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SVETSAREN

THE ESAB WELDING AND CUTTING JOURNAL VOL. 62 NO. 1 2007

FOCUS ON STAINLESS

STRIP CLADDING UNDER THE SPOTLIGHT

LASER-HYBRID WELDING GOES MAINSTREAM

ISO 14001 GAIN FOR ESAB ENVIRONMENTAL MANAGEMENT SYSTEMS'

Svetsaren

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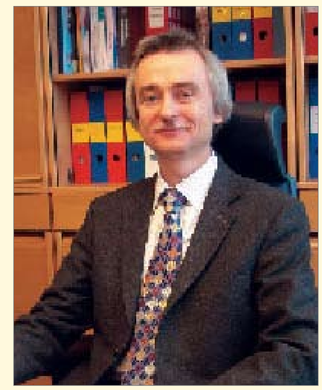
MMA welding of thin stainless pipes in the paper and pulp industry.

Towards a bright and shiny future - together



Leif Karlsson

Dear reader,

Stainless steels are fascinating, versatile materials that affect our lives in more ways than most of us are aware of. Stainless steels are found in environments such as high to very low temperature applications, food and beverage processing, oil, gas and chemicals industries, transportation and architecture. As a group, they outperform all other construction materials in terms of growth - a steady increase of some 5% per year. With greater focus on low long-term maintenance costs, increasing environmental awareness and concerns about life-cycle costs, the demand for stainless steel can only continue to grow.

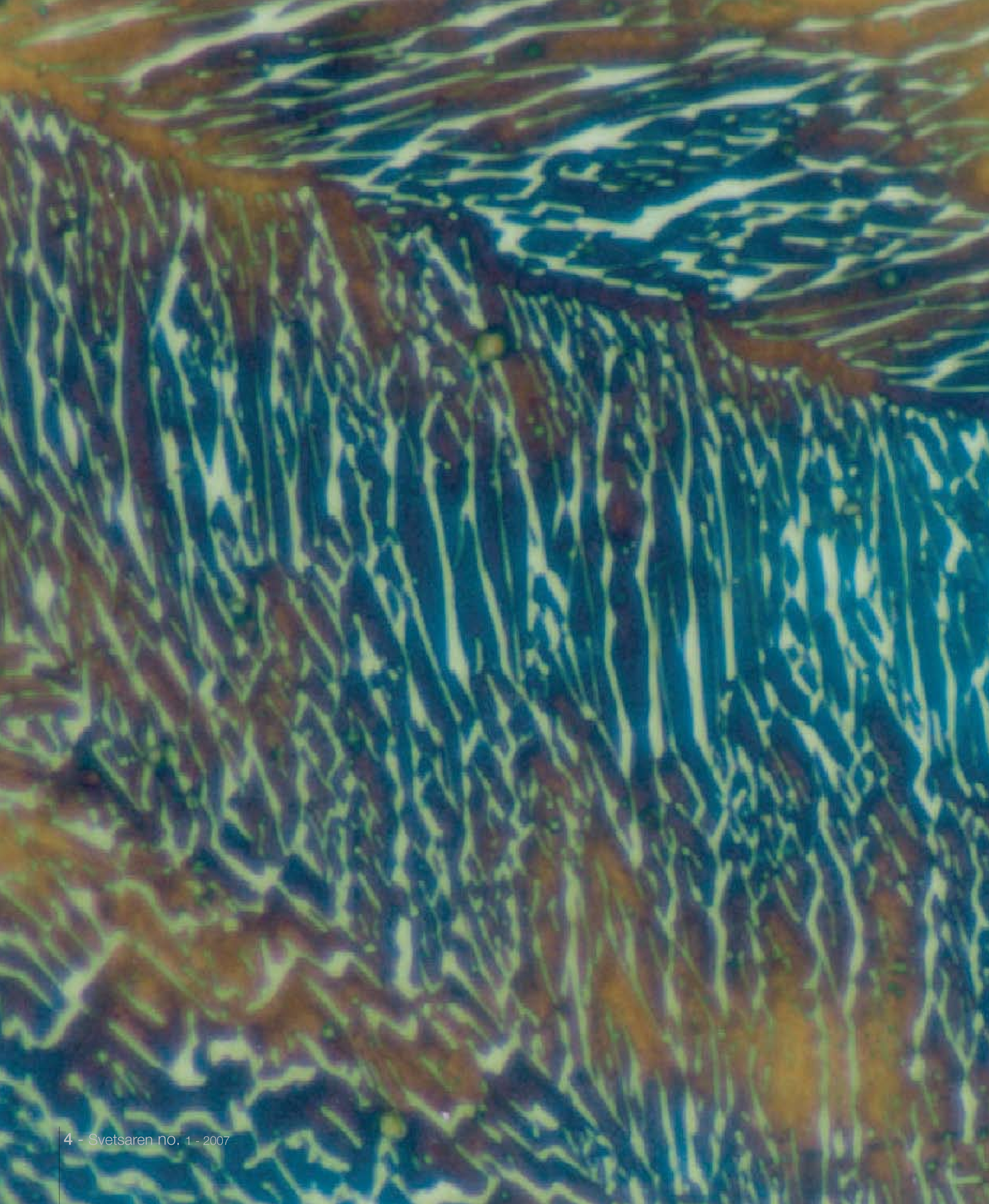
Although consumable manufacturers, naturally, follow the lead of steel makers in formulating new alloys, weldability remains an important aspect in stainless steel development. Potential applications for new grades steel are reduced if welding is a problem, or if suitable welding consumables are not available. ESAB has a long history in stainless steel welding - stainless stick electrodes were early included in the consumables range. In fact, the first issue of Svetsaren, in 1936, reported on an application using the stainless electrode ESAB OK R3 (18%Cr 10.5%Ni 1.5%Mo).

Stainless steel consumables development is still a priority for ESAB. Combining modern consumables with today's advances in mechanisation, software controlled power sources and new welding methods, such as laser-hybrid welding, brings more opportunities to produce high quality, high productivity welds than ever before.

More than one issue of Svetsaren would be needed to give more than just a glimpse of the fascinating world of stainless steel welding. However, we hope that this issue of Svetsaren gives you a flavour of ESABs developments by highlighting environments and applications where our consumables and equipment are used.

And, finally, ESAB will continue to actively contribute to the bright future of stainless steels – and we invite all our customers to join us!

Leif Karlsson
Senior Expert & Manager Research Projects.



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This is to certify that

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WORLDWIDE
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SS-EN ISO 14001:2004

This Certificate is valid for management of environmental aspects associated with:

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Place and date
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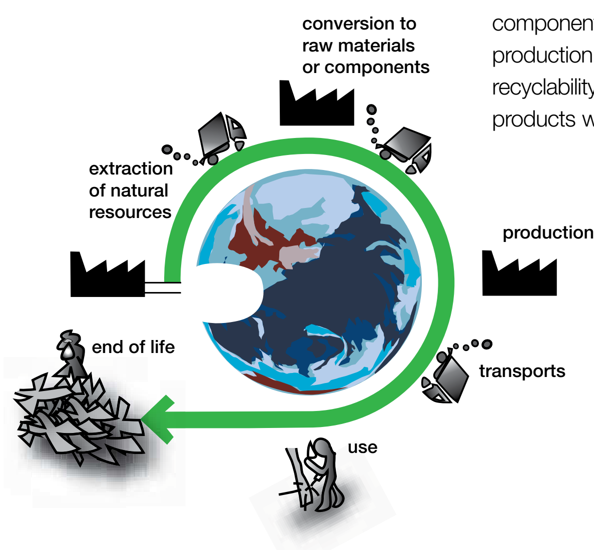
Unique in the welding and cutting industry.

STEFAN LARSSON, ESAB AB, GOTHENBURG SWEDEN

ISO 14001 is the international standard for environmental management systems (EMS), providing organizations with a framework for achieving their environmental and economic goals.



ESAB is one of the very few international companies to have acquired a global ISO 14001 certification, covering everything from design, development and production to sales and service worldwide. Customers are assured that every ESAB product is produced to the same environmental standard with every step taken to minimize environmental impact. Customers striving to obtain ISO 14001 certification themselves, or just aiming to continually improve their environmental performance, will be able to benefit from having ESAB as a dedicated partner.

Reducing environmental impact

The fundamental reason for implementing an environmental management system (EMS) world-wide is to have a structured approach towards minimizing the negative impact of our activities on the environment. Responsibility extends far beyond the office doors and factory gates of ESAB, so it is important to understand the impact of our activities in a broader sense. By using a lifecycle approach, we can map the effects of a product from designer's desk to the end of its life and including disposal. Right from the early stages of development, aspects such as finding alternatives for hazardous components, or energy consumption during production and use, and packaging waste and recyclability are all taken into account. This results in products with a reduced environmental impact.

The fact that this approach, which has already been subjected to external scrutiny, can go hand-in-hand with technological innovation is already proven. In recent years, many welding and cutting products that have undergone this process have been introduced into the market. Amongst these are:

- **OK AristoRod – copper-free welding wire**
  Advanced surface technology applied in the manufacturing of ESAB MAG welding wires has enabled us to avoid the use of copper in production – yet still maintain welding characteristics and integrity at a very high level. As a result ESAB reduces the demand on natural copper resources and eliminates copper emissions into the environment during production. Users benefit from superb weldability and reduced heavy metals in slags and in fumes.

- **ESAB Marathon Pac**
  Use of the foldable, octagonal Marathon Pac bulk drums for welding wire instead of traditional spools improves efficiency along the

Eagle cutting machine.

complete MIG/MAG production chain as well as simplifying storage, handling and disposal. Materials used for Marathon Pac are all fully recyclable.

- **The Eagle plasma cutting machine**
  The Eagle multi-material cutting machine is a perfect example of a technology that brings together the benefits of greater cost efficiency with reduced environmental impact. It achieves this through low energy use and by the application of highly durable cutting tools.
  This, combined with an integrated extraction and filter system, also significantly improves workplace conditions. Cutting slag is collected separately for simpler disposal.

Useful support

This focus on environmental health and safety issues gives us the knowledge to help customers with the information requirements of their individual national authorities, their customers and waste management companies. ESAB's new Safety Data Sheets include information on welding slags, other types of product waste and fume compounds, in addition to safety measures and procedures.

With ESAB, customers have a partner that is both reliable and proactive in helping to fulfill and go beyond relevant legal and other compliance requirements.

The ESAB way

ESAB is committed to continuously improve its environmental performance and eliminate workplace hazards. Our global EMS is now being expanded to also cover Occupational Health & Safety, so as to continuously eliminate or control workplace hazards. We will pursue this course until it is possible to provide safe workplaces and meet the same safety standards universally. ESAB will follow OHSAS 18001, the international specification of OH&S systems.

About the author:

Stefan Larsson is Director Sustainable Development at ESAB AB, Gothenburg Sweden.

ESAB opens its first welding consumables factory in China

The newest factory in the ESAB global manufacturing network was officially opened on Thursday 6th July 2006, in Zhangjiagang, Jiangsu province, China. Zhangjiagang is a newly developed port city on the southern bank of the lower reaches of the Yangtze river, approximately 100 kms northwest of Shanghai. The new factory is part of ESAB's goal to strengthen its position in Asia for which China as a key market.

The opening ceremony was attended by 300 guests, including high-level government officials such as the Party Secretary Mr Huang Qin (right in picture) and Mayor of Zhangjiagang, British Consul General, Swedish Consul General and Charter and ESAB officials - David Gawler Chairman of Charter Board, Mike Foster Chief Executive of Charter and Jon Templeman ESAB CEO (left in picture).

The opening of the new welding consumables factory in Zhangjiagang marks a milestone in ESAB's history and strengthens ESAB's commitment to supporting the fast-paced Chinese manufacturing and construction industry. ESAB is building strong partnerships with government, suppliers and customers to become a leading supplier of welding technology in China and a leading exporter.
The factory is on a site of some 40,000 m^2, and will initially concentrate on the production of both solid and cored welding wires, produced with the very latest European production technology and lean manufacturing systems. Of the annual anticipated output of more than 40,000 tons, a significant proportion will be for the China domestic market. ESAB's new Aristorod™ non-coppered wire with ASC (advanced surface characteristic) technology will be a key product, which will also be offered in ESAB's unique patented bulk pack system – Marathon Pac™. These products have taken MAG welding to new levels of performance, and will improve weld quality and productivity in manual and mechanised environments.

This is the second ESAB factory to be opened in China, after the new cutting machine factory on the outskirts of Shanghai (featured in the last Svetsaren edition) was opened at the end of 2005.

Disbonding of Austenitic Weld Overlays in Hydroprocessing Applications

R. Paschold, ESAB GmbH, Solingen, Germany, **L. Karlsson**, ESAB AB, Göteborg, Sweden and **M. F. Gittos**, TWI, Cambridge, UK

Many large pressure vessels operate at high temperatures and at high hydrogen partial pressures. These are typically fabricated from low alloy Cr-Mo steel and internally weld overlaid with austenitic stainless steel. During shutdown, hydrogen accumulates at the interface between the cladding and the parent material which occasionally causes disbonding of the stainless layer. This paper discusses mechanisms, testing and factors influencing the risk of disbonding, focussing on welding related aspects.

Large pressure vessels are used in hydrogen containing environments, for example, in the petroleum industry in hydrocracking, hydrodesulphurisation and catalytic reforming processes as well as in the chemical and coal conversion industries. Many reactor vessels operate at high temperatures and at high hydrogen partial pressures, with 450°C and 15 MPa often being mentioned as typical values [1]. The vessels are generally fabricated from low alloy, creep resistant steels [1, 2].

It is estimated that well over one thousand hydroprocessing reactors have been fabricated from the 2¼Cr-1Mo alloy, some few dozens from the new generation vanadium modified 3Cr-1Mo steel and a few from vanadium modified 2¼Cr-1Mo steel. Today, with hydrogen partial pressures, in some applications, ranging as high as 35 MPa, the new generation vanadium modified steels exhibit service life improvements and, in many cases cost advantages, in high temperature and high pressure hydroprocessing reactor applications [3].

Weld cladding overlays

All hydroprocessing reactors require internal protection of the reactor vessel walls to resist the high temperature corrosion effects of sulphur in the process stream. This protection is generally provided by stainless steel weld overlays, typically a type 347 (18Cr 8Ni + Nb) deposit. A stabilised 347 composition overlay also prevents sensitisation during the final post weld heat treatment (PWHT) cycle of the reactor [2, 3].

Typical specifications for the cladding include a chemical composition corresponding to AWS EQ347 with a ferrite content in the range of 3 to 8 or 10 % (or Ferrite Number: FN). Some specifications also require disbonding tests to be done by the reactor producer.

Strip cladding

Strip cladding by submerged arc welding (SAW) (Fig. 1) or by electroslag welding (ESW) are the preferred methods for cladding of larger areas such as pressure vessels. Both methods offer a high deposition rate, in terms of both kg/h and area coverage (m^2/h), combined with low penetration and high deposit quality. However, today, single layer electroslag strip cladding tends to be more frequently used than double layer procedures with submerged arc strip cladding.

Figure 1. Strip cladding of vessel head by submerged arc welding (SAW).

Table 1. Selection of austenitic strip electrodes for SAW and ESW weld surfacing.

Product		%C	%Si	%Mn	%Cr	%Ni	%Mo	Other	ASW A5.9	EN 12072
OK Band	308L	<0.03	0.5	1.8	20.3	10.0	<0.03	-	EQ308L	S 19 9 L
OK Band	347	<0.03	0.5	1.8	20.0	10.0	<0.03	Nb<1.0	EQ347	S 19 9 Nb
OK Band	316L	<0.03	0.5	1.8	19.0	12.5	2.8	-	EQ316L	S 19 12 3 L
OK Band	317L	<0.02	0.4	1.8	19.0	14.0	3.8	-	EQ317L	S 18 15 3 L
OK Band	309L	<0.03	0.5	1.8	24.0	13.0	<0.03	-	EQ309L	S 23 12 L
OK Band	309LNb	<0.03	0.5	1.8	24.0	13.0	<0.03	Nb<1.0	-	S Z 23 12 L Nb
OK Band	310MoL	<0.03	0.2	1.5	25.0	22.0	2.1	N=0.13	(EQ310MoL)	S 25 22 2 N L
OK Band	385	<0.02	0.4	2,0	20.5	25.0	4.8	Cu=1.5	EQ385	S 20 25 5 Cu L
OK Band	309L ESW	<0.03	0.3	1.8	21.0	11.0	<0.05	-	(EQ309L)	-
OK Band	309LNb ESW	<0.02	0.3	1.8	21.0	11.0	<0.05	Nb=0.6	(EQ309LNb)	-
OK Band	309LMo ESW	<0.02	0.3	1.8	20.5	13.5	3.1	-	(EQ309LMo)	-

Table 2. Fluxes for submerged arc and electroslag strip cladding with austenitic strip electrodes.

FLUX for SAW	EN 760	Description
OK Flux 10.05	SA Z 2 DC	Standard flux for strip cladding with austenitic strips.
OK Flux 10.06	SA CS 2 CrNiMo DC	For cladding with 309L strip (90x0,5 mm) giving 316L material in one layer.
OK Flux 10.06F	SA CS 2 CrNiMo DC	For cladding with 309L strip (60x0,5 mm) giving 316L material in one layer.
OK Flux 10.09	SA CS 2 CrNi DC	For cladding with 309L strip (60x0,5 mm) giving 308L material in one layer.
OK Flux 10.92	SA CS 2 Cr DC	For strip cladding and joining of stainless steels.
ESW		
OK Flux 10.10	(~SA FB 2 DC)	Standard ES cladding flux for austenitic stainless strips.
OK Flux 10.11	(~SA FB 2 DC)	For ES high speed with stainless and Ni-base strips.
OK Flux 10.14	(~SA FB 2 DC)	For high speed ES cladding with austenitic stainless strips.

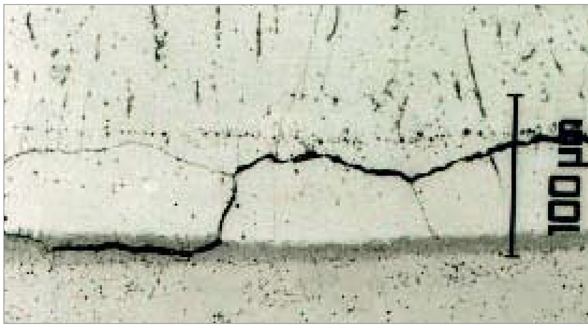


Figure 2. Disbonding in the interface region between parent material (bottom) and an austenitic overlay weld metal (top) [1].

The standard ESAB range of austenitic strip electrodes and fluxes for SAW and ESW strip cladding are presented in Tables 1 and 2. Special-purpose fluxes and strips, such as stainless 13%Cr, duplex and fully austenitic strips, are available on request. The standard size for strips is 60 x 0.5 mm, but other dimensions such as 30 x 0.5 and 90 x 0.5 mm can also be supplied.

Disbonding

Weld overlay disbonding has been observed, in some cases, during cool down of reactors. Crack propagation occurs in a narrow zone at the interface and along grain boundaries in the overlay close to the interface (Fig. 2).
The microstructure in this region is very complex as a consequence of carbon migration during PWHT and incomplete mixing of melted parent and filler materials.

Interface region microstructure

Figures 3 – 5 gives some examples of interface region microstructures showing a band of tempered and/or untempered martensite and carbides typically found next to the interface. A ferrite-free region of typically 20 – 100 µm width separates the parent material from the normal ferrite-containing weld metal structure.

A narrow band of martensite appears clearly in the weld overlay interface region in the as-welded condition (Fig. 3). The structure of the interface region for post weld heat treated welds consists mainly of tempered martensite and carbides (Figs. 4 and 5). However, the higher hardness produced by a single PWHT as compared to double post weld heat treatment cycles suggests that fresh martensite can form during cooling from the PWHT-temperature.
Significant carbon migration is taking place during PWHT, as can be seen from the carbide precipitation and the formation of a 150 – 200 µm wide decarburised zone in the parent material (Figs. 4 and 5). The grain boundaries are also decorated by carbides in, and next to, the interface region [2, 4].

Concentration profiles across the interface region reveal that this region corresponds to a transition in composition between the levels appropriate for the parent material and the clad layer (Figure 6).

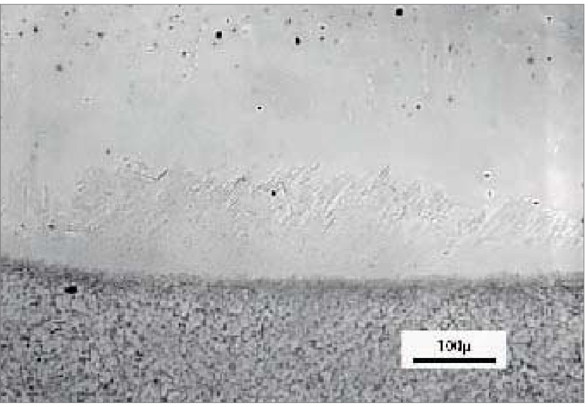


Figure 3. Martensite (light etching) in parent material/ weld overlay interface region of an as-welded SAW overlay (courtesy TWI).

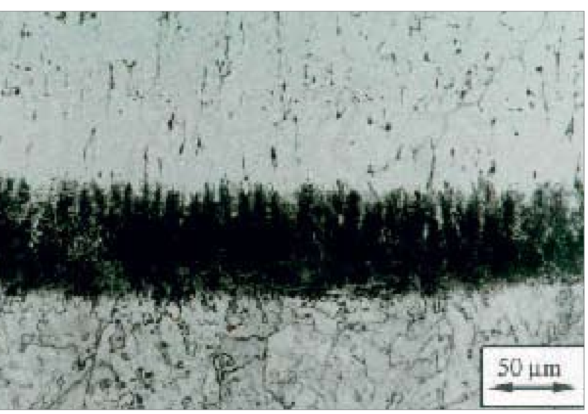


Figure 4. Interface region of SAW overlay weld after PWHT with tempered martensite and carbide precipitation (dark etching) [1].

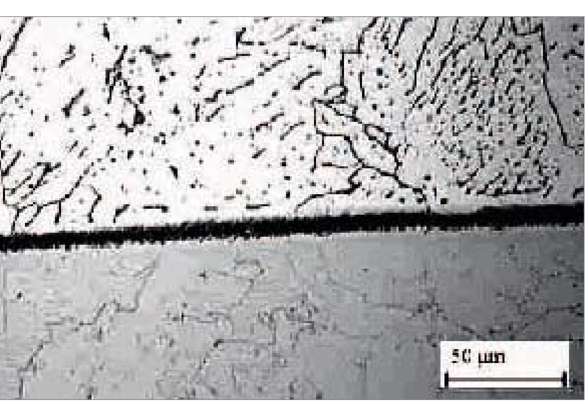


Figure 5. A comparatively narrow dark etching band of tempered martensite and carbides seen in an electroslag welded overlay after PWHT.

Mechanisms

The exact mechanism of disbonding is under discussion, but it is thought to occur, essentially, as a result of hydrogen embrittlement. During operation, atomic hydrogen diffuses into the reactor wall and the hydrogen concentration can build up to levels around 4 – 7 ppm in thick wall reactors. Following shutdown, hydrogen tends to accumulate at the transition zone between the ferritic parent material and the austenitic weld overlay. This occurs because hydrogen is about one order of magnitude more soluble in the austenitic weld overlay than in the base metal, but its diffusivity in the overlay is much slower than in the base material. Therefore, as the hydrogen diffuses from the base metal it tends to accumulate at the weld overlay interface [1 - 3].

As the risk of disbonding is connected to the hydrogen concentration in the interface region, the disbonding tendency increases with increased hydrogen partial pressures and operating temperatures, as well as faster cooling during shutdown. Being essentially a result of hydrogen embrittlement, it is also affected by the interface region microstructure and, thereby, also dependent on the applied PWHT [2]. Several studies [2, 4] have shown, that the highest hardness is measured in the weld metal in the interface region near the parent metal, with maximum values of >450 HV sometimes found after a single PWHT.

Disbonding test methods

Several test methodologies exist for evaluating the susceptibility to hydrogen disbonding:

Autoclave testing

The most common method is by exposure of the test coupon in an autoclave at high temperature and high hydrogen pressure. Typical exposure conditions are [5, 6]:

- Temperature: 300 – 500°C, usually 425°C
- Hydrogen partial pressure: 14 – 20 MPa
- Exposure time: 48±1 h
- Cooling rate: 150°C/h
- Holding time at 24±2,5 °C: 7 days

The test temperature and hydrogen pressures are chosen with reference to the actual service conditions. Following exposure, the specimens are cooled to ambient temperature at a controlled rate. A cooling rate of 150°C/h is commonly used for qualification testing. The specimens are then held at room temperature for a designated period to allow for development of cracking between the stainless overlay and the steel. Following the hold period, the specimens are evaluated for disbonding by ultrasonic methods often combined with metallographic examinations. The size and distribution of the disbonded region(s) are then characterised (Figs. 7 and 8) e.g. according to Table 3.

Table 3. Ranking of ultrasonic test results according to ASTM G 146-01 [5].

Area ranking	Area disbonded (%)
A	≤ 5
B	5 < x ≤ 10
C	10 < x ≤ 30
D	30 < x ≤ 50
E	> 50
Distribution ranking	**Distribution**
1	isolated disbonded regions
2	interlinking disbonded regions
3	disbonding at weld pass overlaps
4	disbonding at joint with side overlay
5	other (to be described)

Various specimen geometries are used but recent configurations utilise a round geometry, overlayed on the top and side surfaces. The intention is to better simulate in-service behaviour with respect to hydrogen diffusion during cool down.

The cylindrical test specimen, according to

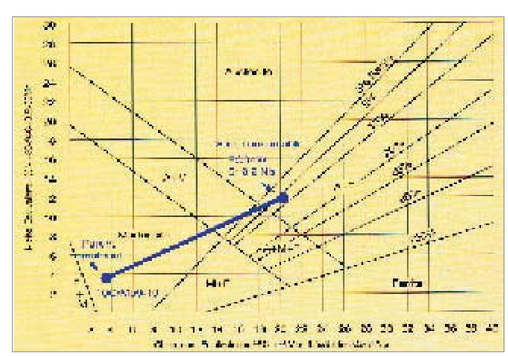


Figure 6. Schaeffler-diagram with line illustrating all possible compositions for different mixtures between parent material and welding strip.

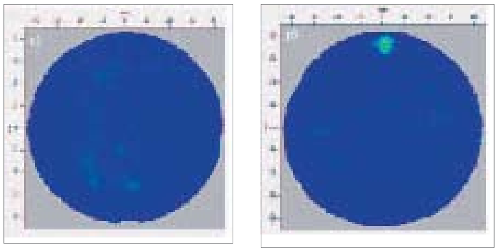


Figure 7. Ultrasonic top view scans showing the area of disbonding after testing.
Left: No disbonding.
Right: With some disbonding. Classification A1 (< 5%, isolated disbonded areas) according to [5].

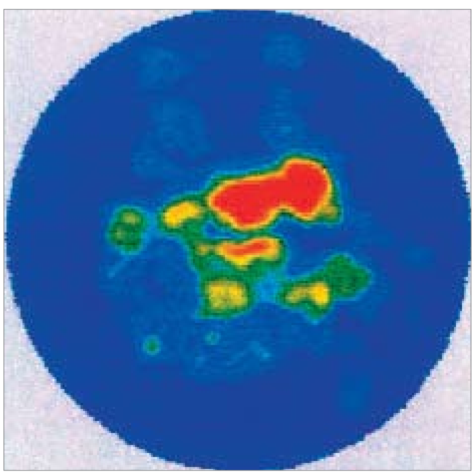


Figure 8. Ultrasonic scans showing significant disbonding. Classification C2 with 10-30% interlinking disbonded regions according to ASTM G 146-01 [5].

ASTM G 146-01, is 73±2 mm in diameter and 45±2 mm thick, or may be reduced to plate thickness [5]. Usually, the specimen is taken from a welding procedure qualification. A stainless overlay is then applied to the cylindrical surface of the specimen to promote through-thickness diffusion of hydrogen following exposure. The specimen is heat-treated in the same way as the reactor. However, if already heat-treated, the side overlay weld shall be heat treated at a temperature of 600°C maximum.

One-sided exposure

An alternative test method corresponds to using the autoclave lid as the test sample. The autoclave lid is fabricated from the candidate overlay material system and placed on the autoclave clad side down. This method is, however, not widely used due to several limitations and disadvantages [7].

Cathodic charging

Cathodic charging could, in principle, be an alternative test method. However, even though it is a rapid and easy technique, it has been shown to only distinguish between extreme cases. It may also act to crack the base metal adjacent to the fusion line, which is not typically observed in hydrogen service evaluations. Using cathodic charging, cracks are also difficult to initiate in the coarse austenitic grains of the overlay. The method is, in practice, therefore, not used for purposes of overlay qualification because of concerns about the applicability to in-service behaviour [7].

Minimising disbonding susceptibility

Vessel wall material

As a first step, the base metal must be resistant to high temperature hydrogen attack, which can be ensured by selecting clean steels containing low levels of impurities (i.e. P, S and trace elements) [8]. A decreased carbon content also acts to reduce the amount of carbon diffusion into the overlay [7].
The newer, vanadium modified Cr-Mo steels tend to have a lower susceptibility to hydrogen effects.

Table 4. Disbonding tests of SAW and ESW weld overlays of the 347 type welded on 52 mm 2.25Cr-1Mo-0.25V steel. No indication of disbonding was found for any of the test specimens.

Welding process and consumables					
Welding process		SAW		ESW	
Strip/Flux consumables	Layer 1	OK Band 309L/ OK Flux 10.05		OK Band 309LNb ESW/ OK Flux 10.10	
	Layer 2	OK Band 347/ OK Flux 10.05		--------------------------	
Welding conditions					
Strip dimensions		60x0.5 mm		60x0.5 mm	
Current		DC+		DC+	
Amperage		750 A		1250 A	
Voltage		28 V		25 V	
Travel speed		7 m/h		10 m/h	
Preheat temperature		≥120 °C			
Interpass temperature		120-175 °C			
PWHT conditions					
Temperature/time		705 °C/30h			
Heating rate		45 °C/h from 300 °C			
Cooling rate		55 °C/h down to 300 °C			
Disbonding test conditions					
Test block dimension		100x50x45 mm			
Temperature		450 °C			
H_2 pressure		150 bar			
Exposure time		48 h			
Cooling rate		150 °C/h	675 °C/h	150 °C/h	675 °C/h
Hold time		10 days before inspection			
Disbonding test results					
Area disbonded		0%	0%	0%	0%

This is claimed to be an effect of finely dispersed vanadium carbide precipitates trapping the atomic hydrogen. Consequently, there is a lower diffusivity of the hydrogen in the steel and the accumulation of hydrogen at the transition zone is lower compared to conventional Cr-Mo steels [3, 9].

Testing of double layer SAW and single layer ESW strip claddings of the 347 type, confirmed the excellent disbonding resistance of V-modified steels (Table 4). Specimens extracted from weld overlays on 52 mm thick 2.25Cr-1Mo-0.25V steels were tested for a typical combination of temperature and hydrogen pressure (450ºC/150 bar) and two cooling rates to make the test more severe: a standard cooling rate of 150ºC/h; and the very high rate of 675ºC/h. No disbonding was detected for any of the test specimens. This is a very promising result, considering the severity of the test for the highest cooling rate.

Weld overlay chemistry and PWHT

The chemistry of the overlay material also affects the disbonding resistance, although some influences are not clear. For example, variable results have been reported for the effect of niobium stabilisation [8, 10]. A reduced carbon level will be beneficial for the structure of the transition zone in the same way as the base metal carbon content. Consequently, low carbon welding consumables are preferred.

Also, the welding process is of importance. Modern strip electrodes contain less than 0.015% carbon and the base materials about 0.10 – 0.12% C. Consequently, the higher the dilution from the base metal, the higher the carbon content of the weld cladding. The process related dilution from the base metal is about 20 – 25% with SAW, but only about 10 – 15% with ESW strip cladding, resulting in lower carbon contents in the weld metal.

Heat input also has an effect on the interfacial microstructure. A higher heat input will give more time for carbon diffusion and, potentially, subsequent grain boundary sensitisation. The heat input will also affect the austenite grain size of the interface region. In both cases, it is likely that the higher the heat input the lower the resistance to disbonding [8]. Using the ESW-cladding method can, therefore, be advantageous since the heat input (per area) is somewhat lower compared to SAW strip cladding. Table 5 gives typical heat inputs for commonly used parameters when welding with a 60 mm strip.

Table 5. Comparison of typical heat inputs (per area unit) for SAW and ESW strip cladding.

Process	Amperage (A)	Voltage (V)	Travel speed (cm/min)	Heat input (kJ/cm²)
SAW	750	28	12	18.7
ESW	1200	24	18	17.1

Double PWHT procedures have been developed [2] to significantly decrease the hardness of the interface region of claddings, compared to the hardness measured after a single PWHT. With a tempering in two steps (690°C/30 h + 600°C/15 h) lower hardness values are to be found,

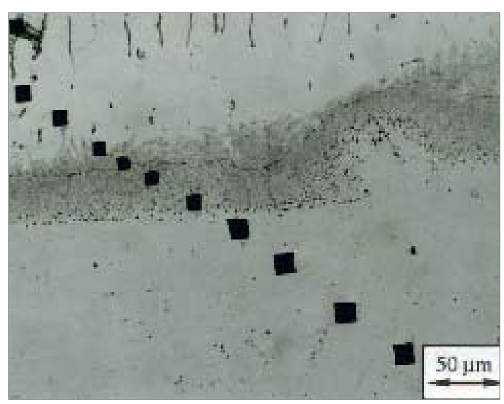


Figure 9. Microhardness (HV0.25) survey across parent material (bottom)/ weld overlay (top) interface on a double PWHT SAW weld overlay.

compared to a single PWHT (690°C/30 h) due to annealing of the fresh martensite formed during cooling from 690°C (Fig. 9). For example, the maximum hardness in the interface region was 483 HV as-welded, 446 HV after a single PWHT and 397 HV after a double PWHT for a SAW overlay weld [1].

The positive effects of a double PWHT have been confirmed by disbonding testing. Only 1% disbonding was reported after a double PWHT compared to 10% disbonding after a single PWHT [2].

An alternative for double layer SAW is the positive effect on disbonding resistance by creating a soft martensitic buffer layer instead of an austenitic. This can be achieved either through a high dilution welding procedure [11] or by using a modified consumable [1].

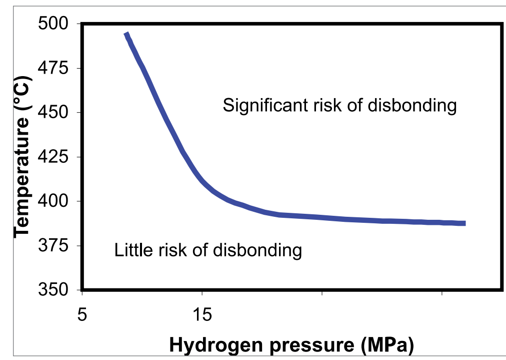


Figure 10. Influence of operating temperature and hydrogen partial pressure on the susceptibility to disbonding in refinery high-pressure hydrogen service [5, 7].

Service conditions

The in-service exposure conditions naturally influence the probability for hydrogen disbonding. The higher the service temperature and/or hydrogen partial pressure, the greater the tendency for disbonding (Fig. 10). An increased number of shutdown cycles may also act to shift the disbonding susceptible zone to lower hydrogen partial pressures and service temperatures [5, 7].

As discussed earlier, the cooling rate during shut-down has a dramatic effect on the susceptibility to hydrogen disbonding. Higher cool down rates (above 150ºC/h) result in a higher concentration of hydrogen at the interface [7].
For this reason, reactor outgassing procedures are established to reduce the hydrogen level in the steel to safe limits during the shutdown cycle of the reactor [3].

Conclusions

Disbonding has occasionally been observed along the weld overlay and base metal interface zone during cool down of hydroprocessing reactors.
It is thought to occur, essentially, as a result of hydrogen-induced cracking.

The most widely accepted test methodology for evaluating the susceptibility to disbonding is based on exposure of the test coupon in an autoclave at high temperature and high hydrogen pressure (e.g. according to ASTM G 146-01).

Modern vanadium-alloyed steels show, by far, a lower susceptibility to disbonding than standard 2¼Cr-1Mo steels.

The susceptibility to disbonding is influenced by the interface region microstructure. Welding and PWHT procedures producing a softer and more fine grained structure are beneficial.

The ESW strip cladding process is an interesting alternative to SAW cladding for disbonding applications. The lower dilution makes it feasible to produce a cladding of desired composition in one layer. In addition, the often, somewhat, lower heat input can have an advantageous effect on the interface region microstructure and, thereby, on disbonding resistance.

Today, factors influencing disbonding of corrosion resistant weld overlays in reactor vessels are well known. The risk of disbonding can, therefore, be minimised by applying state-of-the-art knowledge and procedures during production and operation of reactors.

Acknowledgements

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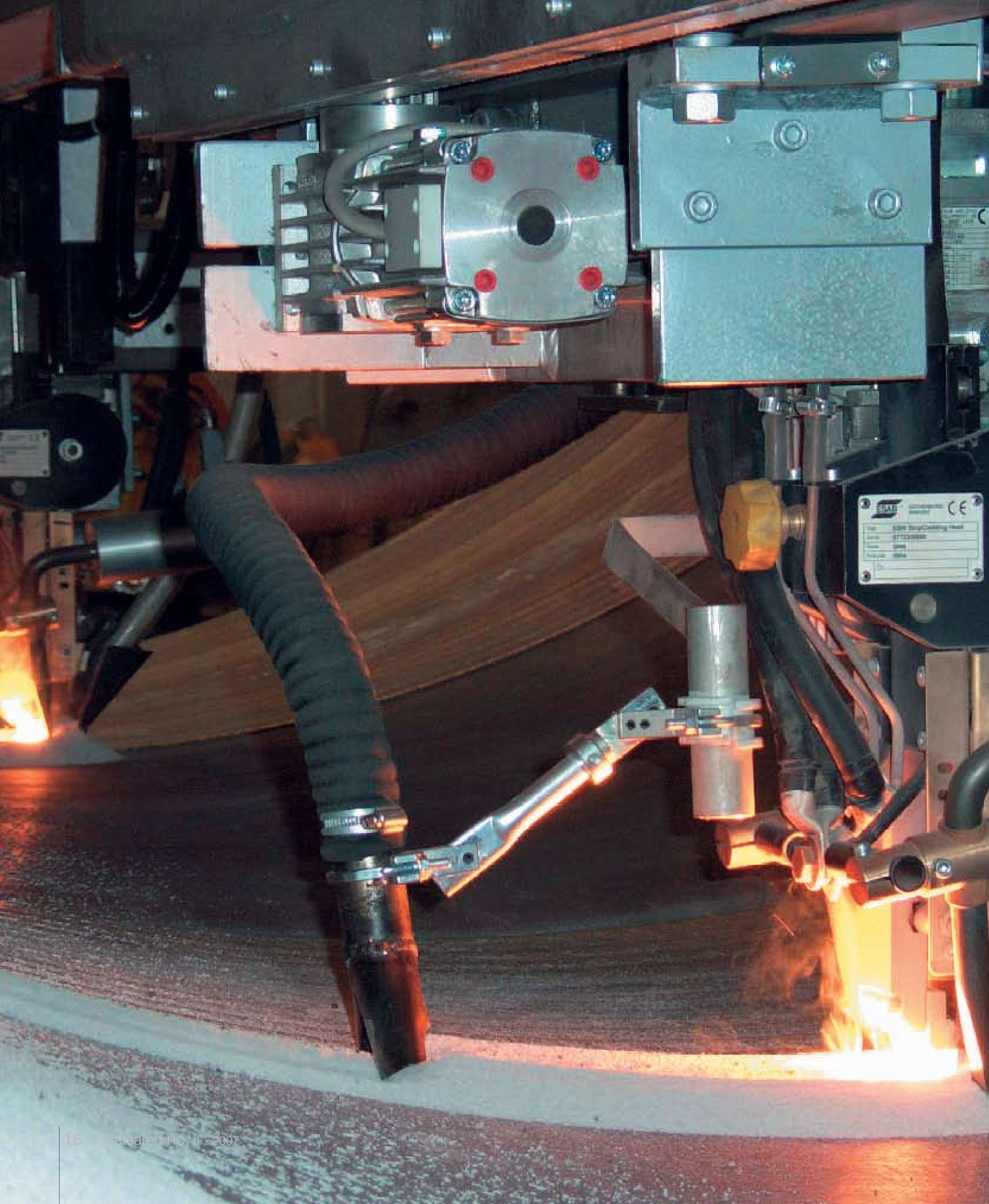


Practical applications of ESAB strip cladding technology

Gabriele Gallazzi, ESAB Italy, **Solveig Rigdal** and **Martin Kubenka**, ESAB AB, Gothenburg Sweden.

Stainless steel strip cladding is a flexible and economical way of depositing a corrosion-resistant protective layer on a load-bearing mild or low-alloy steel. Strip cladding is, therefore, frequently used in the production of components for the chemical, petrochemical and nuclear industries. This article discusses two strip cladding methods and describes applications at two major Italian fabricators – SICES and Ansaldo Camozzi.

The two most productive systems for surfacing large components which are subjected to corrosion or wear are submerged arc and electroslag cladding, using a strip electrode. Both proceses are characterised by a high deposition rate and low dilution and they are suitable for surfacing flat and curved objects such as heat exchanger tube sheets and pressure vessels. Submerged arc welding (SAW) is most frequently used but, if higher productivity and restricted dilution rates are required, electroslag welding (ESW) is recommended.

SAW strip cladding

The well-known SAW method has been widely used with strip electrodes since the mid-1960s. A strip electrode, normally measuring 60 mm x 0.5 mm or 90 mm x 0.5 mm, is used as the (usually positive) electrode and an electric arc is formed between the strip and the workpiece. Flux is used to form a molten slag to protect the weld pool from the atmosphere and helps to form a smooth weld bead surface.

ESW strip cladding

Electroslag strip cladding, which is a further development of submerged arc strip cladding, has quickly established itself as a reliable high deposition rate process. ESW strip cladding relates to the resistance welding processes and is based on the ohmic resistance heating in a shallow layer of liquid electro conductive slag. The heat generated by the molten slag pool melts the surface of the base material and the strip electrode end, which is dipping in the slag and the flux. The penetration is less for ESW than for SAW since there is no arc between the strip electrode and the parent material.

In comparison to SAW cladding, the electrical conductivity of the molten slag must be much higher to avoid arc flash, which disturbs the process. The composition of the welding flux influences the conductivity, the solidification range and the viscosity of the molten slag. Fluxes for ESW strip cladding are high basic, with a high share of fluorides. To increase the cladding speed at corresponding high welding currents, it is necessary to use fluxes producing a slag of even higher electrical conductivity and lower viscosity.
The temperature of the slag pool is about 2300°C and, as it is not fully covered with flux, it emits infrared radiation. The resulting thermal load makes it necessary to water-cool the contact jaws.
Because of the higher currents to be transferred, the welding heads for ESW are more heavily built than welding heads for SAW-strip cladding.

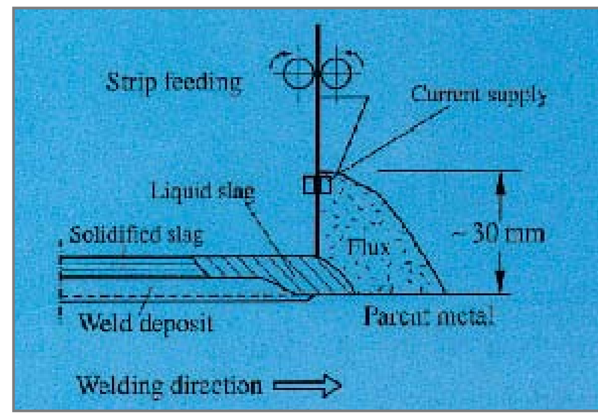


Figure 1. Principles of electroslag strip cladding.

ESW features

Compared to submerged arc strip cladding the electroslag cladding process shows the following features:

- Deposition rate increased by 60% to 80%.
- Only half of the dilution from the base material due to less penetration (about 10-15% dilution).
- Lower arc voltage (24–26 V).

- Higher amperage and current density (about 1000–1250 A with strips of 60 mm width, corresponding to 33–42 A/mm^2). Specially developed fluxes for high productivity purposes can be welded with amperage in excess of 2000 A which corresponds to a current density about 70 A/mm^2.
- Increased welding speed (50%–200% higher), resulting in a higher area coverage in m^2/h.
- Comparable heat input.
- Lower flux consumption (about 0.4-0.5 kg/kg strip).
- The solidification rate of the ESW weld metal is lower, improving the degasification and the resistance to porosity. Oxides can more easily rise from the molten pool to the surface; the overlay metal is cleaner from a metallurgical point of view and thus less sensitive to hot cracking and corrosion.

Practical applications in the process industry
For optimum productivity in weld surfacing it is important to have a high deposition rate and low dilution with the parent material. Submerged arc strip cladding has been widely used for many years for surfacing large areas. However, the electroslag strip cladding technique is becoming well established in the welding industry. Here we highlight two large industrial groups from the north of Italy - Sices and Ansaldo-Camozzi - both with long experience of strip cladding applications.

SICES uses the new ESAB OK Flux 10.14 for electroslag strip cladding
SICES S.p.A. is part of the SICES group which specialises in the supply of turnkey plants and industrial plants, and the design and manufacture of pressure vessels, reactors, towers, heat exchangers, storage tanks and prefabricated piping for the chemical, petrochemical, energy and ecological sectors. The workshop, situated in Lonate Ceppino (Varese), has achieved all important qualifications and certifications including ISO 9001-2000, EN 729.2, Stamp ASME R, S, U, U2.

Table 1. Typical parameters suggested for AWS A5.9: EQ347 single layer cladding.

Is =	2300 A
Us =	25 V
Vs =	410 mm/min
s/o =	40 mm
FH =	45 mm
OK Band 309LNb (S 23 12 L Nb)	
OK Flux 10.14	
E =	86 kJ/cm
A/t=	1.3 m^2/h

Also part of this group are SICES Montaggi S.p.A., SICES Works S.p.A. and Pensotti Idrotermici Srl, specialising in on-site assembly and installation, commissioning and maintenance of industrial equipment and plants and also the design and manufacture of industrial boilers with heat ex-changers, recycling and incinerator boilers.

ESAB deals with the companies of the group as a qualified partner with regards to the welding and cutting process, both as a reliable supplier and as a promotor of new technologies and consumables. One of ESAB's most important objectives has always been research and development of products and technologies aimed at offering its customers a constant increase in productivity, thus providing cost savings by either maintaining or improving the quality of the process or consumable. With this purpose in mind, ESAB has recently presented SICES S.p.A. with a new high-speed flux for electroslag strip cladding. ESAB OK Flux 10.14 is a high basic flux designed for single-layer or multi-layer cladding in combination with austenitic type strips Cr, Cr-Ni, Cr-Ni-Mo at very high deposition rates (up to 450 mm/min with 60x0.5 mm strip) using high power intensity. With the most commonly used 60 mm x 0.5 mm strip size, welding currents up to 2300 A can be used (Table 1).

SICES S.p.A. Quality Managers were immediately impressed by the high level of performance from the new flux, which allows a deposition rate 20% higher than any offered by competitors.
Process qualification tests (PQR) were carried out according to the ASME IX codes and the results obtained confirmed all expectations - with the added benefit of improved quality. The following qualification tests were carried out:
- visual – dimensional control
- ultrasonic test
- liquid penetration test
- chemical analysis
- ferrite content
- bend tests
- disbonding test


Figure 2. – Reactor for refinery - desulphurization plant at sices.

The opportunity to test the new ESW ESAB OK Flux 10.14 in actual production arose only a few days after the successful results of the procedure qualification by carrying out an ESW plating on a reactor for a refinery desulphurisation plant, Figure 2. The reactor was designed in accordance with ASME Code VIII div. 1 and with supplements to the Pressure Equipment Development directive, PED 97/23/CE. The basic material for the bottom parts and the cover are type ASTM SA 387 Gr. 11 C12 welded with the SAW process. Welding consumables: ESAB OK Flux 10.62 + OK Autrod 13.10 SC (AWS A5.23 EB 2R –low impurity wire).

The reactor dimensions were: 23,000 mm (length) – 3,650 mm (diameter) – 75 mm (thickness) – 161,500 litres (volume) – 160 tons (empty weight) – 360 tons (gross weight). The minimum design temperature is – 30°C, whilst the design temperature is 414°C (working 389°C); the hydraulic test pressure was 89 bar, while the working pressure will be 50 bar/f.v. The specification quoted a plated thickness of 8 mm during analysis, in order to reflect the AWS range A5.9 ER 347 at 3 mm from the top. Moreover, the filling material had to satisfy the ferrite range 3-8 before and after PWHT. Following the client's specifications, the plating was carried out in two layers with ESAB consumables: OK Flux 10.14 + OK Band 309LNb (AWS A5.9 EQ309L Nb) OK Flux 10.14 + OK Band 347 (AWS A5.9 EQ347), Table 2. A significant example of this is shown in Table 3 with analysis carried out with the single-layer technique.

Using the high current density technique, the working parameters used by SICES S.p.A. for the plating were:

- 2100 A
- 26 V
- 410 mm/min travel speed

With the more common ESW high-speed parameters these changed to:

- 1400A
- 25V
- 320 mm/min travel speed

It was noted that the quality of the deposit in terms of chemical analysis, ferrite, defectiveness and cosmetics were in fact the same for both deposition rates, thus being able to manage different usage conditions with the same flux, such as: varying vessel diameters, bottom parts and gates, power generator current. The most commonly used power sources are able to supply 1500-1600 A at 100% duty cycle with 60 mm x 0.5 mm strip.

Reasons for selecting ESW rather than SAW are:

- less penetration
- reduced dilution
- higher productivity

The deposition rate diagrams in the figures 3 and 4 compare SAW and ESW standard processes with the high-speed ESW process

Table 2. Chemical analysis of base material and strip.

Materials	C	Si	Mn	P	S	Cr	Ni	Mo	Nb	N
Base material P355N (StE355)	0.19	0.29	1.49	0.02	0.007	0.94	0.94	0.002	0.002	--
OK Band 309LNb S 23 12 L Nb	0.013	0.31	1.95	0.009	0.0005	23.92	12.49	0.02	0.74	0.023

Table 3. Chemical analyses of a single layer weld deposit, including % ferrite, and EN and ASME requirements.

Deposit Materials	C	Si	Mn	P	S	Cr	Ni	Mo	Nb	N	Ferrite
OK Flux 10.14 + OK Band 309LNb	0.055	0.45	1.94	0.013	0.003	18.37	9.82	0.02	0.55	0.023	4.8
EN 1600: E 19 9 Nb	<0.08	<1.2	<2.0	<0.03	<0.025	18-21	9-11	-	8x%C 1.1	-	
ASME II p.C SFA 5.4: E347	<0.08	<0.9	0.5-2.5	<0.04	<0.03	18-21	9-11	<0.75	8x%C-1.0	-	

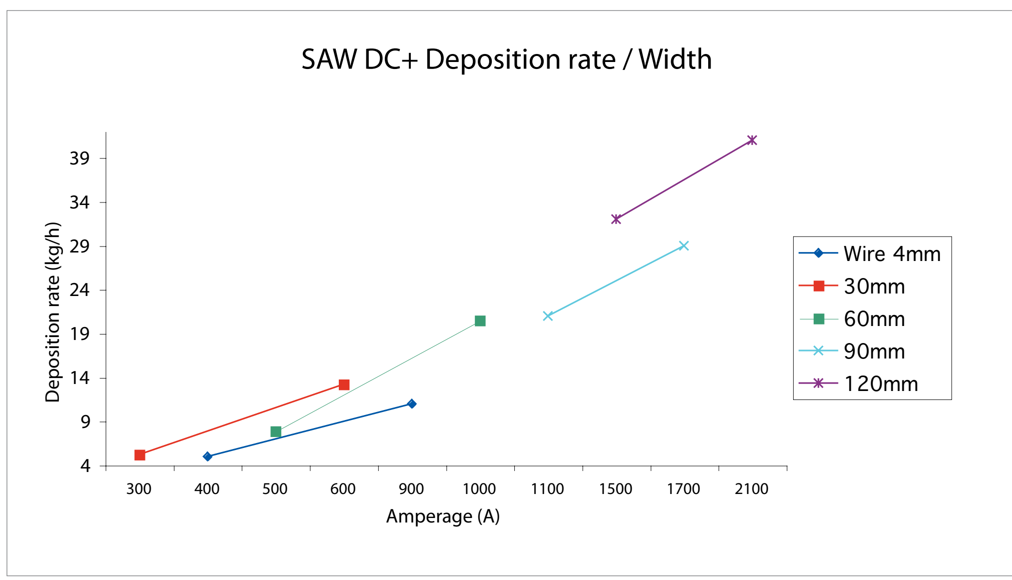


Figure 3. SAW deposition rate.

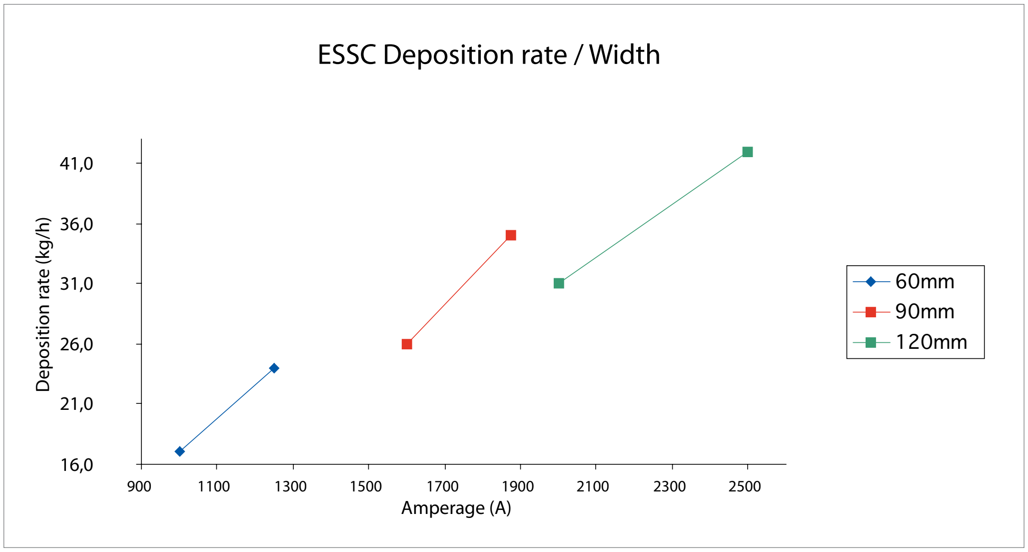


Figure 4. ESW deposition rate.

Figure 5a and b. Electroslag strip cladding of a refinery reactor at Sices.

using ESAB OK Flux 10.14. Once again, ESAB achieved its objectives of quality, productivity and cost saving – the same objectives set by the customer.
Subsequently, a contract was signed for the supply of a modern and sophisticated two-headed cladding equipment.

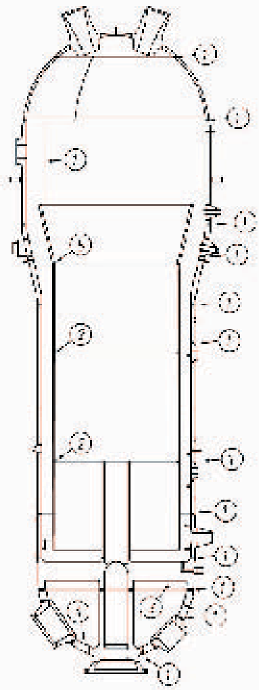
ANSALDO-CAMOZZI producer of nuclear and telescopic components
Ansaldo-Camozzi was created following the acquisition by Camozzi, an industrial group from Brescia, of the Special Components Division of Ansaldo, specialists in the production of components for the nuclear industry.

Ansaldo (formerly Breda) has been active in the production of boilers, turbines and alternators for nuclear plants since 1960. In 1991, it created the “Nuclear Centre” in Milan, with the setting-up of the Special Components Division, purchased in April 2001 by the Camozzi group, thus creating Ansaldo-Camozzi Energy Special Components S.p.A.

Production
Ansaldo-Camozzi concentrates on the production of components for the nuclear and conventional sector and elements for transport and disposal of exhaust nuclear fuel and heat exchangers for nuclear plants. They also produce large telescopes, the dimensions of which may be generous - but tolerances certainly are not. The concept of quality is not only a fundamental pre-requisite within the nuclear industry where safety must be 100% but, within Ansaldo-Camozzi, it is a way of life.

Ansaldo-Camozzi was the first company outside the U.S.A., to obtain the N and NTP ASME Stamp. The list of ASME certificates in accordance with the ASME III Division 1 is impressive. The fact that they also achieved the ISO 9001 2000 standard certification goes almost without saying. To the contrary, the ASME N3 Stamp is extremely important and relates to the design and manufacture of containers for holding and transporting exhausted nuclear fuel elements. This obviously implies that the welding materials supplier also has to have the same quality assurance prerequisites. ESAB Saldatura (Welding) was the first company to achieve the nuclear ASME Stamp certification, in Italy, for the production of welding and cutting consumables.

Ansaldo-Camozzi uses advanced technology for production and quality control of the components and is equipped with plants which are just as advanced. For example, a press weighing over 6,000 tons, which can bend plates up to a thickness of 300 mm, was recently used to make the cover for the biggest heat exchangers ever built in the world, weighing about 800 tons each and destined for the largest American nuclear power station, in Palo Verde, Arizona (Figure 6). Two were produced in 2002, two others were



1. Process: SAW single wire and tandem
   Base material: SA 508 Cl.3 – Thickness: 90 ÷ 220 mm
   Welding consumables: OK Flux 10.62 + OK Autrod 13.40 (Ø 4.0 mm)
2. Process: SAW
   Base material: SA 516 gr. 70 – Thickness: 50 mm
   Welding consumables: OK Flux 10.62 + OK Autrod 12.24 (Ø 4.0 mm)
3. Process: SAW cladding
   Base material: SA 508 Cl.3a – Thickness: 640 mm
   Cladding consumables: SFA 5.14 ERNiCr-3 (60x0.5 mm)
4. Process: SAW cladding
   Base material: SA 508 Cl.3a – Thickness: 220 mm
   Cladding consumables: OK Flux 10.05 + SFA 5.9 EQ309L + SFA 5.9 EQ308L (60x0.5 mm)
5. Process: GMAW
   Base material: SA 516 gr. 70 – Thickness: 50 mm
   Welding consumables: OK Autrod 12.64 (Ø 1.2 mm)

Figure 6. Heat exchanger for the Palo Verde nuclear power station.

delivered during 2005, and the final two were delivered in 2006.

There are essentially two types of base material to be welded for the construction of the exchangers. For the external shell it is a low alloyed forgeable steel, SA508 Class 3A. It must satisfy Rm 620 MPa min and Kv 27 J at -29°C after 25 h of heat treatment. Thicknesses vary from 240 mm for the primary circular bottom to gradually variable thicknesses from 120 mm to 90 mm for the vessel that forms the cover. Considering the thicknesses, all the welding, both longitudinal and circumferential, is carried out in SAW narrow gap with single wire or tandem, with the wire/flux combination ESAB OK Flux 10.62/OK Autrod 13.40. In this instance, packaging in big drums was particularly appreciated; 280 kg drums of wire each allowed continuous use for the whole welding length avoiding costly wire change stoppages, Figure 7. Previously, 100 kg coils were used, which had already saved three stops compared with the standard 30 kg bobbins. The 30 kg bobbins, however, are still used in SAW circumferential welding of gates with specially designed ESAB machines. The inside layer plate of the exchanger is in C-steel and can be up to 50 mm thick. The SAW combination used is OK Flux 10.62/OK Autrod 12.24. In the 640 mm thick hot-blast pipes plate, 25,000 holes are made, in which the INCONEL 690 pipes will be welded with TIG process without filler material. Apart from joining, there are also some parts which need to be surface clad because they are subject to a corrosive environment. Cladding is carried out with a SAW process with a 60 mm x 0.5 mm strip cladding head. The following combinations are used: OK Flux 10.05 with OK Band 309L in the first layer and then OK Band 308L in the following layers, Figure 8.

Also, as indicated in Table. 4, smaller quantities of electrodes are used in positions that are difficult to reach. On the external part of the structures (whose weights and dimensions are huge) some loops are fitted onto which the equipment for lifting and moving the components are attached. These loops are welded using quite a large amount of ESAB OK Autrod 13.29, diameter 1.20 mm with the MIG process, and will then be removed after the final assembly.

Figure 7. Narrow-gap welding of a circumferential joint. Welding wire is fed from 280kg drums to avoid costly downtime for spool exchange.

Figure 8. SAW strip cladding of a heat exchanger component.

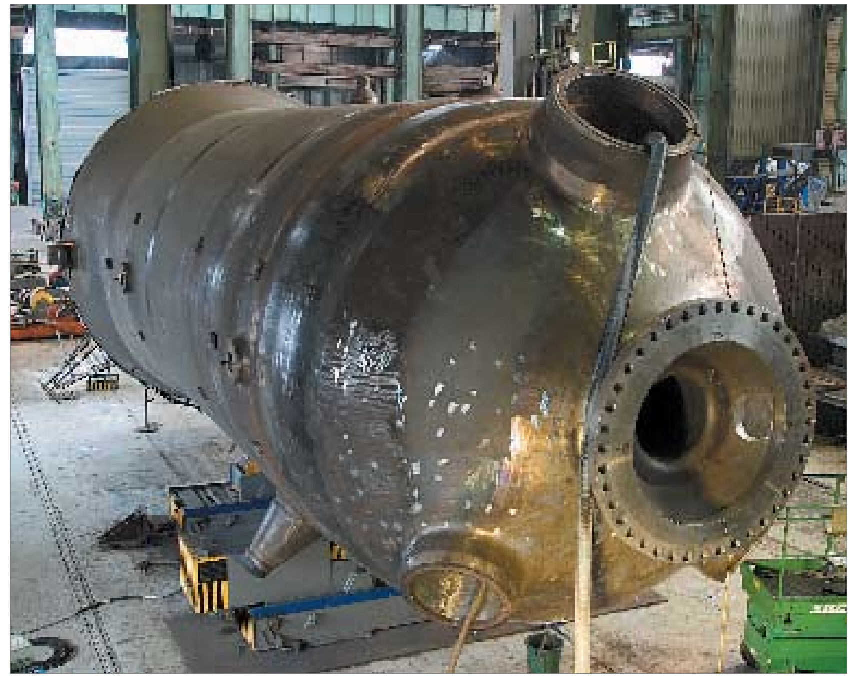


Figure 9. Completed heat exchanger.

Table 4. Deposit metal consumption

Welding material consumption of a heat exchanger	
OK Band 309L	Kg. 1000
OK Band 308L	Kg. 1000
OK Flux 10.05	Kg. 2000
OK Autrod 13.40	Kg. 7000
OK Autrod 12.24	Kg. 1000
OK Flux 10.62	Kg. 8000

Production is carried out in accordance with ASME III Division I (nuclear degree).
Heat treatment: in production is carried out at 610°C for 4h 30 minutes; and for qualifications at 610°C for 25h.

All welding to the external part undergoes 100% radiographical and ultrasonic testing. The internal parts are also checked with radiography and ultrasound, depending on the thicknesses. Surface checks are carried out throughout, with penetrating liquids and magnetic checks. Seal checks are carried out on all pipe/plate welding, using helium. Finally, the hydraulic seal check is carried out at 215 bar, corresponding to 1.5 times the working pressure. All deposit metal is double-checked with regards to mechanical characteristics, impact properties, transition curves. All plated parts undergo a bending test.

Over the last few years, ESAB has also supplied Ansaldo-Camozzi with an impressive fleet of welding equipment:

- three automatic submerged arc welding stations for manholes and/or gates (minimum diameter 260 mm / maximum 1,350 mm). The stations in particular are fitted with an interface to a roll positioner in order to keep the welding bath level in all positions;
- An SAW and/or electroslag (ESW) system made up of a cladding head with ESW 30-60 torch and automatic vertical guiding device (constant stick-out), powered by a 1600 A/46V at 100% rectifier;
- A traditional submerged arc circumferential cladding system with a head for internal parts (30 mm band) able to clad all gates and/or cylinder shaped bodies with 340 mm min. internal diameter and up to 2,500 mm long.
- A submerged arc welding equipment in tandem configuration DC AC type HNG-T suitable for welding very thick cylinder-vessel bodies (up to 350 mm) with Narrow-gap technology and two beads for each layer. The welding head is fitted with two isolated straight blade torches, with an articulated terminal controlled by a particular kinematic mechanism.
- An Automatic guiding device, bi-directional, for the correct measuring of the two vertical and horizontal correcting axis.

Co-operation with ESAB

Overcoming these very demanding conditions, ESAB has established excellent business relationships with both SICES and Ansaldo-Camozzi. Both companies have independently reported and welcomed the close working relationship, quality fit for purpose, excellent service and, in any case of problems, support that is always available and well-timed.

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Providing fresh water to The Middle East

Johan Ingemansson, ESAB Middle East, United Arab Emirates.

World population growth continues unabated, particularly in coastal areas where the majority of people already live! These areas, often, do not have enough sources of sweet water such as lakes, rivers, streams and/or groundwater and, like many countries in the Middle East, depend on industrial desalination of seawater or brackish water. ESAB provides a full range of welding consumables for the many, often exotic, materials and dissimilar joints necessary in the building of desalination plants.

The Hanover Company Belleli Energy SpA, is the principal producer and supplier of MSF (Multi-Stage Flash) and MED (Multi-Effect distillation) units in the Middle East. Its head office, and a large production site, are located in Sharjah in the UAE: other plants are located in Dubai, Saudi Arabia and Qatar. Over the years, they have delivered more than a hundred MSF and MED units in the Middle East and North Africa.

In addition, Belleli Energy is a major manufacturer and supplier of equipment for the oil and gas, petrochemical and power and water industries, for example, reactors, pressure vessels, towers, columns, steam drums, pressure parts for heat recovery steam generators and complete process modules. Employees vary from 1200 to 2200 depending on the type of projects being undertaken at any one time.

Desalination processes

There are two major types of desalination processes in use for the high volume production of fresh water - the thermal process and the membrane process. Less frequently used options include freezing, membrane distillation and solar humidification. The main thermal techniques are MSF, MED and VC (vapour compression) and the main membrane techniques are ED (electro dialysis) and RO (reverse osmosis).
In the Middle East, MSF and MED processes are almost exclusively used: MSF being a larger and more productive unit with a normal production capacity between 10-17.5 million imperial gallons/

Material	MMA	TIG	MIG/MAG	SAW
C/Mn-Steel	e.g OK 48.00 (E7018)	e.g OK Tigrod 12.64 (ER70S-6)	e.g OK Autrod 12.51 (ER 70S-6) OK Tubrod-any unalloyed	e.g OK Flux 10.71/ OK Autrod 12.10
317L	OK 64.30 (E317-17)	OK Tigrod 317L	OK Autrod 317L	
316L	OK 63.XX (E316L-XX)	OK Tigrod 316L OK Tigrod 316LSi	OK Autrod 316L OK Autrod 316LSi OK Tubrod 14.21,31	OK Flux 10.93/ OK Autrod 316L
304L	OK 61.10, 30,35 and 41 (E308L-XX)	OK Tigrod 308L OK Tigrod 308LSi	OK Autrod 308L OK Autrod 308LSi OK Tubrod 14.20,30	OK Flux 10.92/ OK Autrod 308L
309L	OK 67.60 and OK 67.75 (E309L-XX)	OK Tigrod 309L OK Tigrod 309LSi	OK Autrod 309L OK Autrod 309LSi OK Tubrod 14.22,32	OK Flux 10.92/ OK Autrod 309L
904L	OK 69.33 (E385-16)	OK Tigrod 385	OK Autrod 385	OK Flux 10.93/ OK Autrod 385
Duplex	OK 67.50, 51, 53 and 55 (E2209-XX)	OK Tigrod 2209	OK Autrod 2209 OK Tubrod 14.27 and 37	OK Flux 10.93/ OK Autrod 2209
Super Duplex	OK 68.53 and OK 68.55	OK Tigrod 2509	OK Autrod 2509 OK Tubrod 14.28	OK Flux 10.94/ OK Autrod 2509
254 SMO	OK 92.45 (ENiCrMo-3)	OK Tigrod 19.82 (ERNiCrMo-3)	OK Autrod 19.82 (ERNiCrMo-3)	
Cu/Ni 90/10	(OK 94.35) (ECuNi)	OK Tigrod 19.47	OK Autrod 19.47	
Cu/Ni 70/30	OK 94.35 (ECuNi)	OK Tigrod 19.49 (ERCuNi)	OK Autrod 19.49 (ERCuNi)	
Alloy 31	OK 92.59 (EniCrMo-13)	OK Tigrod 19.81 (ERNiCrMo-13)	OK Autrod 19.81 (ERNiCrMo-13)	OK Flux 10.93/ OK Autrod 19.81
Ni/Cu 70/30	OK 92.78	OK Tigrod 19.93 (ERNiCu-7)	OK Autrod 19.93 (ERNiCu-7)	
Titanium grade 2	N/A	OK Tigrod 19.72 (ErTi-2)	N/A	
Al-bronze	N/A	OK Tigrod 19.44	OK Autrod 19.44	N/A
Nickel	OK 92.05 (ENi-1)	OK Tigrod 19.92 (ERNi-1)	OK Autrod 19.92 (ERNi-1)	N/A

day per unit; and MED having a normal capacity of approximately 5-8 million imperial gallons/day per unit (one imperial gallon = 4.546 litres). These two processes provide good water quality, the equipment being reliable, simple and easy to handle and control.

On the negative side, both processes are high energy consumers compared to, for example, the membrane techniques. MED operates at lower temperatures than MSF and is, therefore, considered to be slightly more economical. Market trends indicate a move towards MED rather than MSF.
Often, customers order two small MED units instead of one huge MSF unit, to avoid a complete water production stoppage during maintenance and repair of the installation. Moreover, MED units are generally cheaper to manufacture, because they do not contain as many exotic alloys such as Ni-1, Cu/Ni and Al-bronze.

The MED and MSF processes

Because of their large energy consumption, MED and MSF installations are ideally located near power plants, steel plants or aluminium smelters to provide waste heat to boil the seawater in the first stage of the desalination process. Both processes basically consist of a series of vessels (stages) in which seawater continues to boil, at reducing ambient pressure, without the supply of any additional heat after the first stage. The steam produced in every vessel condensates to water with a higher level of freshness. Finally, before it can be used as drinking water, the fresher water is further processed by filtering, purification and ionising.

Material trends

Usually, the seawater is pre-treated before it enters the MED or MSF units, involving the removal of gases, coagulation and deposits, filtration, disinfection, treatment with activated carbon and addition of additives to inhibit scaling. This primarily protects the installation against aggressive corrosion, although boiling seawater

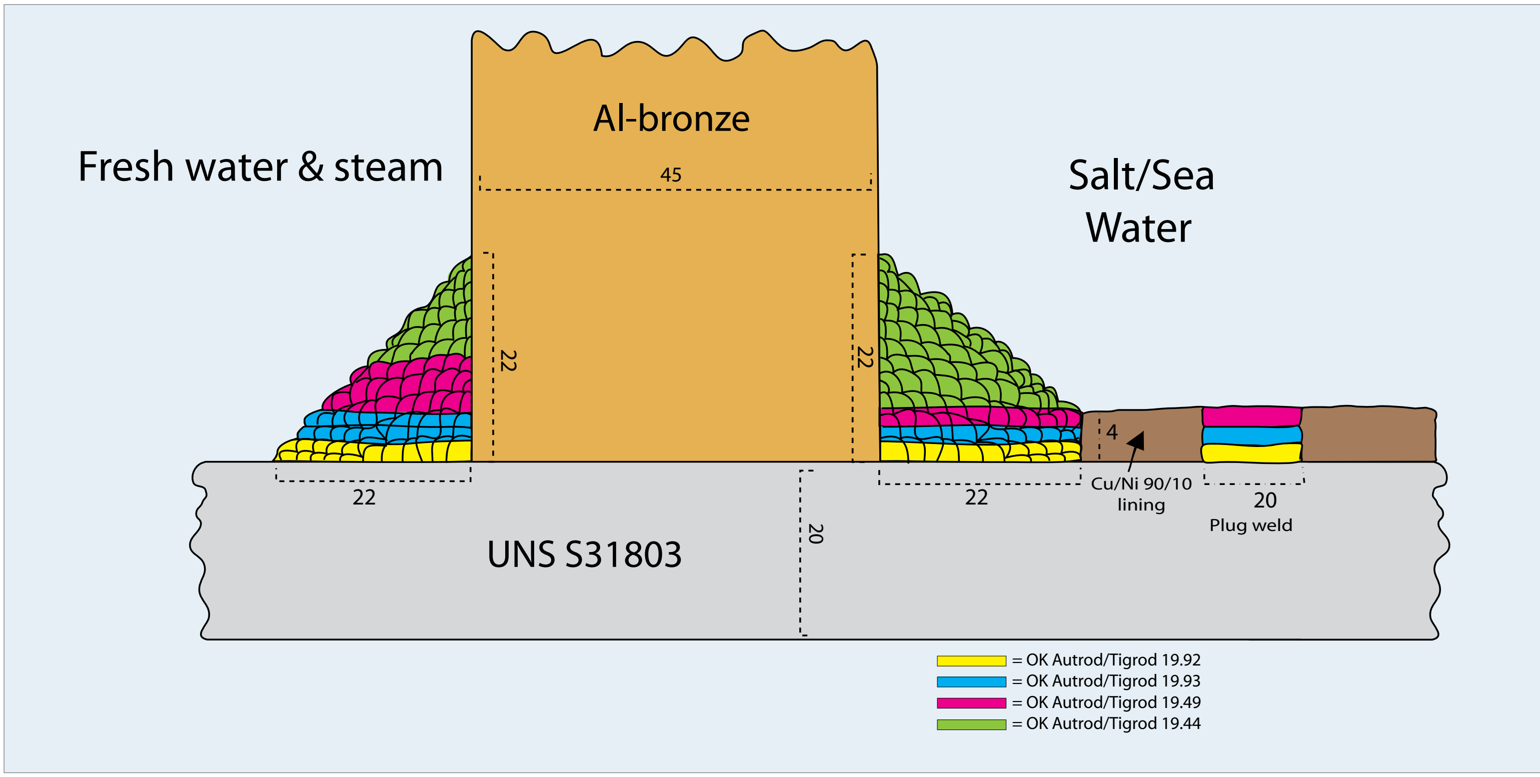


Figure 1. shows a sketch of a joint between the external wall and the water box inside an MSF unit built by Belleli (Figure 2). Salt water is the medium on one side with a Cu/Ni lining and fresh water and steam on the other side. The welding technique used is manual TIG with automatic wire feeding.

Figure 2. MSF installation nearing completion with water boxes connecting the various stages in the desalination process.

with, an increasing salt concentration in every stage, remains a tough environment for any material.

The trend in the market for MED and MSF installations is for 316L and 317L stainless steels to be replaced by different duplex and/or super austenitic stainless steels such as 254 SMO, with a higher resistance to pitting corrosion. Today, material selection for the different components of MSF and MED units is based on modern material

Figure 3 . Macro of a PQR sample of an 'exotic' joint in a desalination installation. 22 mm thick Cu/Ni 90/10 (left) connected to 20 mm thick S 31803 duplex stainless steel (right), welded with manual TIG with automatic wire feeding. The duplex side is first buffered with two layers of OK Autrod 19.92 (ERNi-1) followed by two layers of OK Autrod 19.93 (ERNiCu-7). Subsequently, the two sides are joined with OK Autrod 19.49 (ERCuNi). One layer, with the (acceptable) pore, is welded with MIG, just to get the process approved.

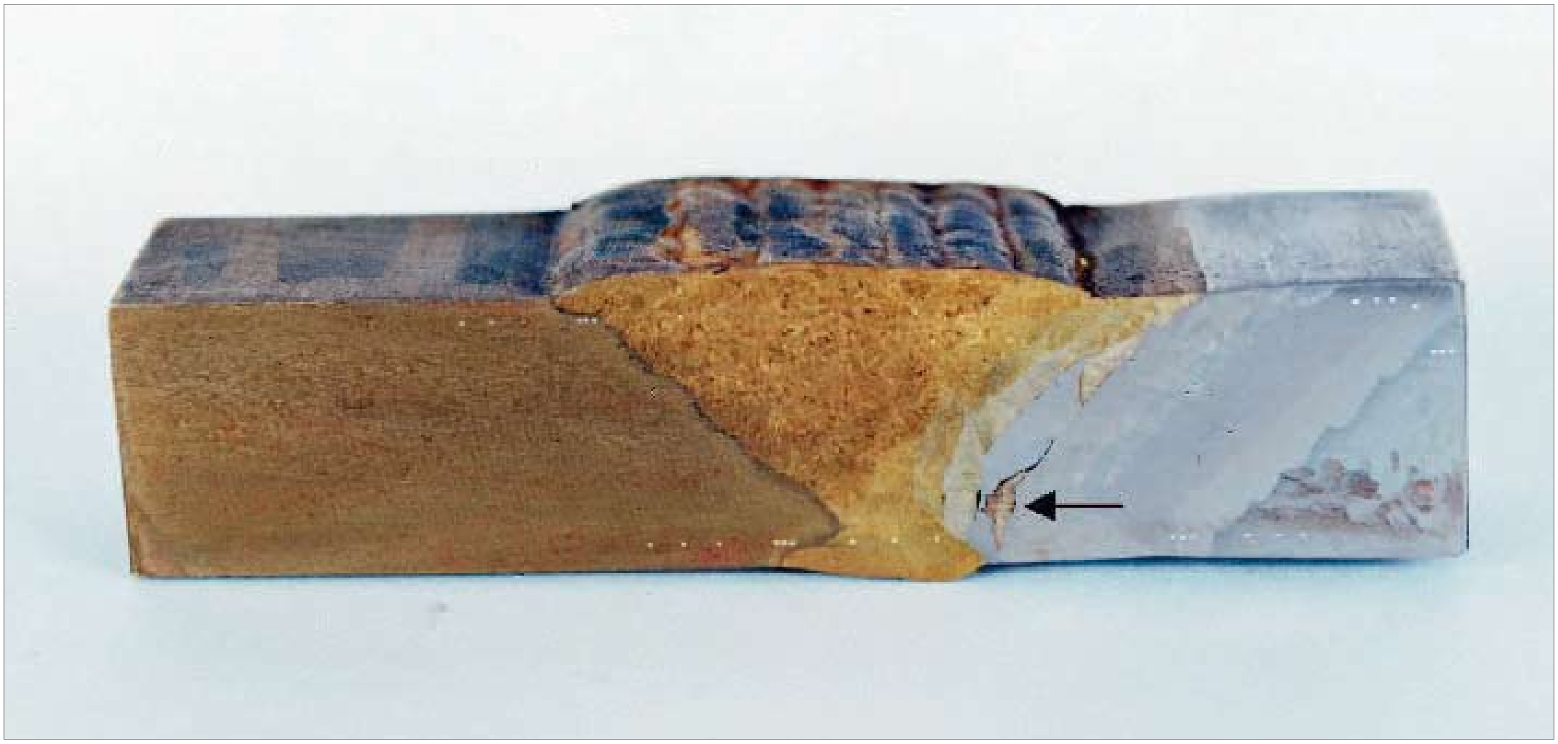


Figure 4. Another example of an exotic joint. Macro of a PQR. 22mm thick CuAl (UNS C61400) connected to 20 mm duplex stainless steel, welded with semi-automatic TIG with automatic wire feeding. The duplex material (right) is buffered with two layers of OK Autrod 19.92 (ERNi-1), two layers of OK Autrod 19.93 (ERNiCu-7) and finally with four layers OK Autrod 19.49 (ERCuNi-7). Subsequently, the two sides are joined with OK Autrod 19.44 (ERCuAl-A2). One layer is welded with MIG, just to get the process approved.
On the duplex side, all buffering layers have been dye-penetrant tested. The first layer of OK Autrod 19.44 (ER CuNi) showed minor indications of cracking. These areas were ground out and repaired with OK Autrod 19.49 before continuing with OK Autrod 19.44. The arrow shows the repaired area on the macro photo.

science and previous experience. Usually, corrosion and other material problems are associated with other system components such as pumps and valves.

Examples of dissimilar joints

As seen in Table 1, a variety of materials is used when building a MSF unit and, naturally, many dissimilar joints have to be welded . Consumables and welding procedures have to be selected to ensure both the highest possible mechanical properties and preservation of excellent corrosion resistance in salt water, as well as avoiding hot cracking problems. In addition, it is often advantageous to have a gradual change in compositions across a dissimilar weld to distribute stresses and strains more evenly. Examples of this approach are shown in procedures presented in Figures 1, 3 and 4.
The duplex steel (UNS S31803) is lined with 4 mm thick 90/10 copper nickel sheet that is plug-welded to the duplex material. The plug welds are made with a very thin layer of OK Autrod 19.92 (ERNi-1), followed by an intermediate layer of OK Autrod 19.93 (ERNiCu-7) and finally a cap layer welded with OK Autrod 19.49 (ERCuNi).

In the fillet welds, four different alloy type consumables are used. As with the plug welds, the first layer is welded with an ERNi-1 type filler to minimise the weld metal Fe-content and, thereby, prevent hot cracking of the following layers. An alternative approach would have been to weld the fillet welds with OK Autrod 19.44 (ERCuAl-A2) only. However, the mechanical properties would not have been on the same level as with the chosen combination.
Figures 3 and 4 show PQR macros of two other dissimilar joints and the complicated welding solutions needed to connect materials that are not directly compatible from a metallurgical point of view. These joints could be described as ‘a welding engineer’s dream’ – but, at the same time, a nightmare.

The future of desalination in the Middle East

The future for new desalination plants in the Middle East looks bright due to increasing development and influx of people. Many countries investing in tourism require green areas such as golf links, parks and gardens, all with high daily water consumption. The general consensus is that future demand for fresh water can only increase.

About the author:

Johan Ingemansson is Product Manager Consumables at ESAB Middle EAST, Dubai, UAE.

ESAB top specialist Dr Leif Karlsson wins TWI Brooker Medal

The TWI Brooker Medal is presented in recognition of the recipient's personal contribution to the science, technology and industrial exploitation of metal joining.

Leif Karlsson receives the Brooker Medal from TWI President, Professor Michael Burdekin.

At the annual general meeting of the TWI, the international materials joining technology institute, held on 20 June 2006, Leif Karlsson, a senior development and applications expert at ESAB, received the TWI Brooker Medal. This annual award, which is held at TWI in Great Abington, UK, and is sponsored by Johnson Matthey Plc, is presented in recognition of the recipient's personal contribution to the science, technology and industrial exploitation of metal joining.

Leif Karlsson is a leading authority on high alloyed and high strength welding consumables and has a key role in ESAB's research and development in these areas. Karlsson received a Ph.D. in materials science from Chalmers University of Technology in Gothenburg, Sweden in 1986 and joined ESAB after graduating. Since then he has been involved in research and development into weld metals and their characteristics.

Currently Karlsson holds the position of Manager of Research Projects and focuses mainly on those projects dealing with corrosion resistant alloys and high strength steels.

Leif Karlsson has authored several technical papers in the field of welding metallurgy. He is a member of Commissions II and IX of the International Institute of Welding and, since 2005, has chaired the Sub Commission IX-H "Welding of Stainless Steels and Nickel alloys".

Photo courtesy Siemens Medical Solutions

Aristo™ robot package appreciated at Siemens Magnet Technology

British producer of superconducting magnets for MRI scanning equipment praises functionality and user-friendliness of ESAB MIG equipment for robot applications.

By Ben Altemühl, editor of Svetsaren

Manufacturing superconducting magnets for Magnetic Resonance Imaging (MRI) equipment is characterised by a high level of control and consistency imposing high demands on the MIG welding process and weld quality. ESAB Aristo™ inverter technology applied on SMT's production robots provides the advanced programming and process functions, including ESAB SuperPulse, needed for this kind of challenging fabrication.

Acknowledgement
Malcolm Faithfull, Welding Engineer, and Martin Smith, Business Excellence Manager, are thanked for enabling our visit to SMT and for providing us with the information for this article.

SMT

Siemens Magnet Technology (SMT), Oxfordshire, UK, is the world's leading designer and manufacturer of superconducting magnets for MRI scanners. More than 30% of the MRI scanners for clinical imaging in hospitals worldwide have at their heart a superconducting magnet produced by SMT. More than 80% of the magnets are incorporated into MRI Systems from Siemens Medical Solutions. Other customers include Toshiba Medical Systems Corporation and Hitachi Medical Corporation. SMT is strategically located in Oxfordshire with access to leading universities, medical research facilities, scientists and researchers.

Twenty five years ago, Siemens Medical Solutions laid the cornerstone for MRI development and an enormous amount of innovation has taken place to turn the first ideas and experiments into today's product line.

MRI is a non-invasive imaging technique for obtaining cross-sectional images of the body. It is particularly useful for visualizing the soft parts of the body, such as muscles, ligaments, tendons, fat and cartilage, as well as vessels. It has widespread applications in the diagnosis of cancer, heart disease and neurological disorders.

Developing shorter magnets with larger patient apertures enabled Siemens Medical Solutions to produce the world's first Open Bore MRI scanner in which patient comfort is key and as a result the patient's experience is less intimidating.

Superconducting magnets

Figure 1 shows a simplified view of SMT's superconducting magnet. The heart of this are the wire coils of the magnet (Figure 2), enclosed in a stainless steel vessel filled with liquid helium to cool the magnet to –269 °C. At this temperature the wire becomes superconducting and has a resistance approximately equal to zero. The helium vessel is suspended in a stainless steel outer chamber that is brought under high vacuum to insulate the magnet and maintain the ultra-low temperature.

Both the helium vessel and the outer vacuum chamber are manufactured from 304L stainless steel. This material is selected for its low magnetic properties – rather than for reasons of corrosion – to avoid disturbance of the magnetic field and keep it uniform. The purchasing specification agreed with the steel supplier contains a band-width for the ferrite content to maintain the magnetic properties at a consistent level. In general, tolerances to the construction are very

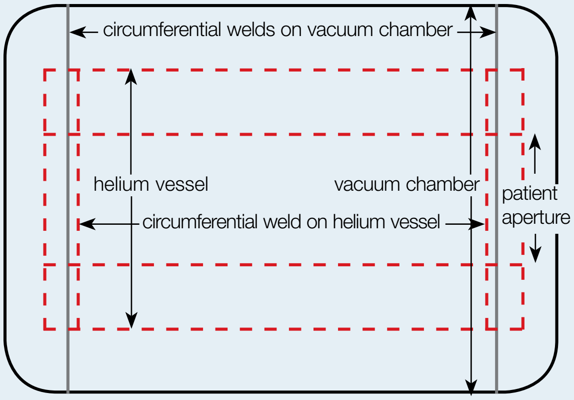


Figure 1. Sketch of the housing of a superconducting magnet, indicating circumferential joints on the helium vessel and the outer vacuum chamber. Longitudinal welds are part of the prefabricated subassembly which is plasma welded according to SMT welding specifications.


Figure 2. Superconducting magnet coil to be contained in the helium vessel.


Figure 3. Motoman robot equipped with the Aristo™ robot package and internal clamp/manipulator.

narrow, due to the requirement of a perfect magnetic field in the middle of the scanner.

Robot stations

Apart from a substantial amount of manual TIG welding on smaller parts, including tacking of the major parts, the important circumferential joints are welded by robotic MIG welding – three or four per vessel, depending on the magnet type (Figure 1). For these welds, SMT uses two robot stations with Motoman UP50 6-axis robots on 2-axis manipulators. Both robots are equipped with the ESAB Aristo™ robot package consisting of an Aristo™ 500 water-cooled inverter power source, a robot mounted Robofeed 30-4 encapsulated wire feeder, cable assembly and torch and the U8 control unit (Figure 3). Communication with the programming software of the robot is through Device Net. The robot head is equipped with a laser sensor for joint tracking and a camera to monitor the welding process on a screen.

The first robot to be equipped with the Aristo™ process package was installed by a UK robot integrator, Bauromat, about 12 months ago, when SMT started manufacturing a new product. The 2nd was a retrofit of an older robot, about 6 months ago.

Weld requirements and welding

The number one requirement for the welds – on the helium vessel and the outer vacuum chamber – is absolute leak tightness. Helium is the second lightest gas known and a "very searching" element that can escape through the most microscopic of apertures, thereby determining the lifecycle of the complete magnet. One complication of this kind of closed construction, are the limited possibilities to perform NDT on the welds. The method applied by SMT is 100% penetrant testing of all welds, the reason being that any unseen defects will only become apparent at final testing, when the magnet is filled with helium and brought under vacuum, and can only be repaired at tremendous costs.

A stable MIG welding process and a consistent and repeatable weld quality are therefore paramount. These are provided by carefully designed and tested welding procedures for the various joints, in combination with the digital programming and arc control features of the Aristo™ robot package. Parameter settings for each layer are stored at memory positions in the U8 control box, using the standard synergic lines with some slight adjustments. During the start-up phase of each product, a coupon plate was tested for each of the first 50 vessels requiring 100% success. Now confidence, backed-up by experience, is so great that only with every 50th magnet a coupon plate is welded, X-rayed and mechanically tested.

As an example, the circumferential joint closing the helium vessel is a 60-70° V-preparation in 4mm to 8mm thick stainless steel welded onto a stainless backing strip. It is welded in two layers – a root pass and a capping pass (Figure 5). The torch is in a fixed position – slightly over 12 o' clock – while the magnet is rotated counter clockwise by a manipulator arm on the robot station (Figure 3).

The filler material is an 1.2mm diameter 308LSi solid wire. The Si-type, in combination with the shielding gas, is chosen to obtain flat welds with a perfect wetting onto the plate edges. The shielding gas is an Ar/He/O_2 mixture, where both the He and the O_2 promotes flatter welds and improves wetting. The finishing touch is given, making use of the SuperPulse facility in the U8 control unit.

SMT uses Pulse-Pulse for the root run – a high current pulse gives the required penetration, while a pulse at a lower current avoids overfilling of the joint. Altogether it gives an excellent weld pool control and the required security in terms of penetration. The capping run is done with traditional pulse with a weaving action.

User-friendly equipment does the job

SMT is very pleased with the performance of the Aristo™ process package in general and the user-friendliness of the U8 control box in particular, according to Malcolm Faithfull, Process Welding Engineer: "Our production is an environment where consistent quality is the number one requirement. In that sense it very much resembles the aerospace industry. Everything is produced to very narrow tolerances. The functionality of the Aristo robot equipment enables us to have complete control over the welding process and obtain a consistent weld result. All you need is there in terms of welding intelligence and all very easily accessible. The whole set-up of the control unit is designed to give you the shortest route to an optimum arc condition".

Figure 4. The tack welding of the backing bar as such, already shows the kind of precision applied in the welding of this advanced medical equipment.

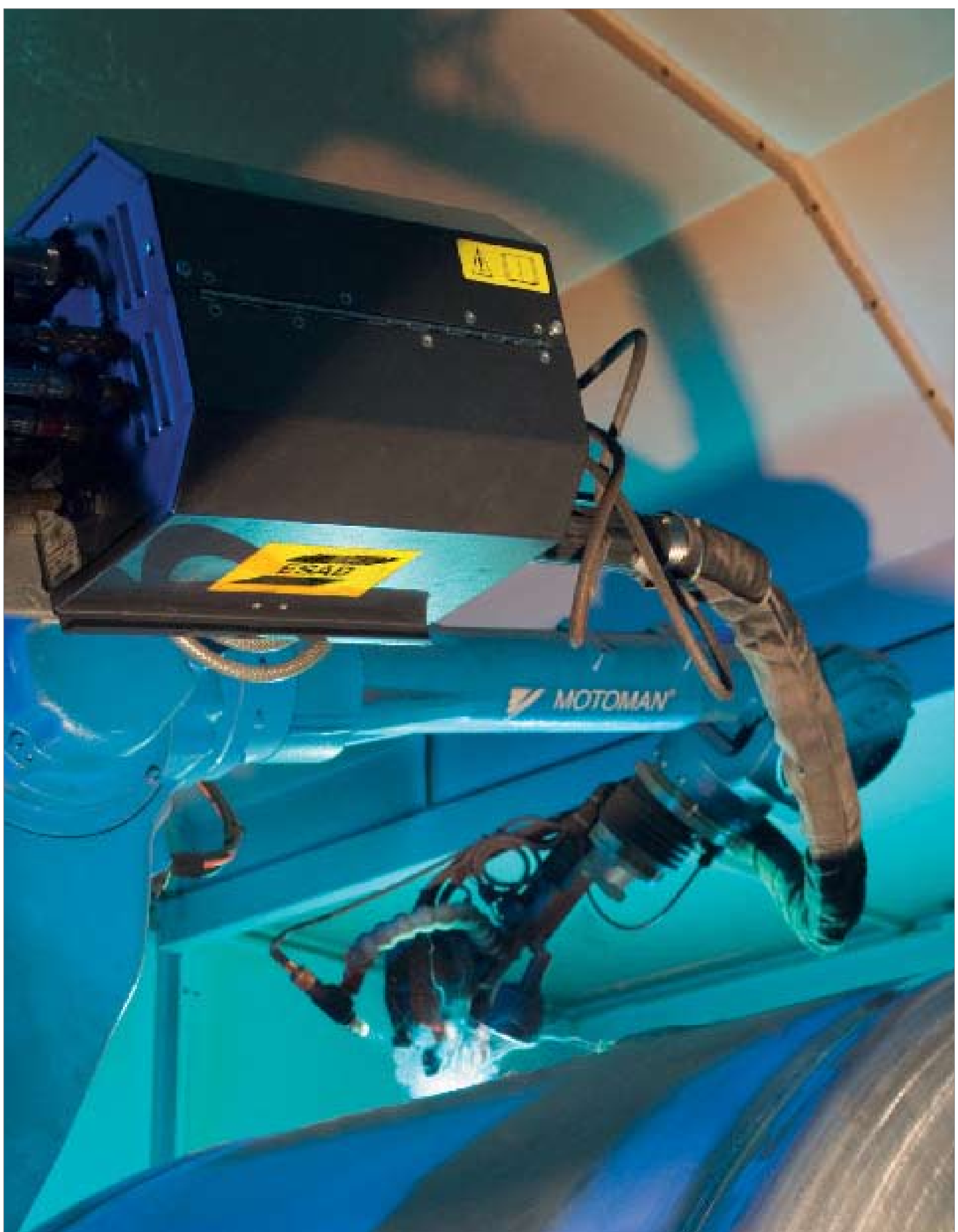


Figure 5. Cross section of a circumferential weld onto a backing strip. The graphs from SMT's high speed logger show the pulse on pulse profile and frequency of both current and voltage for the peak and background phases of the ESAB SuperPulse programme used for depositing the root pass. Values of the original WPAR, coupon plates and sample vessels have been logged for comparison – a useful tool when looking for trends and fault finding. Bottom: TV screen image of the actual welding.

About the author:

Ben Altemühl is Technical Editor within ESAB's Central Marketing Communication Department and Editor in Chief of Svetsaren.

ESAB MMA electrodes for positional welding of thin stainless pipe and sheet

For the petrochemical, paper and pulp, energy and food processing industries.

TAPIO HUHTALA, ESAB AB, GOTHENBURG, SWEDEN

ESAB introduces three new rutile MMA electrodes with excellent all-positions arc control at very low welding currents - OK 61.20, OK 63.20 and OK 67.53. They have been developed in co-operation with the petrochemical and paper and pulp industry - in response to the increasing use of thin-walled stainless pipe and sheet to extend the lifecycle of installations.

Stable arc at low currents
A stable, soft arc at very low current and voltage makes them suitable for both up- and downhill welding of pipes with a wall thickness in the region of 2 mm. The slag system allows a long pull-out length, reducing electrode change time loss.

Low spatter, good slag release and good wetting minimise time loss in post-weld cleaning. Corrosion resistance meets the requirements of demanding environments found in, for example, the petrochemical and shipbuilding industries.

OK 61.20 – for 1.4307 type austenitic stainless steels
This electrode complements the well-established OK 61.30 to cover very thin stainless steel. It has been developed for AISI 304 types of austenitic stainless steel widely used in applications with a moderate corrosion resistance requirement.

OK 63.20 – for 1.4404 type austenitic stainless steels
OK 63.20 is used for 1.4404 type stainless steels (AISI 316) applied in petrochemical plants and for marine applications. In line with the parent material, it is alloyed with molybdenum to provide enhanced resistance to pitting corrosion in chloride-containing media, such as salt water. Another major use is the welding of AISI 304 type stainless steel for similar applications, to provide a weld with a significantly higher corrosion resistance.

OK 67.53 – for 1.4462 type austenitic stainless steels
OK 67.53 is used for welding austenitic-ferritic (duplex) 1.4462 stainless steel applied extensively in the petrochemical and pulp and paper industry, shipbuilding and offshore construction. It is particularly suitable for bridging large gaps in thin-walled material.

- Productive welding
- Reduced post weld cleaning
- Good corrosion resistance in demanding environments

Examples from the industry.
SMAW provides better economy compared to GTAW, mainly due to the avoidance of gas purching, related waiting times, and associated gas costs. The better welding economy makes MMA electrodes a popular choice for applications in thin-walled stainless steel.

YIT and Projektsvets, both located in the Karlstad region of Sweden, specialise in the construction, repair and maintenance of paper and pulp plants, in Scandinavia. ESAB's new electrodes for thin-walled stainless steel have been developed to meet their specific requirements and have been extensively tested by both companies under practical conditions. Both report satisfactory use in pipe shops and on-site applications.

On-site renewal of stainless steel piping at the STORAENSO paper and pulp plant in Skoghall, near Karlstad, Sweden by YIT. The excellent all-position weldability of OK 63.20 is crucial to deliver the highest quality welds.

OK 61.20 used for the vertical down welding of water supply piping in the Projektsvets pipeshop at the Billerud paper and pulp plant near Karlstad, Sweden (AISI 304, 2.5 mm wall thickness). The remote control on the CaddyArc portable inverter is used to prevent burn-through by controlling the arc which is directed at the root of the joint. Welding is carried out in the two o'clock position while the pipe is rotated upwards, manually.

Typical all weld metal properties

	Mechanical properties					Chemical composition all weld metal (wt%)						
	EN 1600	AWS 5.4	Rp0.2 (MPa)	Rm (MPa)	A5 (%)	C	Si	Mn	Cr	Ni	Mo	N
OK 61.20	E 19 9 L R 1 1	E308L-16	430	560	45	< 0.030	0.7	0.8	19.5	10	-	0.09
OK 63.20	E 19 12 3 L R 11	E316L-16	480	580	37	< 0.030	0.7	0.8	18	12	2.8	0.08
OK 67.53	E 22 9 3 N L 3 R 1 2	(E2209-16)*	660	840	25	< 0.030	0.8	0.85	23	9.5	3.2	0.17

* Cr and Mo may exceed the AWS specification, for reasons of improved corrosion resistance.

Approvals

	DNV	SEPROS	VdTÜV
OK 61.20			Pending
OK 63.20		UNA 409820	09716
OK 67.53	x		05422

OK 61.20, OK 63.20 and OK 67.53. are available in ESAB's VacPac vacuum packaging for optimum protection against porosity without costly procedures such as re-baking, holding ovens and quivers.

Dimension range and parameters

Diameter	Length	Current Min	Current Max
(mm)	(mm)	(A)	(A)
1.6	300	23	40
2.0	300	25	60
2.5	300	28	85
1.6	300	15	40
2.0	300	18	60
2.5	300	25	80
3.2	350	55	110
2.0	300	25	60
2.5	300	30	80
3.2	350	70	110

About the author:

Tapio Hutala is Group Product Manager stainless and R&M electrodes at ESAB AB, Gothenburg, Sweden.

Welding of 13% Cr-steels using the laser-hybrid process

Lars-Erik Stridh, ESAB AB, Gothenburg, Sweden

An ESAB Process Centre report on the application of laser-hybrid welding to bus chassis parts in supermartensitic stainless steel.

The group of steels known as supermartensitic stainless steels, typically has a Cr content of 10-13%, a C content of ≤ 0.02% and a Ni content of 1-6%. The role of the nickel content is to stabilise the martensitic micro structure. These materials have a high strength of approximately 550MPa (equal to X80 materials) and very good corrosion resistance, especially within environments containing CO_2.

The limited resistance to H_2S (hydrogen sulphide) is slightly improved by the addition of 1-3% Mo. In areas such as the offshore industry, supermartensitic stainless steels are a cost-efficient alternative to duplex stainless steels.

Steel type	C	Si	Mn	Cr	Ni	Mo	Cu	Ti
12Cr6.5Ni2.5Mo	0.01	0.26	0.46	12.2	6.46	2.48	0.03	0.09
11Cr1.5Ni	0.01	0.18	1.14	10.9	1.55	0.01	0.49	0.01
12Cr3Ni	0.01	0.19	0.24	12.5	3.12	0.02	0.06	0.01

Table 1. Typical chemical composition of supermartensitic stainless steels.

Typical chemical composition (wt.%) of all weld metal								
Wire	C	N	Si	Mn	Cr	Ni	Mo	Cu
OK Tubrod 15.53	<0.01	<0.01	0.8	1.2	12.5	6.8	1.5	0.5
OK Tubrod 15.55	<0.01	<0.01	0.4	1.8	12.5	6.7	2.5	0.5

Table 2. Chemical composition of metal cored wires.

Welding

In many cases, it is required to have the weld matching the strength of the parent material. In this case, superduplex consumables are used, as these just match the strength of supermartensitic steels and are metallurgically compatible. If there is no strength matching requirement, nickel base consumables or 2205 duplex consumables can be used.
There are few references or recommendations regarding heat input limits and interpass temperatures, for supermartensitic stainless steels.

When duplex or superduplex consumables are used, the limits valid for these steel grades are applied and this gives problem-free welding with good mechanical properties. Experience from several users and their PQR / WPARs indicates that preheating is not necessary to avoid hydrogen cracking.

The normal processes, (pulse) MIG, (pulse) MAG, TIG and SAW, are applied to weld supermartensitic stainless steels. In some cases, for example for pipe production, laser welding is used. FCAW is seldom applied, although ESAB has developed metal-cored wires with matching composition for the girth welding of pipes, OK Tubrod 15.53 and OK Tubrod 15.55.

Transport segment

Supermartensitic stainless steels have recently entered the transport segment and are today used by different producers of bus and truck/lorry chassis. The material combines high strength with good corrosion properties. This is a key issue for the industry as transport economy is an environmentally important feature. It is also a safety issue, as one target for the industry is to deliver designs which combine low weight and high strength in order to protect both the onboard passengers as well as the surrounding vehicles.

The plate thickness and the types of joints differ from those used in the offshore industry. Also different are the strength criteria. A bus or a lorry is exposed to vibrations and other dynamic loads and, as a result, fatigue strength is of utmost importance. Because we are supporting serial production, robotic MIG/MAG welding with solid wires is the predominant welding process. However, one of the drawbacks of this process is that wetting and transition to the parent material is not optimal and this can have the affect of greatly reducing fatigue lifetime.

Laser-hybrid welding

Having worked with the laser hybrid process in different applications and in different base materials, we found that the process combines the best properties from both laser welding and MIG welding, often resulting in very good wetting.

When a bus manufacturer asked us if it was possible to improve the quality of a load bearing part and the productivity of the welding process, laser-hybrid welding was the obvious choice for this material and application. Another important effect of the process is that the welding speed is greatly increased, compared to MIG welding, resulting in less heat input. This reduced heat input considerably reduces the risk of deforming the weld pieces, resulting in cost savings on work piece fixturing devices.

The application

The customer is currently welding frames in supermartensitic stainless steel, EN-1.4003. The frame section is simultaneously welded by two MIG robots in a single station. Although the welding sequence is carefully developed to induce as little distortion as possible to the object, distortion remains a disturbing factor that determines the robustness and thereby the price of welding fixtures.

Test set-up

Robot: Motoman ES 165
Laser: Trumpf/haas 4006D Nd YAG, 600 micron fibre, delivery length 20m.
Optics: Trumpf D70, 200 mm focal length.
Power source MIG: ESAB Aristo™ 500 U8.
Consumable: OK Autrod 316LSi, 1 mm diameter.
Shielding gas: Mison 2 (98% Ar + 2% CO_2)

The plate thickness is 4mm and the plate quality is EN 1.4003. Welding was completed in a fixture where only the two ends of the weld object were held. This was done to see if the expected low distortion would allow only minimal fixing of the object. OK Autrod 316LSi was primarily selected to obtain good wetting of the weld onto the plate material in order to improve the fatigue strength of the welds. Metallurgically, the weld metal must have the possibility to dilute with the plate material and remain ductile.

Results

Welding using the hybrid process has proven to be very stable in this material and with this application. Welding speeds achieved in the different joints are up to 6.5 times higher as compared with conventional MIG welding. Heat inputs are low, in the range of 0.25 KJ/mm, but the hardness levels in the joints are still acceptable. The deformation of the actual work piece is so low that, in principle, it would be possible to weld the piece when only fixed to one end. Fatigue tests also show that the fatigue life increases by 100%.

Summary

As higher strength and more corrosion resistant steels are coming into use, it is important that the welding processes are ready to meet the productivity and quality demands that are required by the industry. Laser-hybrid welding is a relatively new

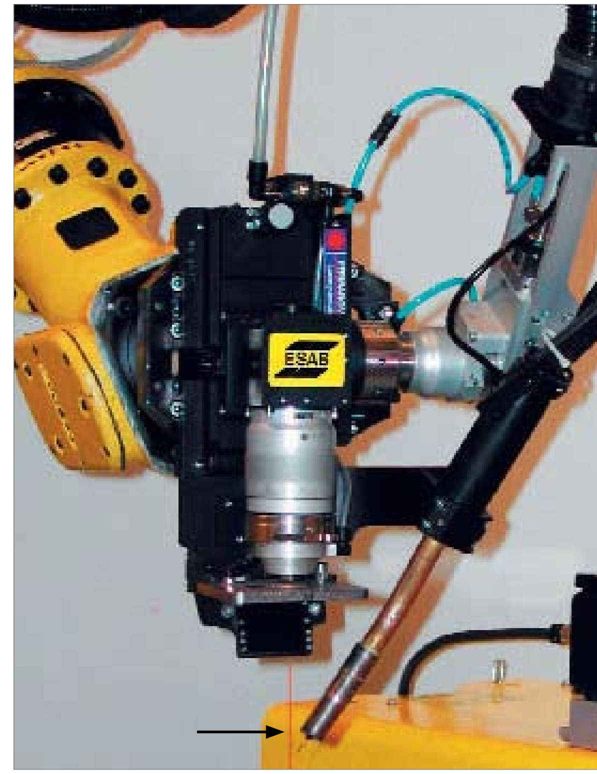
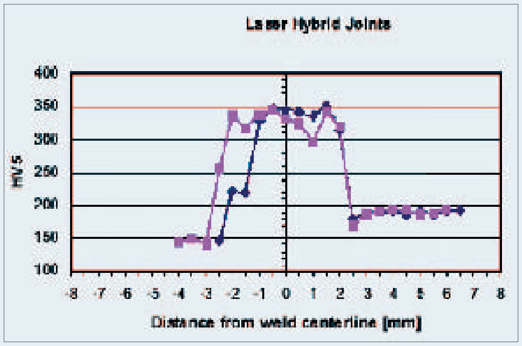


Figure 1. Laser-hybrid welding head. The arrow shows the point where the laser light and the MIG arc join into the hybrid process.

Figure 2. Examples of welded joints. The complete application included overlap joints, corner joints, fillet welds and butt welds.



Hardness values across the welded joint.

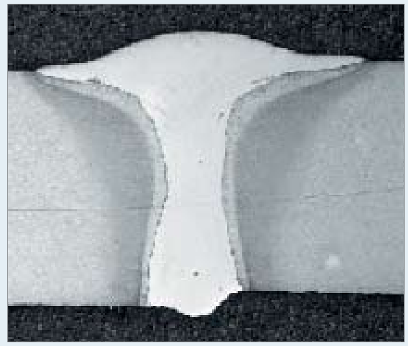
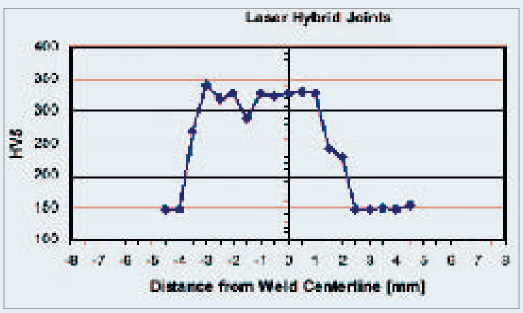
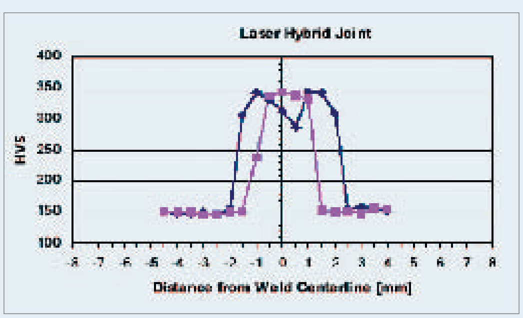


Figure 3. Cross section of a butt weld. Low reinforcement and very good transition between weld metal and parent material.
Welding data: Laser power 4.0 kW
Welding current: 229 A
Arc Voltage: 23.5 V
Welding speed: 58 mm/sec



Hardness values across the welded joint.

Figure 4. Cross section of a fillet weld. Note the brilliant transition to the parent material.
Welding data: Laser power 1.0 kW
Welding current: 284 Amp
Arc voltage: 27.5 Volt
Welding speed: 25 mm/sec.



Hardness values across the weld

Figure 5. Corner joint. Note that the "laserfinger" is actually guided out of the joint into the root. This results from an intentionally induced root gap, so that the light is partially reflected by the joint faces in the root.
Welding data: Laser power 2.1 kW
Welding current: 235 Amp
Arc voltage: 24.3 Volt
Welding speed: 50 mm/sec.

process that fulfils both productivity and quality demands.
The welding of supermartensitic steels allows considerable freedom when choosing consumables. Where it is demanded, matching consumables are preferred in order to meet strength levels, but when other criteria apply, such as fatigue properties, alternative consumables like duplex, austenitic or Ni-base can be chosen.

The process proved capable of meeting the requirements of fatigue, reduced deformation and increased welding speed, meaning that the cycle time can be significantly reduced. A normal welding speed with robotised MIG welding is in the area of 12-15 mm/sec, whereas with the laser-hybrid process operating within the same application the welding speed increases to 55-60 mm/s. The laser-hybrid process has a future for plate thicknesses ranging from 3 mm up to 20 mm. This is the range where the process will lower the cost through enhanced welding speeds, reduced deformation and less post weld labour, reduced joint volumes and increased weld quality.

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Making barrels with drums

Mini Marathon Pac bulk wire - steady force in beer barrel production.

Ben Altemühl, Editor of Svetsaren and **Ales Plihal**, ESAB Czech Republic.

ESAB matte stainless steel MIG wire from Mini Marathon Pac delivers dependability in stainless steel beer barrel production at Schäfer-Sudex in the Czech Republic, providing both process stability and minimum downtime.

Automatic welding of a beer barrel component.

Where else than in the Czech Republic, the country that invented Pilsner Beer and other world famous brands, would one expect to find highly efficient beer barrel production? "Efficiency" is certainly the word that jumps to mind when looking out over the production facility at Schäfer-Sudex, in Ledec. A continuous flow of cold pressed base and top sections, handgrips and other components weaves its way through the workshop to eventually discharge as completed barrels from the final welding station at a rate of 600 barrels a shift, three shifts a day, seven days a week. Purpose-designed welding stations are operator manned to load and unload the various components manually. On first sight this may seem a monotonous task, but on closer inspection it is easy to observe the extent of pride and quality consciousness that is evident in this process as it is across the whole company and its products.

“In this environment there is no room for technical problems arising along the production line”, says Managing Director and Welding Engineer, Dipl. Ing. Rudolf Moder. “Process stability is our number one requirement, be it in cold pressing, bending, marking or welding. Any malfunctioning of equipment will directly result in a loss of factory output, as all steps in the manufacturing process are interdependent. This is also true for the welding wires we use. We expect them to deliver trouble-free performance within the maintenance schedules we apply”.

Schäfer-Sudex is one of five production companies within the Schäfer Group - a family owned German enterprise with sales operations in twenty-two countries and with production activities ranging from industrial tools to household appliances. Sudex was the original name given to the former state owned company prior to privatization. (Sud being the Czech word for barrel).

There’s more to beer barrels than one might think

The outwardly straightforward construction of a beer barrel is not the kind of thing that’s likely to win you an industrial design award but, nevertheless, there are some quite complex production issues that have to be overcome in order to meet the quality and aesthetic requirements of the brewing industry.
The ability to handle 1-1.5 mm thin stainless steel sheet for pressing, bending and welding into barrels that are to be pressure tested to 35 Bar, as well as checked for radial consistency, weld quality, penetration and smoothness and for discoloration is an essential requirement. And those same qualities need to be replicable day in, day out and for month after month.

Figure 1. Finished beer barrel during pressure testing at 35 Bar. The top ring with hand grips and the drum (dotted area) are fully visible. The base ring is partially covered by the clamp from the testing equipment. The central circumferential joint is TIG-welded without consumables. The top and base rings are MIG-welded to the drum.

Figure 2. Top drum section. The orifice for the outlet valve is punched through within the designated reinforced area.

Figure 3. One step further in the process. The outlet valve and the top ring have been welded onto the top half of the drum using automated MIG welding stations. OK Autrod 308LSi stainless welding wire is fed from the Mini Marathon Pac to the various welding stations and pulse welded under Ar/4% CO_2 shielding gas.

In its basic form, a beer barrel consists of three parts – the beer-containing drum itself, a base ring and a top ring with handgrips (Figure 1).

The drum itself forms the part that will contain the beer. This is produced from two cold pressed components – the top half, which in two welding steps receives the outlet valve and the top ring, and the bottom half to which the base ring is welded (figures 2 and 3). Finally, the two components are brought together using automatic TIG welding.

The welds connecting the base ring and the top ring to the top and bottom halves of the drum are where the 1.0 mm diameter OK Autrod 308LSi welding wire fed from a Mini Marathon Pac plays an important role. These welds hold the middle part between base fillet and overlap welds (figure 4) and are pulse welded at 220A/31.5 V and at a travel speed of 1.9 m/min in the downhand position (5G, PG). A single operator loads and unloads two welding stations performing the same welding procedure. Pre-programmed parameters are not used, as experience has demonstrated that optimal settings will need to be varied according to different material batches. Instead, experienced welding technicians optimize the parameters for each shift. Ar/4%CO_2 shielding gas is selected for the high travel speed as it permits a good weld bead appearance. The resultant discoloration is accepted and then removed as part of the cleaning operation after the barrel is completed.

Simultaneously, the bottom half of the drum is connected to the base ring within other MIG welding stations (see cover photo) along the production line.

Matte stainless welding wire in Marathon Pac – a fine combination.

Process stability is the primary requirement of Schäfer-Sudex along the entire production line. The welding process – five automatic MAG welding stations and one automatic TIG station – form crucial steps in the production chain. If one of the stations stops, for whatever reason, the complete line will soon be halted.

"For exactly this reason, OK Autrod matte stainless steel MIG wire, packed in Marathon Pac bulk drums, has earned a reputation as a dependable combination" says Rudolf Moder. "The wire is very clean and – ever since we

Figure 4. Weld connecting the top ring to the drum of a beer barrel. Welds are brushed before acid cleaning in HF and HNO3 to remove discoloring and graphite particles.

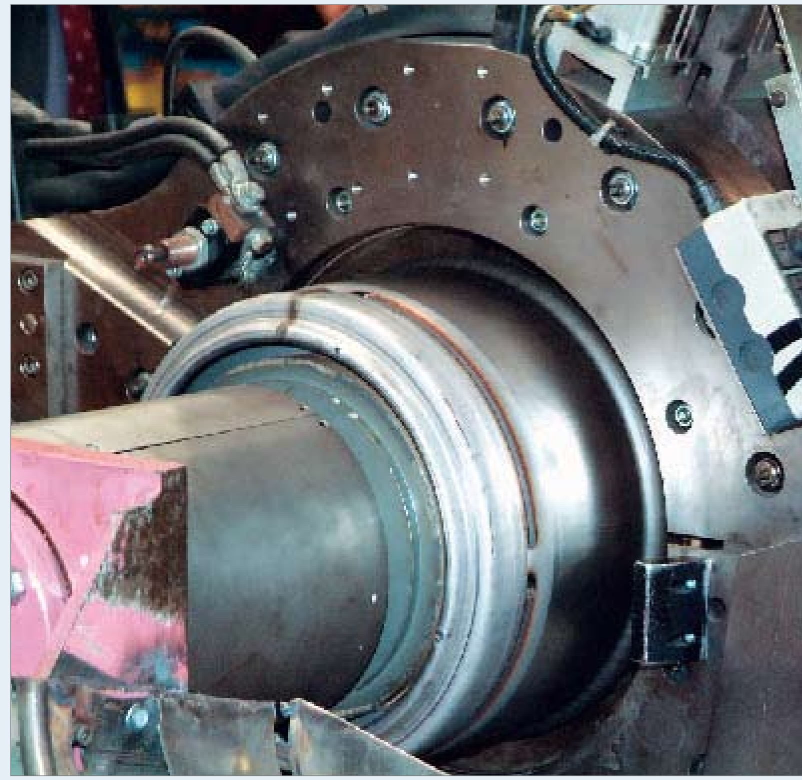

Figure 5. The final step in the production line. Automatic TIG welding of the two barrel halves. Full penetration I-joint welded without filler material. Shielding gas Ar/6% H_2. The weld quality meets the ISO 5817 C standard for the food industry, amongst others. This stipulates a flat, smooth and easy-to-clean weld on the inside, so as to avoid accumulation of beer residues. These essential qualities are provided by the shielding gas.

started using it, two years ago – has never given us the feedability problems we had encountered previously with other wire. Also, we have been able to increase welding speed as a result of feeding regularity and arc stability, whilst experiencing lower contact tip wear and reduced spatter. Now there's no requirement to stop for tip changing outside of normal maintenance intervals and there is no excessive spatter to remove".

Responding to the question of why Schäfer-Sudex has opted for the Mini version of the ESAB Marathon Pac, Rudolf Moder answers surprisingly, "This is more of a mental thing than a rational reason. Previously we were using bulk systems with a greater wire content, but often they gave us feeding problems when they were still only half empty and my production personnel simply lost confidence. Mini Marathon Pac, with 100 kg of wire, is a first step to show them it does actually work prior to us changing to the standard Marathon Pac with 250 kg. Marathon Pac is a great system. It saves a lot of downtime and I want to take the full benefit of that".

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The benefits in a nutshell

OK Autrod matte stainless steel wire
- No slippage due to better grip of feed rolls on matte wire surface
- Lower feeding forces due to improved glide and higher wire stiffness
- Constant cast and helix

Resulting in:
- Stable wire feeding
- Greater arc stability
- Better weld quality
- Higher production output

Mini Marathon Pac
- All the same efficiency advantages and savings of a Marathon Pac, see Svetsaren 1 / 2006
- Lower capital expenditure due to lower filling content

Gas-shielded arc welding of duplex steels

Thomas Ammann, The Linde Group, Division Linde Gas, Germany.

The welding of duplex stainless steels with detailed advice on MIG and TIG shielding gas selection.

1. Introduction

1.1 Fields of application and typical properties

Since their introduction, the use of ferritic-austenitic materials has continued to grow. Applications, primarily in the oil and gas, petrochemical and pharmaceutical industries, are based on the important properties of corrosion resistance and strength. These properties make the materials an interesting alternative to common Cr-Ni steels and Ni-based alloys.

Duplex steels are of two-phase microstructure (hence the name 'duplex'), containing both austenite and ferrite. With such specific microstructure, duplex steels combine, to a certain extent, the advantages of both. On the one hand, there are the ferritic and martensitic chromium-steels that, due to their Cr-contents of 18% and higher, provide relatively high toughness values and very good resistance against stress-corrosion-cracking in chloride-containing agents. Their weldability, however, is limited. Because of high cooling rates appearing at welding, such steels have a strong tendency to hardening and embrittlening through formation of martensitic microstructure. On the other hand there are the austenitic Cr-Ni steels. Generally, they provide good weldabillity, good impact toughness and very good resistance against choride-induced pitting corrosion. Their usable yield strengths and resistance against stress-corrosion-cracking are significantly lower than those of Cr-steels.

The first austenitic-ferritic steels (duplex) had carbon contents, generally, of 0.1 to 0.2% and were, thus, susceptible to intercrystalline corrosion (IC). Therefore, austenitic-ferritic steels with reduced carbon content and additions of nitrogen were developed. Such materials combine good resistance against IC and pitting corrosion, good weldabilty, fair mechanical and technological properties and better workability. The chromium content in duplex steels is in the range 20 to 26%, while the nickel content is in the range 3 to 8%. Almost all grades of duplex steels also contain between 1.5 and 5.5% molybdenum. Such alloying further improves resistance against pitting corrosion. An overview of currently used duplex steel grades is given in Table 1.

Duplex steels can be classified according to the Cr-content, their being two main groups - steels with 22% Cr and steels with 25% Cr. Further classification is the Pitting Resistance Equivalent (PRE), see Table 1. PRE is calculated using an empiric formula in which the favourable effect of

Table 1. Common duplex steel grades.

			Typical chemical composition in %						
EN number	ASTM / UNS	EN short name	C	Cr	Ni	Mo	N	other	PRE
1.4162	S32101	N/A	0.03	21.5	1.5	0.3	0.22	Mn: 5.0	26
1.4362	S32304	X2 CrNiN 23–4	0.02	23.0	4.8	0.3	0.10	Cu: 0.35	26
1.4410	S32750	X2 CrNiMoN 25–7–4	0.02	25.0	7.0	4.0	0.27		42
1.4462	S32205	X2 CrNiMoN 22–5–3	0.02	22.0	5.7	3.1	0.17		35
1.4501	S32760	X2 CrNiMoCuWN 25-7-4	0.02	25.0	7.0	3.8	0.27	Cu: 0.75 W: 0.75	42

particular alloying elements on the pitting corrosion resistance is taken into consideration. There are different formulae but the one commonly used to classify duplex steels is:

PRE = % Cr + 3.3 x %Mo + 16 x %N

Austenitic-ferritic steels, characterised by PRE < 40, are classified as duplex steels, whilst those steels with a PRE value greater than 40, are designated as super-duplex grades. Figure 1 shows the simplified correlation between the pitting corrosion resis-tance (critical pitting temperature, CPT) of different grades of austenitic and ferritic-austentic steels and a PRE formula with the factor 30 x %N.

In the meantime, a further class of duplex steel grades became available – lean duplex steels. They have a slightly lower content of chromium, whilst nickel content has been considerably decreased and partially replaced by manganese. This type of duplex steel provides better corrosion resistance and mechanical properties than a standard 1.4301/304 - type stainless steel and its cost is significantly lower than a standard duplex steel due to its lower nickel content.

Ideally, the microstucture of a duplex steel consists of approximately 50% austenite and 50% ferrite, Figure 2. Such conditions can be obtained after annealing at temperatures of 1020°C and 1100°C for about 5 minutes and subsequent quenching in water. In the Schaeffler diagram, duplex steels are located in the middle of the "austenite + delta ferrite" area. In Figure 3, the Schaeffler diagram indicates the position of a duplex steel grade 1.4462 (AISI 2205). For the calculation of the corresponding Ni_{equ} value, the nitrogen content has also been taken into account (30 x $\%N_2$) /3/.

Initially, any duplex steel solidifies, from the liquid state, into delta ferrite, which is then partially transformed into austenite on further cooling. In the state of equilibrium, the transformation temperature is approximately at 1250°C. The amount of austenite that will be present in the microstructure at ambient temperature depends on the content of alloying elements and cooling conditions, ie, the cooling rate.

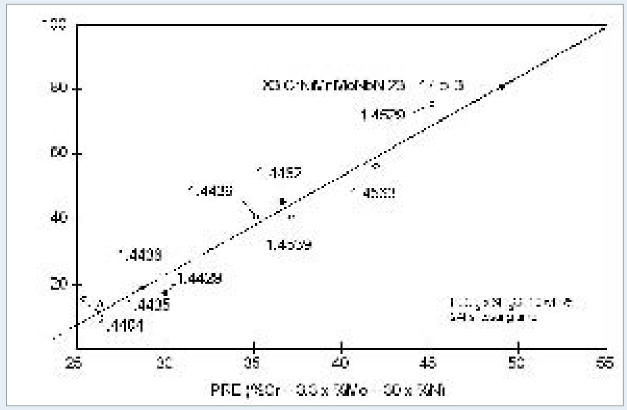

Figure 1. Comparison of CPTs of different materials in dependence of the PRE [acc. to GRÄFEN/KURON]

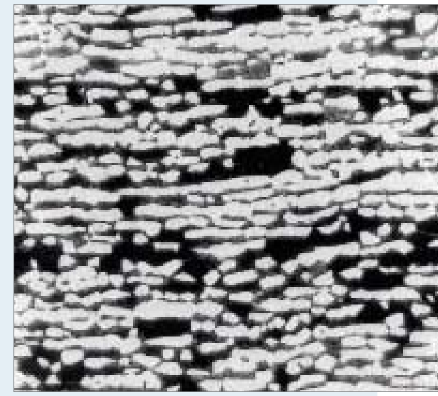

Figure 2. Microstructure of a duplex steel (1.4462), as delivered. Etching Beraha II.
Austenite grains appear white, ferrite grains appear dark. Magnification 750:1

Clearly, maintaining a well-balanced ferrite/ austenite ratio in the weld metal is very important for the properties of a duplex steel weldment. There are, however, different methods of deter-mining the ferrite content in a material. Originally, parent metals and weldments were often specified to have a certain percentage of ferrite. The ferrite percentage is usually determined using metallographic methods, which means that a cross-section of the weld or the parent material is prepared and then examined. Examination of the prepared sample is by manual or computerised planimetry, the result being a direct ferrite percentage.
Using metallographic methods inevitably means destroying the workpiece which, in many cases, is undesirable. Non-destructive methods of determining the ferrite content are usually based on the ferromagnetic properties of ferrite. Early techniques measured the amount of force to remove a permanent magnet probe. Since the correlation between the amount of ferrite and the magnetic force is not exactly linear, the amount of ferrite was indicated in FN (ferrite number). For duplex steels, rough conversion from FN to volume percentage is 70%. For example, 100FN is approximately 70% ferrite /4/. Also, in most of the diagrams used for ferrite prediction - such as the DeLong- or WRC1992-diagram - ferrite content is indicated in FN. Further information on ferrite measurement and FN can be found in ISO 8249 /5/. Today, most ferrite measuring devices make use of electric fields rather than

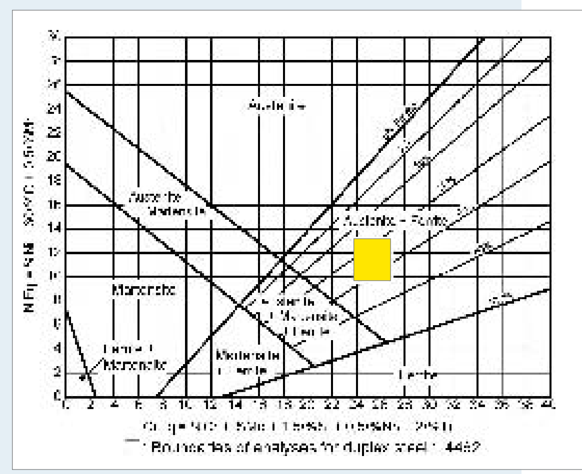

Figure 3. SCHAEFFLER diagram. Indicated is the range of chemical composition of a 1.4462 duplex steel. The nitrogen content was taken into account by adding the factor 30 x $\%N_2$ when calculating the Ni_{eq}.

magnetic forces. All the user has to do is to touch the workpiece with a small probe, shaped like a ball-pen, and the device shows the ferrite content directly in FN or percentage. It is important to stress that these devices need to be adjusted and calibrated on a regular basis.

Table 2. Commonly used filler metals for duplex steels.

Material number	EN-Designation	chemical composition in % C	Cr	Ni	Mo	N	Mn	Other	PRE
~1.4462	G/W 22 9 3 N L	<0.025	23.0	9.0	3.0	0.14	1.6		35
~1.4410	G/W 25 9 4 N L	<0.020	25.0	10.0	4.0	0.25	0.4		42
~1.4501	G/W 25 9 4 N L*	<0.020	25.5	9.5	3.7	0.22	1.5	Cu: 0.8 / W: 0.6	41

*Zeron 100 type

1.2 *Filler materials*

As a rule, filler materials used for welding duplex steels are of same type as the base material. The filler material is usually 2-4% higher in Ni-content than the base material. This provides a well-balanced austenite – ferrite ratio in the weld metal through the austenite-supporting effect of nickel.
A matching filler material composition would shift this ratio excessively towards a higher ferrite content, due to the high cooling rates encountered in welding. Table 2 gives a brief overview of common duplex filler metals and their composition.

Occasionally, particularly for welding the root pass on 22%Cr steels, filler materials with a higher Cr-content are used with the intention of improving the pitting corrosion resistance /1/. It must however be remembered that these filler materials, just like the respective base materials, are more prone to produce intermetallic phases. Thus, impact toughness may be impaired. Welding parameters must, therefore, be carefully selected and closely controlled.
Filler materials for TIG and MIG welding are essentially the same. In TIG welding, under certain conditions it is feasible to make a joint without applying a filler material, provided that special shielding gases are used. Thus, an acceptable austenite-ferrite ratio in the weld deposit can be maintained, see section 4.
The lean duplex steels such as 1.4162/S32101 are either welded using a filler metal containing 23%Cr and 7% Ni or standard 22%Cr filler metals. The parent metal or welding consumable manufacturer should be consulted for further details on welding these steel grades.

Table 3. Recommended combinations of base metal and filler metal.

		Filler material ~1.4462	~1.4410	~1.4501
Base materials	1.4362	+	+	
	1.4410		+	+
	1.4462	+	+	
	1.4501		+	+

2. Welding procedures and techniques

2.1 *General recommendations*

Due to their chemical composition, duplex steels are susceptible to formation of precipitations if they are exposed to too high temperatures for too long a time. Here it is important to mention the 475°C-embrittlement and the formation of sigma- and chi-phases. The risk of such phenomena increases with higher Cr-contents. Therefore, service temperature for duplex steels is limited to 250°C and for super-duplex steel to 220 °C /3/.
The heat input that is encountered during welding may impair corrosion resistance and mechanical properties, particularly when specified interpass temperatures are too high or, if due to the particular shape of the workpiece, heat can not be carried off efficiently. So as a general requirement, the heat input during welding should not be too high. Opposing requirements, ie, higher temperatures and lower cooling rates, would be necessary for best transformation properties of these materials. Since the solidification is primarily ferritic, and transformation into austenite happens in the solid state, too high a cooling rate may partially suppress formation of austenite - leading to unwanted and increased content of ferrite in the weld metal.
The upper limit for the heat input is thus defined by intermetallic phases formation, while the lower limit is set by the requirement to provide an acceptable austenite-ferrite ratio. In the references, different values for the linear energy, a measure for the total heat input per length of weld, may be found. EN 1011-3 recommends a linear energy range of 0.5 to 2.5 kJ/mm for 22%Cr grades and a range of 0.2 to 1.5 kJ/mm for 25%Cr superduplex grades. Due to the fact that there is a wide range of possible parameters, there is no general recommendation in terms of most appropriate values. For each particular job, appropriate parameters should be chosen and tested.

2.2 *Cooling rate, $t_{12/8}$ -concept*

Besides consideration of linear energy input, there is also the concept of $t_{12/8}$ -time for describing cooling conditions. The $t_{12/8}$ -time denotes a time required for cooling down the welding point from 1200°C to 800°C. This method of determining the cooling conditions is generally rather complicated, since it is achieved by introducing thermo-couples into the welding pool. An acceptable value of about 10s is given for the $t_{12/8}$ -time range /2/. If the value is in this range, acceptable properties of material would be achieved.

2.3 *Preheating and interpass temperatures*

Preheating of base material is not generally required. With significant ferrite-austenite transformation occuring between 1200°C and 800°C, preheating temperature of 200°C, maximum, can not essentially decrease the cooling rate. On the contrary, the cooling time between 800°C and 500°C will be increased and, in this range, major precipitation processes occur. For this reason, preheating is likely to have a negative effect, particularly for superduplex grades /1/.

For thicker sections, of 10mm and above, preheating to 100°C can ease the welding process, reduce residual stresses and slow down the cooling rate, especially in the root pass. Typical recommendations for interpass temperatures are maximum 200-250°C for duplex and lean duplex grades whereas maximum 150°C (or lower) should be used when welding superduplex steels.

CRONIGON® 2 (Ar + 2.5% CO_2) CRONIGON® S3 (Ar + 3% O_2) CRONIGON® 2He20 (Ar + 2% CO^2 + 20% He)

Figure 4. Influences of shielding gases on weld surface and penetration profile on stainless steel. Results on duplex are comparable. Mechanised MAG welding, wire feed speed 9 m/min, plate thickness 10 mm.

3. Shielding gases for MIG welding

Generally, the same shielding gases are used for welding duplex steel as for austenitic steels, see Table 4. MIG welding under pure argon shielding is now rarely used, since the arc is unsteady and the penetration is poor. Active gas mixtures consisting of argon and additions of oxygen or carbon dioxide are generally applied. In comparison to the gases used for welding of unalloyed steel, the content of active gases is lower. Argon-oxygen gas mixtures (most common percentage of oxygen is between 1 and 3%) produce very stable electric arc and spatter-free processes. In comparison to the Ar/CO_2 mixtures, the penetration profile is less favourable and the weld surface is more oxidised. The penetration depth might be increased by applying higher oxygen content, but then oxidation of the joint surface is even stronger. Also, losses in toughness and ductility have been reported. Because of this, Ar/CO_2 gas mixtures with a CO_2 content of 2-3% are widely used. These gases provide better penetration with lower oxidisation, Figure 4.

Further improvement can be achieved by adding helium to the gas mixture. Compared to argon, helium has higher thermal conductivity and higher ionisation potential. This leads to better wetting capabilities and higher travel speeds. Another effect that can be observed with the helium-bearing shielding gases is that they seem to cause a more even distribution of oxides on the weld surface, Figure 4. Whereas, in the first two samples, the oxides appear to form 'islands' on the weld surface, the surface of the third sample appears less heavily oxidised, which helps cleaning the weld afterwards.

4. Shielding gases for TIG welding

Compared to the MAG process, heat input in TIG welding is controllable in a wider range. However, the rules regarding linear energy input and cooling rate are also valid here.

The standard shielding gas for TIG welding of duplex steels is pure argon. With this gas, the majority of welding jobs are performed safely and cost-effectively. Argon/hydrogen mixtures that are frequently used for welding of austentic steels, with the intention of increasing welding speed, are not recommended because, under certain circumstances, hydrogen-induced cracking may appear due to the high ferrite content in the material. Argon/helium mixtures offer increased heat input - particularly advantageous for the duplex steels - which has a favourable effect on the viscosity of the base material and provides a wider range of acceptable welding parameters. Arc voltage and linear energy input is also increased with increased helium content. An overview of shielding gases used for TIG welding of duplex steels is given in Table 5. Duplex steels are TIG welded applying filler material in most cases. Duplex filler material usually contains a slightly higher percentage of Ni than the base material. In contrast to the MAG process, in certain cases use of filler material may be avoided, for example in orbital welding of tubes. The advantage in such cases is that welding speed may be increased if filler material is not applied. This leads to shorter welding time, resulting in cost reduction. This welding technique is possible through the use of nitrogen-containing shielding gases. While in non-autogenous welding, the increased content of nickel in the filler material provides a balanced ferrite/austenite ratio, in autogenous welding this task is taken by the nitrogen in the shielding gas. Nitrogen is a strong austenite-promoting element and, as a shielding gas component, can help achieve well-balanced austenite-ferrite-ratios. In any case, it should be noted that tungsten tip wear is more intensive because of nitrogen content, ie, the electrode needs to be re-ground more frequently than if welding in pure argon shield.

Table 4. Shielding gases for MAG welding of duplex steels.

Name	EN439	AWS A5.32	Composition in vol. %			
			Ar	He	O_2	CO_2
CRONIGON® 2	M12	SG-AC-2.5	Bal.	-	-	2.5
CRONIGON® 2 He 20	M12 (1)	SG-AHeC-20/2				
	Bal.	20	-	2		
CRONIGON® 2 He 50	M12 (2)	SG-AHeC-50/2	Bal.	50	-	2

5. Examples of application

As an example, N-containing shielding gases have already been used in orbital TIG welding of tubes made from a 22%Cr grade 1.4462 duplex steel, Figure 5. The wall thickness of the tube was 2 mm, outer diameter was 54 mm. Welding without filler material has been applied. Measuring of the ferrite content in the weld metal was not made through metallographic examination, but with a magneto-inductive method. The values of mean ferrite content should only be taken as trend indicators.

Table 5. Shielding gases for TIG welding of duplex steels.

Name	EN439	Composition in Vol. %		
		Ar	He	N_2
Argon	I 1	100	-	-
VARIGON® He 30/50/70	I 3	Bal.	30 / 50 / 70	-
VARIGON® N2	S Ar + 2 N2	Bal.	-	2
VARIGON® N3	S Ar + 3 N2	Bal.	-	3
VARIGON® N2He20	S I 3 + 2 N2	Bal.	20	2

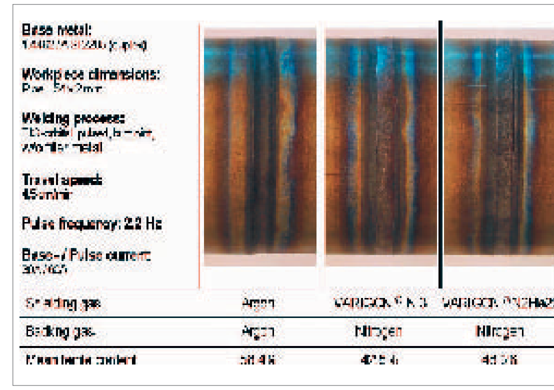

Figure 5. Application example - TIG-orbital welding with N_2-containing gases, without filler metal

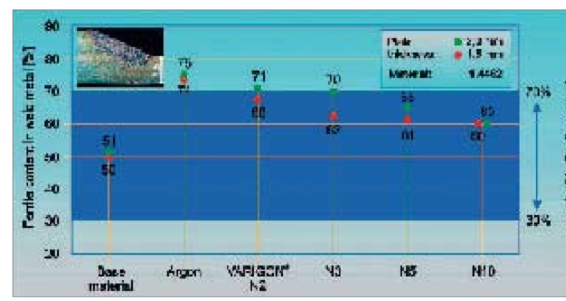

Figure 6. Application example - overlap weld with N_2-containing gases, without filler metal

It is clear how nitrogen strongly reduces ferrite content in the weld metal, in comparison to pure argon, and that the addition of helium (VARIGON®N2He20) stabilises the welding process and improves fusion.

The second example includes welding of an overlap joint without filler material, again on 1.4462 duplex steel. In this particular case, welding was performed applying a shielding gas containing 10% of N_2 (balance was Ar). The effect of the nitrogen may be easily recognised, as presented in Figure 6. The contractors' requirements for this application were that ferrite content in weld metal must not exceed 70%, and this target could be achieved through use of VARIGON® N shielding gas. Cost analysis indicated that the achieved welding speed increase, from 7 cm/min to 13 cm/min, provided significant cost savings. Additionally, a content of nitrogen in the shielding gas can improve the corrosion resistance according to the CPT-test.

6. Shielding gases for root protection

To retain the corrosion resistance of duplex steel, proper root shielding must always be applied. By applying appropriate shielding gas for the root side, air is removed from the root and formation of corrosion inducing layer of tarnish is effectively reduced or suppressed. Generally, the same gases may be used for root shielding as for the austenitic grade steels. However, in this case too, hydrogen content in the root shielding gas must be limited because of higher content of ferrite in the base material - to exclude the danger of hydrogen induced cracking. Therefore, argon and nitrogen, or their mixtures, might be used. For further elimination of tarnish and improvement of corrosion resistance, residual oxygen must not exceed a concentration of 30 ppm at the root side. There is a general rule that pitting corrosion resistance increases with lower residual oxygen on the root side /1/. Appropriate devices for measurement of residual oxygen are available.

7. Conclusion

Two-phase micro-structure, consisting of ferrite and austenite, gives duplex steels excellent mechanical and technological properties and corrosion resistance. Particular attention should be paid to heat input, selection of filler material and shielding gas in order to retain these important properties in gas shielded arc welding processes. The most important requirement is to provide a balanced ferrite-austenite ratio in both weld metal and heat affected zone. The linear energy input and interpass temperature must be limited. Generally, filler materials of identical or similar composition - but overalloyed in Ni - should be selected. Ar-CO_2 or Ar-He-CO_2 gas mixtures are applied for GMA welding while, for TIG welding, Ar, Ar-He or Ar-He-N_2 mixtures may be used.

In certain TIG welding applications, the use of filler material may be omitted, resulting in cost reductions. In such cases, shielding gases should contain nitrogen.

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About the author:

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Product News

A NEW ERA IN ESAB´S MECHANISED TIG PRODUCT RANGE

ESAB is launching three new products to increase productivity and reduce costs in orbital welding. First, the Aristo™ MechTig C2002i is a compact, robust, user-friendly power source that features an integral water cooler and high-specification controller with graphical interface, program library and auto-generation of welding programs.

Second, the Aristo™ MechControl 2 control unit has the same control features as the Aristo™ MechTig C2002i but without the power source and cooler. Third, the Aristo™ MechControl 4 is similar to the Aristo™ MechControl 2, with additional arc voltage control (AVC) and weaving control. When used with suitable welding heads, all three are highly efficient at producing top-quality tube welds in the food, beverage, dairy, chemical, pharmaceutical/biochemistry, semiconductor, aerospace, shipbuilding and general engineering industries.

Mechanised TIG welding is an efficient way to increase productivity, improve quality and reduce costs when welding tubes. ESAB's new modular Aristo™ MechTig C2002i power source is highly adaptable, enabling systems to be configured to precisely match customers' requirements. The machine delivers 180 Amps at a 35% duty cycle, or 110 Amps at a 100% duty cycle. Both the rotation motor and the wire feed motor are controlled by the control unit, which ensures that the welding parameters remain close to the ideal. Getting the most out of the power source is simple by virtue of the 10inch colour display; a Windows-like user interface enables operatives to call up a program from the built-in library or generate a program automatically by entering data such as the material, outer diameter and tube thickness. Programs generated this way can be added to the library. Alternatively, all welding parameters can be set manually via a graphical or spreadsheet interface.Navigation in the system and changing of parameters is very easily handled by a single knob.

Another feature of the Aristo™ MechTig C2002i is the integral printer that can output a hard copy of the programmed welding parameters and the measured values for speed, current, voltage, wire and power. Time and date stamps, plus the power source ID, run number and total weld time, aid compliance with traceability requirements.

A USB (universal serial bus) connection enables users to transfer welding programs between machines, store backups and update the welding programs.

If the customer needs higher current then we can offer the power source Aristo™ Tig 4000i together with the control unit Aristo™ MechControl 2. The user interface is the same as for the Aristo™ MechTig C2002i power source.

For applications requiring arc voltage control and/or weaving, the Aristo™ MechControl 4 control unit provides the necessary additional functionality when used together with a suitable power source. ESAB offers numerous welding heads that are compatible with the three new machines, enabling complete orbital welding systems to be assembled to match the requirements of particular applications.

Aristo™ MechTig C2002i single knob

Aristo™ MechTig 4000i with Aristo™ MechControl 4

In addition, further options include the Weldoc WMS 4000 Welding Monitoring Documentation System for compliance with the ISO 9000/SS-EN 729 international welding quality standard.

WELDING WIRE FEEDERS OFFER RUGGED CONSTRUCTION AND PRECISION CONTROL

ESAB have introduced the Aristo™ Feed 3004 and Aristo™ Feed 4804 welding wire feeders to deliver high performance in conjunction with suitable Aristo™ MIG power source. Both machines feature a four-wheel feeder mechanism with grooves in the feed and pressure rollers and electronic control to maximise feeding stability and minimise wire wear. As a result, the units give a very smooth, controlled feed that helps to optimise weld quality.

The Aristo™ Feed 3004 has 30mm diameter rollers and can handle wire diameters up to 1.6mm; the Aristo™ Feed 4804 has 48mm rollers for wires up to 2.4mm. To prevent overheating of water-cooled torches, the feeders incorporate ESAB's LogicPump (ELP) that automatically starts the water pump during welding. Both machines can be equipped with any of the Aristo™ MA4, Aristo™ MA6, Aristo™ U6 or Aristo™ U8 man-machine communication (MMC) panels. These are easy to operate, with accurate settings to suit the welding requirements. ESAB's TrueArcVoltage system ensures that the correct arc voltage is maintained regardless of the length of the cables used.

All four MMC panels feature 2/4 stroke, crater filling, adjustable burn-back time, creep start, gas pre/post flow and digital V/A meters. In addition, all but the Aristo™ MA4 panel benefit from hot start, gas purge/wire inching, pre-programmed synergic lines (>100 for the Aristo™ U8), a memory for ten sets of welding parameters (200 for the Aristo™ U8), and pulse/synergic pulse. The Aristo™ U8 can also be used to create new synergic lines.

To help keep the cost-of-ownership low, ESAB has designed the feeders to be very easy to

maintain. For example, a single pressure device adjusts the feeding pressure, and all wear parts on the Aristo™ Feed 3004 can be replaced without tools.

A wide range of accessories is offered for the Aristo™ Feed machines, including a lifting eye, counterbalance, wheel kit, cable strain reliefs, spool covers and remote control units.

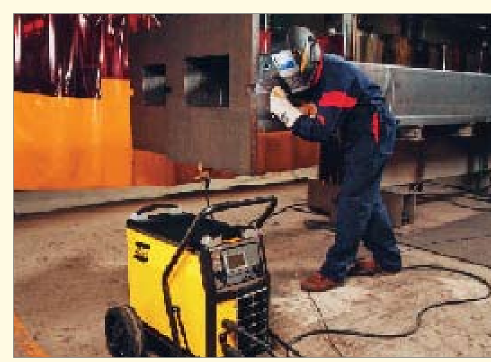
WELDING POWER SOURCES OFFER OUTSTANDING PERFORMANCE

ESAB can offer the Aristo™ Arc 4000i/5000i and Origo™ Arc 4000i/5000i welding power sources for applications indoors or outdoors where rugged construction and high performance are required. Suitable for production, maintenance and repair tasks, the machines use inverter IGBT technology and CAN-bus control communications to deliver high reliability and consistently superior welding characteristics. While the 4000i models have a 16-400A welding range, the 5000i models have a range of 16-500A.

The power sources can be used for MMA (manual metal arc) welding on most metals, including alloyed and non-alloyed steel, stainless steel and cast iron. Electrodes up to 7mm in diameter can be used with the Aristo™ Arc 5000i and Origo™ Arc 5000i, and gouging electrodes up to 10mm diameter can be used with the Aristo™ Arc 5000i.

Depending on the application requirements, customers can select either the Origo™ A2 MMC (man-machine control) or the Aristo™ A4 MMC. While the Origo™ A2 has a simple two-knob layout for setting and adjusting welding current and arc force, the more sophisticated Aristo™ A4 has a single knob for current control, plus soft keys for selecting the electrode type (rutile, basic or cellulose) and making adjustments to the Hot Start and Arc Force. The MMC panel A4 has a digital A/V display.

Users that may need to operate from more than one electricity supply can opt for the Multi-Voltage Unit that can be supplied as an integral unit with the power source or separately with its own carrying handles. This Multi-Voltage Unit gives



users the opportunity to work from six different three-phase supply voltages.

Other accessories for the Aristo™ Arc 4000i/5000i and Origo™ Arc 4000i/5000i machines include a trolley, remote controls, cables and a voltage peak reduction unit.

The Aristo™ Arc 4000i/5000i and Origo™ Arc 4000i/5000i welding power sources replace, respectively, the Aristo Arc 400/500 A4 and Aristo Arc 400/500 A2 machines.

MIG WELDING MACHINE IS ROBUST AND VERSATILE

ESAB can offer the Origo™ Mig 320 step-switched power source for MIG/MAG welding. This robustly constructed machine is both powerful and versatile, delivering 320A at a 30 per cent duty cycle and capable of being used with interconnection cables up to 35m long. Different mounting options enable the Origo™ Feed 302 wire feeder to be mounted on the power source or separately, depending on the application requirements.

A combination of proven technologies, a rugged galvanised casing and special software deliver high reliability, even in tough industrial environments. To make the machine easy to move, ESAB has equipped it with large wheels and an undercarriage that is designed for lifting with a fork lift truck.

ESAB's Origo™ Mig 320 can be used with a choice of three-phase electricity supplies.

The setting range is from 40A/16V to 320A/30V, enabling the power source to deliver outstanding welding characteristics with a variety of filler materials and shielding gases. All types of cored wires can be used with the Origo™ Mig 320.

An optional digital meter provides an easy-to-read and accurate display of the welding parameters, which remains on the screen even after welding has finished. Other accessories for the Origo™ Mig 320 include an air filter, cable holder, transformer for a CO_2 heater, a stabiliser and interconnection cables ranging in length from 1.7 to 35m.

ESAB LAUNCHES CLASS-LEADING TIG TORCHES

ESAB is launching the TXH range of TIG torches for welders who want the best quality torch with features that truly meet the needs of their applications. Designed with the operator in mind, the torches are easy and comfortable to use.

The compact TXH TIG torches are particularly suitable for applications where access is difficult, yet ergonomics and performance remain uncompromised. In addition, their rugged construction ensures that the torches give trouble-free operation with minimal maintenance.

Five models of TXH torch are available with 60 per cent duty cycles ranging from 120A to 400A, the smaller models being air-cooled and the larger ones having water cooling. Customers can specify whether or not the torch has an integral gas valve and a flexible neck, plus there is a range of around 40 different tungsten electrodes. Whatever combination of options is selected, all TXH TIG torches are fully compatible with ESAB's TIG welding machines that are equipped with an OKC connection.

NEW ESAB ORIGO™ TIG 3000I FAMILY MEETS MOST TIG WELDING NEEDS

ESAB is launching three new TIG welding machines, the Origo TIG 3000i models TA23, TA24 and TA24AC/DC. All three have different characteristics and features, making them suitable for a wide range of applications. But, as a family, they offer something for everyone, whether the need is for a powerful but compact unit for industrial use, repair and maintenance, or machines that are considerably more advanced than most for demanding applications in virtually all weldable metals.

For industrial, repair and maintenance tasks, the Origo TIG 3000i TA23 is sturdy and robust, yet it is also compact and easy to move to wherever it is needed. Both stainless and mild steel can be TIG welded, in plate thicknesses of 1.0mm or more. The machine is simple to set via the control panel that has all of the basic Tig welding parameters; settings for post-gas and slope-down help to avoid cracking and oxidation. MMA welding can also be performed using the Origo TIG 3000i TA23 with electrodes up to 5.0mm in diameter.

Slightly larger than the TA23 model, the Origo TIG 3000i TA24 is designed for high-quality industrial, structural, repair and maintenance operations where there is a need for a safe start and a stable arc. High-quality welds can be produced with all types of stainless and mild steel, plus most other weldable metals, with plate thicknesses of 0.5mm and above. As with the smaller model, the TA24 can also be used for MMA welding with electrodes up to 5.0mm in diameter. To help users increase their productivity, the Origo TIG 3000i TA24 features a two-program function so that two different sets of welding parameters can be stored, and the operator can switch between them during welding. A further benefit of this machine is that it includes DC pulsed TIG welding to give improved control of heat input and the weld pool.

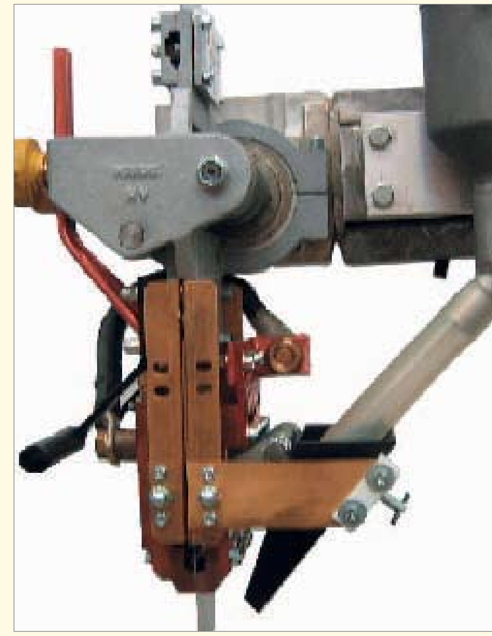
Where high-quality TIG welding in both AC and DC modes is required, ESAB is offering the Origo TIG 300i AC/DC TA24AC/DC model. Virtually all types and thicknesses of metal can be welded with this machine, which delivers excellent start and arc characteristics. It can also be used as an MMA power source, with Hot start, Arc force and polarity switching. In order to deliver enhanced arc control and low noise when TIG welding, the machine incorporates QWave™ technology. Like the TA24 model, this machine benefits from DC pulsed TIG welding and a two-program function. Despite its exceptional capability, the Origo TIG 3000i AC/DC TA24AC/DC remains easy to use thanks to the intuitive control panel.

Options available for the three new welding machines include a water cooling unit, two- or four-wheel trolleys, and remote controls. Customers also have a choice of TIG torches.

NEW STRIP WELDING HEAD FOR 60 – 90MM STRIPS

Right from the start of the project, the demands for this electro slag strip cladding welding head were tough. Jointly developed by ESAB and TECH Products Sweden AB, the main challenges were to keep the temperature of the welding head low and to have a design that delivers a disturbance-free process. The electro slag process is similar to the SAW process but demands slightly more technically advanced equipment.

- The welding head is equipped with an ESAB VEC-motor.
- The current contact conductors have large flat areas designed to shield the head against spatter sticking to the strip and disturbing the process. The reverse side of the current contact area is covered by a cooling unit that is designed for maximum flow. This is necessary since it is exposed to direct heat radiation. Welding with 2,300A, the temperature of the conductors never exceeds 60°C and this low temperature helps to reduce wear and energy losses.
- The very efficient WP20SC cooling unit, which was developed by TECH Products, is thermostat controlled.
- The flux supply unit is designed to enable the operator to easily control the amount of flux and the flux height.
- At high speed welding with ESAB OK Flux 10.14, a higher flux flow is necessary as well as precise control of the flux height.
- Electromagnets can be mounted on each side of the welding head for more precise control of the weld bead width.
- If needed, an extra flux supply unit can be mounted on the opposite side so as to allow the head to be used for SAW process applications as well.
- The ESAB PEH box provides full process control and monitoring of the welding.
- The equipment is designed for LAF power sources.



- When a higher current is required, it is recommended to connect two LAF 1250 power sources or two LAF 1600 sources in parallel.

NEW ESAB WEB SITES GO LIVE

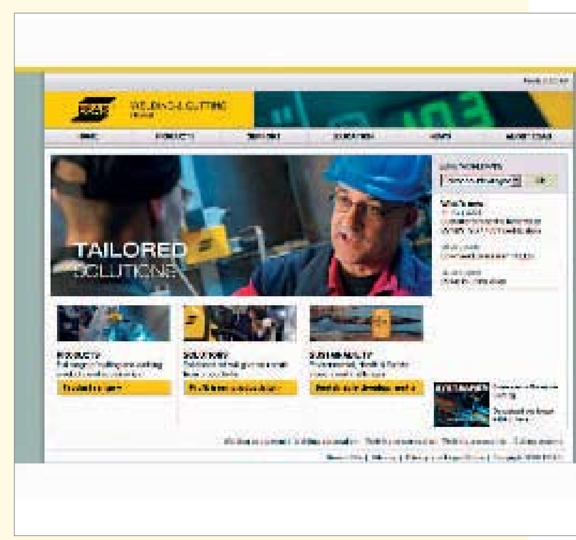
In the last few months ESAB has launched two completely new web sites - a new international corporate site at www.esab.com and a new site for ESAB in North America at www.esabna.com. Both sites display a revised ESAB brand global identity and have been structured to greatly enhance usability and faster access to required information.

ESAB's previous web site design was first introduced in 2001, but since then there have been many new demands for additional online facilities and new information requirements. In addition, as a global manufacturer marketing products across more than ninety countries, ESAB has undertaken a major review of its global brand to improve graphic and image consistency. This new design, with its cleaner structure and more intuitive navigation, is not only easier for visitors to use but also is much easier to roll out across individual subsidiary sites across the world and operating in many different languages.

Web users have also developed new requirements from corporate websites over the last few years. Sites can no longer exist as just an online brochure, today's user regards the corporate website as their first point of reference when investigating organisations, looking for technical details, researching information or looking at product offerings.

ESAB's new corporate site and the ESAB North American site are the first two to be launched under the new design and navigation platform. Over time the modern and progressive look and feel to the pages will be implemented across all other ESAB regional and national sites. Key benefits include:

- Improved navigation structure that enables required information to be found and extracted easily



- Intuitive links and design
- Access to more information and data than previously
- Full multi-language capability. Allows users in countries with several languages to view the ESAB web site in their chosen native language

HEAVY-DUTY MIG WELDING MACHINES ARE ROBUST AND VERSATILE

ESAB can offer the Origo™ Mig 410/510 step-switched power sources for heavy-duty MIG/MAG welding. These robustly constructed machines are both powerful and versatile - the Origo™ Mig 410 delivers 400A/34V at a 50 per cent duty cycle and the Origo™ Mig 510 delivers 500A/39V at a 60 per cent duty cycle. Both may be used with interconnection cables up to 35m long.

Different mounting options enable the Origo™ Feed 304 or Origo™ Feed 484 wire feeders to be mounted on the power sources or separately, depending on the application requirements.
A combination of proven technologies, a rugged galvanised casing and special software deliver high reliability, even in tough industrial environments. To make the machines easy to move, ESAB has equipped them with large wheels, sturdy lifting eyes and an undercarriage that is designed for lifting with a fork lift truck.

The Origo™ Mig 410/510 machines can be used with a choice of three-phase electricity supplies, and the setting range is from 50A/16.5V to 400A/34V for the 410 model and from 50A/16.5V to 500A/39V for the 510 model. Consequently the power sources deliver outstanding welding characteristics with a variety of filler materials and shielding gases. All types of cored wires can be used with the Origo™ Mig 410/510.

For applications where water cooling is required, the ESAB LogicPump automatically starts the integral water pump when a water cooled gun is connected to the wire feeder. This eliminates the risk of the gun overheating, thereby avoiding the need for costly repairs.
An optional digital meter provides an easy-to-read

and accurate display of the welding parameters, which remains on the screen even after welding has finished. If required, the machines can be used in conjunction with ESAB's MiggyTrac and Railtrac kits for simple mechanisation. Other accessories for the Origo™ Mig 410/510 include an air filter, cable holder, transformer for a CO_2 heater, water flow guard, stabiliser, reinforcer kit for counterbalance and interconnection cables ranging in length from 1.7 to 35m.

COMPACT MIG POWER UNITS FROM ESAB

The ESAB Origo™ Mig C280 PRO and Origo™ Mig C340 PRO are sturdy and robust step-controlled power units for medium duty MIG/MAG welding with solid wire of steel, stainless steel or aluminium and cored wires, with or without shielding gas.

The machines are made with a strong galvanised metal casing to withstand harsh environments. The large wheels and built-in wire feeder ensure that the units are practical for mobile situations.

The Origo™ Mig C280 PRO is a 10 voltage step unit. The operator can adjust wire feed speed, burnback time and spot welding time. The Origo™ Mig C340 PRO is a 40 voltage step unit. The operator can adjust wire feed speed and can select 2/4 stroke control and creep start.

Both units can be equipped with V/A digital meter, air filter and transformer for CO_2 heater. They can also operate with air cooled welding torches.

The wide current and voltage range and the two inductance outlets make it easy to optimise settings for a wide variety of filler materials and gases.

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