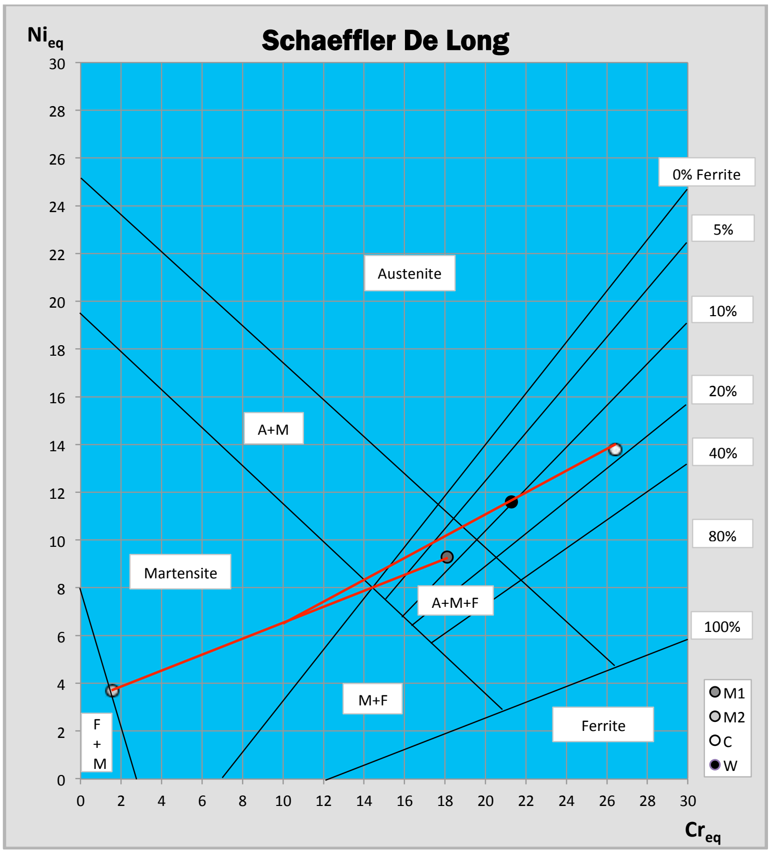


Figure 8.

PRACTICAL ADVICE FOR WELDING DISSIMILAR JOINTS

- Weld with the lowest possible heat input, kJ/mm.
- Interpass temperatures up to 150 °C
- If the steel requires preheating and an interpass temperature of 150 °C: Where necessary, first weld a so-called buttering with 309MoL. Complete welding with a normal stainless austenitic material.
- String welding and/or weaving max twice the the electrode diameter.
- Root pass grinding recommended (rear).

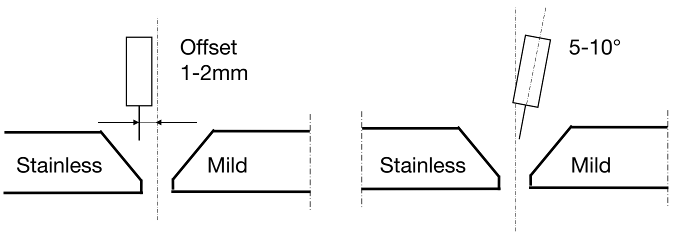
If heating above 600 °C is required after welding, consider that nickel-based additive materials have advantages in austenitic-ferritic weld joints, including joints subjected to heat treatment after welding.

- Moreover, nickel-based filler metals are not susceptible to embrittlement at high temperatures.
- The expansion coefficient lies between the ferritic-martensitic and austenitic steels.
- They remain very malleable at low temperatures and are resistant to oxidation at high temperatures.
- Try to maximize mixing at 30%, i.e. weld with the lowest possible amperage.
- Use 50% string overlay to minimize dilution from the base metal.
- Always use a short arc.
- Avoid craters at the weld end by making a circular motion back and extinguish the arc of the actual weld joint.

- NOTE 309 types are not recommended in dissimilar joints exposed to H_2, high temperature and high pressure such as in petro chemistry.

There are some technical tricks to minimize dilution between base and filler materials.

Offset the electrode/weld gun or set it at a slight angle to the stainless steel material; see fig 9. As a general rule, the root gap should be slightly wider than for standard stainless steels when welding duplex stainless steels, and by opening up the joint a bit, good welds are achieved when welding SS to CMn steels (fig 9).



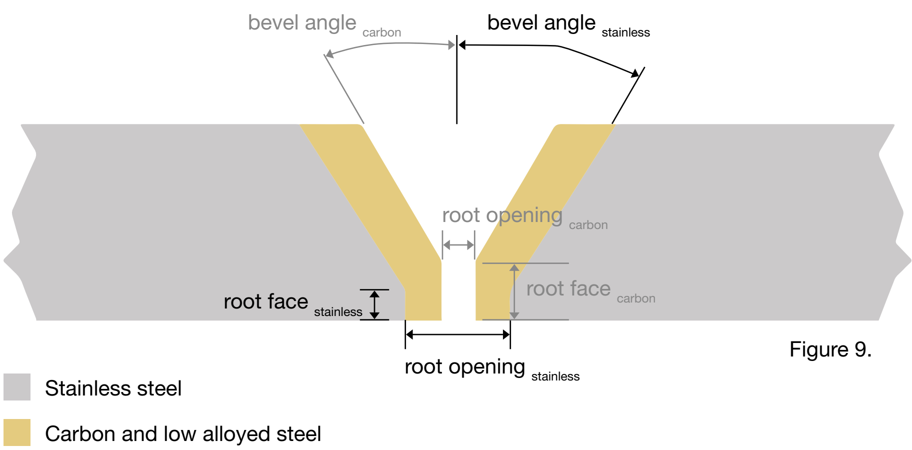


Figure 9.

CHOOSING A WELDING PROCESS

Many factors affect the choice of process:
- Quality/accessibility
- Parent material
- Productivity
- Thickness of material
- Properties of weld metal
- Weld position
- Weldability

GMAW
Group 1 steels: Cromamig LDX Diam: 1.2 mm
Group 2 steels: Cromamig Duplex Diam: 0.8-1.0-1.2 mm
Group 3 steels: Cromamig 2507 Diam: 0.8-1.0-1.2 mm
Shielding gases: Spray arc: Ar, 14-16 l/min
Short arc: Ar or Ar-He-O_2-mix to improve the wettability and weld bead geometry, 12-14 l/min.
Backing gas: Ar or Formier.
Good weldability in out of position welding requires pulsed arc.
Typical GMAW welding parameters:

	Short-arc		Spray-arc	
Diam.	Current	Voltage	Current	Voltage
1.0 mm	75-140 A	18-21 V	170-200 A	26-28
1.2 mm	130-160	18-21 V	175-250 A	26-28

Table 13.

GTAW
GTAW is often recommended especially for root passes in pipes.
Group 1 steels: Cromatig LDX
Group 2 steels: Cromatig Duplex
Group 3 steels: Cromatig 2507
Shielding gases: Ar or Ar+He mixtures, sometimes N_2 addition to the gas are used to compensate for N-losses from the weld metal, normally 3-5% N_2 addition is used.
Backing gas is very important. Ar, Ar+N_2 or N_2 or Formier gases (90%$N_2$10%H_2) are used. The latter is recommended as it improves root side pitting resistance. To achieve good pitting resistance in the root, the level of oxygen in the root area has to be very low (<100 ppm).

When very high ferrite levels (≥ 70%) in the root area are anticipated, H_2 in the backing gas can produce micro cracking in the ferrite and should therefore be avoided. In these applications, Ar, Ar+N_2 or N_2 backing gas is recommended.

FCAW
FCAW wires are available for welding of DSS
Group 1 steels: Cromacore LDX P
Group 2 steels: Cromacore 2209T1

Group 3 steels: Cromacore 2507

Shielding gas: 80% Ar + 20% CO_2 or pure CO_2 is used, 20-25 l/min.

SMAW

Group 1 steels: Cromarod LDX
Group 2 steels: Cromarod Duplex (a rutile normal recovery)
Cromarod Duplex-140 (rutile, 140%, high recovery for higher productivity)
Cromarod Duplex-LP, (rutile thin coated type for pipes and narrow joints)
Cromarod Duplex-B, (basic coated type for high Charpy toughness at –460 °C.)
Group 3 steels: Two types of Super Duplex electrodes are available: Cromarod 2507B, (basic type) and Cromarod 2507R, (rutile type)

The basic electrodes have higher CVN-toughness, due to the lower oxygen content of the weld metal.
Typical oxygen content in the basic electrode is 500-700 ppm and in the rutile 800-1000 ppm.

	Welding current (A)	
Core diameter (mm)	17% ferritic weld deposit	19% Cr-10% Ni austenitic weld deposit
2.4 mm	50-100	40-90
3.2 mm	80-110	60-100
4.2 mm	110-160	90-150
5.0 mm	150-230	130-220

Table 14.

SAW

Group 1 and 2 steels: Wire and flux recommendation: SDX 2209 + SWX 220.
The highest productivity in 1G position is achieved with SAW.
Group 3 steels: Wire and flux recommendation: SDX 2594 + SWX 220.
Up to 3.0 kJ/mm has been used with good results. The welding is therefore normally carried out with a 2.4-3.2 mm wire. The minimum plate thickness is ~10 mm and double sided welding using X- or V-joints with root face are normally used. One side welding requires a root run with SMAW or FCAW before filling with SAW.

Typical SAW -welding parameters:

Diam.	Current	Voltage	Travel speed
2.4 mm	300-500 A	26-32 V	30-50 cm/min
3.2 mm	400-600 A	26-34 V	40-60 cm/min

Table 15.

CHOOSING
ELECTRODE COATINGS

When should you use basic coated electrodes and under what circumstances are rutile electrodes the right choice?

Rutile

The characteristics of rutile welding are fine spray droplets, excellent welding performance, a stable arc, less spatter, a smooth concave weld and easily removed slag. Rutile coated electrodes are available in any enclosure dimensions, e.g. thin to medium welding from 1.5 mm thick and up to plate alt. pipe welding in all positions. Electrodes intended for vertical down welding have a thinner coating to minimize the total amount of slag. Thick electrode housings are suitable for high productivity, especially for use in horizontal positions and fillet welds. Joint angle should exceed 50° due to shell thickness. Small, cramped joints bind and enclose slag easily.

Basic

Higher impact resistance, especially at low temperatures, can be achieved for weld metal using basic coated electrodes. Basic coated electrodes provide medium to coarse droplet transmission. The slag is easy to control and you can string weld or commute. They are suitable for all welding positions except vertical. The weld is smooth, but not very smooth, with a slightly convex fillet weld profile.

Rutile basic

Electrodes in this category have slightly better mechanical properties than pure rutile casings. The weldability is good for all positions except for falling vertically.

Comparison table properties

Electrode coating	Rutile	Basic	Rutile-basic
AWS classification	XXXX-16/-17/-26		XXXX -15/-25
Welding current	DC+/- or AC	DC+/-	DC+ or AC
Droplet transfer	Spray	Globular	Globular spray
Mechanical properties	+	+ + +	+ +
Arc stability/break	+ + +	-	+ +
Positional welding	+ +/+++	+ +	+ +
Re striking	+ +	-	+
Fillet profile	+ + +	-	+ +

Table 16.

Cromarod index

- **L** L stands for low carbon, C max 0.030%. Standard rutile coating.
- **LP** Thin coat; for pipe welding in difficult positions. Welds with very low current.
- **LT** Good impact toughness at -196 °C, max 0.5 UN, suitable for urea and cryogenic applications.
- **LV** A thin covered electrode specially designed for descending vertical welding.
- **R** Rutile, high recovery electrode, 160% yield.
- **140** High recovery electrode, 140%. Provides high deposition rates. Designed for high productivity welding.
- **B** Basic coated. Provides high impact strength at -196 °C.
- **H** Controlled carbon content, C: 0.04 -0.08% for creep strength and high temperature applications.

STORAGE, HANDLING AND POST WELD CLEANING

In most applications it is essential to clean the weld and remove slag, tint and other defects. To restore corrosion resistance properties, the weld should be brushed and pickled.

Spatter, surface pores, cracks and crevices must be avoided or removed, in most cases removed mechanically.

Stainless steel plates and materials/consumables should be stored separately from CMn steels and grease/oil.

Use tools such as brushes, grinding wheel, edge folding tools etc. that are specially made for stainless steel.

Cleaning procedures

- Chemical
- Electropolishing
- Pickling
- Grinding
- Blasting
- Brushing

Summary (examples)

1. Grinding (removing defect e.g. slag)
2. Pre-cleaning to remove organic contamination (e.g. oil, grease)
3. Pickling (e.g. paste or bath)
4. Rinsing with water (e.g. water jet)

There are different guides for welding in stainless steels. Figure 10 shows a part of "Reference Photo Guide for Stainless Steels Welds" from Euro Inox, Brussel (B).

Superior

Filler 2-5 mm,
19.9L rutile-acid
coating.
I: 60-70 A
U: 21-27 V

Observations:
As-welded condition, the coarse rippling is typical of this welding position and welding method. The left photo shows surface oxides.

Pickled surface (right)

The section shows a rather convex reinforcement.

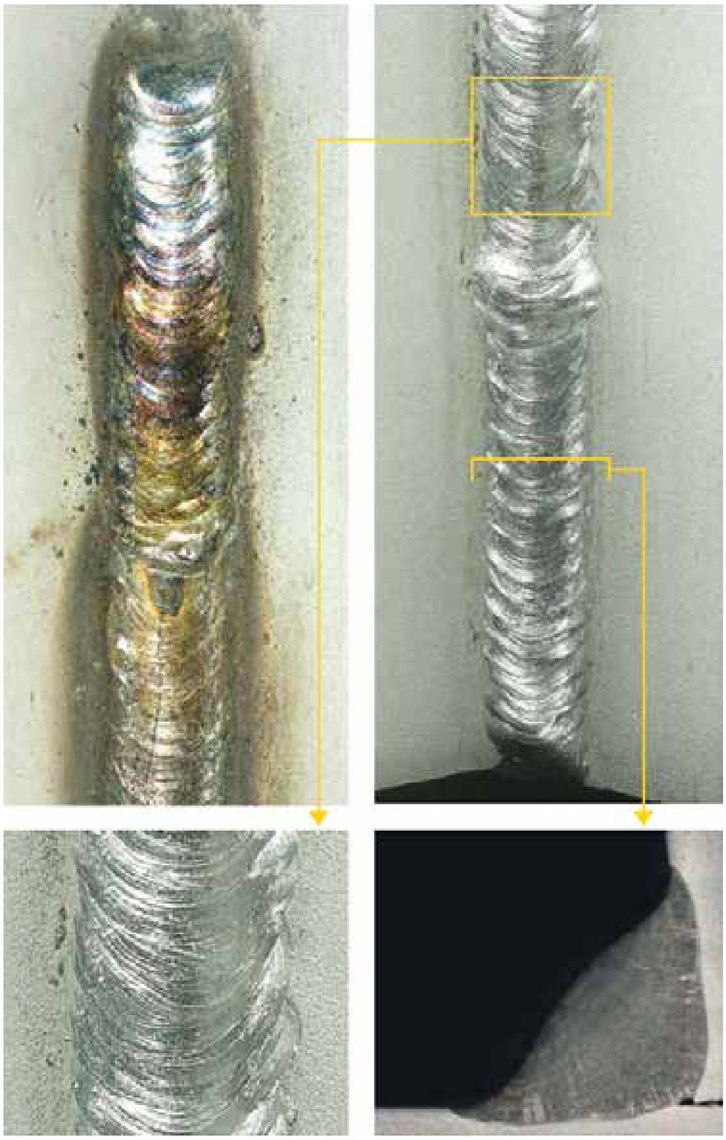


Figure 10. Euro Inox, Brussels (B)

CONSUMABLE GUIDE

ENnr/ASTM	1.4003/-S40977	1.4016/430/-	1.4006/410/S41000	1.4162/-/S32101	1.4362/-/ / S32304	1.4462/-/S32205/S31803	1.4410/-/S32750	1.4310/301/S30100	1.4301/304/S30400	1.4307/304L/-	1.4311/304NL/S30453	1.4541/321/S32100	1.4401/316/S31600
1.4003/-S40977	A,E	Y,A	Y	Y,T	Z,T	Z,U	Z,V	D,X	Y	Y	Y	Y	Z,Y
1.4016/430/-	Y,A	E,Y	Y	Y,T	Z,T	Z,U	Z,V	D,X	Y	Y	Y	Y	Z,Y
1.4006/410/S41000	Y	Y	A,D	Y,T	Z,T	Z,U	Z,V	D,X	Y	Y	Y	Y	Z
1.4162/-/S32101	Y,T	Y,T	Y,T	T,U	T,U	T,U	U,V	T,Y	T,Y	T,Y	T,Y	T,Y	T,Y
1.4362/-/S32304	Y,T	Y,T	Y,T	T,U	T,U	T,U	T,V	T,Y	T,Y	T,Y	T,Y	T,Y	T,Y
1.4462/-/S32205/S31803	Z,U	Z,U	Z,U	T,U	T,U	U	U,V	Z	U,Z	U,Z	U,Z	U,Z	U,Z
1.4410/-/S32750	Z,V	Z,V	Z,V	T,V	T,V	U,V	V	Z,V	Z,V	Z,V	Z,V	Z,V	Z,V
1.4310/301/S30100	D,X	D,X	D,X	T,Y	T,Y	U,Z	U,V	E	D,E	E	E	E,F	E,H
1.4301/304/S30400	Y	Y	Y	T,Y	T,Y	U,Z	Z,V	E,D	E	E	E	E,F	E,H
1.4307/304L/-	Y	Y	Y	T,Y	T,Y	U,Z	Z,V	E	E	E	E	E,F	E,H
1.4311/304NL/S30453	Y	Y	Y	T,Y	T,Y	U,Z	Z,V	E	E	E	E	E,F	E,H
1.4541/321/S32100	Y	Y	Y	T,Y	T,Y	U,Z	Z,V	E,F	E,F	E,F	E,F	E,F	F,H,E
1.4401/316/S31600	Z	Z	Z	T,Y	T,Y	U,Z	Z,V	H,E,	E,H	E,H	E,H	F,H,E	H
1.4404/316L/S31603	Z	Z	Z	T,Y	T,Y	U,Z	Z,V	H,E	E,H	E,H	E,H	F,E	H,E
1.4571/316Ti/S31635	Z	Z	Z	T,Y	T,Y	U,Z	Z,V	H,I,E	I,H	I,H	I,H	F,I	H,I
1.4438/317L/S31703	Z	Z	Z	Z,T	Z,T	U,J	V,J	J,Z	J	J	J	J	J
1.4439/317LMN/S32726	Z	Z	Z	Z,T	Z,T	U,J	V,J	J,Z	J,K	J,K	J,K	J,K	J,K
1.4466/-/S31050	Z	Z	Z	Z,T	Z,T	U,Z	V,Z	Z	Z	Z	Z	Z	Z
1.4539/904L/N08904	Z	Z	Z	U,Z	U,Z	U,Z	V,L	Z	Z	Z	Z	Z,F	Z
1.4547/-/S31254	Z	Z	Z	U,Z	U,Z	Z	R	Z	Z	Z	Z	Z,I	Z
1.4565/N08028	Z	Z	Z	U,Z	U,Z	Z,R	Q	Z	Z	Z	Z	Z,I	Z
1.4652/-/S32654	Z	Z	Z	U,Z	U,Z	Z,Q	Q	Z	Z	Z	Z	Z	Z
1.4724 /-/-	X,A	X,A	X	X	X	X	X	X	X	X	X	X	Z,X
1.4818/-/S30415	X	X	X	Y	X	Y,S	Y	D,X	E,X	E,X	X	F,X	H,X
1.4833/309S/S30908	X	X	X	Y	Y	Y	Y	X	X	X	X	X	X
1.4835/-S30815	X	X	X	Y	S	O,S	Y	O,X	O,X	O,X	O,X	O,X	O,X
1.4845/310S/S31008	X	X	X	O,X	O,X	O,X	O,X	X,P	O,P	O,P	O,P	O,P	O,P
Unalloyed steel	X	X	X	X	X	Z,U	Z,U	X,Z	X,Z	X,Z	X,Z	X,Z	X,Z

CONSUMABLES	**A = 13**	**B = 25 4**	**D = 19 9**	**E = 19 9 L**	**F = 19 9 Nb**	**H = 19 12 3L**
Cromarod	(410)		308H	308L/LP	347/B347	316L/LP
Cromamig			308H	308L/LSi	347Si	316LSi
Cromacore				308LT0/-1	347	316LT0/-1

CONSUMABLES	**M = 25 22 2 NL**	**O = 21 10 N**	**P = 25 20**	**Q = NiCr25Mo16**
Cromarod	(310)	253	310	-
Cromamig	(310)	-	310	-
Cromacore				

CONSUMABLES	**U = 22 9 3 NL**	**V = 25 9 4 NL**	**X = 22 12**	**Y = 23 12 L**
Cromarod	Duplex/Duplex B	2507 R/B	309L	309L
Cromamig	Duplex	2507	309LSi	309LSi
Cromacore	2209T1	2507	309LT0/-1	309LT0/-1

1.4404/ 316L/ S31603	1.4571/ 316Ti/ S31635	1.4438/ 317L/ S31703	1.4439/ 317LMN/ S32726	1.4547/-/ S31254	1.4565/ N08028	1.4652/-/ S32654	1.4565/ N08028	1.4652/-/ S32654	1.4724 /-/-	1.4818/-/ S30415	1.4833/ 309S/ S30908	1.4835/- S30815	1.4845/ 310S/ S31008	Unal-loyed
Z,Y	Z,Y	Z	Z	Z	Z	Z	Z	Z	X,A	X	X	X	X	X
Z,Y	Z,Y	Z	Z	Z	Z	Z	Z	Z	X,A	X	X	X	X	X
Z	Z	Z	Z	Z	Z	Z	Z	Z	X	X	X	X	X	X
T,Y	T,Y	T,Z	T,Z	T,Z	U,Z	U,Z	U,Z	U,Z	X	Y	Y	Y	O,X	X
T,Y	T,Y	T,Z	T,Z	T,Z	U,Z	U,Z	U,Z	U,Z	X	Y	Y	O	O,X	X
U,Z	U,Z	U,J	U,J	U,Z	U,Z	Z,R	Z,R	Z,Q	X	Y,S	Y	O,S	O,X	Z,U
Z,V	Z,V	J,V	J,V	Z,V	V,L	R	Q	Q	X	Y	Y	Y	O,X	Z,U
E,H	E,H,I	J,Z	J,Z	Z	Z	Z	Z	Z	X	D,X	X	O,X	X,P	X,Z
E,H	I,H	J	J,K	Z	Z	Z	Z	Z	X	E,X	X	O,X	O,P	Z,X
E,H	H,I	J	J,K	Z	Z	Z	Z	Z	X	E,X	X	O,X	O,P	Z,X
E,H	H,I	J	J,K	Z	Z	Z	Z	Z	X	X	X	O,X	O,P	Z,X
F,E	F,I	J	J,K	Z	Z,F	Z,I	Z,I	Z	X	F,X	X	O,X	O,P	Z,X
H,E	I,H	J	J,K	Z	Z	Z	Z	Z	Z,X	H,X	X	O,X	O,P	Z,X
H	H,I	J	J,K	Z	Z	Z	Z	Z	Z,X	H,X	X	O,X	O,P	Z,X
H,I	H,I	J	J,K	Z	L,Z	Z	Z	Z	Z,X	I,X,O	X	O,X	O,P	Z,X
J	J	J	J	J	J	J	J	J	Z,X	I,X,O	X,Y	O,X	X,P	Z
J,K	J,K	J	K,L	K,L	K,L	K,L	J	J	Z,X	I,X,O	X,Y	O,X	X,P	Z
Z	Z	J	K,L	M	Z,L	L	Q,L	Q,L	Z,X	X,Y	X,Y	O,X	P	Z
Z	I,Z	J	K,L	Z,L	L	L,R	L,R	L,Q,R	Z,X	X	X	O,X	X,P	Z
Z	Z,I	J	L,K	L	L,R	R	R,Q	Q	Z,X	X	X	O,X	P	Z,R
Z	Z,I	J	J	L	L,R	R,Q	Q	Q,R	Z,X	X	X	O,X	P	Z,Q
Z	Z	J	J	L	L,Q,R	R,Q	R,Q	Q	Z,X	X	X	O,X	P	Z,Q
Z,X	Z,X	Z,X	Z,X	Z,X	Z,X	Z,X	Z,X	Z,X	Z,B	X	X	O,X	P	Y
H,X	I,O,X	I,O,X	I,O,X	Y,X	X	X	X	X	X	O,X	X	O,X	P	X
X	X	X	X	X	X	X	X	X	X	X	O,X	O,X	X,P	X
O,X	O,X	O,X	O,X	O,X	O,X	O,X	O,X	O,X	O,X	O,X	O,X	O	O,P	O,X,S
O,P	O,P	X,P	X,P	P	X,P	P	P	P	P	P	X,P	O,P	O,P	X,P,S
X,Z	X,Z	Z	Z	Z	Z	Z,R	Z,Q	Z,Q	X	X	X	O,X,S	X,P,S	

I = 19 12 3 Nb
318
318Si

J=317L
-
317L

K = 19 13 4 NL
-
317L

L = 20 25 5 CuL
385
385

R = NiCr 21MoFeNb
625
625
625T1

S = NiCr15Fe6Mn
82
82

T = 23 7 NL
LDX
LDX
LDXP

Z = 23 12 2L
309MoL/MoLP
309MoL
309MoLT1

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