General characteristics of stainless steels
Basic requirements and behaviour of
Stainless electrode coatings
Cromarod – Stainless product programme

General characteristics of stainless steels

Stainless steel

Stainless steel is not a single specific material, but the name given to a group of corrosion-resistant steels. Stainless steels are those steels that have a chromium content of at least 11%. Varying additions of nickel, molybdenum, nitrogen, copper, manganese, wolfram, titanium, niobium, cerium and other elements may also be present. Interest in nitrogen as an alloying element is growing and many stainless steel grades, both austenitic and duplex, containing relatively large amounts of nitrogen, have come onto the market during the last 10 years. It is well established that nitrogen, in combination with molybdenum, greatly improves resistance to pitting corrosion. Nitrogen also increases the yield strength by solution hardening on the austenite. Since mechanical properties and behaviour in service of each type of stainless steel depend upon its composition and microstructure, it is vital to consider the various properties of each grade before selecting one for a particular application.

Corrosion resistance

All stainless steels have two characteristics in common – they contain chromium and possess resistance to corrosion. This remarkable immunity to attack is conferred by the naturally occurring chromium-rich oxide film which is always present on the surface of the stainless steel. Oxide steels have the unique property – unattainable in separately applied films – of self-repair. If the oxide film is removed or damaged by abrasion, or if the raw metal surface is exposed by cutting the steel, a new film is immediately formed by reaction between the steel and the atmosphere or other sources of oxygen. Protection is instantaneously re-established, and it is therefore possible to choose a steel which is quite unaffected even by aggressive marine atmospheres, many acids, alkalis and other chemicals

Strength and formability

The stainless steels offer a remarkable range of strengths. Even in the fully soft condition they have tensile strengths somewhat greater than that of mild steel. Hardness varies in a similar manner, from relatively soft annealed austenitic stainless steel to extremely hard martensitic material such as that used for razor blades or ball bearings. In general, ductility varies inversely with strength. The soft austenitic steels have exceptional ductility, elongation exceeding 50%. The austenitic stainless steels can therefore be cold worked to give an extensive range of semi-fabricated and finished products. The cold working may be adjusted so that the final condition attained has the most advantageous combination of strength and toughness. The ferritic stainless steels offer good strength and ductility, but without the outstanding formability of the austenitic varieties. The martensitic steels can be formed in the annealed condition, and subsequently heat treated to give high strength and hardness.

High and low temperature service

Stainless steel discolours if heated to very high temperatures, but it will not deteriorate by scaling like plain carbon steel, and it retains a high proportion of its strength when heated. Consequently it is used in industry for many applications where durability at a high service temperatures is vital. The strength of a metal decreases when it is heated, the amount of reduction depending upon many factors, one of the most critical being the composition of the alloy concerned. In addition, certain stainless steels are very resistant to insidious, slow-but-steady elongation under stress at high temperatures, known as creep, and are selected by designers for this quality alone. High temperature corrosion (scaling) is of cause deleterious and heat resistant stainless steels are outstanding in this respect, since they are durable in contact with air and most combustion products at temperatures up to 1100°C.

Quite a few processes are carried out at extremely low temperatures, down to -196°C (or even lower). At such temperatures many materials lose their ductility and toughness and fail by brittle fracture. For such applications specific austenitic stainless alloys and also Ni-base alloys are ideally suited.

Stainless steels can be put to use over an almost unique temperature spectrum, from very hot to very cold. As regards mechanical properties and service life, it is essential to select the right grade for specific applications.

Basic requirements and behaviour of stainless electrode coatings

Coating selection
When should one use basic coated electrodes?
Under what conditions should rutile coated electrodes be selected?

Basic coatings

Higher impact energy, particular at low temperatures, can be achieved for weld metal deposits produced with basic coated electrodes, compared with rutile coated electrodes. Standard basic coated electrodes produce a medium to coarse droplet transfer. Slag control is good – the welder can use the stringer bead or weaving technique – and the electrodes are suitable for all positions except vertical down. The bead surface is regular but not particularly smooth and fillet welds are convex in profile. Slag is generally easy to remove from the weld, but not self-detaching.

Rutile-basic coatings

Electrodes in this category display better impact properties at low temperatures than straight rutile coatings. Operability is good in all positions except vertical down. Fillet welds show a mitre profile and slag detachability in close to that rutile electrodes.

Rutile coatings

Characteristic for rutile coated electrodes is the fine spray droplet transfer, excellent operability, stable arc, low spatter, smooth concave bead appearance and good slag detachability. Rutile coated electrodes are available in all possible coating thicknesses.

Thin to medium coatings are designed for thin plate or fully positional pipe welding. Electrodes specifically designed for vertical down welding have a thin coating to minimise the total amount of slag developed. Thick coatings are chosen for high productivity, with particular advantage in down hand and fillet welding. With these thick coatings it is recommended to use joint angles exceeding 50°C. Small, narrow grooves will trap slag and give inclusions.

Coating property comparison

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

Cromarod Index

L	Stands for low carbon content, C max 0,030%. Standard rutile coating.
LP	Thin coated, for pipe welding, fully positional. Operates stably at very low current.
LT	Good CVN toughness at -196°C, FN max 0,5, Urea and cryogenic applications
LV	A thin coated electrode specially designed for vertical down welding
R	Rutile, 160% high recovery type of coating
S	Synthetic, mild steel core wire. Possible to use long electrodes and high current. All alloying elements in electrode coating.
140	140% high recovery version. Intended for high productivity welding. Offers high deposit rate.
B	Basic type of coating, high toughness at -196°C
H	Controlled carbon, C 0,04 – 0,08

Cromarod – Stainless product programme

Cromarod	AWS A5.4/A5.11	Type-analysis	Consumable characteristics	Complementary products			
				GMAW Cromamig	GTAW Cromatig	FCAW Cromacore	SAW Cromasaw
410NiMo	E410NiMo-25	12.5Cr4.5Ni0.6Mo	Synthetic type, basic coating, martensitic deposit, improved toughness	X	X		X
308L	E308L-17	19Cr 10Ni	Rutile coating, excellent all positional operability	X	X	X	X
308LP	E308L-17	19Cr 10Ni	Thin coated, excellent fully positional operability			X	
308L-140	E308L-17	19Cr 10Ni	140% high recovery version				
308H*	E308H-17	19Cr 10Ni	Controlled carbon, for creep at high temperature applications	X	X	X	X
347	~E347-17	19Cr 10Ni 0.25Nb	Low carbon+Nb stab. Primarily intended for resistance to intergranular corrosion	X	X	X	X
309L	E309L-17	23.5Cr 12.5Ni	Dissimilar joints	X	X	X	X
309LP	E309L-17	23.5Cr 12.5Ni	Thin coated version of 309L, excellent fully positional operability				
309MoL	E309MoL-17	23.0Cr 12.5Ni 2.5 Mo	Rutile coating, excellent all positional operability	X	X	X	X
309MoLP	E309MoL-17	23.0Cr 12.5Ni 2.5 Mo	Thin coated version of 309MoL, excellent fully positional operability			X	
309MoL-150	E309MoL-17	23.0Cr 12.5Ni 2.5 Mo	150% high recovery version				
309MoL-S	~E309Mo-26	23.0Cr 12.5Ni 2.5Mo	Synthetic 309Mo version, possible to use in 600mm length				
307B	~E307-15	18Cr 9Ni 5Mn	Basic version of 307 DIN 18 8 Mn - type	X	X		
312	~E312-17	29Cr 9Ni	For difficult-to-weld steels and dissimilar joints. Ferrite = FN 50	X	X	X	X
316L	E316L-17	18Cr 11.5Ni 2.8Mo	Rutile coating, excellent all positional operability	X	X	X	X
316LP	E316L-17	18Cr 11.5Ni 2.8Mo	Thin coated, excellent fully positional operability			X	
316LV	E316L-17	18Cr 11.5Ni 2.8Mo	Vertical down version				
316L-140	E316L-17	18Cr 11.5Ni 2.8Mo	140% high recovery version				
316LT	~E316L-17	17Cr 13.5Ni 2.5Mo	Good CVN toughness down to -196°C. FN max 0.5. Urea applications				
318	~E318-17	18Cr 11.5Ni 2.8Mo 0.25Nb	Low carbon+Nb stab. Primarily intended for resistance to intergranular corrosion	X	X		
317L	E317L-17	19Cr 13Ni 3.5Mo	Higher pitting corrosion resistance than 316L	X	X	X	X
317LP	E317L-17	19Cr 13Ni 3.5Mo	Thin coated, excellent fully positional operability				
317L-140	E317L-17	19Cr 13Ni 3.5Mo	140% high recovery version				
Duplex	~E2209-17	23.5Cr 9Ni 3Mo 0.15N	Excellent pitting corrosion resistance, high strength	X	X	X	X
Duplex-140	~E2209-17	23.5Cr 9Ni 3Mo 0.15N	140% high recovery version				
Duplex LP	E2209-17	23.5Cr 9Ni 3Mo 0.15N	Thin coated, excellent fully positional operability			X	
2507R	~E2553-17	25.0Cr 9Ni 4Mo 0.23N	Super Duplex grade, higher PRE than Duplex	X	X		X
2507B	~E2553-15	25.0Cr 9Ni 4Mo 0.23N	Basic coating, higher toughness down to -50°C				
385	E385-17	20Cr 25Ni 4.5Mo 1.5Cu	Highly corrosion resistant grade, sulphuric acid	X	X		X
385MoN	~E385-17	20Cr 25Ni 6Mo 0.15N 1.5Cu	Futher enhanced corrosion resistant grade, sulphuric acid				
383	E383-17	27Cr 31Ni 4.0Mo 1.0Cu	Highly corrosion resistant grade, phosphoric acid		X		
310*	~E310-17	26Cr 21Ni	For corrosion and oxidation resistance at high temperatures, 1150°C in air	X	X		
310Cb*	E310Cb-17	26.5Cr 20.5Ni 0.4Mo 0.8Nb	Enhanced resistance to hot cracking				
253*	-	23Cr 10.5Ni 0.15N	High temperature use up 1150°C. Cerium alloyed, for base material 253MA				
82*	ENi Cr Fe-3	16Cr 70Ni 6Mn 2.2Nb	Ni-base electrode for Inconel 600 types. For service at elevated temperatures	X	X		X
625	ENi Cr Mo-3	22Cr 63Ni 9Mo 3.4Nb	Excellent corrosion resistance. For Inconel 625 / 254SMO steel	X	X		X
625-170	~ENi Cr Mo-3	21Cr bal.Ni 9Mo 2.5Nb 6Fe	170% recovery, Ni-base electrode for fillet, butt and overlay welding				
59	ENi Cr Mo-13	23Cr 59Ni 16Mo	Enhanced corrosion resistance, for alloy 59, C276, 254SMO, 654SMO	X	X		X

* Products are intended for service at elevated temperatures

ConSel: Software database program

Cromarod electrodes for welding dissimilar joints

Advisible consideration for austenitic-ferritic dissimilar joints

ELGACROM dissimilar welding – chart

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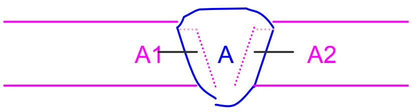
General understanding in welding dissimilar metals

All stainless steel deposits on carbon or low-alloyed steel should be made with filler metal of sufficiently high alloy content to ensure that normal amounts of dilution by carbon steel will not result in brittle weld.
In general, filler metal metals of type 308L, 316L or 347 should not be deposit directly on carbon or low-alloy steels.
Deposits of type 307, 309L, 309L-140, 309MoL, 309MoL-150, 309MoL-S or 312 are acceptable.
Welds made with types 309L and 312 filler metals are partially ferritic and therefore highly resistant to hot cracking.

Stainless steel filler metal is deposited only in that proportion of the weld where the stainless steel cladding has been removed, and carbon or low-alloyed steel filler metal is used for the reminder. The back-gouged area of the stainless should be filled with a minimum of two layers of stainless steel filler metal. The two first layers must be high in alloy content to avoid cracking as a result of normal dilution by the base metal.

Proportion of the filler metal, having contribution to the formation of the fusion zone is proportional to the cross sectional area (A), comprised between the exterior profile of the weld bead and the external face of the base materials.
Mixed welded joint: Stainless steel 316L to a Mild steel of low carbon with electrode Cromarod 309MoL.



A1: 316L steel to A2: Mild steel

Definition of dilution in % = $\frac{A}{A1+A2}$ — A: Cromarod 309MoL; A1+A2: 316L steel + Mild steel

Filler and base metal analysis, %

Grade	C	Si	Mn	Cr	Ni	Mo	Ti	Nb	Cu	Co	N	*FN
Cromarod 309MoL, 70%	0,023	0,83	0,83	23,13	12,30	2,50	0,010	0,015	0,10	0,05	0,080	23
316L Steel, 15%	0,023	0,44	1,34	17,05	11,22	2,09	0,010	0,010	0,05	0,05	0,016	4
Mild Steel, 15%	0,052	0,22	1,20	0,00	0,00	0,00	0,000	0,000	0,00	0,00	0,055	0

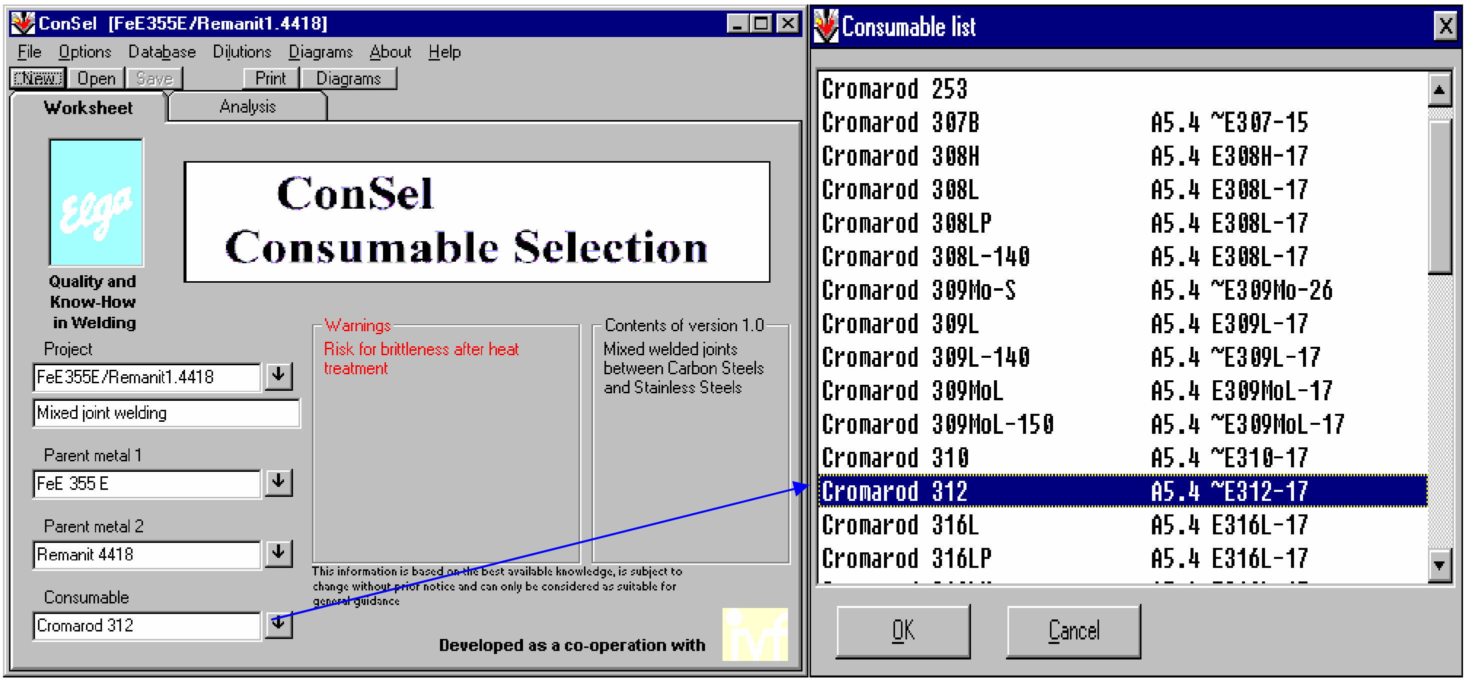
Calculated weld metal analysis based on total dilution of 10 up to 50% in the dissimilar welded joint

Total dilution	C	Si	Mn	Cr	Ni	Mo	Ti	Nb	Cu	Co	N	*FN
10%	0,024	0,78	0,87	21,67	11,63	2,35	0,010	0,014	0,09	0,05	0,076	18
20%	0,026	0,73	0,92	20,21	10,96	2,21	0,010	0,013	0,09	0,05	0,071	14
30%	**0,027**	**0,68**	**0,96**	**18,75**	**10,29**	**2,06**	**0,010**	**0,012**	**0,08**	**0,04**	**0,067**	**10**
40%	0,029	0,63	1,01	17,29	9,62	1,92	0,010	0,011	0,07	0,04	0,062	6
50%	0,030	0,58	1,05	15,83	8,96	1,77	0,010	0,010	0,06	0,04	0,058	3

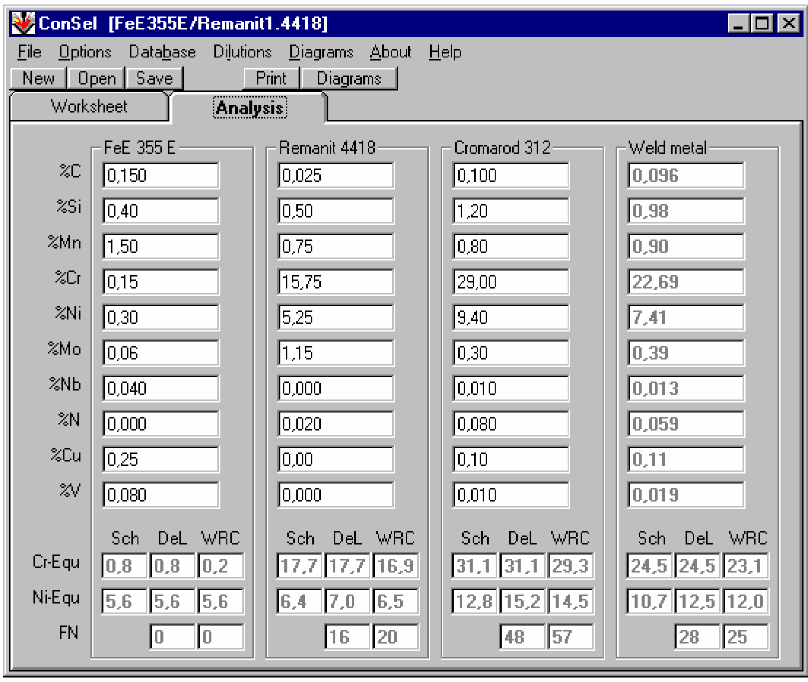
*FN, WRC-1992 Diagram, “Calculated ferrite number”, according to **A**merican **W**elding **S**ociety,
Cr-eq.= %Cr+%Mo+0,7*%Nb, Ni-eq= %Ni+35*%C+20*%N+0,25*%Cu
Ferrite number, determination for stainless grade of consumables are performed with a Fischer Ferit Scope MP3.
In total, five measurements are determined and the average FN will be stated in the batch certificate to customers.

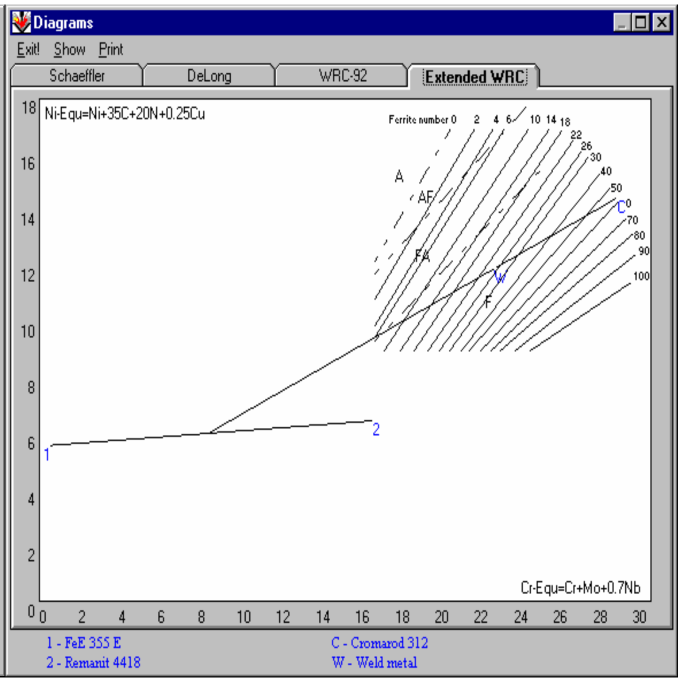
ConSel: Software database program

ConSel is definitely the most user-friendly software for selecting welding consumable in mixed welded joints between carbon- and stainless- steels.



You operate ConSel with few clicks in worksheets, selecting type of steels and consumables. First choice is parent metal of carbon, the second is the stainless parent metal, all based in the database list. Specified consumables are selected by welding-method in the program, or by Yourself, as a User-specialist.





A print-out screen of the base-materials, consumable as well as the diluted weld metal. The extended WRC-diaram.

ConSel allows to pre-set dilution´s and options for best suitable conditions.

Selections is based on information from welding handbook, Volume Four, Seventh Edition 1982.

ConSel displays Analysis and Ferrite Number of the selected steelgrades, consumable, weld metal as well as Schaeffler-, DeLong- and WRC-92 diagram. In case of problems warnings will be printed out for technical discussions or future project files.

Content: The ConSel program consists of three floppy discs for Windows 3.1/3.11/95/NT.

Instructions in English is attached. ConSel is an open database where You can add /or delete steel grades/consumables.

Cromarod electrodes for welding dissimilar joints

In general, only high alloyed filler metals are used for the joining of low alloyed steels or unalloyed to stainless steels. Below are listed some typical Cromarod electrodes used dissimilar joints.

Cromarod	Type-analysis
309L	23.5Cr 12.5Ni
309MoL	23.0Cr 12.5Ni 2.5 Mo
309MoL-S	23.0Cr 12.5Ni 2.5Mo
309MoLP	23.0Cr 12.5Ni 2.5 Mo
309MoL-150	23.0Cr 12.5Ni 2.5 Mo
307B	18Cr 9Ni 5Mn
312	29Cr 9Ni
Duplex	23.5Cr 9Ni 3Mo 0.15N
Duplex-140	23.5Cr 9Ni 3Mo 0.15N
310	26Cr 21Ni
82	16Cr 70Ni 6Mn 2.2Nb
625	22Cr 63Ni 9Mo 3.4Nb
625-170	21Cr bal.Ni 9Mo 2.5Nb 6Fe
59	23Cr 59Ni 16Mo

- The major task of all dissimilar welding filler metal are to obtain a tough crackfree welded joint.
- Only dry or rebaked electrodes should be used. Important is that only austenitic electrodes gives a deposited weld metal with low hydrogen.
- An important step to take in order to avoid the possible occurance of hydrogen induced cold cracking is the correct selection and control of preheating and interpass temperatures, which are selected taking into concideration the chemical composition and the carbon equvivalent of the ferritic steels in question.

Advisible concideration for austenitic–ferritic dissimilar joints

- Weld with lowest possible heat input, kJ/mm
- Interpass temperature of up to 150°C
- When the steel requires preheating and an interpass temperature above 150°C, first deposit a buttering
- layer or a joint welding with dry electrodes. Second the welding can be completed with a normal austenitic stainless filler.
- Welding stringer beads or maximum weaving of twice of the electrode-diameter
- Back grinding of the root pass and the deposition of a backing run is advisable.

If heat treatment above 600°C are necessary after the welding, pay attension to that;
Nickel-base weld metal behaves better where a subsequent post weld heat treatment is to be applied to an austenitic-fe rritic dissimilar joint.

- Further, nickel-base weld metal are not sensitive to embrittlement at high temperature by sigma phase formation.
- Expansion coefficient is between ferritic and martensitic steels and that of austenitic steels.
- They remian very ductile at low temperature and resist oxidation at high at high temperature.
- Try to stay at maximum dilution of 30%.
  Which means that we allways should control and stay at a lowest possible current range.
- Use 50% bead overlapping to minimize dilution from base material.
- Always use a short welding arc.
- Avoid crater cracks when ending the welding. Make a circling movement backwards and distinguish the arc on top of the ready weld.

Microstucture in duplex materials

Duplex is … "different but not difficult"

Joint preparations

Welding methods

Consumables

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General understanding in welding Duplex Stainless Steels, DSS.

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 established as a alternative to carbon steel, other types of stainless steel and nickel base alloys.

In fabrication many different types of joints are welded. The welding methods used are SMAW, GTAW, GMAW, FCAW and SAW. When planning welding operations, therefore, it is of paramount importance to give careful considerations to the choice of welding consumables and processes, the establishment of comprehensive welding procedures and the need for a thorough understanding of the problems with the storage and risk of moisture pick up in the consumables, handling and fabrication of stainless steel plates.

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

Group 1: PRE ~25 23Cr4Ni0.1N (Mo-free) -SAF2304, Uranus 35N-WNr1.4362

Group 2: PRE ~ 35 22Cr5.5Ni3Mo 0.14N -SAF2205, Uranus 45N, Remanit 4462 , Falc 223 W-Nr 1.4462

Group 3: PRE ~41 25Cr7Ni4Mo 0.25N,Super Duplex, -SAF2507, Uranus 52N+, Falc 100, Zeron 100

Typical properties for DSS = 1.4462 compared to other stainless steel types:

As can be seen the duplex 1.4462 is 50% more expensive compared to the standard 304L grade in terms of Price, per kg, but less expensive if we are comparing Price/PRE and Price/Yield strength.

Steel Grade	Analysis Typical	Rp0.2 N/mm^2	Rm N/mm^2	*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

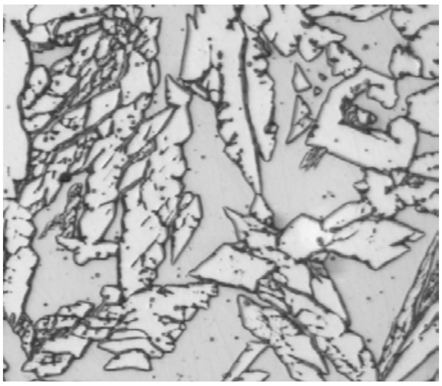
March-95, Pitting Resistance Equivalent, *PRE = %Cr+3.3* %Mo+16* %N.

The greatest benefit of molybdenum and nitrogen in stainless steels are improving resistance to pitting and crevice corrosion, especially in chloride containing environments. One way of measuring this benefit is measuring the critical temperature.That is determining the highest test temperature in a standard test exposure to ferric chloride which does not cause pitting or crevice corrosion. The higher the PRE - the grater resistance to corrosion.

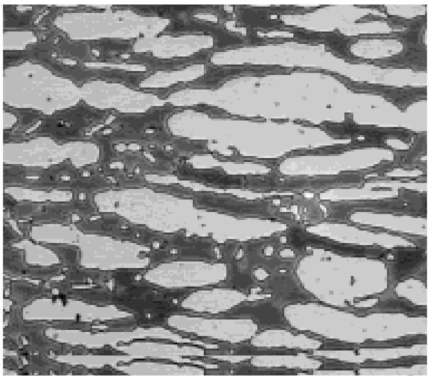
Resistance to pitting corrosion is normally established with the ASTM G48 test. The critical pitting temperature - CPT, is the temperature at which pitting corrosion starts in the specimen immersed in the ferric chloride solution.

Typical microstructure in duplex material:

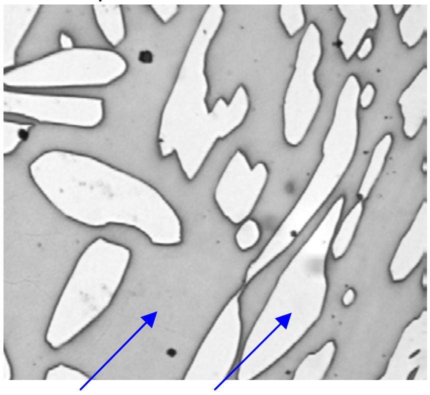
Duplex Weld Metal, 200x



Wrought Duplex, 200x



Cast Duplex, 200x



Normally the weld metal contains 25-65% ferrite.

Duplex Stainless Steels consists of 50% ferrite and 50% austenite.

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 the heat input and the plate thickness, faster cooling rates produce more ferrite.
Too slow or too fast cooling rates, can result in other "micro structural problems", causing problems with reduced corrosion resistance and/or reduced impact strength.
To get 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 because of dilution with the lower Ni-content base material. ** (Cromasaw Duplex – 56% ferrite, Cromacore DW 329AP - 35% ferrite).

Precipitation of secondary austenite in multipass duplex weld metal or HAZ, can be possible. These precipitates of austenite can also reduce the 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 increased austenite level of the filler metal.
Careful recommendations regarding welding parameters for especially 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 as welding the highly alloyed group 3 DSS.
To get a proper phase balance and to avoid precipitation relations the following parameter ranges are to be 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	-"-
25Cr7Ni4Mo 0.25N	0.4-1.5	Max. 150°C

The heat input is chosen to suit the thickness of the material and the welding process, e.g. for thin-wall tubes (t=1,5 mm) ~ 0.5 kJ/mm is optimum, and 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 can cause embrittlement and low impact values in the root region.

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

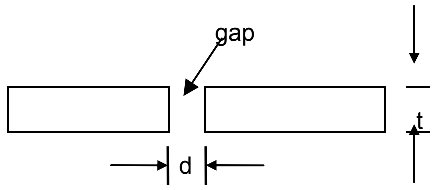
Joint Preparation

If the plates are prepared with plasma cutting, the oxide layer should be removed by machining or grinding.

A general rule, when welding duplex stainless steels, the root gap should be slightly wider than for standard stainless steels.

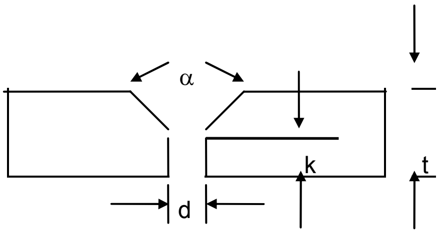
Typical joint preparation for two-sided butt welding:

	t	d
	mm	mm
SMAW	3-4	2-3
GTAW	3-6	2-3
GMAW	3-6	2-3
FCAW	3-8	2-3



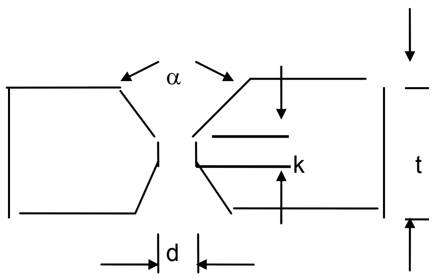
V- groove

	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°



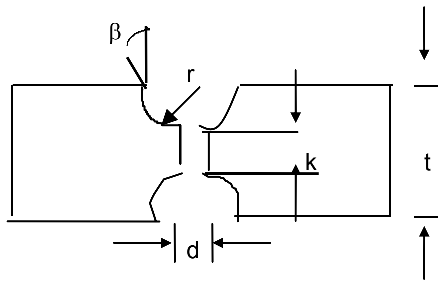
Double V- groove

	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	r	β
	mm	mm	mm	mm	
SMAW	>30	2-3	2-3	6-8	15°
GTAW	>16	2-3	1-2	6-8	15°
GMAW	>16	2-3	2-3	6-8	15°
FCAW	>30	2-3	2-3	6-8	15°
SAW	>30	0	3-5	6-8	15°



SMAW

Consumable for welding Duplex stainless steels are specified in some international standards:

AWS A5.4-92 E 2209	standard Duplex	AWS A5.4-92 E 2553	Super Duplex
EN 1600-97 E 22 9 3 N L	standard Duplex	EN 1600-97 E 25 9 4 N L	Super Duplex

For group 1 + 2 steels: four types of Duplex electrodes are available:

- Cromarod Duplex, a rutile normal recovery
- Cromarod Duplex-140 a rutile,140%, high recovery for higher productivity
- Cromarod Duplex-LP, a rutile thin coated type for pipes and narrow joints
- Cromarod Duplex-B, a basic coated type for high charpy toughness at -46°C.

For group 3 steels: two types of Super Duplex electrodes are available:

• Cromarod 2507B = basic type • Cromarod 2507R = rutile type

The basic electrode 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.

GTAW

GTAW is often recommended especially for root passes in pipes.

Two types are available:

Group 1 + 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-mixtures or formier gases (90%$N_2$10%H_2) are used. The later is recommended because of improving the root side pitting resistance.

To get 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 ($\geq$ 70 %) in the root area is expected - H_2 in the backing gas can produce micro cracking in the ferrite and should therefore be avoided. In these applications pure argon backing gas is recommended.

FCAW

FCAW-wires are available for welding of DSS, group 1 + 2:

- Cromacore DW 329A for horizontal position welding
- Cromacore DW 329AP for positional welding, especially in PF/3G position

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

GMAW

Group 1 + 2: Cromamig Duplex Diam 1.0-1.2 mm Group 3: Cromamig 2507 Diam 1.0-1.2 mm

Shielding gases: Spray arc: Ar + 0,03% N_2, 14-16 l/min Short arc: Ar + 0,03% N_2 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 V
1.2 mm	120-150	18-21 V	175-250 A	26-28 V

SAW

Consumable for group 1 and 2, wire and flux recommendation: Cromasaw Duplex + Cromaflux 300B.

The highest productivity in 1G position is found with SAW.

For group 3, wire and flux recommendation: Cromasaw 2507 + Cromaflux 300B.

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