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SUBMERGED-ARC SURFACING OF HIGT-ALLOY STEELS BY FLUX-CORED WIRES

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Cored wires are used in numerous welding processes with or without external gas or flux shielding. Submerged arc welding (SAW) with cored wires, seamed or seamless, for joining mild and low alloyed steel grades is a technique that has demonstrated clear advantages during the three last decades. Ever since its invention, the SAW process has evolved with one main goal: to combine quality with productivity. With low alloy wires, the benefits have already been clearly demonstrated and widely exploited. However, little has been written on SAW and cladding with cored wires for corrosion or heat resisting applications. Its extension to high alloy compositions brings corresponding benefits and adds some specific and unique features. This paper focuses on consumable specificities and on the quality and productivity features of SAW with CRA (corrosion resistant alloy) cored wires. It describes the potential as well as the limitations of this technique. Cored wires are now used for submerged arc welding of almost all stainless steels ranging from soft martensitic to super-duplex, and for a series of nickel base compositions as well as for cladding cobalt base alloys. Examples of industrial applications with austenitic, duplex, martensitic and heat resisting stainless steels are given to illustrate the potential of the cored wire solution. 13 Ref., 4 Tabl., 25 Fig.

Keywords: Submerged arc welding, surfacing, cored wire, high-alloy steels

Submerged arc welding (Figures 1–4). The process allows deposition rates and welding speeds greater than most other welding processes and is very productive. It can produce deeply penetrating high quality welds as well as it can be used for weld surfacing where shallow penetration is required. It exists in many forms and it can be adapted to allow the welding of stainless steel base material from a few millimeters thickness up to more than 150 mm. The flux covering suppresses fume and the operator is not hindered by the light of the arc which dispenses him from a welding shield.

The disadvantages are not serious: the weld pool cannot be seen, the flux can get into machinery parts and welding must be carried out in the flat or horizontal vertical positions. Circumferential welds are more difficult to be made in small diameters because the flux falls away.

There are two kinds of consumables for submerged arc welding: solid wire (the most commonly used) and cored wire. The characteristics of cored wire give advantages over solid wire. Cored wires comprise a metal sheath and a core. This core consists of a mixture of various metallic ingredients (such as nickel, iron or molybdenum powder) and non-metallic powders (for instance, slag forming components or agents that clean and deoxidize the weld).

The deposition efficiency (but not systematically the deposition rate) will increase with the amount of metallic core ingredients in a composite tubular wire up to a given degree of compaction above which, metal cored unlike flux cored wire, will almost have the same characteristics as solid wire.

Figure 1. Submerged arc welding with cored wire: Duplex UNS S32205

Figure 2. Submerged arc welding with cored wire: Austenitic CrNi steel AISI 310S

Compares submerged arc welding to other most common arc processes for welding stainless steel

Parametrs	SAW	SMAW	GMAW	GTAW	PAW	FCAW
Welding positions	1G, 2G	All	All	All	1G, 2G	All
Heat input	High	Moderate	Moderate	High	Moderate	Moderate
Slag cover	Yes	Both sides	No	No	No	Both sides
Investment	High	Very low	High	Moderate	High	Low
Analysis available	Limited	Any	Limited	Limited	Limited	Any
Possibility to modify composition	Limited	Yes	No	No	No	Yes
Employability	Limited	Everywhere and always	Often	Everywhere (gas)	Limited	Often
Set time	Long	Short	Longer	Longer	High	Short
Sensitivity to contamination	Low	Low	High	High	High	Low
Heat / Filler supply	Together	Together	Together	Separate	Together	Together
Slag	Yes	Yes	No	No	No	Yes
Spatter	No	No / Few	No / Few	No	No	No / Few
Weld bead protection	Good	Good	Good/Moderate	Excellent	Excellent	Good
Welding speed	High/very high	Moderate	Low/moderate	Low	Very high	Moderate/high
Distortion	Moderate/high	Moderate	Low/Moderate	High	Low	Low/Moderate
Automate	Yes	No	Yes	Yes	Yes	Yes
Duty cycle	High	Moderate	Moderate	Low	High	Moderate
Dilution	30-70%	10-25 %	5-50%	0-100%	100%	10-25%
Visible arc	No	Yes	Yes	Yes	Yes	Yes
Welding fumes	No	Yes	Some	A few	A few	Yes
Weld appearance	Excellent	Very good	Good	Excellent	Excellent	Very good
Micro-slag inclusions	Yes	Yes	No	No	No	Yes
Sophisticated power ources	No	No	Yes	Yes	Yes	No
Backing gas / Ceramic	No/Ceramic	No	Gas	Gas	Gas	Ceramic
Undercut	No	No	Sensitive	No	No	No
Deposit rate in position	N.A.	Moderate	Low	Low	N.A.	High

When welding with a tubular electrode, most of the welding current is conducted by the metal sheath. In a solid wire the current travels through the entire cross-section of the wire. Thanks to this difference, cored wires for submerged arc welding provide advantages:

At an equivalent amperage setting, a cored wire will experience higher current densities than a solid wire. The resulting increased melt-off rates, in combination with a high percentage of metallic core ingredients, offers higher deposition rates. At high currents, the difference between solid wire and cored wire is amplified.

The benefit of an increased deposit rate, for a given wire diameter, at same amperage and same wire stick out is amplified by the physical characteristics of the strip. The electrical resistivity of stainless steel is higher when compared to mild or low alloy steel hence, for a given weld metal composition,

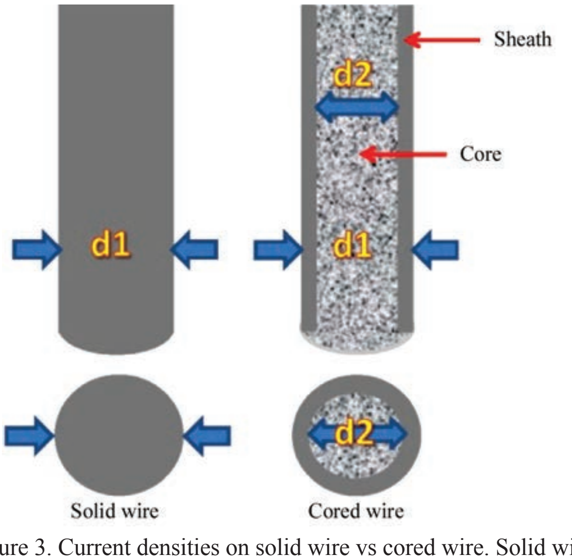


Figure 3. Current densities on solid wire vs cored wire. Solid wire = 3.14·(d1²)/4, cored wire = 3.14·(d1² – d2²)/4

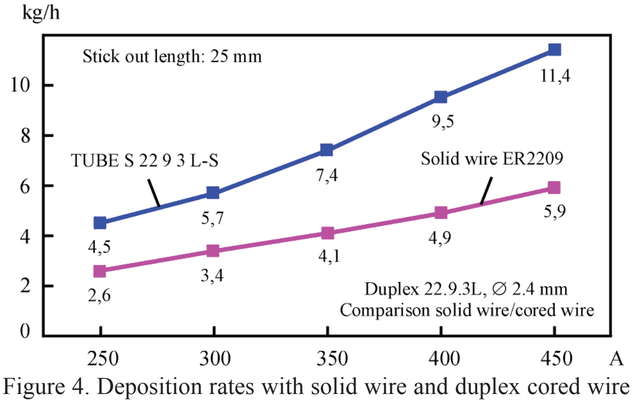


Figure 4. Deposition rates with solid wire and duplex cored wire for submerged arc welding — Duplex UNS S32205. Measured for application Fig. 1

deposition rates achieved with stainless steel cores wires will usually outperform these of solid wires having the same composition. The stainless steel sheath composition, its quality and dimensions, the production route of the cored wire as well as wire cross section design revealing filling ratio are important contributors not only to deposition rate but also to global weld performance.

Cored wires contribute to provide productivity which is important in any business. With stainless steels, corrosion resistance properties as well as metallurgical specificities such as embrittlement or hot cracking tendency are often the limiting factor. In many cases, these can be dealt with easier by exchanging solid to metal cored wires, without sacrificing productivity.

An efficiency of 99 % is used when calculating the deposition rates of stainless steel solid wires when used in the SAW process. In comparison, TUBE S metal cored wires use a 98 % efficiency rate for calculating deposition rates.

In many cases, stainless steel cored wires for SAW are formulated differently than those designed to run with shielding gas. For example, they contain additions to improve slag release or to enhance impact toughness.

Stainless steel cored wire designs (Figures 5, 6). The overriding majority of submerged arc wires for corrosion resistant application are seamed. The seam is overlapped. Cored wires with a seam are all manufactured from strip formed into a U-shape, filled and closed to give a round section. They are then reduced to the desired diameter by drawing or rolling.

In the case of drawing, the wire is reduced by passing it through a series of dies lubricated with soap. Drawing soaps contain hydrogen and must be eliminated at the end of the cycle to avoid porosity and excessive hydrogen content in the weld metal.

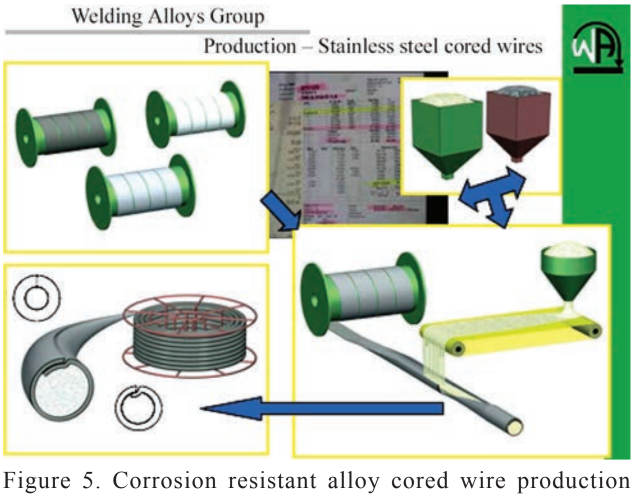


Figure 5. Corrosion resistant alloy cored wire production schematic description

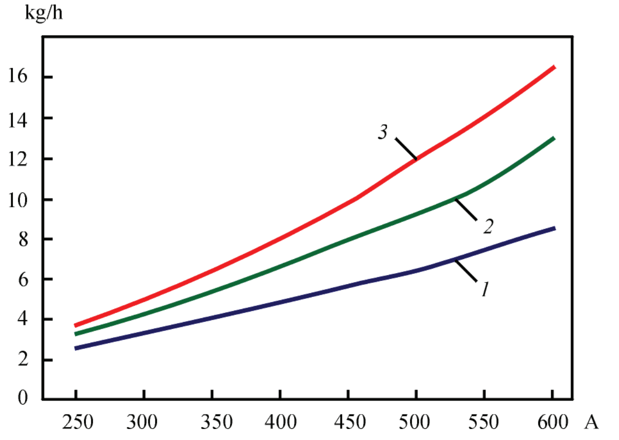


Figure 6. 308L composition. Deposition rates diameter 2.4 mm. Stick out length 25 mm: *1* — solid wire; *2* — seamless cored; *3* — seamed cored

Lubrication residues remaining on the wire surface must be removed either by dissolution or by baking.

In the case of rolling, the reduction is carried out in a more gradual manner with little or no lubricant, between rolls of appropriate profile. Rolling and drawing may be combined during the manufacture of cored wires.

High alloy seamless wires can be produced today as well. Low alloy seamless wires are manufactured from a metal tube filled by vibration then drawn to the desired diameter with intermediate annealing.

It is difficult to produce high alloy stainless grades his way because of the limitation in filling ratio. However, new production techniques for seamless high-fill wires are now possible. One starts from a strip formed into a U-shape, filled with powder and then seam-welded by a proprietary laser system. The wire is then drawn to the required diameter with eventual intermediary annealing(s).

A drawback of stainless steel seamless wires for submerged arc welding is their lower performance in deposition rate.

Quality. Virtually all stainless steel compositions are feasible with cored wires. In order to obtain a weld deposit with the desired composition, structure, mechanical properties and corrosion resistance, the cored wire manufacturer has at his disposal a vast variety of strip analyses, which he combines with metal and/or mineral powders, with or without binders.

What determines the quality of the finished product is the experience and knowledge brought to bear in production. Close attention is essential to ensure the core is continuous and homogeneous. Strict quality control must be exercised from the procurement of raw materials until the finished product is prepared for dispatch.

Stainless steel cored wires are produced mainly by rolling and may undergo one or several heat

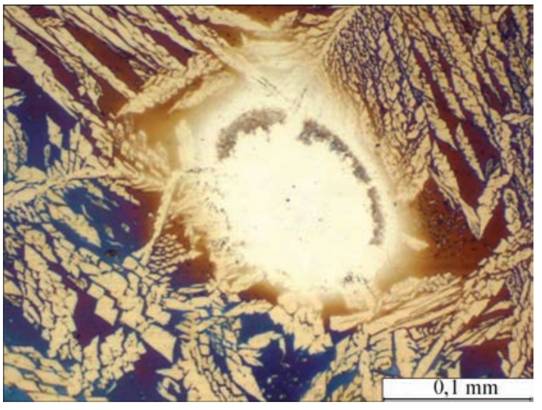


Figure 7. Submerged arc duplex cored wire 2.4 mm. Low parameters: 250 A, 28 V, 40 cm/min. Coarse molybdenum metal. Unmolten molybdenum in structure. Pitting corrosion temperature under 22 °C

treatments. One may arrive at a particular weld deposit analysis starting from a more or less highly alloyed strip. The composition is adjusted by adding elements to the flux filling of the tube. For example, it is possible by this means to produce a 316L austenitic stainless steel cored wire with using mild steel, 430L, 304L or 316L strip.

The performance of high alloy cored wires for submerged arc welding in terms of productivity and weldability in addition to mechanical properties and resistance to various forms of corrosion — according to the type of stainless steel deposited — depends on a large number of factors:

- the strip: composition, dimensions, surface finish, impurity levels, general condition;

- the manufacturing process: rolling sequence, lubrication system, heat treatments etc;

- the core type: flux or metal cored, amount and type of non-metallic additions, wet mix or dry mix.

The details of the slag/core formulation, the consistency of the raw materials used, their grain size and their purity are of overriding importance: it is well known that cored wires of the same classification from different manufacturers are never quite the same. Economic considerations (raw material prices, production output and initial cost price of the wire) should not occult the stringent requirements in terms of formulation otherwise problems will arise sooner or later (Figure 7)

Cored wires for submerged arc welding — advantages. The main benefits of the cored wire route for submerged arc welding stainless steels can be summarized as follows:

- tailored compositions to cope with specific dilution levels or to achieve particular compositional requirements and mechanical / corrosion resistance properties (fabrication welding and weld overlay);

- increased productivity: higher deposition rates and / or improved corrosion resistance;

- higher welding speeds: reduced heat input, reduced warping of welded structures,

- enhanced weldability: excellent wetting, easy slag release even for the first beads in narrow preparations, very good weld appearance,

- versatility: it is possible to weld the first layers, for example the first run on a root pass at low settings (e. g. < 250 A for Ø 2.4 mm) and to fill the joint with the same wire, taking benefit from the improved deposition rates at higher parameters (e. g. 450 A for Ø 2.4 mm);

- logistical advantage: one wire diameter can be used for all thicknesses.

The above advantages are illustrated by some examples of applications

Joining of common chrome nickel austenitic stainless steel. Submerged arc welding is commonly applied to joining applications. As it is restricted to work in the flat position and the weld pool is not visible, it has been developed essentially as an automatic or robotic process.

Pressure to increase productivity, reliability and quality is unrelenting. Thus, nowadays we find many possible combinations: tandem, twin, tandem-twin, multi-wire and a series of derivatives or digressions from these techniques. Whatever process is used, cored wire can increase quality and productivity. A simple change of consumable can bring clear benefits, as shown on figures 8 and 9. Using cored

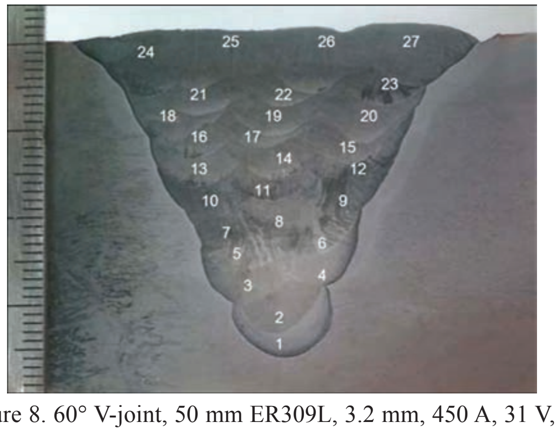


Figure 8. 60° V-joint, 50 mm ER309L, 3.2 mm, 450 A, 31 V, 50 cm/min, 27 runs

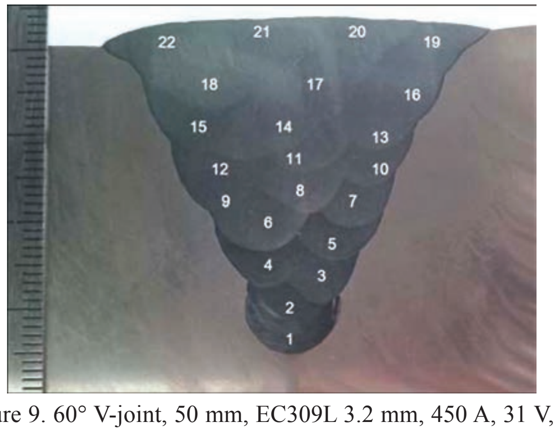


Figure 9. 60° V-joint, 50 mm, EC309L 3.2 mm, 450 A, 31 V, 50 cm/min, 22 runs

Figure 10. Submerged arc welding with EC316L wire

Figure 11. Macrography illlustrating bead shaping possibilities and penetration

wire instead of solid wire, a higher deposit rate is achieved with fewer passes.

Thanks to its wide parameter range, cored wire can be used for a large range of submerged arc applications, from two-run processes to multi-pass groove welding (Figure 10).

Weld bead shapes are easier to adjust, less weld preparation is required, as fewer layers are necessary to complete the joint, less flux is consumed and there is less downtime and distortion (Figure 11).

Joining of standard chrome nickel austenitic stainless steel (Figures 12, 13). As a rule of thumb, most austenitic stainless steels with a Cr_{eq}/Ni_{eq} > 1.5 with Cr_{eq} = %Cr+%Mo+0.7*%Nb and Ni_{eq} = %Ni+35*%C+20*%N+0.25*%Cu are quite easy to weld, provided some elementary precautions are taken. They do not normally require preheat, post-heat or post weld heat treatment. Austenitic weld metal with adequate ferrite content has good resistance to hot cracking.

Austenitic stainless steels undergoing a primary austenitic solidification (A or AF) are more sensitive to hot cracking and require special care during welding (example 310, 385).

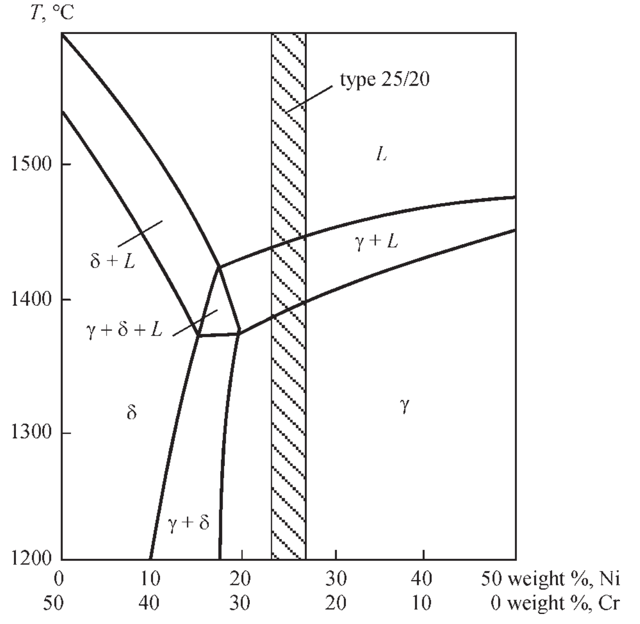


Figure 12. FeCrNi diagram 18Cr/8Ni composition. FA solidification mode

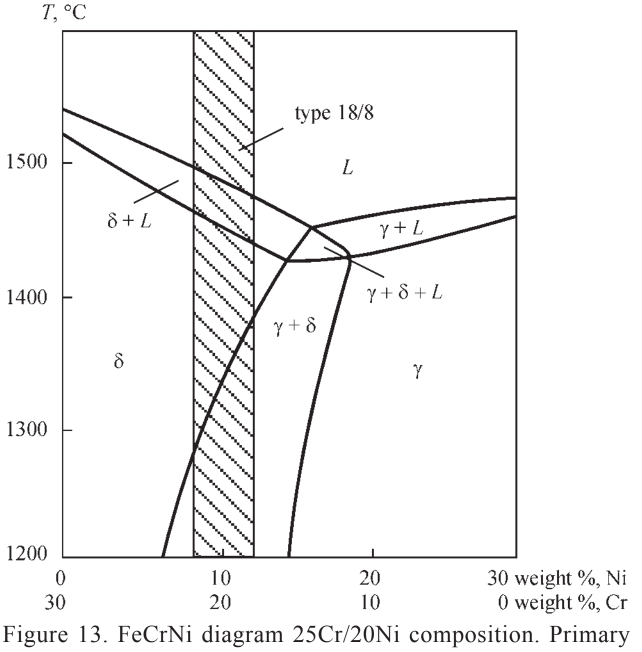


Figure 13. FeCrNi diagram 25Cr/20Ni composition. Primary austenitic solidification mode

Austenitic stainless steels have lower thermal conductivity than carbon and low alloy steels, the welding zone will be at high temperatures for longer. During welding, impurities can become concentrated at the grain boundaries resulting in a risk of cracking. To avoid this, welding conditions and welding consumables must be chosen with care:

- control residual impurity levels (S, P, B etc.) in the weld metal i.e. in wire and flux;
- limit oxygen content in weld metal;
- alloy with manganese when possible and allowed;
- avoid burn off of alloying elements;
- control dilution;
- keep heat input low;

- work with a low inter-pass temperature;
- adapt welding speeds;
- check weld bead geometry (width/depth ratio).

With cored wire, welding can be carried out at a low heat input with a higher deposition rate than with solid wire. Thus, cored wires allow quality to be combined with productivity including for austenitic stainless steels.

He SAW process using cored wire wire is now being implemented with success on AISI 310 stainless steel. Cored wire improves hot cracking resistance when compared to solid wire. The constructions are for example H_2S reactors and involve thicknesses above 40 mm. PWHT is specified with a holding time at 870 °C. Other PWHT is solution annealing at 1080 °C.

Joining duplex stainless steels. Lean duplex, duplex and super-duplex steels have good weldability as well. Duplex stainless steel cored wires can be tuned in order to achieve required composition, ferrite level and mechanical properties according to specific joint preparations or specific requirements on the cladding. Though submerged arc welding is a process that uses a high heat input it is well adapted to welding duplex stainless steels. Cored wire is often an attractive solution to expand the possibilities of the submerged arc welding process with these materials.

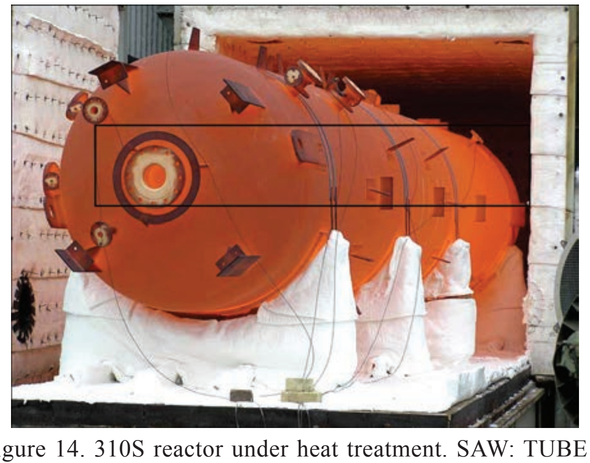


Figure 14. 310S reactor under heat treatment. SAW: TUBE S 310-S + WAF 380

Figure15. Reboiler in duplex stainless steel FCAW – TETRA S B 22 9 3L-G. SAW – TUBE S 22 9 3L-S + WAF 385

Duplex cored wire TUBE S 22 9 3L-S allows deposit rates 30 % higher than those of solid wire of the same diameter to be attained (Figures 14, 15).

Cladding applications (Figures 16–18). Stainless steel cladding involves careful monitoring of the dilution. The Schaeffler, Espy and WRC 92 extended constitution diagrams are useful tools to predict the structure of a weld metal in the case of weld overlays. The closer one comes to the boundary of the martensite region of the diagrams, the greater is the risk of cold cracking. Procedure qualification according to EN ISO 15614-7 & ASME IX prescribes bend tests to reveal any cracking tendency and to guarantee the soundness of the weld deposit.

The electroslag welding process (ESW) is currently very widely used for cladding on account of its advantages: low dilution, high deposition rate, high quality.

This process is however sometimes difficult to use for several reasons:

- size: strip width + the magnetic steering system;
- minimum base metal thickness is required: approximately half the width of the strip (e.g. minimum base metal thickness of 30 mm if a 60 mm wide strip is used);
- high distortion due to the high heat input;
- need of a high-current power source delivering typically 1200 A for a 60 mm strip.

Submerged arc deposits with cored wire are characterized by bead profiles that are wider and less penetrated than solid wire. Thus, at the same parameters (330 A, 30 V, 41cm/min), SAW with cored wire will involve less dilution and a lower risk of martensite formation in weld metal (about 10 % less dilution with cored wire at same parameter settings). This martensite is a problem, for example during the bend tests.

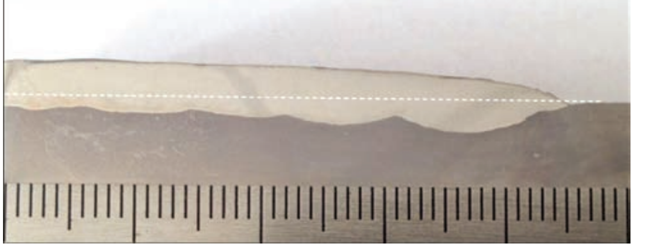


Figure 16. Cladding ER309L 3.2 mm, 330 A, 30 V, 41 cm/min, 30 % dilution

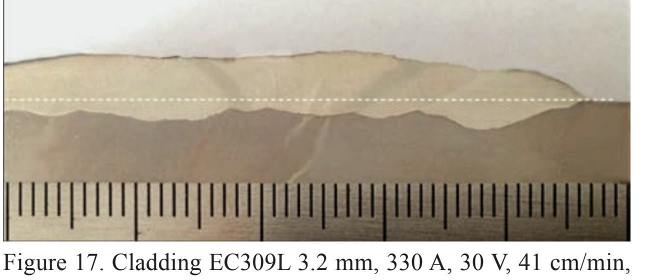


Figure 17. Cladding EC309L 3.2 mm, 330 A, 30 V, 41 cm/min, 23 % dilution

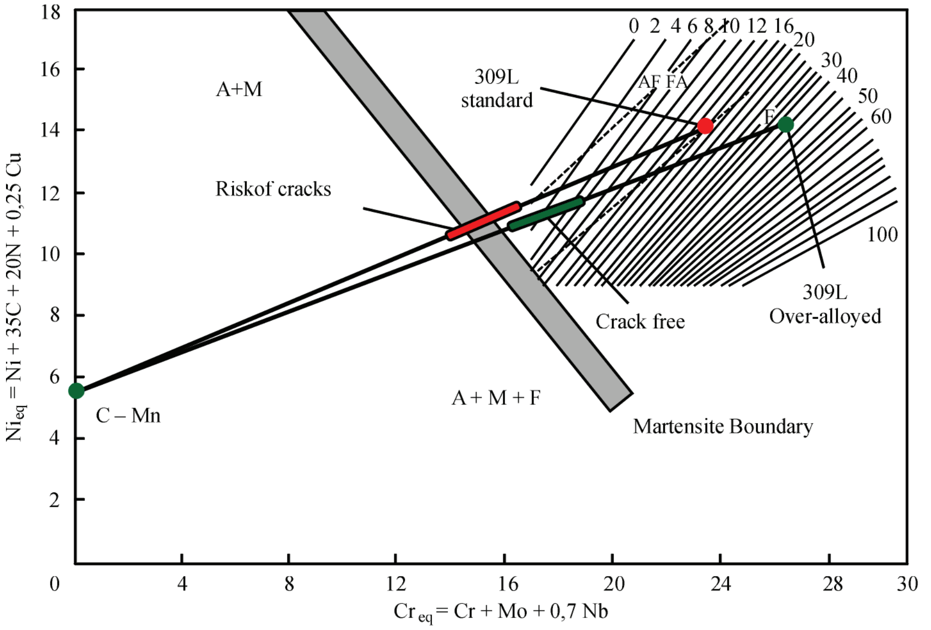


Figure 18. Extended WRC 1992 Diagram. High dilution tolerance with cored wire

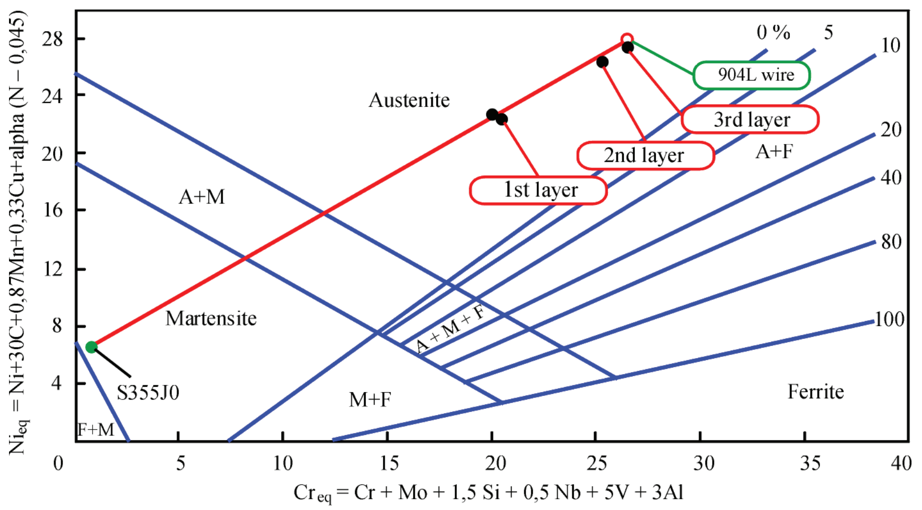


Figure 19. Extended WRC 1992 Diagram: 385 cladding

Despite the high deposition rates offered by SAW, it is difficult to use it as a substitute for ESW due to its high dilution with solid wires and the lack of suitable compositions to compensate this dilution.

With cored wire this problem is overcome by working with an over-alloyed 309L alloy for use as a buffer layer. By increasing the amount of chromium, one move away from the martensite boundary and provide high dilution tolerance (more than 40%). Thanks to this custom-made buffer wire, one can obtain the required chemical analysis in two or three layers with no risk of cracking in the first layer.

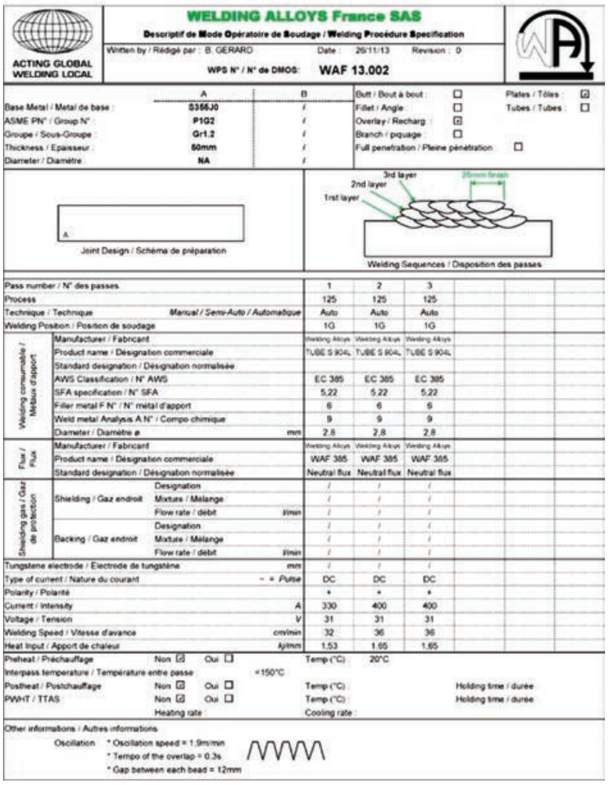
This enables SAW cored wires to be used in numerous applications, for example:

- restoration of cladding (e.g. longitudinal and circular seams of pressure vessel equipment);
- overlay welding of components with limited access;
- flexible groove preparation.

Cladding — focus on UNS N 08904 austenitic overlay welding. UNS N 08904 is a multipurpose high corrosion resistance austenitic stainless steel developed 40 years ago. Due to combined additions of chromium (20 %), molybdenum (4.3 %), copper (1.5 %) combined with its high nickel content, the grade is recommended for most applications dealing with medium to severe corrosive solutions and is particularly used in sulfuric and phosphoric acids applications. It is well adapted to clad plates applications.

When welding with rutile cored wire or shielded metal arc electrode, it is common practice to weld a 309LMo buffer layer before cladding with 385 (20 25 5 Cu N L) which is the matching filler metal for UNS N 08904. No buffer layer is required when cladding with a metal cored wire for submerged arc welding.

Cladding — Focus on martensitic overlay welding. Continuous caster rolls in steel mills



WELDING ALLOYS France SAS

Descriptif de Mode Opératoire de Soudage / Welding Procédure Specification

ACTING GLOBAL WELDING LOCAL

Written by / Rédigé par : B. GERARD Date : 26/11/13 Revision : 0

WPS N° / N° de DMOS: WAF 13.002

	A	B
Base Metal / Metal de base :	S355J0	/
ASME PN° / Group N° :	P1G2	/
Groupe / Sous-Groupe :	Gr1.2	/
Thickness / Epaisseur :	50mm	/
Diameter / Diamètre	NA	/

Butt / Bout à bout : ☐ Plates / Tôles : ☑
Fillet / Angle : ☐ Tubes / Tubes : ☐
Overlay / Recharg : ☑
Branch / piquage : ☐
Full penetration / Pleine pénétration ☐

Joint Design / Schéma de préparation

3rd layer
2nd layer
1rst layer
25mm finish
Welding Sequences / Disposition des passes

Pass number / N° des passes			1	2	3
Process			125	125	125
Technique / Technique		Manual / Semi-Auto / Automatique	Auto	Auto	Auto
Welding Position / Position de soudage			1G	1G	1G
Welding consumable / Métaux d'apport	Manufacturer / Fabricant		Welding Alloys	Welding Alloys	Welding Alloys
	Product name / Désignation commerciale		TUBE S 904L	TUBE S 904L	TUBE S 904L
	Standard designation / Désignation normalisée				
	AWS Classification / N° AWS		EC 385	EC 385	EC 385
	SFA specification / N° SFA		5.22	5.22	5.22
	Filler metal F N° / N° métal d'apport		6	6	6
	Weld metal Analysis A N° / Compo chimique		9	9	9
	Diameter / Diamètre ø	mm	2.8	2.8	2.8
Flux / Flux	Manufacturer / Fabricant		Welding Alloys	Welding Alloys	Welding Alloys
	Product name / Désignation commerciale		WAF 385	WAF 385	WAF 385
	Standard designation / Désignation normalisée		Neutral flux	Neutral flux	Neutral flux
Shielding gas / Gaz de protection	Shielding / Gaz endroit	Designation	/	/	/
		Mixture / Mélange	/	/	/
		Flow rate / débit l/min	/	/	/
	Backing / Gaz endroit	Designation	/	/	/
		Mixture / Mélange	/	/	/
		Flow rate / débit l/min	/	/	/
Tungstene electrode / Electrode de tungstène		mm	/	/	/
Type of current / Nature du courant		~ = Pulse	DC	DC	DC
Polarity / Polarité			+	+	+
Current / Intensity		A	330	400	400
Voltage / Tension		V	31	31	31
Welding Speed / Vitesse d'avance		cm/min	32	36	36
Heat Input / Apport de chaleur		kj/mm	1.53	1.65	1.65

Preheat / Préchauffage Non ☑ Oui ☐ Temp (°C) : 20°C
Interpass temperature / Température entre passe <150°C
Postheat / Postchauffage Non ☑ Oui ☐ Temp (°C) : Holding time / durée
PWHT / TTAS Non ☑ Oui ☐ Temp (°C) : Holding time / durée
Heating rate : Cooling rate :

Other informations / Autres informations
Oscillation * Oscillation speed = 1.9m/min
* Tempo of the overlap = 0.3s
* Gap between each bead = 12mm

Figure 20. Submerged arc cladding with cored wire EC385. Welding procedure

operate in particularly harsh service environments. Mold fluxes are added to the top of the continuous casting mold in order to cover the liquid steel. Within the caster, molten steel poured from a tundish flows into an oscillating copper mold where it forms a skin against the water cooled copper plates. The partially solidified slab is then pulled out of the mold through a series of containment segments containing drive rolls.

The slab is usually bent into the curved section of the caster, and unbent towards the run-out portion. Within the containment of the caster, the slab is subjected to water spraying to promote solidification.

In order to optimize roll reclamation and service life, cladding consumables have to be designed with the aim of preventing the failure mechanisms described above.

The most important requirements for continuous caster roll clad layers are listed below:

- elevated temperature oxidation resistance;
- resistance to localized pitting and crevice corrosion;
- maximum resistance to stress corrosion cracking and corrosion fatigue;
- maximum tempering resistance to prevent softening during service;
- resistance to thermal and thermo-mechanical fatigue;
- high thermal conductivity;
- low coefficient of thermal expansion;

Figure 21. Submerged arc cladding with cored wire EC385. Macrography-stinger bead technique

- high hardness and resistance to abrasive and adhesive wear;
- high strength and sufficient toughness;
- good weldability;
- reasonable cost.

In order to obtain the required hardness, strength, wear resistance and corrosion resistance required in this application, stainless steels with martensitic microstructures are preferred. They are cost effective, provide high hardness, strength and wear resistance,

Figure 22. Submerged arc cladding with cored wire EC385. Side bend tests

as well as a low coefficient of thermal expansion hence improved thermal fatigue resistance.

A minimum of 12 % chromium generally provides the adequate corrosion and elevated temperature oxidation resistance necessary for slab caster operation. The presence of ferrite is believed to reduce the hardness and strength of the deposit, a δ-ferrite content of less than 10 % is often required. The addition of controlled amounts of nickel and molybdenum improves the high temperature properties. Nickel also raises the toughness of the deposit and stabilizes martensite, whereas molybdenum improves resistance to localized corrosion as well as it increases hardness and temper resistance.

Further improvement can be obtained by substituting part of the carbon normally added to martensitic stainless steels with nitrogen, a potent austenite promoting element. Nitrogen-enhanced 12 % chromium martensitic stainless steels exhibit faster re-passivation kinetics, a fine homogeneous distribution of nitride precipitates which inhibit grain growth and an increase in the stability and passivity range of the oxide film. This results in improved oxidation and corrosion resistance, higher strength, improved impact toughness, enhanced

CHROMECORE 414N-S — Typical all-weld analysis with flux WAF 415

C	Mn	Si	Cr	Ni	Mo	N
0.08	1.0	0.6	13.5	4.3	0.5	0.10
Structure: martensite, hardness – 3 layer deposit as welded: 44 *HRC*.						

Operating conditions (recovery: 95 %)

Wire diameter, (mm)	Current (A)		Voltage (V)		Stick-out (mm)	
	Range	Optimum	Range	Optimum	Range	Optimum
2.4	200 - 450	350	26 - 30	30	25 - 60	30
2.8	250 - 550	400	28 - 32	30	25 - 60	30
3.2	300 - 650	500	28 - 32	30	25 - 60	30

temper resistance, and higher resistance to thermal and thermo-mechanical fatigue. These improved properties result in considerably less material loss during service and explain the success of our 400N series pioneered and designed by Welding Alloys.

Incorporating the required amount of nitrogen up to the solubility limit and without porosity by submerged arc welding has proven to be an effective solution (Tables 2, 3).

Cladding f ocus on high chromium cast irons overlay welding (Figures 23–25). During its whole service life, mechanical equipment is undergoing the deleterious effects of corrosion and/ or wear. In most cases, wear or corrosion are synonym of lost metal and parts reduced down to the stage where they can no longer efficiently perform their intended function.

Flux and metal cored wires are implemented for joining, cladding and hardfacing application.

Cladding consists in depositing a corrosion resistant surfacing on a base metal providing mechanical strength whereas hardfacing is a solution to increase wear resistance.

Hardfacing has numerous advantages:

- longer service life of wear parts;
- improved efficiency to plant operation and an increase in production;
- reduced idle time in plant operation;
- use of reconditioned components rather than costly new replacements, and a reduction in labor costs due to fewer replacements;
- basic savings of replacing expensive alloy steel parts with cheaper mild or Iow-carbon steel parts, hardfaced with a minimum amount of superior wear-resistant alloy located only in the area of wear;
- reduced overall dependence on replacement parts and considerable saving in maintenance costs.

High chromium cast irons are cost effective solutions when abrasion is the main wear factor. The choice of a given composition within this family of products depends on whether or not secondary wear mechanisms such as temperature, impact or corrosion are present.

Hardness is not a guarantee of abrasion resistance: a suitable microstructure is. Microstructure for high chromium cast irons, is governed by two elements: carbon and chromium. The ratio between chromium and carbon is of paramount importance to guarantee the presence of primary carbides and to optimize their amount: both are essential for wear resistance.

Figure 24. Continuous casting roller cladding with cored wire CHROMECORE 414N-S

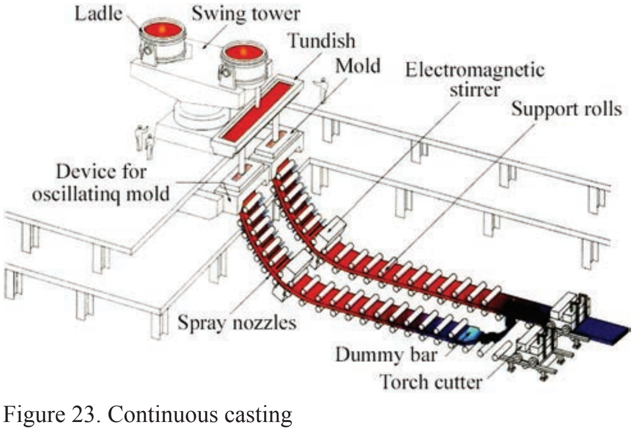


Figure 23. Continuous casting

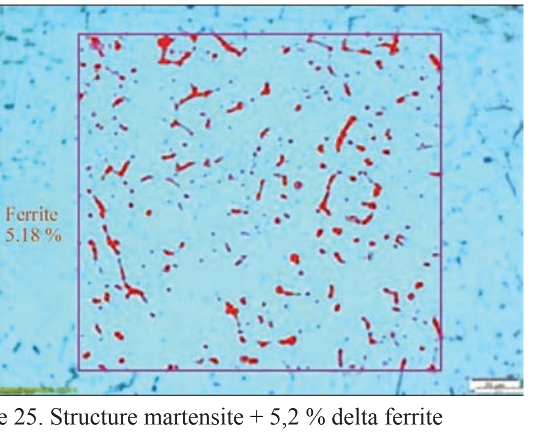


Figure 25. Structure martensite + 5,2 % delta ferrite

Typical chemical composition high chromium cast irons (weight %)

WA HARDFACE	Symbole	C	Cr	Nb	Mo	W	V	Hardness
HC-O	Fe15/PKE	5.0	27	-	-	-	-	60 HRC
CN-O	Fe15/KKA	5.5	22	7	-	-	-	62 HRC
CNV-O	Fe16/KKA	5.5	22	7	7	2	1	64 HRC

The welding procedure actually influences the orientation of these carbides, thus the overall performance of the weld deposit. Wear resistance often is a compromise: extreme resistance to abrasive wear is synonym of a lower resistance to impact. Taking this into account, three families of high chromium cast irons are available to the end user:

Near eutectic compositions that present a good solution for applications where besides abrasion resistance, a combination of resistance to impact and eventually corrosion is required

Primary carbides with eutectic for extreme resistance to abrasion

Primary carbides + alloy carbides in a eutectic austenite/carbide matrix. Such deposits contain harder and finer carbides for improved resistance to a wider range of abrasives and/or combined wear mechanisms, for example abrasion + temperature.

Globally, if we do not consider the «black magic trend» three or four compositions are enough to cope with most of the abrasion related applications.

Conclusion. For years [1–13], the submerged arc welding process has evolved with one main goal: to combine quality with productivity. Cored wires depositing corrosion resistant alloys are dedicated to this process. They offer satisfactory versatility both in joining and in cladding and provide useful and economically attractive process improvements as well as high quality performance required for corrosion and heat resisting application.

References

1. Fils tubulaires pour le soudage d'aciers inoxydables, JM Bonnel, N Vass, N.C Pease, Soudage Automatique – Applications Industrielles du Soudage avec Fil Fourré – Institut de Soudure – 11/12/2001.
2. Tubular wire welding, D. Widgery, Abington Publishing, ISBN 1 85573 088X.
3. Cored wires for corrosion resistant alloys: status report 2006, JM Bonnel, N.C. Pease, International Institute of Welding Congress, 8-10/03/2006, Stellenbosch, South Africa.
4. EN ISO 4063: Welding and allied processes – Nomenclature of processes.
5. Gevulde draad MIG/MAG en onderpoederdek lassen van austenitisch en duplex roestvast staal, JM Bonnel, Welding Alloys - Seminarie Belgisch Instituut voor Lastechniek, Stivak en De Nayer Instituut, 2001.
6. Fils fourrés à poudre métallique, JM Bonnel – Journée d'étude «Soudage et mise en œuvre de l'acier inoxydable», Institut Belge de la Soudure – 28 novembre 2002.
7. EN ISO 17633: Welding consumables – Tubular cored electrodes and rods for gas shielded and non-gas shielded metal arc welding of stainless and heat-resisting steels – Classification.
8. Proceskeuze van modern lastechnieken in roestvast staal, F. Neessen, H. Meelker, F. Naber – Lincoln, Roestvaststaalgids 2012.
9. ASME II C SFA-5.22: Specification for stainless steel flux cored and metal cored welding electrodes and rods.
10. Technical report ISO/TR 17671-5: Welding - Recommendations for welding of metallic materials - Part 5: Welding of clad steels.
11. Which process? Peter Houldcroft, Abington Publishing, ISBN I 85573 008 1.
12. Arcelor Product Information: URANUS B6 and B6N. A multipurpose Austenitic stainless steel with PREN ≥ 34.
13. Submerged arc welding with tubular cored wires: Welding & cladding of high alloy steels, B.Gerard, N.C. Pease, Welding Alloys.

ЗВАРЮВАННЯ ТА НАПЛАВЛЕННЯ ПІД ФЛЮСОМ ВИСОКОЛЕГОВАНИХ СТАЛЕЙ ПОРОШКОВИМИ ДРОТАМИ

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Порошкові дроти використовуються в численних процесах зварювання з або без зовнішнього газового або шлакового захисту. Дугове зварювання під флюсом (SAW) з порошковими дротами (зі швом або безшовні) для зварювання низько- та середньолегованих марок сталей є технікою, яка продемонструвала чіткі переваги протягом трьох останніх десятиліть. З моменту свого створення процес SAW розвивався з однією головною метою: поєднати якість з продуктивністю. Завдяки низьколегованому дроту, переваги вже були чітко продемонстровані і широко використовуються. Проте, про SAW було написано мало для порошкових дротів при застосуванні для корозійностійких та жароміцних сталей. Розширення SAW для високолегованих композицій приносить відповідні переваги і додає деякі специфічні та унікальні особливості. Стаття присвячена особливостям витратних матеріалів та особливостям якості та продуктивності SAW з порошковими дротами. Порошкові дроти тепер використовуються для дугового зварювання під флюсом майже всіх нержавіючих сталей від мартенситних до супердуплексних, низки нікелевих композицій, а також для наплавлення сплавів на основі кобальту. Приклади промислового застосування з аустенітними, дуплексними, мартенситними і жароміцними нержавіючими сталями наведені для ілюстрації потенціалу використання порошкового дроту.

Ключові слова: зварювання під флюсом, наплавлення, порошковий дріт, вісоколеговані сталі

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