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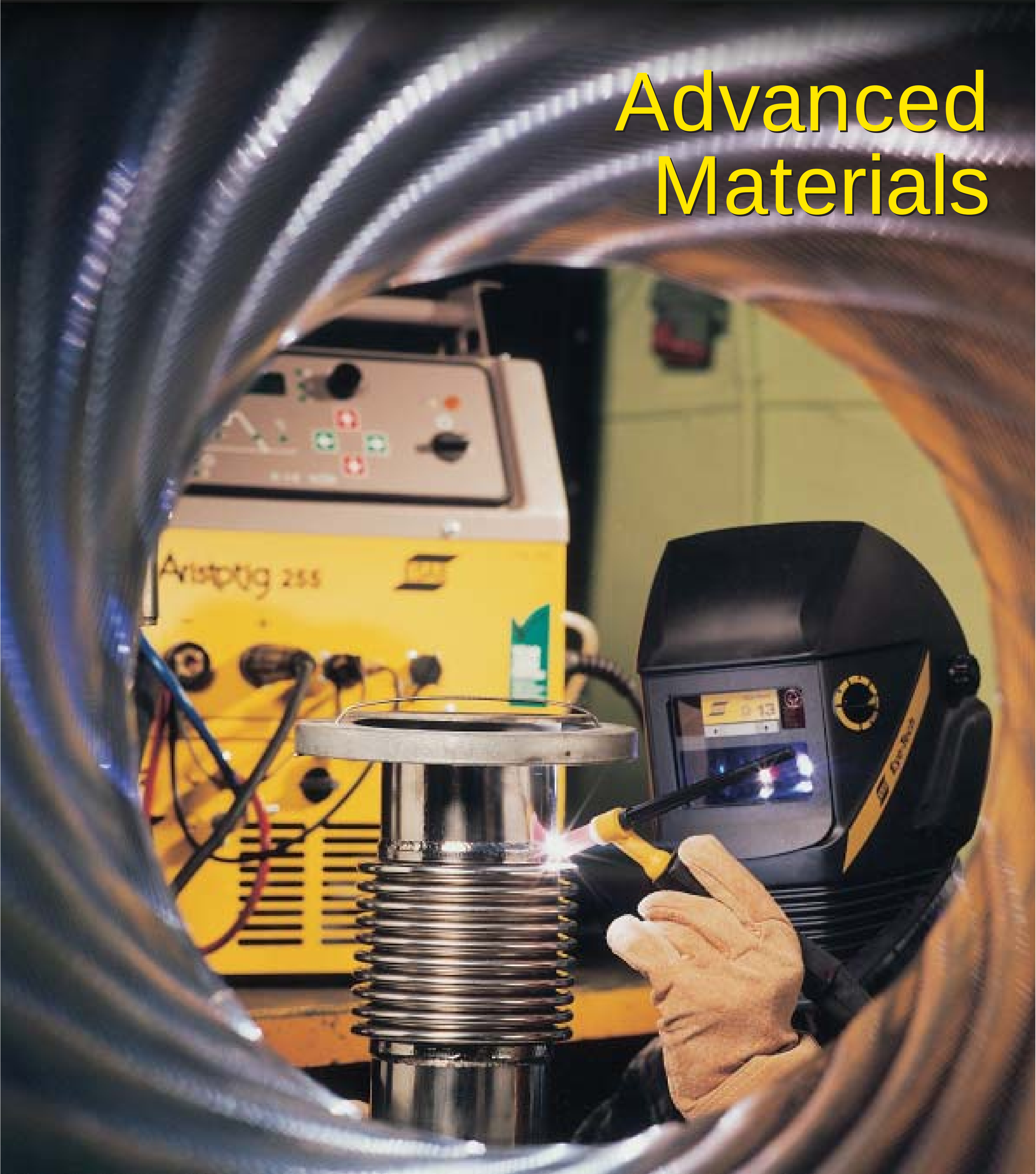
THE ESAB WELDING AND CUTTING JOURNAL VOL. 57 NO.2 2002

Advanced Materials



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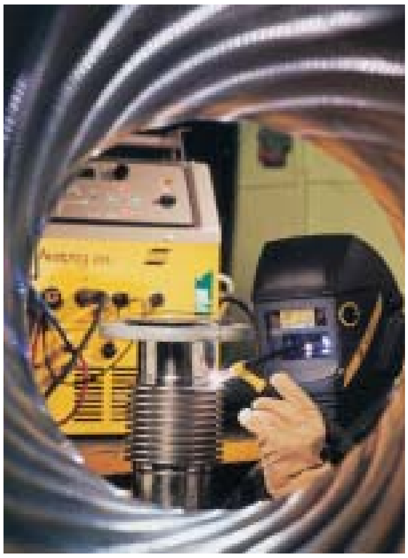

Advanced Materials

Contents Vol. 57 No. 2 2002

High deposition welding of Francis turbine runners for the Three Gorges dam project

By: Nils Thalberg, Solveig Rigdal, Leif Karlsson, John van den Broek and Herbert Kaufmann, ESAB AB

This paper was originally presented at the Stainless Steel World America 2002 Conference.

The world's largest hydroelectric project, the Three Gorges dam in China, will comprise 26 Francis turbines for the production of electricity. Each turbine runner is 10m in diameter, weighs 450 tonnes and will generate 700 MW. The runners are made of solid 410 NiMo type martensitic stainless steel (13% Cr, 4% Ni, 0.5% Mo) castings. Welding is used for the assembly and repair of casting defects. ESAB is involved in the production of the runners with consumables and equipment for SAW and GMAW.

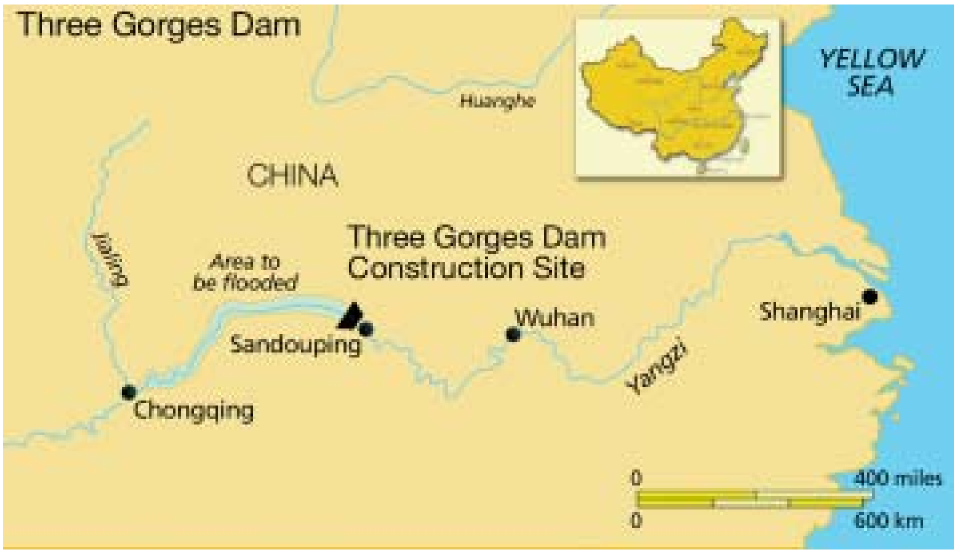

Figure 1. Location of Three Gorges Dam.

Three Gorges – the world's largest hydroelectric project

In 1994, construction work began on the massive Three Gorges dam near Yichang (Fig. 1). This dam is expected to help control the flooding of the Yangtze River valley; in addition, river flows will make the Three Gorges complex the largest electricity generating facility in the world. The negative consequences of the project include the forced relocation of more than one million people and the permanent flooding of many historical sites, not to mention the feared environmental effects.

A lake about 650km long with an average width of 1.1km will form behind the dam, which is 185m high and about 2,309m wide. The water storage capacity of the dam will be 39.3 billion cubic metres handling 451 billion cubic metres of Yangtze River water flowing into the reservoir every year. Dam sponsors say that the 22.1 billion cubic metre flood control storage capacity of the reservoir should reduce the frequency of large downstream floods from once every 10 years to once every 100 years.

The Yangtze River was diverted after four years in

November 1997, thereby completing the first major construction stage. Phase 2 began in 1998 and is due to end in 2003, when the water level will rise to 156m and the dam will start generating electricity. There are plans to open a permanent ship lock for navigation in the same year. The ship lock will consist of five locks, each 280m long and 35m wide, with a water depth of 5m, capable of handling 10,000-tonne barges. In addition, a one-stage vertical ship lift capable of carrying 3,000 tonne passenger or cargo vessel will be built. River shipping through central Yangtze is expected to increase from 10 million to 50 million tonnes annually, with a reduction in transportation costs of 30-37 percent.

Phase 3 is scheduled for completion in 2009, when full power generation will begin. By then, 102.6 million cubic metres of earth and stone will have been excavated and 27.2 million cubic metres of concrete and 354,000 tonnes of steel reinforcing bars will have been used. In the centre of the dam, there will be a 484-metre spillway section with 23 bottom outlets and 22 sluice gates. On the left and right hand sides of the spillway, there will be two giant power stations (Fig. 2).

Figure 2. Overview of the Three Gorges dam project showing ship-locks (right), a spillway in the centre of the dam and power plants on the left and right banks (3).

Table 1. Dimensions and weights of main parts of turbine components.

Size of main turbine components	
Max. Diameter of runner	10 m
Throat diameter of runner	9.8 m
Max. outer diameter of stay ring	16 m
Height of stay ring	4 m
Spiral case outline (X-X)/(Y-Y)	34 m/30 m
Max. outer diameter of head cover	13.3 m
Diameter of wicket gate circle	11.6 m
Height of head cover	1.8 m
Height of guide vane	2.9 m
Diameter of main shaft (body)	4 m
Weight of main turbine components	
Runner	450 t
Stay ring	400 t
Spiral case	700 t
Head cover	380 t
Main shaft	140 t
Single guide vane	9.5 t
Total weight of turbine	3300 t

Power generation

The installed total electricity power-generation capacity of 18,200 megawatts, or as much as 18 large nuclear power stations, will make the Three Gorges number one among the world's largest hydroelectric projects:

Three Gorges, China,	18,200 MW
Itaipu, Brazil and Paraguay,	12,600 MW
Grand Coulee, United States,	10,100 MW
Guri, Venezuela,	10,100 MW
Tucuruii, Brazil,	7,500 MW
Sayano-Shushensk, Russia,	6,400 MW
Krasnoyarsk, Russia,	6,100 MW
Corpus-Posadas, Argentina and Paraguay,	6,000 MW
LaGrande 2, Canada,	5,300 MW
Churchill Falls, Canada,	5,200 MW

The two power stations flanking the central dam spillway will operate 26 of the world's largest turbine generators, each with a generating capacity of 700 MW. The total electric energy of 84.7 billion kWh produced annually is equivalent to burning 40 million tonnes of coal in conventional fossil fuel-heated power stations.

Design and fabrication of turbines

Two international consortia will be responsible for the construction and manufacture of the 14 turbine generator assemblies in the left-bank powerhouse to be installed during Phase 2 of the project. GE Energy in Norway (previously Kvaerner Energy, Norway), as a sub-contractor, is responsible for the hydraulic design of eight turbines contracted by Alsthom. Five of the runners and core components for the turbines will be produced under GE Energy's management, partly in co-operation with Harbin Electric Machinery Company Ltd in China with ESAB as an important supplier of equipment and consumables. The three remaining runners contracted by the first consortium will be produced to the Kvaerner design by GEC-Alstom in France. The second consortium, including Voith in Germany and GE in Canada, will jointly develop the hydraulic design of the other six turbines in the left powerhouse.

The manufacture of runner blades and the fabrication and welding for the entire runner will be carried out in a number of countries including Romania, Brazil, Norway, Canada, France and China. Typical dimensions and weights of the main components of the turbines are given in Table 1.

The 12 turbines in the right powerhouse will be installed during Phase 3. A technology transfer condition in the contracts of the international suppliers of the first 14 turbine-generator pairs requires that they assist Chinese manufacturers in producing the remaining 12 units.

Welding turbine runners

The turbine runners are made of solid 410 NiMo type martensitic stainless steel (13%Cr, 4%Ni, 0.5%Mo) castings. The mere size (table 1) and the complex shape of the turbine runner means that it has to be produced

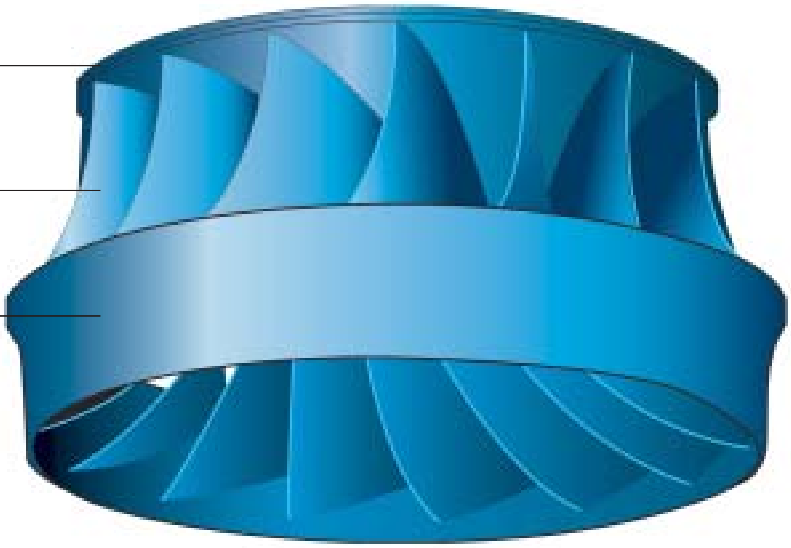

Figure 3. Main components of a Francis turbine runner.

from a number of smaller (yet still impressively sized) castings. Welding is used to join the separate castings and repair the casting defects. A combination of different welding techniques, including manual metal arc welding (MMA), semi-automatic techniques such as gas metal arc welding (GMAW) with solid or cored wires and fully-mechanised welding with submerged arc welding (SAW), is being used. The specific choice of method varies depending on factors such as joint geometry, accessibility and the cost of labour, equipment and consumables. Different combinations of welding techniques and consumables will therefore be used for different turbine runners depending on location and the responsible company.

The three main components of a Francis turbine runner are the runner crown, the vanes and the runner band (fig. 3). In all, approximately 7-10 tonnes of welding consumables will be used for the assembly of each runner. Most of this is needed to join the vanes to the crown and the band. The first sections will focus on the SAW twin-wire solution chosen by GE Energy for joining the vanes to the crown. Pre-production tests and experience of using semi-automatic welding with metal-cored wires will then be discussed.

Figure 4. New compact SAW twin arc welding head.

Figure 5. Welding station with manipulator and welding head positioned for welding turbine runner.

Fully-mechanised SAW of vanes to runner crown

GE Energy in Norway (formerly Kvaerner Energy) secured the contract for building three runners, partly in co-operation with Harbin Electric Machinery Company Ltd, which received the contract for two additional turbines. Welding methods with the highest possible deposition rates were specified to manufacture runners of this considerable size in a cost effective manner. The design criteria set by Kvaerner Energy AS, Norway, were to achieve a deposition rate of no less than 16 kg/hour. After evaluating different possibilities, SAW with two wires (twin-arc) was considered to be the best method based on productivity and weld metal quality criteria, as well as previous experience from other critical applications. However, the full productivity potential needs to be utilised while the welding head precisely follows the approximately 4m long joints with complicated three-dimensional geometry between the turbine runner vanes and the runner crown/runner band (Fig. 3). The limited access for the welding head between the vanes is another complicating factor. A high-accuracy manipulation and control system is therefore necessary to obtain all the benefits from a fully-mechanised welding process and achieve the required productivity.

Welding equipment

ESAB Welding Equipment AB received a contract from Kvaerner Energy A/S, Norway, for the design and supply of two complete, numerically controlled welding manipulators for welding the Francis turbine runners. To fulfil the requirements, a new compact welding head had to be designed (Fig. 4). The mounting permits vertical, horizontal and rotating movements to allow precise adjustments as the welding head moves along the joint.

To make it possible to follow the 4m long joint, the welding head is mounted on a column and boom manipulator, thereby permitting welding within a working volume of 2 x 4.3m horizontally and 2m in height (Fig. 5). The manipulators can be programmed through "teach-in", which means that the welding head is positioned at various points along the weld preparation and all the necessary data is stored in the control-box memory. Individual weld beads can be easily programmed by simply adding a suitable offset, thereby minimising the amount of programming required for a multipass weld.

SAW consumables

Approximately three to four tonnes of SAW filler wire will be used to join the vanes to the crown for each turbine runner. The welding of root runs and, wherever necessary, the supplementary welding of filler beads will mainly be done with GMAW using a metal-cored wire, as described in a later section.

In addition to the equipment and productivity aspects, the mechanical and metallurgical properties of the weld metal and the base material in the as-welded condition, as well as after PWHT, must comply with stringent requirements. The specified classification for the wire is AWS ER 410NiMo, modified as required to fulfil mechanical and weldability requirements. This consumable will deposit a weld metal with a composition similar to that of the 410 NiMo type martensitic stainless steel (13% Cr, 4% Ni , 0.5% Mo) used in the castings.

The requirements that have to be fulfilled by the combination of flux and wire include:

- A diffusible hydrogen of less than 3ml per 100g weld metal.
- A minimum flux basicity index of 2.7.
- Minimum Charpy-V impact toughness of 50 J at 0ºC after PWHT and a minimum of 20J in the as-welded condition.
- Accepted bend tests in the as welded condition and after PWHT.
- Minimum yield strength of 550 MPa and minimum tensile strength of 760 MPa after PWHT.
- Good weldability, including wetting characteristics, slag detachability and weld surface appearance for a maximum welding current of 970A.

After initial tests, the new ESAB wire/flux combination, OK Autrod 16.79 (2x Ø 2.4mm)/OK Flux 10.63 (Table 2), was shown to deposit a weld metal fulfilling all the above requirements.

Weld tests

The final acceptance tests for the welding consumables and welding stations included:

a) welding in 60mm thick material in a symmetrical 45º X-joint and

b) welding on a specimen simulating a 300mm thick vane to be welded to a 200mm thick section of the crown in a symmetrical double J joint.

All the tests were performed on cast material of the quality to be used in production.

A preheat of 100-150ºC and a maximum interpass temperature of 200ºC were used with welding parameters of 970A, typically 31V and welding speeds of 60-70 cm/min. All the tests were performed with two Ø 2.4mm wires in line.

Table 2. Welding consumables used for SAW twin wire welding of vanes to runner crown.

Consumable	Classification	Flux basicity	Typical all-weld metal composition (wt. %)					
			C	Si	Mn	Cr	Ni	Mo
OK Flux 10.63 OK Autrod 16.79	EN 760 SA FB 1 55 AC H5 AWS A 5.9 ER 410 NiMo mod.	3.2 -	0.02	0.4	0.7	12.3	4.3	0.5

Table 3. Mechanical data from acceptance tests.

Weld	Test condition	Cross weld tensile strength (MPa)	Impact toughness at 0ºC (J) Weld metal	Hardness (HV10) Weld metal	Side bend testing (180º, 6xt)
60 mm X-joint	As welded	824-829**	34, 31, 33	369-394	no remarks
	PWHT*	728-739**	86, 88, 87	284-300	no remarks
300 mm double J-joint	PWHT*	838-866**	82, 86, 83	290-305	no remarks

* Post weld heat treatment: 580ºC/ 4 h
** Fracture in base metal

The acceptance criteria included weldability aspects such as wetting characteristics, slag detachability and weld surface appearance, mechanical properties (Table 3) and non-destructive testing using ultrasonic and radiographic examination. The test results were satisfactory and ESAB was awarded a contract for the delivery of two complete welding stations with an option also to purchase consumables.

Production experience

The thickness of the vane varies along the 4m long joint, but it is mainly between 70 and 220mm. With a typical welding current of 700-800A and a welding speed of 70cm/min, some 200-300 weld beads have to be deposited with heat inputs of about 2kJ/mm for each joint. Consistent performance and reliability are therefore just as important as deposition rates during welding. The welding stations were delivered and assembled in Huludao in China towards the end of 2000. Non destructive testing has confirmed the high and consistent quality of the weld metal and welding is proceeding as planned without major complications.

GMAW with metal-cored wires

ESAB has a wide range of consumables for hydro-turbine solutions, not only for SAW but also for GMAW and MMA. In particular, the range of metal-cored wires (MCW) has a long and successful track record.

Productivity and weldability

Productivity from cored wire welding, regardless of the wire type used, is always superior to that of manual welding with manual metal arc stick electrodes, due to the higher duty cycle. In addition, deposition rates are on a much higher level. MCWs have little or no slag forming ingredients in the fill and they also have only a small amount of arc stabilisers. As with solid wires, welds display only small islands of de-oxidation products, making them popular for productive multi-run welding without inter-run de-slagging. This explains their widespread use for mechanised and robotic operations. The metal-cored types for turbine applications are medium filling-rate wires suitable for manual, mechanised and robotic operation, in all welding positions.

The advantages for turbine fabrication and repair can be summarised as follows.

- High duty cycle compared with other manual and semi-automatic welding methods.
- Low spatter operation with well wetted, flat and fully penetrating beads, leading to significantly reduced post weld labour.
- Good all-positional weldability, even in the low-current range.
- Can be welded with conventional or pulsed arc power sources.

Metal-cored wires for hydropower turbine applications

FILARC PZ6166 is a MCW which has been specially developed for welding 410 NiMo type martensitic stainless steel in the hydro power industry. The wire is available with diameters of 1.2 mm and 1.6 mm and is welded with either 98%Ar/2%O_2 or 98%Ar/2%CO_2. The second of these shielding gases produces the smallest amount of silicate on the bead surface. The rolling manufacturing technology guarantees wires with a weld metal hydrogen content in the "extra low" class (HDM <5ml/100gram), the typical value in 98%Ar/2%CO_2 determined at 250A welding current and with a 15mm stick-out length is < 3ml/100 grams. The typical all weld metal chemical composition and mechanical properties are given in Tables 4 and 5.

Fabrication of Francis runners

GE Energy, Norway, was one of the first companies to use metal-cored wires for fabricating Francis turbine runners (Fig. 6). The wires were introduced after successfully completing an extensive test programme, replacing manual welding with stick electrodes by semi-automatic GMAW welding.

The use of special welding guns with long nozzles, which are necessary to obtain access to the joints, did not present any problem in terms of feedability and weldability. Savings on fabrication time are estimated to be around 30%.

The runners for the Three Gorges project produced by the Harbin Electrical Machinery Company Ltd in China are welded partly with metal-cored wires and

Table 5. Metal cored wire used for fabrication and repair welding of turbine components.

Consumable	Classification	Typical all-weld metal composition (wt. %)					
		C	Si	Mn	Cr	Ni	Mo
FILARC PZ6166	AWS 5.22 E410NiMo-T2~	0.02	0.7	1.2	12.5	4.5	0.4

Consumable	Tensile properties			Impact toughness (J)	
	R_m (MPa)	$R_{p0.2}$ (MPa)	A_5 (%)	+20ºC	-20ºC
FILARC PZ6166	>760	>570	>15	50	40

Table 4. Typical all-weld metal mechanical properties for the metal cored wire PZ6166 after post weld heat treatment at 580-600ºC for 8 hours.

partly with the SAW two-wire process with solid wire as described above. FILARC PZ6166 was introduced after a test programme was successfully completed, showing that requirements relating to mechanical properties and hydrogen levels could be fulfilled. However, other important aspects included weldability features, such as good penetration, excellent wetting and low spatter, ensuring a minimum of post weld cleaning, grinding and repair. The consumption for the metal-cored wire is estimated at roughly 7-10 tonnes per runner.

Another Chinese company, the Dongfang Electric Machine Company as a subcontractor in the Voith consortium, has also considered metal-cored wires (in combination with solid wires) as a possible solution for the production of turbine runners. A smaller Francis turbine runner was therefore successfully produced, using the FILARC PZ6166 metal-cored wire, as a pre-fabrication test to evaluate the suitability of this consumable for the Three Gorges project.

Figure 6. Section of a Francis turbine runner welded with the metal cored wire FILARC PZ6166.

Final comments

Close co-operation between ESAB and GE Energy proved fruitful when it came to finding a complete package solution. The development of a new wire/flux combination made it possible to comply with the requirements relating to consumable weldability and productivity, in combination with the stringent requirements imposed on the mechanical and metallurgical properties of the weld metal. This combination proved to be very successful and it is now the standard combination for the SAW of hydro-turbines in 410NiMo martensitic stainless steels. The development of the new, compact welding head, which was necessary for welding in the limited space available and is capable of following the complicated joint geometry, was greatly facilitated by input from GE Energy.

Depending on the preferences of the manufacturing facility and the selected technical solutions, different degrees of mechanisation and, consequently, different choices of welding method and consumable, will produce the optimum combination of productivity and cost. A combination of different solutions is often applied, as a complex object, such as a turbine runner, may be partly well suited to mechanisation, whereas other joints can be more economically welded using manual methods. In the Three Gorges project, GMAW welding with metal-cored wires has been chosen as either the preferred welding method or the best method to complement mechanised SAW welding.

Acknowledgements

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Welding of copper-nickel alloys at Kvaerner Masa-Yards

By Kari Lahti and Juha Lukkari, ESAB Finland

A modern ship contains many materials that represent the most advanced technical solutions currently available. One of them is copper-nickel alloys, which are used as pipes in applications where contact with seawater or biofouling media causes problems.

The welding of copper-nickel alloys is traditionally regarded as fairly demanding due to the thermal properties of copper. It is difficult to obtain a stable weldpool and to weld without lack of fusion. Those problems are a thing of the past at Kvaerner Masa Yards (KMY) in Finland. Orbital TIG welding was the key to improved quality and increased productivity in the welding of copper-nickel piping.

To braze or not to braze

Brazing was the main joining process used at KMY in Helsinki prior to the unprejudiced thoughts of welding engineer Eero Nykänen, together with Hannu Mutkala and Kalevi Selvinen from the outfitting department. They contacted ESAB in Finland in order to find out whether it was possible to weld copper-nickel instead of brazing. The defect rate during brazing was fairly high and, in addition, the open flame used inside a ship's hull was considered to be a safety risk.

Figure 1. Test welding at ESAB Oy, Finland, using a Prowelder 160 power source and PRB 33-90 welding head.

Alloy type	UNS Alloy No.	ISO name	Cu	Ni (%)	Fe (%)	Mn (%), max	Ti (%)
90Cu-10Ni	C70600	CuNi10Fe1Mn	Bal	9.0 – 11.0	1.0 - 1.8	1.0	-
70Cu-30Ni	C71500	CuNi30Fe1Mn	Bal	29.0 - 33.0	0.4 - 0.7	1.0	-
Consumables	AWS A5.7	DIN 1733					
70Cu-30Ni	ERCuNi	SG-CuNi30Fe	Bal	29.0 – 32.0	0.40-0.75	1.0	0.20 – 0.30
-"-	Esab OK	Esab OK					
	Autrod 19.49	Tigrod 19.49	-"-	-"-	-"-	-"-	-"-

Table 1. Compositions of most common copper-nickel alloys.

The second weld performed at the welding laboratory at ESAB Finland was already a success. The orbital TIG welding of copper-nickel alloy CuNi10Fe1Mn was found to be fairly easy using a PROWELDER power source and a PRB welding head (Figure 1). The finish of the weld was excellent full penetration all the way (Figure 2). The basis for quality and productivity improvements had been established.

Improvements in productivity compared with brazing were very high. It took only around one-tenth of the time compared with brazing. This was also confirmed in yard practice.

What are copper-nickel alloys?

Copper-nickel alloys known as Cunifer were developed for seawater use. They typically contain between 5 and 30% nickel with specific alloys with additions of iron and manganese. The two grades that are typically used in welding applications are 90-10 and 70-30 copper-nickel alloys (Cu/Ni) (Table 1). Copper-nickel alloys, or cupro-nickels, can be welded with most arc welding processes: MMA, MIG, TIG. Surprisingly enough, it also is fairly easy to resistance spotweld, in spite of the high copper content. The addition of nickel reduces the electrical conductivity to such an extent that a joint can be made.

An all-purpose welding consumable for copper-nickel alloys is of the 70-30 type with the addition of titanium as a deoxidiser. The typical composition is shown in Table 1, together with the most common alloy nominations.

How to make a good weld

If copper-nickels are treated with the same kind of care in welding as stainless steels, no problems should arise with the weldments. As copper-nickel alloys are prone to oxidisation, precautions to prevent this must be taken, just as they are when welding stainless steels. Gas purging inside piping is also necessary as proper gas protection on the surface side. The use of Ar-H_2 mixed gases reduces the risk of oxidisation and leaves a brighter surface after welding compared with pure argon.

The welding of copper-nickel alloys is very similar to the welding of low-alloyed steels as far as weld pool fluidity is concerned. The use of welding wire is highly recommended because autogenous welds are more likely to have porosity. If it is possible to organise, copper backing bars can be used. This widens the available parameter range and helps to ensure full-penetration welds.

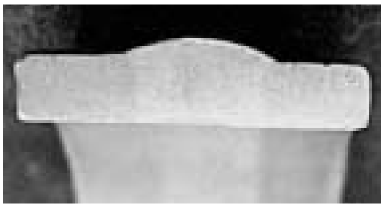

Figure 2. Weld appearance and macro of orbital weld.

Bevelling for orbital TIG welding is not necessary up to thicknesses of approximately 3 mm. Butt-joints with a zero gap are recommended. However, for thicker materials, a U-groove preparation with a 1.5 mm root face, 1.5 mm extension and 2 mm radius and zero gap is recommended. The bevelling angle depends on the process that is used for filling runs. For TIG filling, a bevelling angle of 2° may be enough, while for other processes 25-30° is more suitable.

Links about welding copper-nickel alloys:

- http://marine.copper.org
- www.twi.co.uk

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Friction Stir Welding – progress in R&D and new applications

By Lars Göran Eriksson and Rolf Larsson, ESAB AB, Welding Automation, Laxå

In spite of its very recent introduction into industry, Friction Stir Welding is already frequently used in production. This article presents some recent results from the continuous research work that is in progress on the process, a new machine series that is going to be introduced and an extremely fascinating new application in the welding of thick copper.

Metallurgical considerations in Friction Stir Welding

Friction Stir Welding is a comparatively new welding process introduced by TWI in the UK in 1991. The very first applications in production were in the 6000 series aluminium alloys at SAPA in Sweden and Hydro Marine Aluminium (shipbuilding) in Norway, followed by the automotive industry in Australia, Sweden and Norway, also using the 6000 series.

High-strength aluminium alloys in the 7000 series grades started the evolution in the aerospace industry. The FSW process is still finding new applications in aluminium alloys. Other materials such as copper and magnesium alloys are ready to be introduced in production. Steel and the joining of dissimilar materials such as copper and aluminium are shortly expected to leave the laboratories, while titanium and stainless steel are waiting for tests of tool materials to withstand the heat.

The FSW plant at DanStir, Denmark.

The process

FSW is a solid state welding process in which the weld is completed without creating molten metal. A rotating tool specially designed for its purpose generates heat and deformation of a superplastic nature close to the tool, which moves along the joint interface (Figure 1). The tool usually has a large-diameter shoulder and a smaller threaded pin. The rotating tool creates a thin plasticised zone around the pin and material is transported from the front to the rear by a solid-state keyhole effect. The process is thus characterised by high strain rates and super-plasticity near the rotating tool.

The thermal cycle created by the spindle action at different speeds is a controlling factor for the microstructures found in the stirred zone and the heat affected zone. A temperature gradient is superimposed on the super-plastic deformation between the top surface and root of the weld. When the energy input is increased by higher rotation speed, the hardness across the nugget zone is more equal and the grain size increases. At very high tool rotation speeds, the nugget properties start to deteriorate due to the precipitation around the coarse grains. It is obvious that there is an optimum speed constellation of rotating speed and the forward feed for a given material and thickness.

Developments started with welds from one side, where the distance between the tool end and the root has an important effect on the welding result. Subsequent applications include two-sided welding with two heads and a bobbin tool on solid material and with two heads on hollow extrusions. With these systems, the tolerances in material thickness are easier to cope with and they create new opportunities in production technology. Curved surface welding is also on the way.

Quality assessment

The best way to determine the weld qualities of FSW is to compare the properties obtained in FSW with those produced by other welding methods. The very local deformation at low heat inputs in solid state FSW makes this welding method superior to other welding methods such as MIG and MAG welding. Structures with rigorous performance requirements, such as rockets and aircraft, and applications in which high quality is required by codes are other areas for FSW. In the as-welded condition, FSW has demonstrated properties superior to those produced by other welding methods. The welding speed and the high quality obtained without any pre- or after-work on the welds will result in the steady extension of applications. Most design and welding codes currently accept FSW due to the high quality that has been demonstrated world wide.

Increased welding speed in the 6000 series aluminium alloys

ESAB and other companies and research institutes have done a great deal of research on the 6000 series of aluminium alloys. These alloys are the most commonly used in railway wagons, ship panels and the automotive industry and they are now also starting to attract the interest of aircraft manufacturers. Normal welding speeds in production are 0.8-2.0 m/min. for 5 mm thick workpieces. As 6082 material is often used in the T6 condition (heat treated to produce higher mechanical properties), one task for R&D is to reduce the decline in hardness in order to retain as much as possible of the T6 treatment effect. One solution is to weld quickly. It is not often that a high welding speed means higher quality, but in this case it does.

In the ESAB laboratories in Laxå, a great deal of test welding has been performed with the aim of increasing the welding speed. A year ago, 3 m/min. was reached, but recent tests with refined procedures have shown that 6 m/min. in 5 mm 6082 material is possible and that this very high speed is definitely not the ultimate limit. These very promising results will further increase the number of profitable applications for Friction Stir Welding.

Research centres using ESAB SuperStir®

- The FSW process was invented and developed by TWI in the UK. TWI is still leading the way to new applications and materials. With its new FSW – plant, it is well equipped for future interesting tasks.
- The aerospace industry demonstrated great interest in the new process at a very early stage. The Boeing Company at Huntington Beach, Ca, USA developed the process for aerospace applications, together with TWI, and it is continuously working in its laboratories on new tasks for aerospace, aircraft and other applications (Figure 2).
- Boeing in St. Louis is conducting a great deal of research for the aircraft industry to produce new Friction Stir Welded parts. Among other things, a new hollow profile floor section has been produced together with SAPA in Sweden.
- Following Boeing's success, other aerospace and aircraft research institutes have invested in advanced machines for research work and test welding. EADS in France, together with Institute Soudure, Alenia Spacio in Italy and EADS in Germany, are examples of these institutes. Other companies have chosen to conduct their tests at ESAB, TWI or other research centres.
- For the automotive and other segments, Tower Automotive in the USA has a well-equipped FSW centre for research, test welding and test production.
- DanStir in Denmark is one of several companies focusing on test welding, the production of test series and low series production with FSW. DanStir, however, has a large, flexible FSW plant well suited to different tasks (photo page 11).
- The research and development of production data is continuously being conducted by the producers of aluminium structures, such as Hydro Marine Aluminium in Norway and SAPA in Sweden.

Figure 1. FSW process in a butt joint against backing bar.

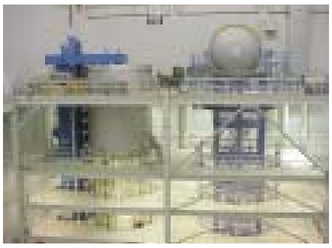

Figure 2. Take-over test of the FSW plant supplied by ESAB AB, Welding Automation to Boeing's space rocket plant.

- At its plant in Laxå, ESAB has two FSW machines for research work, demonstrations and test welding for customers (Figure 3). Its engineering division is well equipped to comply with customers' requirements for production solutions, including the design, manufacture, commissioning and service of FSW machines and complete production plants world wide.

New modularised machine series

In order for manufacturers to invest in the FSW welding technique in a cost-effective manner, ESAB is now launching a new modularised machine series called LEGIO™, new members of the ESAB Super Stir™ programme. With the new machines, material with a thickness of between 1.4 and 100 mm can be welded. The spindle power ranges from 1.5 kW to 100 kW. The machine series consists of two main types, the S series for straight welds and the U series for straight welds in the X or Y directions, as well as in optional patterns such as circles, squares and so on. Each series has two main designs, one floor mounted with vertical surfaces for mounting large fixtures, circumferential welding units or a lower head assembly for double-sided welding and one type with a table for mounting small fixtures.

The FSW 3 UT (Universal type with table, 11 kW spindle, max. capacity 10 mm in the 6000 series) will be introduced at the Essen Alu Fair in Germany in 2002 (Figure 4).

Welding thick copper material with FSW

Developments in the Friction Stir Welding (FSW) of copper will take a further step forward, as the Swedish Nuclear Fuel and Waste Management Co. (SKB) is investing in a full-scale FSW plant at its canister laboratory in Oskarshamn, Sweden. The background to SKB's interest in welding thick copper sections is the Swedish decision to deposit high-level nuclear waste in copper canisters at a depth of 500 metres in the bedrock. The sealing of the copper canisters needs to be of a very high quality, as it must remain intact during the 100,000-year service life of the repository.

SKB has studied different welding methods in co-

Figure 3. At the test centre at ESAB Laxå, FSW process development and investigations of different customer applications are made.

Figure 4. FSW 3 UT – one example of the new modularised machine series from ESAB AB, Welding Automation.

operation with TWI in the UK. Full-scale electron beam welding tests have been performed. In 1998-1999, a test rig was built at TWI for the Friction Stir Welding of mock-up canisters. A fixture holds the canister and rotates it during welding (Figure 5). The lid is pressed down with four hydraulic cylinders. The welding speed reaches 150 mm per minute. At the beginning, the trials were exclusively limited to welding segments, but, after fine-tuning the process, a full circumferential weld could be completed in November 2000. The FSW process has functioned well and SKB now feels confident about taking the next step in the development and has decided to install a full-scale FSW machine at its canister laboratory in order to investigate the feasibility of the process for the production of canisters (Figure 6). SKB has assigned the task of designing, manufacturing, testing and commissioning the machine to ESAB AB, Welding Automation, Laxå. Test welding in Oskarshamn is scheduled to start early in 2003. SKB can then begin the work of optimising the welding parameters. This has not been possible with the test rig at TWI.

When welding a circular seam with FSW, a hole is left in the material when the FSW tool is retracted. This hole can be filled afterwards or simultaneously when the tool is retracted. A more simple and reliable method is to finish the weld in solid material outside the joint (Figure 7). In the latter case, SKB is planning to finish the weld at the top of the lid. However, the hole may create difficulties for the non-destructive testing after welding. Remaining R&D work will also focus heavily on the design of the lid and the testing methods. The testing methods that are developed by SKB in co-operation with Uppsala University at the SKB canister laboratory are digital radiography, ultrasonic and inductive testing. Another important part of the development of the welding and testing techniques is to determine the criteria for the size and form of the weld defects that can be accepted.

Conclusion

The new findings, new machine series and new applications presented above confirm our previous statements that FSW will continue to expand. We are convinced that the large automotive segment will take off in the near future, together with other segments that are currently showing substantial interest in the FSW method. The increased productivity that results from FSW compared with other manual or automatic welding methods and, in many cases, the high investment levels require large volumes. This demand can be met by installing FSW plants to meet several manufacturers' needs, if their own volumes are not sufficient. However, the new machine series introduced by ESAB will minimise investments, thereby making it possible for more manufacturers of aluminium structures to install FSW systems.

Figure 5. The SKB trial test rig at TWI.

Figure 6. A sketch of the FSW plant that shall be supplied by ESAB Welding Automation to SKB, Sweden during 2002. The welding head rotates during the process around the fixed canister.

Figure 7. The picture shows the hole from the retracting tool and how it can be placed beside the weld joint in solid material.

About the authors

Lars Göran Eriksson, MSc Electrical Engineering, joined ESAB in 1973. He has held different management positions within the Automation and Engineering departments, and within International Operations. He has been leading ESAB´s development and introduction of new inventions such as automation of ship panel production, robotic arc welding, narrow gap welding of pressure vessels, fully automatic production systems for anchor chains, and the FSW process.

Rolf Larsson, Mech. Eng., is Technical Manager for the marketing & sales group responsible for FSW and resistance welding within in the business area Automation & Engineering in Laxå, Sweden. He holds a number of patents within the Friction Stir Welding technology.

Welding of supermartensitic stainless steels

Recent developments and application experience

By: Leif Karlsson, Solveig Rigdal, John van den Broek, Michael Goldschmitz and Rune Pedersen, ESAB

This paper was originally presented at the Stainless Steel World America 2002 Conference.

Recent developments in the welding of supermartensitic stainless steels and the typical all-weld metal properties of matching-composition welding consumables are presented. The article compromises the GMAW orbital narrow gap girth welding of supermartensitic pipes in 5G-down position, the production of longitudinally welded 20” pipes using a combination of plasma arc and submerged arc welding, and dissimilar joining of supermartensitic and superduplex pipes.

Introduction

The recently introduced weldable supermartensitic stainless steels have become an economical alternative for many applications in the oil and gas industry. These steels offer sufficient corrosion resistance for sweet and mildly sour environments, in combination with high strength and good low-temperature toughness (1, 2). Supermartensitic steels are also well suited to field welding where preheating and long term post-weld heat treatment (PWHT) is impracticable.

The successful application of a material requires that welding can be performed reliably and economically and that the welds comply with requirements relating to strength, among other things. For example, reeling is a common operation when laying offshore flow lines. This operation involves bending pipes, introducing significant plastic deformation. Local straining at welds may occur when welding consumables with under-matching strength are used. Matching composition supermartensitic welding consumables, guaranteeing overmatching yield strength, are therefore specified for several current and future projects.

Significant alloy development in matching composition consumables has taken place over the past few years and our understanding of the relationship between chemical composition, microstructure and properties has improved rapidly (3-8). However, the development of further optimised consumables and economical welding procedures is still a challenging area of activity.

The present paper presents the application of matching composition welding consumables to the GMAW orbital narrow gap girth welding of supermartensitic pipes in the 5G-down position and to the production of longitudinally welded 20" pipes. The welding procedures and properties are discussed, illustrating that supermartensitic consumables can be used with realistic

fabrication welding procedures to produce high quality welds with satisfactory properties. Finally, some experience from the dissimilar welding of supermartensitic stainless steels to superduplex steels is presented. The advantages and disadvantages of using different filler materials are discussed in terms of weldability, mechanical properties and corrosion resistance.

Supermartensitic weld metal properties

The first sections of this paper deal with supermartensitic pipes welded with matching-composition consumables. The level of dilution with the parent material inevitably influences the properties of these welds. Typical chemical compositions and mechanical properties of all-weld metals, produced with the same commercial supermartensitic metal-cored wires (MCW), are therefore presented as reference information in Tables 1 and 2 below. The wires deposit a fully martensitic 13%Cr-type, Mo-alloyed, extra-low carbon weld metal designed primarily for welding supermartensitic steels.

Wire	C	N	Si	Mn	Cr	Ni	Mo	Cu
1.5 % Mo, metal cored wires:								
OK Tubrod 15.53*	<0.01	<0.01	0.8	1.2	12.5	6.8	1.5	0.5
OK Tubrod 15.53S**	<0.01	<0.01	0.8	1.1	12	6.8	1.5	0.5
2.5 % Mo, metal cored wires:								
OK Tubrod 15.55*	<0.01	<0.01	0.4	1.8	12.5	6.7	2.5	0.5
OK Tubrod 15.55S**	<0.01	<0.01	0.5	1.6	12	6.7	2.5	0.5

*Pulsed GMAW using Ar+30%He and GTAW with Ar or Ar+He. **SAW with OK Flux 10.93.

Table 1. Typical chemical composition (wt.%) of all-weld metals produced with matching composition metal cored wires.

OK Tubrod 15.53 & 15.53S are recommended for steels with up to 1.5%Mo, whereas OK Tubrod 15.55 & 15.55S should be used for steels with higher Mo contents. The weld metal is designed for use in the as welded, tempered or quenched and tempered condition depending on the toughness and hardness requirements.

Recommended shielding gases for GMAW are Ar+30%He or Ar+0.5%CO_2. Gases with a higher CO_2 content can be used, but they will increase the weld metal C and O content, which will result in a higher weld metal hardness. Pure Ar or Ar+He mixtures should be used for GTAW.

Orbital narrow gap pipe welding

The term orbital pipe welding generally refers to the equipment that is used when an application calls for pipes to be welded in a fixed position. However, the term is misleading when using the GMAW/FCAW processes. If the pipe is in the horizontal position, welding is performed using either a double-up (6 to 12 o'clock clockwise, followed by 6 to 12 o'clock anti-clockwise) or a double-down technique (12 to 6 o'clock clockwise, followed by 12 to 6 o'clock anti-clockwise). MCWs only form small isolated silicate islands on the solidified weld bead. They can be removed by brushing between passes or they can simply be welded over, as they will re-melt and float to the weld pool surface. MCWs are therefore well suited for welding double up as well as double down. For all-position welding, a pulsing power source is preferred in order to obtain the appropriate droplet transfer and weld pool control.
With the right kind of joint design, double-down welding can be performed using relatively high travel speeds in the 38-75 cm/min range. One technique to provide better weld pool control at these high speeds downhill is to use a narrow J-groove geometry. The joint geometry is narrow enough to allow each pass to bridge from wall to wall without oscillation, apart from the capping layer where slight weaving is necessary to complete the last layer.

Welding trials

Four companies undertook a collaborative project to evaluate the performance of the new wires with supermartensitic pipe material and to demonstrate acceptability for orbital pipeline welding (9, 10). A narrow J-groove was selected for use without a root gap (Fig. 1). An expanding clamp with copper backing

Table 2. Typical all-weld metal mechanical properties in the as welded condition.

Consumables	Impact toughness (J)		Tensile properties			Hardness (HV10)	Welding method
	-40ºC	20ºC	$R_{p0.2}$ (MPa)	R_m (MPa)	A_5 (%)		
		1.5 % Mo, metal-cored wires:					
OK Tubrod 15.53/Ar	>100	>110	700-850	950-1050	>15	< 350[3]	GTAW
OK Tubrod 15.53/ Ar+30%He	>40[1]	>50[1]	700-850	950-1050	>10[2]	< 350[3]	GMAW
OK Tubrod 15.53S/ OK Flux 10.93	>30[1]	>35[1]	700-850	950-1050	>5[2]	< 350[3]	SAW
		2.5 % Mo, metal-cored wires:					
OK Tubrod 15.55/Ar	>100	>110	700-850	950-1050	>15	< 350[3]	GTAW
OK Tubrod 15.55/ Ar+30%He	>40[1]	>50[1]	700-850	950-1050	>10[2]	< 350[3]	GMAW
OK Tubrod 15.53S/ OK Flux 10.93	>30[1]	>35[1]	700-850	950-1050	>5[2]	< 350[3]	SAW

1 PWHT at 580-620ºC will, depending on time (5-30 min.), typically increase impact toughness 20-100%.
2 Degassing at 250ºC/16 h or PWHT at 580-620ºC will increase elongation to >15%.
3 PWHT at 580-620ºC will, depending on time (5-30 min.), typically decrease hardness 20-50 HV10.

Pass	Position	Amperage (A)	Arc Voltage (V)	Wire feed (m/min)	Welding speed (cm/min)
Root	12-4 o'clock	210	18.8	9.3	70
Fill 2,3,4	12-4 o'clock	215	21.5	9.0	50
Cap*	12-6 o'clock	140	18	3.0	18
Root	4-6 o'clock	178	17.5	6.0	22
Fill 2,3	4-6 o'clock	175	17.5	6.0	22
Cap*	12-6 o'clock	140	18	3.0	18

*Slight weaving

Table 3. Typical welding parameters: Shielding gas 99.5% Ar/0.5% CO_2; No backing gas (welding against copper backing). Total welding time 14 minutes.

shoes was used to ensure precise pipe alignment and uniform root bead penetration.

The Pipeliner System, manufactured by Magnatech, interfaced with an ESAB Aristo LUD320W power source, was used for the trials. The ESAB Aristo LUD320W is a synergic-type power source, which means that there is a pre-programmed relationship between the pulsing parameters/power output and wire feed speed. A new synergic line was programmed for the MCW (OK Tubrod 15.55 with a diameter of 1.2 mm). Samples of 322 mm (12") NKK-CR13WS2.5 (13Cr-6.5Ni-2.5Mo) pipe with a wall thickness of 14.6 mm were supplied by NKK for the trials.

Test welds were made and used to develop a welding procedure (Table 3 and Ref. 11). Figures 2 and 3 illustrate the smooth bead appearance of the weld cap and the excellent side wall fusion. For the filling layers, there was no need for weaving in order to obtain reliable side wall fusion, thereby permitting increased travel speed and higher productivity while maintaining a low defect rate. It was clearly demonstrated that, with the proper equipment, welds could be performed reliably and effectively with MCWs in a narrow J-groove geometry.

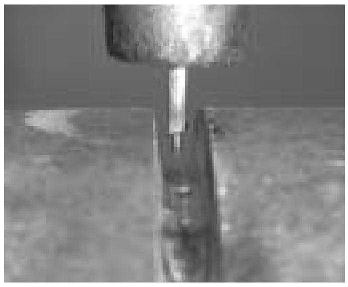

Figure 1. The applied 'narrow gap' J-joint has a small land.

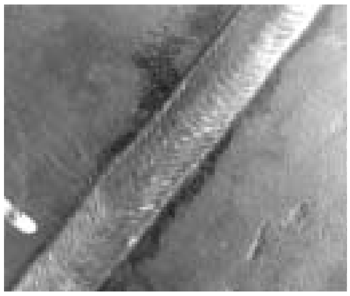

Figure 2. Close up of the orbital weld seam in the supermartensitic pipeline material.

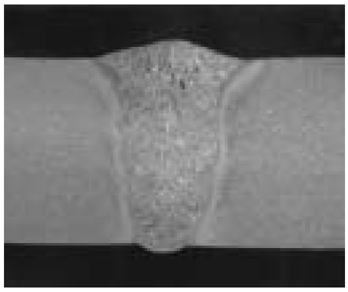

Figure 3. Cross section of narrow gap girth weld illustrating the excellent side wall fusion. A slight weaving is only necessary for capping. The total welding time for the 12 " (wall thickness 14.6 mm) pipe is approximately 14 minutes.

Weld properties

The weld metal toughness and strength were determined in house by preparing a tensile bar and five ISO-V Charpy specimens transverse to the weld (11). The tensile bar (21.1x12.9mm) broke in the pipe material at 900 MPa, showing that the weld metal clearly overmatched the pipe material. Impact toughness was tested at –40°C in the as-welded condition and after a short PWHT at 600°C. The heat treatment was performed in a Gleeble weld simulator (electrical resistance heating) with rapid heating, a holding time of five minutes, followed by air cooling. Individual Charpy values were 44, 41 and 42 J in the as-welded condition and 50 and 52 J after PWHT, illustrating the beneficial effect of a short PWHT.

The weld metal oxygen content was measured, as it is known to have a dramatic effect on the impact toughness of supermartensitic weld metals (12). The measured range of 285-350 ppm correlates well with the observed impact toughness, according to earlier studies (12), suggesting that there is potential to increase toughness still further by improving the gas shielding. This is possible using a special nozzle in combination with a small, designed gas cup or the use of a 100% inert gas.

The results of additional tests performed at TWI (13) were in line with the above findings. Cross weld tensile testing resulted in fracture in the parent steel. The all-weld metal yield strength was 680 MPa and the tensile strength 923 MPa after PWHT at 637°C for five minutes. Impact toughness was measured as an average of 47 J at -46°C after PWHT at 651-661°C for five minutes. Four-point bended sulphide stress corrosion cracking (SSCC) testing for 30 days in slightly sour (10 mbar H_2S) formation water and condensed water indicated no susceptibility to SSCC.

Longitudinal pipe welding

The production of large-diameter supermartensitic pipes in the range of 18" (475 mm) to 30" (760 mm) with a wall thickness of up to 30 mm involves longitudinal seam welding. Currently, the inside and outside seams are welded by SAW, as a result of which the back-gouging of the root pass is necessary to eliminate the risk of flaws in the root pass.

Plasma arc welding is a high energy density welding process capable of producing high quality welds using the keyhole technique and it is therefore suitable for root runs on thick pipe sections. In the present study, the combination of a plasma arc root pass welded with an inert gas backing and SAW for the fill and cap layers was tested. The aim was to avoid the need for back gouging, thereby increasing productivity and consequently reducing costs.

Welding details

A 20 mm thick plate of 12Cr 4.5Ni 1.5Mo material was used to produce a length of a 20" (508 mm outer diameter) pipe at EEW (Erndtebrücker Eisenwerk, GmbH & Co. KG). Machining, forming and welding presented no problems, although magnetism was more evident than in the butt welding of plates. However, when the correct precautions were taken, this presented no difficulties. Welding was done in an X-joint preparation using plasma arc welding with Ø 1.2 mm OK Tubrod 15.53 for the root pass. Fill passes were deposited from the outside and inside with SAW using a Ø 2.4 mm OK Tubrod 15.53S/ OK Flux 10.93 wire/flux combination (Figure 4). The heat input was in the range of 1.0-1.7 kJ/mm for SAW, whereas a somewhat higher heat input was used for the plasma arc welding. A maximum interpass temperature of 150ºC was used and a 30 minute PWHT at 630ºC, followed by air cooling, was applied after welding.

Microstructure and properties

The microstructure of the welded joint, including the weld metal, HAZ and parent material, consisted after PWHT of tempered martensite as illustrated in Figure 5.

Weld metal hardness and toughness were comparable to those of the HAZ (Tables 4 and 5). For example, the maximum weld metal hardness was 278 HV10 and the maximum hardness at the fusion boundary was 280 HV10. The Charpy-V impact toughness was lowest in the weld metal in the high-dilution region at mid-thickness, averaging 62 J at –40ºC. The weld metal toughness was somewhat higher (70 J at –40ºC) when locating the specimen at the outer surface, similar to the 77-79 J measured in the HAZ in the fusion boundary region. The weld metal strength was highest in the high-dilution region at mid-thickness and somewhat lower, but still overmatching, closer to the outer surface (Table 6).

The strength and toughness of the weld metal are in very good agreement with previous all-weld metal tests after PWHT for 30 minutes at 620ºC (8). The recommendations in Table 2 suggest 580-620ºC as the optimum PWHT temperatures based on tests indicating the formation of new martensite on cooling from PWHT temperatures of 640ºC and above. However, the present test suggests that a somewhat higher temperature could be beneficial for the 1.5%Mo material in order to maximise toughness. Precise temperature control is recommended, however, as previous studies have shown a rapid drop in yield strength, toughness and elongation once too much untempered martensite and retained austenite is present in the microstructure (8).

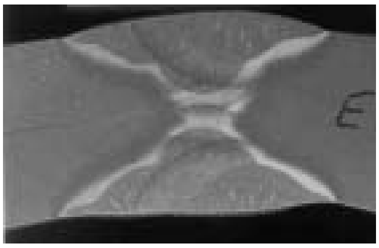

Figure 4. Cross section of longitudinal pipe weld (wall thickness 20 mm).

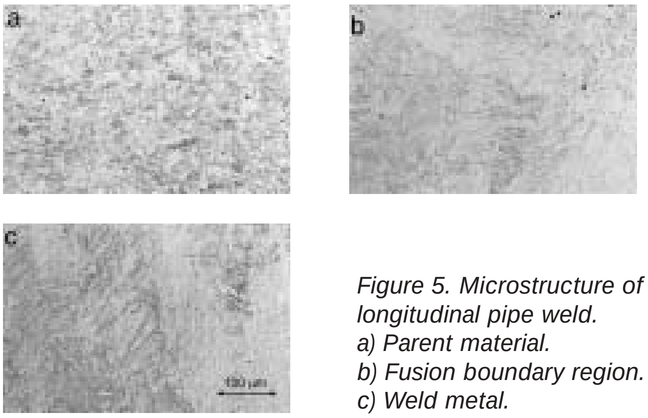

Figure 5. Microstructure of longitudinal pipe weld.
a) Parent material.
b) Fusion boundary region.
c) Weld metal.

Dissimilar joining

Dissimilar joints are not uncommon in oil and gas process equipment, as the temperature and corrosiveness of the process media vary and different materials therefore need to be used for different components. One interesting dissimilar combination involves joining supermartensitic and superduplex pipes of different wall thickness. The following section will briefly describe two recent examples from Norwegian offshore projects where Ni-base and superduplex consumables were used.

Welding procedures

Supermartensitic pipes (K-X80-CR13WS2, outer diameter 324 mm/wall thickness 16 mm) were joined to superduplex pipes (UNS 32760, outer diameter 335 mm/wall thickness 22 mm) using the GTAW method. The welding was done at Arctos Industrier AS in Sandefjord (Norway), using either Alloy 59 type Ni based (SG-Ni Cr23Mo16, Ø 2 mm) or superduplex (EN 12072 G/W 25 9 4 N L, Ø 2 mm an 2.4 mm) consumables. The compositions of the parent and filler materials are given in Table 7.

Welding was performed with the pipes fixed in the horizontal position. A 60º V-joint preparation was used with a 2 mm root gap for the Ni-base consumables and a 3-4 mm gap when using superduplex filler material. Pure Ar was used as the shielding and purging gas in both cases. A somewhat higher interpass temperature (max 150ºC) and heat input (0.9-1.2 kJ/mm) was permitted for the superduplex consumables compared with the Ni-base welds, where the interpass temperature was kept below 100ºC and the heat was 0.9-1.1 kJ/mm. Approximately 45 beads were required to complete the Ni-base consumable weld as compared to 35 beads when using superduplex consumables.

Position	Hardness (HV10)	
	Min	Max
Parent material	233	263
Fusion line	242	280
Weld metal	264	278

Table 4. Hardness of longitudinally welded pipe, post weld heat treated at 630ºC for 30 minutes.

Specimen position	Notch position				
	Weld metal	FL	FL +2mm	FL +5mm	Parent material
Outside	70	77	79	77	104
Mid thickness	62	87	70	123	102

Table 5. Charpy-V impact toughness (J at -40ºC) of longitudinally welded pipe, post weld heat treated at 630ºC for 30 minutes.

Specimen position	Longitudinal tensile properties		
	$R_{p0.2}$ (MPa)	R_m (MPa)	A_5 (%)
Outside	880	974	15
Mid thickness	954	1001	16

Table 6. Weld metal tensile properties in longitudinal weld after a 630ºC/ 30 min PWHT.

Testing and inspection

The welds were subjected to an extensive test programme, including non-destructive testing, microscopy, transverse and longitudinal testing at room temperature and at 115°C, Charpy-V testing at -46°C, bend testing, hardness measurements and sulphide stress corrosion cracking (SSCC) testing.

Radiographic inspection and sectioning of the welds revealed no defects and the microstructure was judged to be sound. One comment can, however, be made; microscopy revealed some precipitation of nitrides and secondary austenite in the HAZ of the superduplex pipe in the Ni-base weld. The superduplex weld had a ferrite content ranging from 30.4% in the root to 51.5% in the cap and no comments were made on the HAZ microstructure.

Mechanical testing

The yield and tensile strength of the Ni-base weld was lower than that of the superduplex weld at both room and elevated temperature (Table 8). However, fracture in cross-weld testing took place in the parent material, regardless of the consumable and test temperature. It should be noted that the strength of the superduplex weld decreased significantly more with increasing temperature than that of the Ni-base weld. For example, the yield decreased by 136 MPa for the superduplex weld and by 79 MPa for the Ni-base weld when going from 20°C to 115°C.

Both welds passed the 180º face and root bending tests (mandrel 5xT for Ni based and 4xT for superduplex). Hardness surveys across the welds 1.5 mm below the top and root surfaces revealed very similar behaviour for the two welds. The highest hardness was found in the HAZ in the supermartensitic pipe (up to 380 HV10) and the weld metal hardness was higher in the root than in the cap. Ni-base weld metal hardness averaged 235 HV10 in the cap region and 314 HV10 in the root, whereas the corresponding hardness was 281 HV10 and 319 HV10 respectively for the superduplex weld. The hardness of the HAZ in the superduplex pipe was in the range of 325-345 HV10.

Charpy-V impact toughness was measured using standard 10x10 mm specimens extracted at various locations close to the cap and root surfaces (Table 9). The hardness was on a high level in both welds. The lowest average toughness that was measured was 87 J at the fusion line in the superduplex pipe welded with Ni-base consumables. Weld metal toughness ranged from 112 J to 141 J in the Ni-base weld metal and from 114 J to 196 J in the superduplex weld metal. The supermartensitic pipe material toughness was typically above 200 J, whereas the superduplex pipe toughness ranged from 87 J to 157 J.

SSCC testing

The resistance to sulphide stress corrosion cracking was tested according to EFC Document No. 17 and the Norsk Hydro 33-1A-NH-R52-00002 specification. Testing was performed at room temperature in condensed water (1000 mg/l NaCl, 400 mg/l NaAc, pH adjusted to 3.6 with HCl or NaOH) and formation water (38890 mg/l NaCl, 400 mg/l NaAc, pH adjusted to 5.2 with HCl or NaOH) at 4 mbar partial pressure of H_2S. Constant load and four-point bending specimens were prepared transverse to the weld at the pipe inner surface. Constant load specimens from the Ni-base weld were only tested in condensed water. However, four-point bending specimens from the two welds and constant load specimens from the superduplex weld were tested in both condensed and formation water. The four-point bending specimens were loaded to 100% of the weld metal yield strength and the constant

Table 7. Chemical composition (wt.%) of pipe materials and filler wires used for dissimilar joints.

	C	N	Si	Mn	Cr	Ni	Mo	W	Cu	Fe
Supermartensitic pipe	0.015	0.012	0.2	0.17	12.3	5.9	2.2	-	0.05	rest
Superduplex pipe	0.017	0.23	0.36	0.68	25.6	7.4	3.5	0.6	0.6	rest
OK Tigrod 19.81	0.003	-	0.05	0.2	22.8	rest	15.4	-	-	0.4
OK Tigrod 16.88*	<0.003	0.25	0.5	0.5	25.0	9.5	4.0	-	-	rest

* typical all-weld metal analysis

Consumable	T	All-weld longitudinal tensile properties $R_{p0.2}$ (MPa)	R_m (MPa)	A_5 (%)	Cross weld tensile strength R_m (MPa)	Location of fracture
Ni-base	+20ºC	589	818	37	864	Supermartensitic pipe
	+115ºC	510	726	-	780	Supermartensitic pipe
Superduplex	+20ºC	744	879	25	843	Supermartensitic or superduplex pipe*
	+115ºC	608	763	-	738	Supermartensitic pipe

* 3 specimens fractured in supermartensitic pipe material and 1 specimen in superduplex pipe.

Table 8. Tensile properties of dissimilar welds.

load specimens to 90% of yield strength and they were tested for a period of 30 days.
The result was very similar for both welds. No cracks were found on any of the specimens in either of the two environments. The conclusion was therefore that all the specimens passed the sulphide stress corrosion cracking test. Some localised corrosion was, however, found on the end face of the supermartensitic side of specimens tested in formation water. One localised attack was also found on the side edge of a four-point bending specimen from the Ni-base weld, tested in formation water. This attack also took place in the supermartensitic pipe material.

Concluding remarks

As exemplified above, matching-composition supermartensitic consumables are well suited both to the production of longitudinally-welded pipes and to girth welding. There are different options for the dissimilar joining of supermartensitic and superduplex material and the preferred choice will depend on the specific application.

Supermartensitic welding consumables

The development of matching-composition supermartensitic welding consumables and welding procedures is still in progress. However, it is obvious that this concept offers a number of advantages in terms of properties, productivity and the possibility to perform a PWHT when required. Another frequently overlooked advantage, compared with duplex or superduplex consumables, is that a martensitic weld metal microstructure is expected for all levels of dilution with the parent material.
The parent material delivery condition strength can vary, depending on the exact composition and heat treatment cycle. Experience has shown that superduplex consumables usually produce overmatching or closely-matching weld metal strength at room temperature. However, at an operating temperature of above 100ºC, the situation is frequently reversed, as the yield of the supermartensitic material increases, whereas the duplex material strength level typically decreases by 10-15% (8, 14).
For a number of reasons, it is therefore most probably only a matter of time until supermartensitic consumables become the preferred choice in the welding of supermartensitic stainless steel.

Dissimilar welding consumables

The study revealed that both Ni-base and superduplex consumables can be used successfully for the dissimilar joining of supermartensitic and superduplex pipe material. It is well known, however, that Nb-alloyed, Ni-base consumables are less suitable due to the risk of brittle Nb-and N-rich phases forming next the fusion boundary in the duplex material. Nb-free consumables, such as Alloy 59 used in this study, are therefore to be preferred to Alloy 625, for example.

The use of superduplex consumables is more straightforward in the sense that no problems are anticipated on the superduplex side of the joint and because duplex and superduplex consumables have been used extensively to weld supermartensitic material. However, depending on the relative dimensions of the pipes to be joined and the operating temperature, the lower drop in the yield of the Ni-base weld metal with increasing temperature might be beneficial. Problems have also been encountered with hydrogen cracking in the HAZ of supermartensitic pipes welded with superduplex consumables (15).

Table 9. Charpy-V impact toughness (J at -46ºC) of dissimilar welds between supermartensitic and superduplex steels.

Consumable	Specimen position	Notch position: Weld metal	Supermartensitic pipe FL + 2mm	Supermartensitic pipe FL + 5mm	Supermartensitic pipe FL	Superduplex pipe FL + 2mm	Superduplex pipe FL + 5mm	Superduplex pipe FL
Ni-base	Cap	112	192	207	233	94	104	92
	Root	141	208	-	-	87	-	-
Superduplex	Cap	196	224	200	220	124	157	118
	Root	114	235	-	-	114	-	-

Similar problems are not expected with a Ni-base consumable due to the high solubility and slow diffusion of hydrogen in an austenitic microstructure.

In conclusion, both Ni-base and superduplex consumables are suitable for the dissimilar joining of supermartensitic and superduplex material and the choice should be based on factors such as joint geometry and operating conditions.

Acknowledgements

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Chicago Bridge & Iron Company Meets Challenge of Stainless Steel Welding for Cryogenic Rocket Fuel Tanks

Welding stainless steel can be a demanding task. The task becomes even greater when the job involves welding large cryogenic storage tanks such as those for the Boeing Space Launch Complex 37 at Cape Canaveral Air Force Station, Florida. Chicago Bridge & Iron Company (CB&I) discovered this first-hand recently when they were hired by Raytheon, Inc., to design and build the storage tanks that hold the liquid hydrogen and liquid oxygen used to fuel the Boeing Delta IV rocket.

Jim Smith, CB&I's project manager for the job, describes the tanks as "large thermos bottles." The tanks are double-walled spheres consisting of an inner wall of stainless steel and an outer wall of carbon steel with insulation in between. The liquid hydrogen tank has an inner diameter of 61 feet (18.6m), with an outer diameter of 67 feet (20.4m). The smaller tank for the liquid oxygen has an inner diameter of 41 feet (12.5m) and an outer diameter of 47 feet (14.3m). Anyway you look at it, there was a lot of welding to do.

But big welding jobs are CB&I's specialty. The world-renown engineering and construction firm specializes in design and building steel plate structures. The 112 year-old company started out building bridges but soon turned to other steel applications and built its reputation on its ability to design innovative storage facilities and erect them in the field. Today, the company is best known for its ability to engineer and construct flat bottom tanks, spherical storage vessels, elevated water tanks, refrigerated storage and process systems, vacuum chambers for the space industry, and industrial process vessels (see www.chicagobridge.com).

The Cape Canaveral project was somewhat unique in the rigors of its specifications. The tanks are required to hold temperatures of –424ºF (-253ºC) for the hydrogen and –320ºF (-196ºC) for the oxygen. In addition to the size and temperature challenges, the welders soon discovered an additional challenge resulting from the windy conditions of the ocean side site. The welding surface had to be protected by a shield gas to ensure the integrity of the weld.

According to Smith, they needed a homogenous weld that would offer excellent strength and meet the requirements of AMSE Code, Section 8, Division 1. CB&I also wanted to use a semi-automatic welding process to cut down on labor time and improve productivity. They found their answer in ESAB's Cryo-Shield 308L flux-cored wire. Cryo-Shield 308L is an all-position wire designed for cryogenic applications requiring good weld metal strength. It offers tensile strength of 80,000 psi (550MPa) and yield strength of 60,000 psi (410MPa) with CVN toughness of 25 ft.-lbs. (34 J) at –320ºF (–196ºC). Use of an argon/CO_2 shield gas protected the weld from the elements.

Part of ESAB's Shield-Bright family of flux cored wires for stainless steel welding, Cryo-Shield deposits welds at substantially higher welding currents than the other stainless steel electrodes that were considered, resulting in a higher deposition rate. In this case, the use of Cryo-Shield helped CB&I complete their project with just 10 months in the field and pass all X-ray qualifications tests with ease. It also offered a self-peeling slag for fast, easy clean-up.

CB&I has used ESAB filler metals for 30 years, but this was their first experience with this relatively new product. They found Cryo-Shield to be extremely user-friendly, productive and capable of meeting the most stringent specifications. ESAB's excellent on-time delivery and customer support were also top-notch, according to Smith.

Chicago Bridge & Iron is known as an innovative company, always looking for unique and better ways to solve their clients' problems. Working with vendors such as ESAB Welding and Cutting Products, CB&I was able to deliver on-time and within the specifications to keep this space project on schedule for countdown.

Welding high strength pipelines: from laboratory to field

By: D.J.Widgery, ESAB Group (UK) Ltd

This article was first published in the September/October issue of World Pipelines.

Although the first X80 pipelines were laid in the 1980s, it was only around the turn of the century that the next major programmes were started by Transco and TransCanada Pipelines. Both the welding technology and the requirements placed on the joints have moved on since the 1980s, and contractors and welding manufacturers have had to come to terms with this.

Field welding showed up a lack of robustness in procedures developed in the laboratory, but new welding consumables were developed and performed well in the field. More work will be needed to ensure that X100 pipes can be reliably welded, but much has already been done and manufacturers will be ready when the pipe arrives.

High strength pipelines

In 1999, Transco announced a programme of pipeline construction in X80 steel. This was not the first X80 in Europe: a few kilometres were laid in Germany in the 1980s and 250 km by Ruhrgas in 1992-3, using manual metal-arc welding. At about the same time, Nova Corporation in Canada started laying X80 pipe using mechanised welding. Steels of similar strength had been used for many years in naval applications, so no major problems were envisaged when procedure testing started in the UK in the spring of 2000. In the event, lines were successfully laid in 2000 and 2001, but contractors had to learn some costly lessons first.

The use of X80 pipe offshore has not yet begun, but the experience of onshore lines should help in this more demanding application. Still higher grades of pipeline steel will certainly be used in the future and steelmakers and consumable manufacturers are working to make the welding of these as straightforward as possible.

X80 Pipelines – mainline welding

Pipeline welding may be divided into mainline welding, where speed is critical and there is access for backing systems; tie-in and repair welding, where speed may be less important and there is no internal access, and double jointing, where it is possible to roll the pipe and to weld in the flat position. Although mechanised welding systems have been available for many years and are almost exclusively used offshore, the turn of the century marked a watershed which saw the first large-scale application of mechanised systems in the UK and the USA. In mainline welding, these systems allow the use of a narrow joint preparation.

By welding downhill in a narrow compound bevel, productivity benefits in two ways. The sidewalls help support the weld metal at relatively high currents and deposition rates, while the reduced joint volume requires less metal to fill it. The narrow joint has another effect: the rapid extraction of heat from the weld gives cooling rates well above those normally found in structural welding. As a result, the weld metal strength is higher than that found in a typical all-weld metal test such as those used for classifying consumables.

When mechanised welding was first used on X80 pipes in Canada, a carbon-manganese solid wire was found to give adequate strength: the mean weld metal yield strength was above 630 MPa. The mean pipe yield strength was around 600 MPa, so most welds showed real overmatching. Transco, in the UK, required the weld metal yield strength to overmatch the pipe's specified minimum yield stress by 5%, giving a minimum of 578 MPa. This is easily achieved by carbon-manganese consumables using single torch equipment, though with some twin torch systems the results are close to the minimum and higher alloying may be preferred.

In the 1960s, when semi-automatic gas shielded welding was first used in the UK and USA on transmission pipelines, it was found that wires containing a small amount of titanium gave the best results. The burn-off rate of the wire was reduced, so the proportion of the arc energy available to melt the edges of the weld preparation was correspondingly increased. This led to a reduction in lack of fusion defects, the most serious problem in semi-automatic pipe welding. The titanium containing wires also gave good weld toughness, and were generally adopted when mechanised welding systems were developed to replace semi-automatic welding.

Today, many users have realised that modern mechanised or fully automatic pipe welding systems eliminate defects through engineering rather than through wire chemistry, so carbon manganese wires without titanium are gaining in popularity. Both types are now capable of producing excellent toughness, Table 1.

Even with mechanised welding systems, productivity continues to be an issue and contractors have started to look at the use of metal-cored wires as a direct substitute for solid wires in mechanised downhill welding. Productivity improvements of up to 20% seem to be possible and because the wires are formulated with small amounts of material to improve the arc characteristics and the wetting of the joint by the pool, process tolerance is improved. To help in this, wires are designed with a higher oxygen content than is found in solid wires, so a small nickel addition may be made to counteract any adverse effect on weld toughness. The first production pipeline welds with metal-cored wire were made in the year 2000, and Table 2 shows a procedure for welding X80 pipe with a 0.8% Ni metal-cored wire.

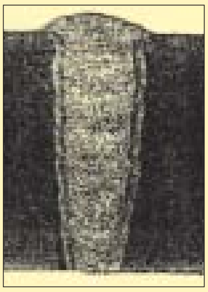
The degree of strength overmatching here is fully acceptable, but in earlier work it was found that on different X80 pipe materials, transverse tensile tests failed in weld metal at strengths up to 768 MPa. A 1.5% Ni, 0.3% Mo wire could be used if real overmatching is specified for such pipe. Up to now, however, the view in the UK has been that that would not be necessary for onshore pipe. This has not been put to the test yet because the pipe delivered so far has not shown such extreme strength.

X80 Pipelines – repair and tie-in welding

Unlike mainline welds, repair and tie-in welds have to be made with no backing systems or internal welders. Nor is it often possible to re-bevel on site to produce an accurate compound bevel. This leads typically to the use of cellulosic electrodes for the root: these may be of the softer E6010 type for greater ductility and crack resistance. Increasingly, flux-cored wire is used for the fill and cap, being suitable for a wider joint such as the 60° included angle API bevel. The wires are of the all-positional rutile type and are used in the uphill direction.

At the outset of the current campaign of X80 pipe laying in the UK, it was envisaged that there would be few problems with tie-in procedures, since steel of equivalent strength had long been welded with rutile flux-cored wires in submarines, cranes and earth moving equipment. Unfortunately in pipe welding, where welding is always on the critical path for construction, the slow, careful procedures and strict control of heat input and interpass temperatures which have led to success in military applications are not popular. It immediately became clear that welding with stringer beads would not be acceptable, and that the higher interpass temperatures and wider weaves that would be used would require more highly alloyed weld

Welding procedure



Pipe	48” X80, 31.8 mm w.t.
Welding consumable	OK Autrod 12.66, 1.0 mm
Welding process	mechanised GMAW
Preheat temperature	108°C
Interpass temperature	110-135°C
Welding direction	downwards
Shielding gas	root: CO_2
	fill & cap: 30%Ar, 70% CO_2
Polarity	electrode positive
Root	Copper backing, 240-295A, 25-27V, 0.9m/min, 0.39-0.48 kJ/mm
Fill runs 1-10	210-260A, 24-28V, 0.36-0.53m/min, 0.49-0.85 kJ/mm, weave 1.5-6 mm at 1.8-5.8 Hz
Cap runs 8,9	180-215A, 20-23V, 0.32m/min, 0.63-0.87 kJ/mm weave 8.6 mm at 0.6Hz

MECHANICAL PROPERTIES

	Tensile properties			Charpy toughness, J at -30°C	
	PS (MPa)	TS (MPa)	El %		
Longitudinal	693	806	20	root:	110
Transverse		665-678	Broke outside weld	cap:	84
CTOD at -30°C, mm	0.25, 0.39, 0.25, 0.80, 0.80, 0.84				

Table 1. Welding procedure for X80 pipe using carbon-manganese solid wire.

metals for the same steel strength. A wire giving a minimum yield strength of 620 MPa in an all-weld-metal test was quickly formulated and gave the necessary degree of overmatching if the heat input was closely controlled. In practice, it was found that in a 16 mm thick joint, a full weave could be used on all passes except the cap, which had to be completed in two passes.

While some contractors accepted this limitation, others regarded it as too restrictive and wanted to use a fully weaved cap. A further wire was offered to them. This had been developed for 690 MPa steels. At this strength level, the wire had to be formulated to produce weld metal with a lower oxygen content. As a result, the surface tension of the transferring droplets increased, the droplets became coarser and spatter increased slightly. Procedures with the two wires are shown in Table 3.

In the event, main contractors opted for the increased tolerance to misuse afforded by the stronger wire, and sub-contractors were also told to use this. As a postscript, in 2001 a contractor using downhill welding dropped out at short notice and a 38 km X80 line was entirely welded using the uphill tie-in procedure, Fig 2, with a repair rate approaching 1%.

X80 Pipelines-double jointing

For onshore lines in the UK, double jointing is rarely an option because the rights of way restrict movement of 24 m pipe lengths. Procedures have however been developed for offshore work and these are also suitable for more open landscapes, especially in the Middle and Far East. Solid wire has been used for many years in submerged arc double jointing, and since the seam weld of the pipe is made by the same process, alloy grades for welding all types of pipe are readily available. Double jointing is carried out off line, so in many cases speed is not critical. A more recent development arises from the use of triple and quadruple jointing on laybarges, where it becomes difficult to keep up with the speed of the fixed position welding. In that case the use of tubular wire in submerged arc can help to redress the balance. Tubular wire has recently been used for quadruple jointing on the Blue Stream project in the Black Sea. It may be that the expected new Alaska pipeline, which could involve over 100,000 double joints, will see the first onshore use of tubular wire with submerged arc.

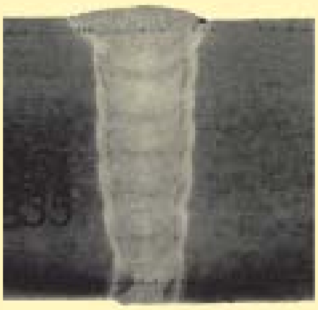
X100 and beyond

If welding of X80 pipe involves a relatively straight-forward extrapolation of well tried technologies, albeit with a steep learning curve for those contractors not accustomed to having to control welding procedures, higher grades of pipe will represent more of a quantum step for consumable manufacturers and users alike.

Most codes for pipe welding require that the weld metal matches the specified minimum yield and tensile strengths of the pipe material, but a recent trend is for clients to look for welds which match the actual pipe properties. Steelmakers have less experience of high strength pipe and may be tempted to aim high to avoid missing strength targets. If welding manufacturers have to ensure that the bottom end of the weld metal strength distribution exceeds the top end of the pipe strength distribution, they may have to supply what is effectively an "X120" weld metal, with a yield strength of 830 MPa or more, to weld X100 pipe. Such products have been used in other industries in closely controlled workshop conditions, but the challenge is to provide a robust means of welding pipelines in the field.

Welding procedure

Welding consumable	PZ 6104, 1.2 mm
Pipe	X80, 24” x 25.8 mm wt
Welding process	mechanised GMAW
Preheat, °C	100 min
Interpass temp, °C	200 max
Welding direction	downwards
Shielding gas	80% Ar, 20% CO_2
Polarity	Electrode positive
Root	Copper backing
Fill runs 1-8	24V, 260A, 0.68 kJ/mm



MECHANICAL PROPERTIES

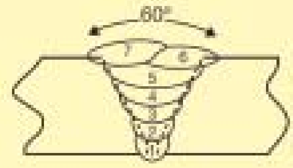
	Tensile properties			Charpy toughness, J at –40°C	
	PS (MPa)	TS (MPa)	El %		
Longitudinal	667	728	18	root:	87
Transverse		608-632	Broke outside weld	cap:	74

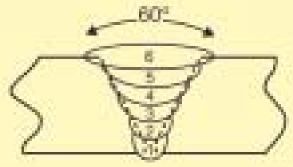
ANALYSIS (%)

C	Si	Mn	P	S	Ni
0.08	0.59	1.68	0.012	0.008	0.73

Table 2. Welding procedure for X80 pipe using 0.8% Ni metal-cored wire.

Welding procedure





Welding consumable	Tubrod 15.07, 1.2 mm		Tubrod 15.09, 1.2 mm	
Welding process	mechanised FCAW			
Preheat , °C	100 min			
Interpass temp, °C	150 max			
Shielding gas	$80Ar-20CO_2$			
Polarity	electrode positive			
Root	E6011, DC-			
Hot pass	E9010, DC+		E8010, DC+	
Fill, runs 3-5	170A, 23V, 0.24 m/min, 0.98kJ/mm, full weave		220A, 25V, 0.24 m/min, 1.38kJ/mm, full weave	
Cap	170A, 23V, 0.24 m/min, 0.98kJ/mm, 2 runs, split weave		190A, 25V, 0.24 m/min, 1.19kJ/mm, 1 run, full weave	
MECHANICAL PROPERTIES				
Tensile properties				
	PS (MPa)	TS (MPa)	PS (MPa)	TS (MPa)
Longitudinal	721	765	670	721
	El %	R of A %	El %	R of A %
	17	63	21	67
Transverse tensile strength	641 MPa, broke outside weld		641 MPa TS, broke outside weld	
Charpy toughness				
J at -40°C	118, 108, 116, Av 114		82, 84, 84, Av 83	
WELD METAL CHEMISTRY				
C	0.053		0.042	
Si	0.32		0.34	
Mn	1.43		1.17	
Ni	2.06		2.56	
Mo	0.04		0.25	

Table 3. Procedures for tie-in welding of X80 with flux-cored wire

Hydrogen-induced cold cracking (HICC) is likely to be the greatest problem encountered in welding very high strength pipelines, and a major programme to look at this is being run by VTT in Helsinki, with the co-operation of European and Japanese industry. Welding consumables with very low hydrogen contents will be needed and weld microstructures will assume greater importance. Manufacturers and research institutes are collaborating on the next generation of welding procedures and will be ready to work with clients and contractors to ensure their success.

About the author

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Fig 2. Mechanised uphill welding with rutile flux-cored wire on the X80 Hatton-Silk Willoughby line
Photo courtesy of Gridweld Ltd.

Synergic Cold Wire (SCW™) Submerged Arc Welding

Application of a new cost efficient welding technique to stainless steels

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The Synergic Cold Wire (SCW™) process is a recent development of submerged arc welding (SAW) in which a cold wire is fed in synergy with the wire electrode into the weld pool. In the present study, SCW™ has been applied for the first time to the welding of 22%Cr duplex stainless steel. Experimental welds with good mechanical properties and good corrosion properties were produced in a highly productive manner.

Introduction

Submerged arc welding (SAW) is currently a well established method for welding most grades of the more widely used stainless steels. Offering high productivity in combination with good weld quality and environmental advantages, SAW is an attractive method, especially when it comes to welding thicker materials like those in large pipes and vessels, for example.

The Synergic Cold Wire (SCW) process is a recent development which was invented in 1998 (1) and offers the chance to increase the deposition rate in submerged arc welding by more than 50%. In SCW-SAW, a cold wire is fed in synergy with the arc wire into the weld pool where it melts (2, 3). Consequently, the arc and cold-wire deposition ratio always remains constant once the wire diameters have been fixed. The cold wire can be either trailing or leading, depending on penetration versus build-up requirements. The weld metal chemistry and deposition rate are thereby easily controlled and pre-selected.

The SCW process is preferably used for welding material thicknesses above approximately 8 mm, where several passes are required. SCW welding can be used with an endless variety of combinations of solid and/or cored wires for single-, twin- (the Synergic Cold Wire Twin [SCWT™] process), tandem- and multiple-wire applications. As no arc emanates from the cold wire, it is also possible to incorporate "hard to weld"' alloys in cored wires. Further advantages include less distortion due to a lower effective heat input, a reduced number of weld beads and lower flux consumption in comparison with conventional SAW. SCW welding is also very operator friendly as no additional control unit or separate feeding device is needed.

In just a short time, SCW welding has proven its advantages when applied to the welding of C-Mn steels (4). This paper presents the first results relating to the SCW welding of duplex stainless steels, illustrating the benefits and potential of this new technique. The effect of welding procedure on weld metal composition and properties will be discussed and it will be demonstrated that excellent weld metal properties can be achieved in a reliable, cost-effective and productive manner. It will also be shown that lowering the "effective heat input", compared with conventional SAW, makes the method particularly well suited to the welding of steel grades where productivity is hampered by heat input restrictions.

Experimental procedure

Welds were produced in EN 1.4462 standard duplex stainless steel plate material using the SCW technique and were subjected to X-ray inspection, metallographic studies, corrosion testing and mechanical testing. In addition, a number of welds were produced in 20 mm mild steel with conventional single-wire SAW and with SCW in order to compare deposition rates.

Duplex SCW welds

Three SCW welds were produced in duplex stainless steel plate material with a thickness of 14-22 mm using a wire electrode with a diameter of 3.2 mm in combination with a cold wire with a diameter of 2.4 mm. Details of joint preparation and welding parameters are presented in Table 1 and the weld set-up is shown in Figures 1 and 2.

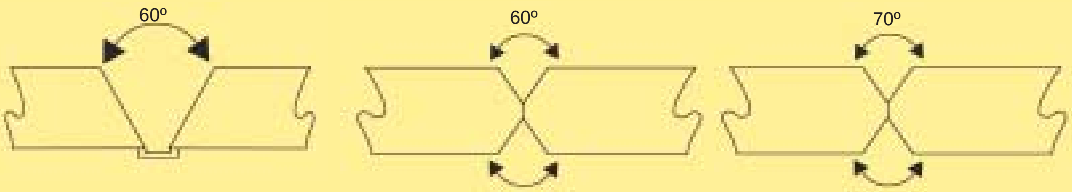
Weld	V-22	V-14	X-20
Parent material	EN 10088 / X2 CrNiMoN 22-5-3		
Plate thickness (mm)	22	14	20
Joint preparation	V–joint	V–joint	X–joint
Joint angle	60º	60º	70º
Root face (mm)	0	4	4
Joint			
Consumables	OK Autrod 16.86/OK Flux 10.93		
Electrode Ø (mm)	3.2	3.2	3.2
Cold wire Ø (mm)	2.4	2.4	2.4
Weld passes	FCAW: 2 SCW™: 7	Side 1: 1 SCW™ Side 2: 1 single wire	Side 1: 1 SCW™ Side 2: 1 SCW™
Current (A)	520–550	540–560	560–575
Voltage (V)	31–33	32–33	33–34
Travel speed (cm/min)	55–60	45–50	50–55
Heat input (kJ/mm)	1.7–2.0	2.1–2.5	2.1–2.2
Remarks	Root welded against backing with OK Tubrod 14.27, Ø1.2mm	Side 2 welded with single wire	

Table 1. Welding details.

Testing and metallography

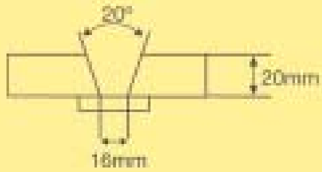
Full-size (10x10mm) Charpy-V specimens were prepared at mid-thickness and tested at –60°C, –40°C and –20°C at the weld metal centre and at the fusion line for the V-joint in 22 mm plate. Full-thickness, cross-weld tensile specimens were tested for all three procedures together with 120º, face and root bend testing over a mandrel with a diameter of three times the plate thickness. HV10 hardness profiles were measured across the welds 2 mm below the top and root surfaces.

The pitting corrosion resistance was assessed by testing 25 x 50xt mm specimens in a standard 10% ferric chloride solution for 24 h at 25°C. The top and root surfaces were tested in the as-welded condition, whereas cut surfaces were ground to a 1,000 grit finish. One specimen from the weld in 14 mm plate material (weld V-14) was re-tested after regrinding and increasing the temperature by 2.5°C until pitting occurred.

The microstructures were studied by light optical microscopy after polishing and the electrolytic etching of cross-sections in 10% oxalic acid. A quantitative estimate of the ferrite content variation within the welds was obtained by measuring the Ferrite Number (FN) at 10 randomly distributed points using a Fischer Feritscope.

Figure 1. Submerged arc welding equipment (ESAB A6 Mastertrac) with Synergic Cold Wire kit.

Figure 2. SCW™ set up showing the leading position of the cold wire to the left of the wire electrode (welding direction is to the left).

Parent material	Mild steel			
Joint configuration				
Consumables	OK Autrod 12.22 / OK Flux 10.71			
Process	SAW	SCW™	SAW	SCW™
Polarity	DC+	DC+	AC	AC
Electrode Ø(mm)	3.0	3.0	3.0	3.0
Cold wire* Ø(mm)	-	2.0	-	2.0
Current	500 A			
Voltage	32 V			
Travel speed	55 cm/min			
Heat input	1.75 kJ/mm			
Effective heat input	1.75 kJ/mm	1.21 kJ/mm	1.75 kJ/mm	1.21 kJ/mm
Weld passes	20	13	18	12
Relative deposition rate	100%	154%	100%	150%

* leading cold wire

Table 2. Welding details and productivity comparison between conventional SAW and SCW for an ISO joint in 20 mm plate.

SAW and SCW comparison

A set of welds was produced in an ISO all-weld test joint configuration, in 20 mm mild steel, with conventional SAW and with SCW. Tests were performed with DC+ and AC, while keeping the current, voltage and travel speed constant. Details relating to joint configuration, consumables and welding parameters are presented in Table 2.

Results

Duplex SCW welds

A somewhat smaller face had to be used in SCW compared with conventional SAW to avoid incomplete penetration. However, X-ray inspection and microstructural studies revealed no weld imperfections after fine-tuning the joint preparation and welding procedure. The possibility to produce a flat and even bead profile is illustrated in Figures 3 and 4. The cross-sections in Figure 4 show the absence of defects such as lack of fusion or incomplete penetration.

Weld metal composition and microstructure

The chemical compositions of the last deposited beads are presented in Table 3. Dilution with the parent material was larger for welds deposited with fewer beads, as can be seen from the lower Ni content in welds V-14 and X-20 compared with that in weld V-22.

All the welds had a typical duplex weld metal microstructure (Fig. 5). They were free from intermetallic phases and contained only small amounts of secondary ferrite. The average ferrite content varied from 46 FN for weld V-14 to 75 FN for weld X-20 (Table 4). A comparatively small variation in the ferrite content of each weld was noted in particular for the X-20 high-ferrite weld where the measured range was only 71-79 FN (Fig. 5b).

Mechanical properties

The mechanical properties were on a high level for all three welds (Table 5). Fracture in tensile testing took place at 748-788 MPa in the parent material, well away from the weld, and all the welds passed the root and face bend tests without any remarks. Charpy-V impact testing was only performed for the V-22 weld. The average impact toughness at -20ºC was 125 J at the weld metal centre and 154 J at the fusion line (Table 5).

Figure 3. Typical smooth and flat weld bead surface appearance of SCW™ weld in duplex stainless steel.

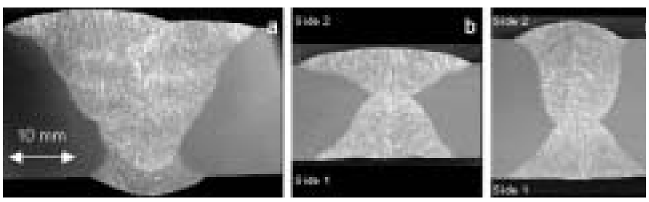


Figure 4. Cross sections of duplex SCW™ welds.
a) One sided V-joint in 22 mm plate (weld V-22).
b) V-joint in 14 mm plate (weld V-14).
c) X-joint in 20 mm plate (weld X-20).

Element	Weld V-22	V-14	X-20
C	0.019	0.019	0.020
Si	0.51	0.52	0.48
Mn	1.29	1.39	1.14
P	0.017	0.021	0.018
S	0.004	0.004	0.002
Cr	22.6	22.2	22.5
Ni	8.0	6.8	7.2
Mo	3.1	3.1	3.1
O (ppm)	470	410	410
N	0.15	0.17	0.16

*The chemical composition was determined using optical emission spectrometry except for N and O where a combustion furnace technique was used.

Table 3. Last bead weld metal chemical composition (wt.%).

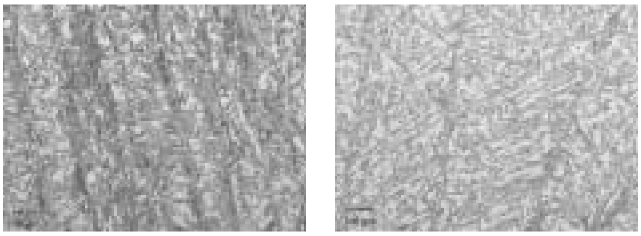


Figure 5. Typical duplex weld metal microstructures of SCW™ welds.
a) Second bead in weld V-14.
b) First bead in weld X-20.

Weld	Ferrite content (FN)* Range	Average
V-22	52-69	61
V-14	43-57	46
X-20	71-79	75

Table 4. Weld metal ferrite content.

**measured at 10 randomly distributed points using a Fischer Feritscope.*

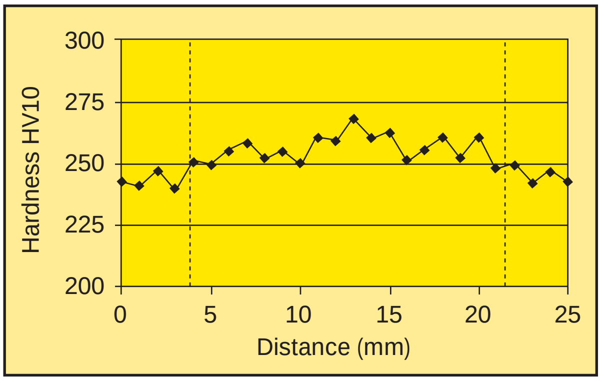


Figure 6. Hardness profile across duplex SCW™ weld V-14 measured 2 mm below top face.

The weld metal and HAZ hardness was in the range of 240-280 HV10 for all three welds. In all cases, the variation across the weld was small, as is illustrated in Figure 6 for weld V-14.

Corrosion resistance

All the welds passed the ferric chloride tests at 25ºC without any indication of pitting attack. A specimen from weld V-14 was re-tested at gradually increasing temperatures, while regrinding the cut surfaces between each test period. Corrosion was not observed until 32.5ºC when pitting took place in the first deposited weld bead.

SAW and SCW deposition rates

The comparison between conventional SAW and SCW welding clearly demonstrated the higher deposition rates that can be achieved with SCW. As can be seen in Table 2, the number of beads required to complete the joint, while keeping welding parameters fixed, decreased from 20 to 13 in the DC+ mode and from 18 to 12 passes in the AC mode.

Discussion

Microstructure and properties

These first preliminary tests using SCW for the welding of duplex plate material clearly illustrate that high-quality welds which are free from imperfections can be produced in a highly productive manner. The mechanical properties, including strength, toughness and hardness, all complied with the normal requirements (Table 5 and Fig. 6), as did the pitting corrosion resistance.

The microstructure contained no unwanted phases (Fig. 5), in agreement with the observed good pitting corrosion resistance. However, the ferrite content of the X-joint in the 20 mm plate was on the high side (71-79 FN), although the properties were still satisfactory. The relatively high ferrite content can be understood in terms of somewhat high dilution with the parent material (Table 3) and a “low effective heat input”, as discussed in the following paragraph. As can be seen from welds V-22 and V-14, a ferrite content of below 70 FN (Table 4) can be easily obtained if a suitable combination of joint preparation and heat input is used.

Weld	Tensile strength (MPa)	Impact toughness (J) -60ºC weld centre	-60ºC fusion line	-40ºC weld centre	-40ºC fusion line	-20ºC weld centre	-20ºC fusion line	Bend testing (120º, 3xt) Face	Root
V-22	763*	68	92	107	125	125	154	no remarks	no remarks
V-14	788*			not tested				no remarks	no remarks
X-20	748*			not tested				no remarks	no remarks

**fracture in parent material*

Table 5. Mechanical properties of duplex SCW™ welds.

Productivity aspects

The potential advantages of using SCW welding instead of conventional SAW are most obvious for thicker material where the productivity gains can be significant. Fewer beads are needed for a given joint, thereby increasing productivity. In SCW, the wire electrode and the cold wire are fed in synergy at the same speed. It is therefore easy to calculate the theoretical increase in deposition rate from the cold wire and wire electrode diameters (Equation 1).

[1] Increase in deposition rate $=100 \times d_{cw}^2/d_e^2$ (%)
where: d_e = diameter of the wire electrode and d_{cw} = diameter of the cold wire

As can be seen from Table 6, the theoretical increase, at a constant wire feed speed and constant travel speed, ranges from 25% to 69% for typical wire electrode/cold wire diameter combinations. In practice, some adjustments to the welding parameters are normally required to optimise the welding for a given joint. For example, as discussed earlier, a somewhat smaller face often has to be used in SCW compared with conventional SAW to avoid incomplete penetration.

Nevertheless, the deposition rate comparison presented in Table 2 clearly illustrates that the theoretical increase of 44% for a 3.0 mm wire electrode/2.0 mm cold wire combination can also be achieved in practice. The estimated increases in deposition rate were 54% and 50% for the SCW DC+ and AC welds respectively. The difference between the theoretical and measured increase in deposition rates can be understood in terms of variations in the reinforcement height and penetration depth.

Effective heat input

Heat input restrictions often apply to the welding of stainless steels in order to avoid the precipitation of deleterious phases in the weld metal or HAZ. For example, a maximum heat input of 2.5 kJ/mm is normally recommended when welding standard 22%Cr duplex stainless steel (5). The nominal heat inputs (Table 1) were in the range of 2.0-2.5 kJ/mm for the SCW™ passes, thereby approaching the upper recommended limit for this material.

It has been argued that the "effective heat input" in cold wire welding is less than the nominal heat input as part of the energy is used to melt the extra wire and is therefore not available for melting and heating the parent material HAZ. Two effects would then be less penetration and a narrower high-temperature HAZ. An effect on penetration was indeed observed and a somewhat smaller face had to be used to avoid incomplete penetration. The effect on the HAZ was difficult to assess. However, the somewhat higher weld metal ferrite content, compared with that normally expected from experience of similar conventional SAW procedures, also suggests that the "effective heat input" is lower for cold wire welding.

Wire Ø(mm) Wire electrode	Cold wire	Heat input reduction factor*	Increase in deposition rate**
4.0	3.0	0.64	56 %
4.0	2.5	0.72	39 %
4.0	2.0	0.80	25 %
3.2	2.4	0.64	56 %
3.0	2.5	0.59	69 %
3.0	2.0	0.69	44 %
3.0	1.6	0.78	28 %
2.5	2.0	0.61	64 %
2.5	1.6	0.71	40 %

* *SCW™ heat input reduction factor:* $C_f=d_e^2/(d_e^2 + d_{cw}^2)$
where: d_e *= diameter of the wire electrode and* d_{cw} *= diameter of the cold wire.*
** *Increase in deposition rate is calculated as* d_{cw}^2/d_e^2

Table 6. Heat input reduction factor and increase in deposition rate.

A heat input reduction factor has been proposed on the basis of the relative diameters of the "hot wire" and the cold wire. Although this is a simplified approach, experience has shown that this factor produces satisfactory results when used to design welding procedures for the SCW welding of C-Mn steel. An "effective reduced SCW heat input" can therefore be calculated by multiplying the nominal heat input by the factor in Equation 2 below.

[2] SCW heat input reduction factor:
$C_f=d_e^2/(d_e^2 + d_{cw}^2)$
where: d_e = diameter of the wire electrode
d_{cw} = diameter of the cold wire.

With a 3.2 mm wire electrode and a 2.4 mm cold wire, the SCW heat input reduction factor is 0.64 (Table 6). The range of effective heat inputs for the duplex SCW welds can then be calculated as (0.64 x 2.0) to (0.64x2.5) kJ/mm = 1.3 to 1.6 kJ/mm. Assuming this approach to be valid, it would be possible to increase the maximum nominal heat input to (2.5/0.64) kJ/mm = 3.9 kJ/mm for standard 22%Cr duplex material. Whether or not this is realistic has to be verified, but the practical implication is that further productivity increases are possible.

The high ferrite content in weld X-20 shows that even higher heat inputs, further increasing productivity, could be used or might even be preferable when applying SCW to the welding of duplex stainless steels. Further tests are needed, however, to determine the upper and lower heat input limits for different joint configurations. One interesting implication is that SCW welding might be particularly suited to highly alloyed stainless steels such as superduplex and superaustenitics known to be sensitive to high heat inputs.

Conclusions

The SCW process offers an opportunity to increase the deposition rate in submerged arc welding by more than 50%. Good agreement was found between the theoretical and measured increase in deposition rate in 20 mm plate material.

- Synergic cold wire submerged arc welding (SCW) has been applied successfully to the welding of 22%Cr duplex 14-22 mm plate material.
- High-quality welds with good mechanical properties and good corrosion properties were produced in a highly productive manner.
- No intermetallic phases or significant amounts of secondary austenite were detected.
- The smaller penetration and higher ferrite content than expected from experience of conventional SAW suggest that the effective heat input is lower in SCW. An approximate SCW heat input reduction factor is therefore proposed on the basis of the electrode and cold wire dimensions.
- SCW is well suited to the welding of stainless steels and might, as a result of the lower effective heat input, be particularly well suited to welding grades sensitive to high heat inputs.

Acknowledgements

The skilful application of SCW to duplex stainless steel by Vital Batista (ESAB AB, Sweden) is gratefully acknowledged. Lars Östgren and Lennart Wittung (ESAB AB, Sweden) are thanked for valuable discussions and for proposing the heat input reduction factor.

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About the authors

Solveig Rigdal, MSc, EWE, joined ESAB in 1982 and has since then worked with product development and market support within the R & D department in Gothenburg. During the last years, her main focus has been submerged arc welding of stainless and high alloyed steels and strip cladding.

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Welding tramway rails in Bucharest

By: Ben Altemühl, editor of Svetsaren

The Bucharest transport authority (RATB) is facing the important task of overhauling and extending the city's tramway rail infrastructure. In all, 100 kilometres of track are in the process of being renewed. ESAB is involved in the construction of line 41, a completely new section, through its distributor Scandio S.A., who obtained approval from the RATB to utilise the enclosed welding process with ESAB consumables.

Acknowledgement

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Introduction

As in many cities behind the former iron curtain, Bucharest's tram lines were constructed during the communist era. The rail bars were produced in Russia and were of a poor quality. Over the years, the intensive use of the lines, in combination with the inferior steel, caused damage to the rails and repair work was a daily routine. Repairs were carried out with MMA. They were, and still are, difficult to perform, because the rails are sunk in the streets and the welder's visibility at the weld pool is hampered. In addition, welders were often poorly qualified and had to do the job in weather of all kinds. It is not difficult to imagine that the current RATB inherited a railway infrastructure in very poor condition, with innumerable worn or badly repaired spots. A great deal of work has since been done by qualified welders using the appropriate welding procedures to improve the condition of the tram lines and the number of breakdowns has declined significantly. Nevertheless, the need gradually to modernise the lines in order to arrive at a permanent solution still remains.

Line 41 is a completely new section under construction, with a length of 16 kilometres. It is being built by CCCF, one of Romania's largest construction companies which specialises in the construction of tramways and railways. The switches, crossings and bends are prefabricated by one of CCCF's subcontractors, VAE Apcarom, whose contract includes connecting the prefabricated parts to the main track.

ESAB's distributor in Romania, Scandio S.A., suggested the use of the enclosed welding method to VAE Apcarom, for which approval was obtained from the RATB after having successfully completed the qualification tests. The actual work is now being done successfully by welders from the construction branch of Scandio.

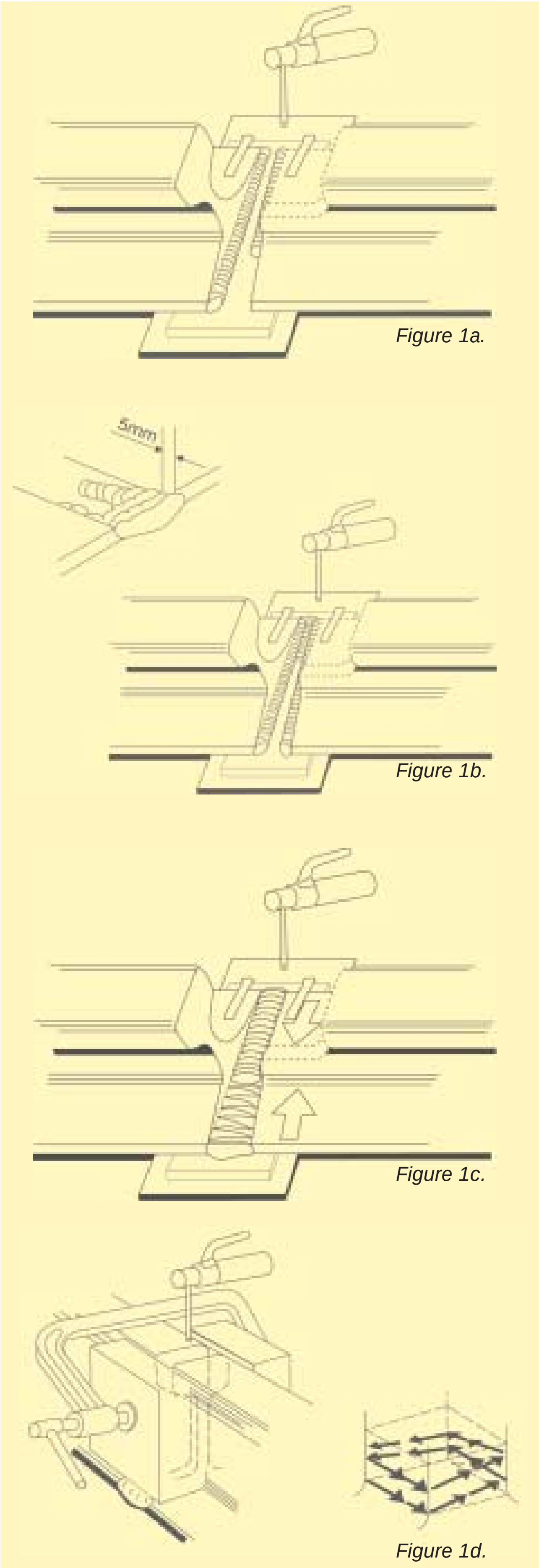

Figure 1a.

Figure 1b.

Figure 1c.

Figure 1d.

Figure 1. Enclosed welding in steps, as explained in the text. 1a. and 1b.: Welding the root onto the rail foot. 1c. Completing the foot. 1d. Mould welding.

Why enclosed welding?

Exothermic or thermit welding is the principal method that is used for joining rails in the straight parts of the track, which contain the majority of the welds. It is an established method, in both tramway and railway construction.

Enclosed welding, or mould welding, is more suitable for use in confined spaces such as switches and crossings, as the space required is not much greater than the size of the copper moulds. The process has additional advantages, however, making it interesting for other rail - welding applications as well. They are as follows.

- It requires roughly the same time to deposit a mould weld as an exothermic weld, but the cost is eight times lower.
- The weld metal from mould welding is homogeneous and free of porosity, resulting in superior bending properties.
- The top layers are performed with a hard-facing alloy to produce superior wear resistance.
- The heat input is lower, resulting in less distortion.
- Repair of mould welded joints is possible.

The opportunity to obtain welds with extra wear resistance at the bends, switches and crossings was the key argument for the RATB to give the go-ahead to use the enclosed welding method. This naturally only took place after welding procedure qualifications had proven successful in delivering sound welds with the right mechanical properties.

Principle of enclosed welding

Enclosed welding was developed by ESAB in co-operation with the Swedish Railways. It is a method based on manual welding with stick electrodes, unlike exothermic welding in which the rail ends are connected by casting. Consequently, the weld metal properties are different, as described above.

The weld preparation is a parallel-sided gap between the rail ends, which is filled from foot to head. The root gap is 15-17mm. The welding begins on a special backing strip made of glued sand, OK Backing 21.21 (Figure 1a.). The principal welding consumable is OK 74.78, a basic, high tensile basic electrode with slag behaviour tuned to match this process.

The gap is closed in three steps. Firstly, one bead is deposited onto each rail foot and the gap is then closed (Figure 1b). From the fourth bead, the gap is filled by fully weaving. The top layer of the foot is laid from two sides towards the heart of the rail using a zig-zag movement (Figure 1c).

Next, a copper mould is put in place to create the enclosed space for the mould welding of the web and the head of the rail. Spacers on the mould halves provide a certain distance between the mould and the rails, which is needed to dispose of excess slag. The enclosed space is filled by moving the arc in a square while dwelling for a short time in each corner (Figure 1d).

Figure 2. Alignment of the rail, an important task.

Figure 3. Placement of the ceramic backing strip OK Backing 21.21.

Figure 4. Welding of the rail foot.

Figure 5. Mould welding with OK 74.78. Note the use of electrodes from VacPac vacuum packaging.

Table 1. Chemical composition and mechanical properties of rail steel according UIC 860.

Grade	C-eq.	%C	%Si	%Mn	Hardness HB	Rm (MPa)
800A	0.50-0.66	0.45-0.60	0.05-0.35	0.95-1.25	230-270	740-900
900A	0.64-0.86	0.60-0.80	0.10-0.50	0.80-1.30	260-290	880-1030

Table 2. All-weld metal chemical composition and mechanical properties of OK 74.78 and OK 83.28.

Type	%C	%Si	%Mn	%Mo	%Cr	Rm (MPa)	Rp0.2 (MPa)	CVN J at -40	Hardness HRC
OK 74.78	0.06	0.35	1.5	0.35	-	650	600	60	-
OK 83.28	0.1	<0.7	0.7	-	3.2	-	-	-	30

Table 3. Welding parameters for mould welding with OK 74.78 and hardfacing with OK 83.28. Rail type NP4aS.

	Type	Diameter	Polarity	Current	Arc voltage
Foot (1)	OK 74.78	5mm	DC+	230-260A	20-30V
Web (2)	OK 74.78	4mm	DC+	200-220A	20-30V
Head (3 & 4)	OK 74.78	4mm	DC+	200-220A	20-30V
Hardfacing (5,6,7)	OK 83.28	4mm	DC+	160-180A	20-30V

It is important to keep welding without allowing the slag to solidify, so electrodes have to be changed as quickly as possible. Interruption of the process is time consuming, because the mould has to be removed in order to detach the slag and provide a clean weld to re-start the process.
Some 6-8mm below the surface of the head, the mould welding is stopped, the mould is taken off and the slag is removed in order to provide a clean surface for hard-facing with OK 83.28, which is deposited in two layers.

The above is a general description of the process. The techniques used in mould welding are, however, very specific and welders really need good training before they can produce a sound rail weld. This training comprises not only welding techniques but also the alignment of the rails, a knowledge of pre-heating and the post-weld heat treatment of various rail grades, as well as grinding the joint to the final geometry. Detailed instructions on mould welding are available from ESAB.

Procedure qualification

ESAB assisted Scandio in the welding procedure qualification that was needed to obtain the approval of the RATB to use enclosed welding on line 41. Under the supervision of Scandio's welding engineer, Laurentiu Chiritescu, a few welders were trained by ESAB and a welding procedure for the specific steel grades was established. The steel grades that were included were UIC 860: 800A and 900A (Table 1). Table 2 gives the product data of the ESAB stick electrodes used.

Table 3 shows the welding parameters used for mould welding with OK 74.78, including the electrode sizes used for the foot, the web and the head of the rail. For both rail grades, 800A and 900A, Scandio applies a preheat temperature of 350°C, a maximum interpass temperature of 400°C, and a PWHT of 600°C/15 min.

The procedure qualification report submitted to the RATB comprised the results of dye–penetrant testing, bending tests, hardness tests and macro- and micro-structural analyses.
These reveiled a defect- and porosity-free weld with a ferritic-perlitic structure and a hardness below that of the rail itself. Bending tests yielded properties that were superior to exothermic welded joints. The hardfacing layer deposited with OK 83.28 shows a bainitic micro-structure with a hardness of approx. 30HRC. On the basis of this report, Scandio obtained approval to use enclosed welding.

Welding line 41

Scandio has access to six welders qualified to perform the enclosed welding method. They have been trained by the company's own welding department, assisted by ESAB. The work on line 41 is being performed round the clock, whenever the weather permits . Fortunately, this summer's floods in Central Europe hardly affected Romania and the city of Bucharest, although work on rail 41 was hindered by frequent showers during which no welding could take place. Nevertheless, Scandio is making good progress with the project that started at the end of August and is expected to be finished by October.

The net arc time for one weld is approximately one hour, but the entire procedure, including the alignment of the rail ends, preheating, post-weld heat treatment and grinding, takes some three to four hours. The alignment of the joint (Figure 2) in particular is a precise, responsible job, as any misalignment will unavoidably lead to friction, shock and extra wear when the trams pass.
Figures 3 and 4 show the placement of the backing strip and the welding of the foot.

The most difficult part for the welders is when the copper moulds are in place and the welding can no longer be interrupted. They work close to the preheated rails, while having to continue welding with a very large weld pool, maintaining the special technique that is needed. The rail type that is being used for the curved tracks is NP4aS (Figure 5), which has a slot along the centre line to prevent the tram from tilting. This requires additional welding skills, because part of the head has to be welded with copper backing on one side only.
In the often very humid weather conditions, stick electrodes would easily pick up moisture when not protected. The fact that ESAB packs its repair and maintenance electrodes as standard in VacPac vacuum packages (Figure 5) ensures low-hydrogen weld metal and thereby protection from hydrogen-induced cracking. This is essential for rail steels, which have relatively high hardenability.

The RATB is very satisfied with the performance of Scandio on line 41 and has a great deal of confidence in the quality produced by the enclosed welding method. Its use on other Bucharest tramway lines is anticipated.

The mechanised MAG welding of the Clare natural gas line

Proof of the pudding for OK 12.65 copper-free wire

by Vittorio Carucci, ESAB and Andrea Fulcini, Ghizzoni

As one of three pipeline contractors, the Italian company Ghizzoni is involved in the extension of the Irish national gas grid to the west of the country.

The new 335 km long pipeline is an EU funded project of considerable economic importance for the western counties of Galway, Clare and Limerick, as until now they have been excluded from the grid. The decision to commence with the project had been pending for a long time, but it was really boosted by the discovery of massive gas supplies at the Corrib Field, off the Irish coast. The first environmentally-friendly natural gas will reach the mid-west households and industries by early 2003, when the extension becomes operational.

The line section that falls under the responsibility of Ghizzoni runs through the county of Clare and has a length of 100 km. For this purpose, the Italian contractor with 800 employees world-wide, has established a temporary project head office in the picturesque city of Limerick, right on the border between the counties of Limerick and Clare. A staff of 238 personnel, including welding engineers, welders and inspectors, many of whom are Italians, has given the historic site a Latin touch ever since the project started in February 2002 . Italian flags flying from car antennae were a common sight during the 2002 World Cup football games and among the crowd of fans supporting the Irish team in the local pubs, many were remarkably dark-haired. Guinness with Martini appears to be a good mix!

Although the landscape may be scenic, the local climate, with more than 200 days of wind and rain a year, did not really turn this project into a holiday trip for the "Azzuri". The Irish mud is deep and sticky and maintaining the front-end laying speed of the line requires a huge effort, careful organisation, a high degree of self-support, and of course, a dependable welding technology.

Mechanised downhill MAG welding

To weld the 30-inch OD and 11mm WT API 5LX65 grade pipeline, Ghizzoni utilise a well-established yet remarkable technique, downhill MAG welding with solid wire under CO_2 shielding gas. The mere thought of this would send shivers down the spine of any welding engineer in shipbuilding or offshore, but for pipelines it has proven to be a dependable and highly economic method.

Ghizzoni use automatic welding equipment consisting of two welding tractors walking from 12 to 6, clockwise and counter-clockwise, over a track fixed to the pipe circumference with a quick snap coupling (Figure 1). The internal clamp is equipped with copper shoes to provide the root pass backing. The welding parameters and stick-out length for each pass are pre-programmed in a control unit that moves, with the

Figure 1. Mechanised pipe welding equipment running ESAB OK 12.65 EcoMig wire.

power source, along the line on a truck. Once clamped onto the track, the welders position the torch using a simple panel and set the right parameters by selecting the bead sequences on a remote control, both mounted on the tractors.

Solid wire MAG welding under CO_2 gas protection is a process rarely used in other industries, because of the unfavourable globular droplet detachment and the high spatter level involved. In semi-automatic welding, the use of argon based mixed gases dominates because of the stable arc characteristics and the high possible welding currents.

The pipeline business is, however, an industry in its own right, with its own typical rules. The one and only decisive factor is the front-end laying speed and any welding process that promises a higher speed while offering the required weld quality, is interesting by definition. For pipeline fabricators, CO_2 as a shielding gas has one important benefit that overrides all the disadvantages, the very secure weld penetration. This helps to realise the objective of limiting the weld volume, leading to the type of joint preparation with a small included angle shown in Figure 2, which is actually being used by Ghizzoni for the Clare gas line project.

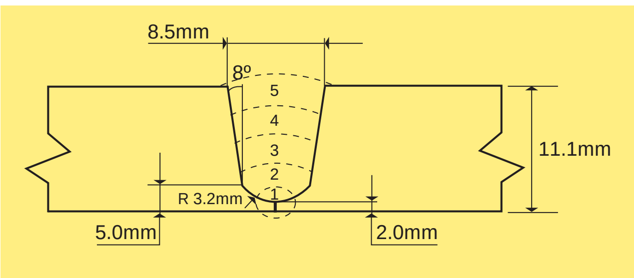

Figure 2. Joint design for the Clare gas line.

The root pass can be seen as an I-joint in 2mm material thickness. It is welded vertically down at 250-280A/21.5-23.5V and a travel speed of 60-85 cm/min. No weaving is applied. All the arc energy is directed towards the centre to obtain full penetration against the copper backing shoe, aided by the wide and deep penetration profile created by CO_2. At these carefully selected welding parameters, the spatter stays within acceptable limits and no time consuming grinding work is needed before the next layer (Figure 3). In semi-automatic welding it would be extremely difficult to control the spatter, because the parameter box to remain within is very small and impractical to handle manually. With mechanised welding, the parameters are fixed and, if weld edges and pipe out-of-roundness are carefully kept within the specified tolerances, the arc can remain stable throughout the entire weld length.

The hot pass is also done under CO_2 gas shielding, but in this case a little weaving is applied to ensure good sidewall wetting. Subsequently, the travel speed is reduced to 45-55 cm/min.

As soon as the hot pass is finished, the internal clamp is removed and the scene is struck by a flurry of activity. The root/hot pass welders and their equipment, the truck with the power sources, and the welding tent move on to the next position where the beveled and preheated joint with the guide track attached are waiting for the internal clamp and the welding tractors to be positioned.

For the filling passes, welding speed is no longer the dominant factor, since the front-end laying speed is determined by the time needed for the root/hot pass. As many teams as needed can be put on the filling job to keep up with the front-end welding. In this case, Ghizzoni's welding procedure prescribes the use of 50%Ar/50%CO_2 mixed gas running the equipment at

Figure 3. Root pass produced under CO_2 gas protection. Note the rim in the heart the weld, which is typical for CO_2.

slightly lower parameters with full weaving, and a travel speed that goes down towards the cap layer. This reduces the spatter, improves the bead appearance, and reduces the amount of silicates on the weld surface, whereas the larger weld pool ensures good sidewall fusion (Figure 4).

It must be said that the welding procedures for the mechanised solid wire MAG welding of pipelines differ from contractor to contractor. This is due to differences in equipment and consumable quality, but also to history and tradition. Procedures are known in which the root pass is performed with argon base mixed gas and the filling with CO_2. Contractors develop their welding procedures to match their own situation, but the aim for all of them is to obtain an optimal front-end speed and consistent and dependable weld quality.

OK Autrod 12.65

OK Autrod 12.65 (AWS A5.18: ER70-S6) is a version of the successful ESAB line of copper-free MAG wires, with a chemical composition adapted to the special conditions associated with mechanised pipeline welding.

The wires have a copper-free surface to avoid process disturbances due to copper flaking in liners and contact tips. Feedability and current transfer are optimised with a special surface treatment, resulting in a consistently stable arc. ESAB copper-free wires are very successfully used in welding applications with a high duty cycle where feedability problems lead to inconsistent weld quality or even to costly downtime, such as robotic welding stations in the automotive industry. In mechanised pipeline welding, the duty cycles are lower and the liners considerably shorter. Arc stability, however, remains an important prerequisite, because of the narrow process tolerances described above. Welds are normally 100% ultrasonically tested, and any defect may lead to costly repair procedures.

Ghizzoni is one of the first pipeline contractors to use OK Autrod 12.65 in a mechanised pipeline project, the Clare gas line. The 1.0mm wire is supplied on 5kg spools that fit on the automatic equipment. It is being used to full satisfaction. No feedability problems have been reported throughout the construction, confirmed by a very low repair rate.

Figure 5. Downhill welding of a tie-in with Pipeweld 6010 cellulosic electrodes.

Tie-in procedures

Any pipeline project inevitably has a number of locations at which mechanised welding can not be applied, such as bends, crossings, elevations and T-joints with other lines. Due to their geometry, they have to be welded without internal backing for the root pass. This work is therefore often done manually with stick electrodes.

Ghizzoni use ESAB Pipeweld 6010 plus electrodes for the uphill welding of the root and Pipeweld 8010 for filling and capping downhill. Pipeweld electrodes have a penetrating arc and a fast freezing, easily detachable slag. They are very tolerant for welding joints with poor fit-up, as is often the case with tie-in jobs.

Figure 4. Finished weld. Filling and capping is done under 50%Ar/50%CO_2 mixed gas.

About the authors

Vittorio Carucci (33) joined ESAB in 2000 and is currently global manager for the pipeline segment. Before ESAB, he worked as field welding engineer for Saipem on main pipeline projects, both on- and offshore.

Andrea Fulcini (36) joined Ghizzoni in 1987 and is currently technical manager and company welding engineer. In this position, he has co-ordinated and managed main pipeline projects across Europe.

CONSUMABLE DEVELOPMENT FOR OXIDISING CHLORIDE CONTAINING PROCESS ENVIRONMENTS

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The use of high-alloyed austenitic and duplex stainless steels has steadily increased in modern process equipment, as a result of new processes and more aggressive environments. Pulp and paper processes, chemical reactors, desulphurisation plants and sea water structures are among the most typical applications in which these new stainless steel grades are used. To improve corrosion resistance, these steels are more alloyed in chromium, nickel, molybdenum and nitrogen. The welding of these steels becomes more demanding, however, and this calls for the development of new, more corrosion resistant consumables, especially for Cl-containing and oxidising process environments causing general transpassive weld metal dissolution.

Introduction

Stainless steels structures and the welded joints in them in particular are mainly corroded by localised corrosion mechanisms which are rapidly enhanced in the presence of chlorides. In welded joints, corrosion attacks are also affected by inhomogeneous composition in the weld metal (segregation), weld oxidation and weld geometrical effects. For these reasons, it has been found necessary to use high-alloyed welding consumables that eliminate localised corrosion problems in the weld metal region. As a result, high-alloyed austenitic stainless steels are normally welded with high Mo-alloyed, Ni-base consumables. This enables the inhomogeneity caused by weld segregation to be eliminated because the lower alloyed weld regions (dendrite cores) will have a corrosion resistance that is equal to or higher than that of the base metal. This reduces the nucleation and growth of corrosion pits in the weld metal region and the localised corrosion resistance of a weld is thus improved.

In highly oxidising conditions such as in chlorine dioxide (ClO_2) bleaching, there is, however, a need to consider not only localised corrosion but also general corrosion of welds and base metals. There is evidence that a weld that is optimised for localised corrosion resistance shows insufficient resistance to general corrosion via transpassive dissolution mechanisms, see Fig. 1. To find new solutions to this ”balance“ problem, an R&D project “Optimisation of corrosion resistance of welds for oxidising industrial processes” was implemented in 1999-2001. The objective of this project was to clarify how the general corrosion resistance of high-alloyed stainless steel welds can be improved in highly oxidising environments, while still maintaining adequate localised corrosion resistance. A mathematical model was developed to improve our understanding of the corrosion phenomena and for the selection of appropriate weld alloying. The project was carried out jointly with ESAB AB, Andritz Oy, Kemira Chemicals Oy, the National Technology Agency, the Tohoku University in Japan and VTT Industrial Systems in Finland. This article summarises the main results of the research project.

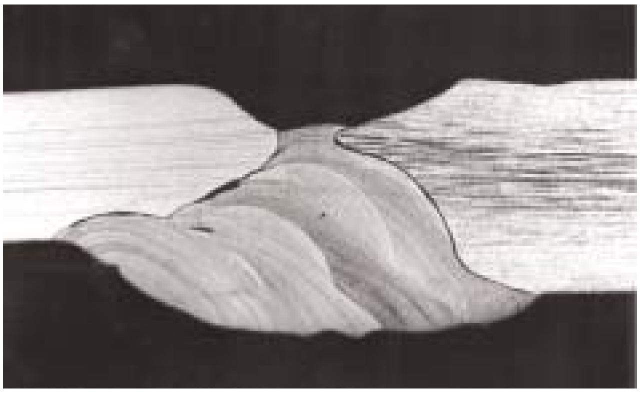

Fig. 1. General corrosion propagating in a Ni-base site weld of a high alloyed (6%Mo) stainless steel. The sample is taken from a mixer to tower pipeline of D1/P1-stage. The estimated corrosion rate has been 0.4 mm/a.

Localised corrosion of welds in oxidising conditions

The presence of chlorides is the main reason for the localised corrosion of stainless steels and their welds.

The susceptibility to localised corrosion also increases with rising temperatures and with increasing oxidising capacity of the environment. Strong oxidisers such as chlorine dioxide (ClO_2) and ozone (O_3) used in pulp bleaching, therefore play an important role from the point of view of localised and general corrosion susceptibility.

The weld metal microstructure plays a major role with respect to local corrosion resistance. The corrosion behaviour of weld metal differs from that of the more homogeneous base metal that has been manufactured by rolling and subsequent heat treatment. A solidified weld metal, instead, remains in the ”as-cast” condition, showing far more pronounced inhomogeneity than the base metal. The main reasons for this inhomogeneity are the microsegregation which takes place during weld solidification and the uneven partitioning of alloying elements between different phases during phase transformations. In high-alloyed austenitic stainless steel welds, the microsegregation of Mo and Cr in particular leads to a remarkably inhomogeneous weld composition. After weld solidification, the dendrite cores are, therefore, depleted in Cr and Mo, whereas the interdendritic regions are enriched in these elements. Consequently, the dendrite cores are more easily attacked in a chloride-containing environment, which results in inadequate corrosion resistance unless the weld composition is overalloyed. The corrosion resistance of a weld may also be created by the precipitation of Cr- carbides and intermetallic phases such as sigma-phase in the weld metal microstructure [1-7].

To avoid the above mentioned problems, the weld composition is normally overalloyed to eliminate local underalloyed regions from the weld microstructure. To achieve this, it has been generally recommended to use Ni-based consumables when welding high-alloyed stainless steels. For example, the welding of 254 SMO - steel (6 %Mo) is usually carried out with a high Mo-containing (9 %Mo), Ni-base consumable. For 654 SMO (7.5 %Mo), the Mo- content of the consumable is increased to 15 %.

The use of overalloyed Ni-base consumables has some limitations, however. The weldability of these consumables is technically quite demanding, as a result of the more viscous weld pool behaviour, and a skilful welder is therefore needed to avoid weld imperfections. The weld fusion line may also show inadequate corrosion resistance due to the formation of an unmixed zone in the dissimilar joint, see Fig. 2. This is due to the fact that the unmixed zone solidifies in a similar manner as the base metal, leaving a pronounced microsegregation in this narrow weld region.

General corrosion in highly oxidising conditions

In highly oxidising conditions, such as in ClO_2- bleaching, the dominant corrosion mechanism may change from localised corrosion to the so called transpassive

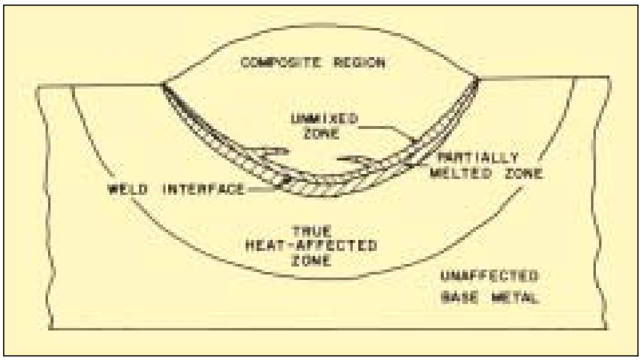

Fig. 2. Schematic presentation of different weld zones [8].

dissolution which causes general corrosion in the base and weld metals. The resistance to general corrosion in highly oxidising conditions depends not only on composition but also on pH, temperature, and on the oxidising potential (ClO_2- content) of the environment.

Research studies as well as practical experience have shown that Ni-base alloys and stainless steels display a different behaviour in ClO_2 -bleaching environments. With stainless steels, the transpassive corrosion rate increases with the oxidising potential of the environment as well as with increasing Cr-, Ni- and Mo- contents of the steel. At low pH- values (< 2), there is no striking difference between stainless steels and Ni-based alloys. As soon as the pH- value exceeds 3, the transpassive corrosion rate of stainless steels decreases, while that of the Ni-based alloys increases. Consequently, the dissolution rate of Ni-based alloys is more pronounced in neutral solutions than in acid environments [9-12].

Both Ni-based alloys and stainless steels display an increased transpassive corrosion in oxidising conditions when the Cr-, Ni- and Mo- contents of the alloys are increased. This is due to the fact that all these elements display more pronounced dissolution rates in oxidising conditions.

General corrosion of welds in highly oxidising conditions

To take account of the possibility of general corrosion, the composition of a weld metal must be optimised to minimise transpassive dissolution. This is important, especially when the localised corrosion resistance of a weld has been maximised with Ni-based consumables, without noticing any enhanced risk of general dissolution. There is clear evidence that, in oxidising and acidic conditions (pH = 3-6), Ni-based weld metals can display a relatively rapid general dissolution via transpassive mechanisms. Important alloying elements (Cr and Mo), which are added to increase localised corrosion resistance, as well as Ni added to maintain an austenitic microstructure, have shown to be harmful with respect to general corrosion resistance. This has led to development work on new welding consumables and welding techniques that take both corrosion mechanisms into account.

It has been demonstrated experimentally that the general corrosion resistance of stainless steels increases in oxidising conditions with an increasing weld metal Fe- content and a decreasing Ni- content [14,15]. It has, therefore, been concluded that the weld metal should contain more than 15 % Fe and less than 50% Ni to ensure the general corrosion resistance of a weld [16,17]. More evidence to support this recommendation has been obtained by testing overalloyed Fe-based consumables with improved general corrosion resistance instead of Ni-based ones. On the other hand, the presence of chlorides must also be taken into account to avoid localised corrosion in the weld metal region.

Experimental welds

Welding procedure tests were carried out in order to measure and optimise weld corrosion resistance in oxidising conditions. The base metal was a high-alloyed austenitic stainless steel, 654SMO, with a sheet thickness of 5.5 mm. The first series of tests welds were performed using the GMA- process with Ni-base wire OK Autrod 19.81 (NiCr23Mo16) using pure Ar shielding gas. Further test welds were carried out with new consumable types developed as a result of the first tests. The composition and test results obtained with these consumables are given below.

The filling sequence of the test coupons was varied so that the composition at the weld surface could be varied via base metal dilution. For this purpose, part of the welds were produced with two single runs from both sides using an I-groove. Some welds were performed using a V-groove (60°) and one to two runs from one side. In these welds, a backing plate manufactured from the base metal was used. The previous welding procedure tests were carried out within a welding energy range of 0.5 - 1.1 kJ/mm. In addition, an all-weld-metal sample was fabricated by depositing filler wire on eight overlapping runs on the base metal.

After welding, the weld composition obtained in various tests was measured by chemical analysis from a cross section close to the weld metal surface (Table 1). The measured compositions and those obtained from the analysis data of base metal and filler wire were compared using the dilution lines shown in Fig. 3. It was noted that measured and predicted compositions were close to each other, showing a base metal dilution ranging from 0-40%.

Corrosion testing of experimental welds

The transpassive corrosion resistance of the experimental welds was examined using different electrochemical test methods in simulated bleaching solutions (2 g/l SO_4^{2-}, 1 g/l Cl^-, pH = 3 and 6, T = 70 °C). The results showed, that the transpassive corrosion resistance of all the experimental welds is significantly inferior to that of the base metal 654SMO. In the polarisation measurements, this inferior resistance was seen as higher measured current densities in the whole of the potential range which was investigated (Fig 4). In the

Materials	Joint No.	Chemical composition (final pass, base metal, filler metal)			
		%Cr	%Ni	%Fe	%Mo
Welded joints					
I-groove, 1+1 runs	1	23.0	50.8	8.7	15.8
60°V-groove, 1 run, 654 SMO backing	4	23.1	45.1	13.9	15.7
60°V-groove, 2 runs, 654SMO backing	5	22.7	55.2	4.9	15.8
All-weld-metal sample, 8 runs on 254 SMO plate	10	-	-	-	-
Base metal 654 SMO	-	23.4	20.4	47.3	7.2
Filler metal OK Autrod 19.81	-	22.5	61.2	0.4	15.5

Table 1. Chemical compositions of the weld metal surfaces obtained in the various welding procedure tests.

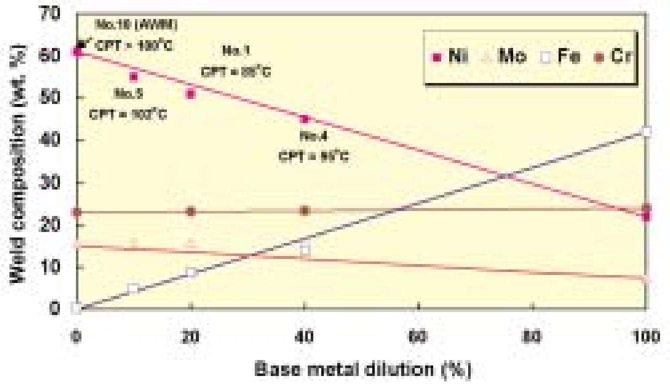

Fig. 3. Weld composition and CPT-values vs. base metal dilution for the welds of 654 SMO with an OK Autrod 19.81 filler metal.

impedance spectroscopic measurements, the inferior resistance was seen in lower charge transfer resistance (R_t) values (Fig. 5).

The transpassive corrosion rate of the welds increased as the base metal dilution decreased. For example, the transpassive oxidation rate of weld No. 5, with a base metal dilution of 10%, was comparable to that of the all-weld-metal sample No. 10, whereas the reaction rates for weld 1 and especially weld 4 were lower. This result correlates to the fact that weld 4 has the highest Fe content (and, accordingly, the lowest Ni content), which is due to the highest base metal dilution (40%). The higher transpassive corrosion rate of weld No. 1, for example, in comparison to weld No. 4 is further substantiated in Fig. 5 in which the impedance spectra of the two welds in the same conditions are shown for similar polarisation potentials. The charge transfer resistance R_t (approximated by the high-frequency semicircles in the spectra in Figs. 3-4) can be regarded as being inversely proportional to the transpassive corrosion rate. The value of R_t for a potential of 1.05 V is approximately one order of magnitude higher for the weld No. 4 in comparison to weld No. 1, and, accordingly, the transpassive corrosion rate is one order of magnitude lower.

In addition to the transpassive corrosion experiments, the pitting corrosion resistance of the experimental welds was evaluated with immersion tests in a ferric chloride solution (6% $FeCl_3$ - 1% HCl). The results showed that the critical pitting temperature (CPT) of the experimental welds decreased as the base metal dilution increased (Fig. 3), unlike the transpassive corrosion resistance.

Modelling of transpassive dissolution

According to the proposed electrochemical kinetic approach, the stainless steels and nickel-base stainless alloys in the transpassive region are assumed to be covered by a mixed iron-chromium oxide film, the composition and structure of which are analogous to those of the film formed in the passive region [12,14-17]. The film is based on chromium(III) oxide with a certain amount of Cr(VI), Ni(II), Fe(III) and some Mo-containing species. Two types of interfacial reactions are considered, namely the electrochemical metal dissolution through the oxide film (transpassive dissolution) and the growth of the oxide film balanced by its chemical dissolution in the medium. The interfacial reactions are coupled by ion and electron transport through the film. We assume that film growth plays a minor role, as the main part of the corrosion current is consumed by the transpassive dissolution processes. Subsequently, our analysis focuses on the processes at the film / solution interface (Fig. 6). No separate reaction path for the dissolution of Mo from the film as Mo (VI) is included in the present approach. Instead, it is assumed that adding Mo to the alloy substrate has a catalytic effect on the transpassive dissolution of Cr via the formation of soluble molybdate species that accelerate the abstraction of Cr(VI) from the outermost layer of the anodic film. The influence of Mo in the reaction layer at the oxide/solution interface on the transpassive dissolution of Ni is also taken into account: we assume that Mo favours the dissolution of Ni from the surface layer in an autocatalytic step.

A non-linear, least- squares routine implemented in the Microcal Origin 6.0 software was used to fit the model equations simultaneously to the real and imaginary part of the measured impedance for a specific weld at several polarisation potentials and to the steady-state current vs. potential curve. Statistical weighting was used for the experimental data set and the errors of parameter estimation were multiplied by the square root of the reduced chi-square value resulting from the fit. In spite of the relatively large number of parameters, this resulted in a sufficient number of degrees of freedom in the system to obtain statistically reliable values for the kinetic parameters.

The correspondence between calculation and experiment is illustrated in Fig. 4 (current vs. potential

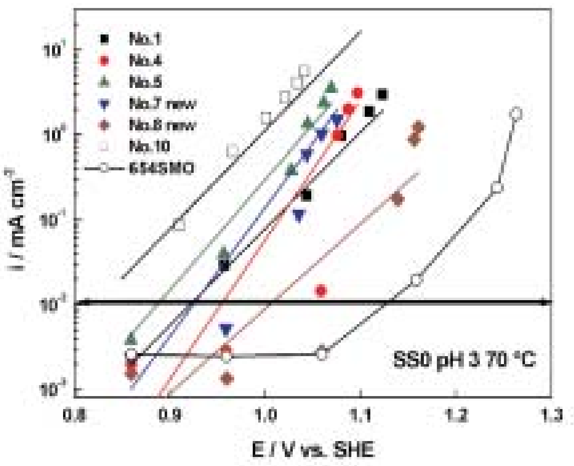

Fig. 4. Experimental current vs. potential curves (points) and predicted curves of maximum transpassive corrosion rate of the welds in the simulated bleaching solution, pH 3 solution at 70°C, expressed as current density. A corrosion current of 0.01 mA cm^{-2} is equal to 0.08 mm y^{-1} of corrosion penetration (double arrow line). Note: The solid line connecting the points for 654 SMO is just a guide for the eye, i.e. it is not a result of a model prediction as in the case for the welds.

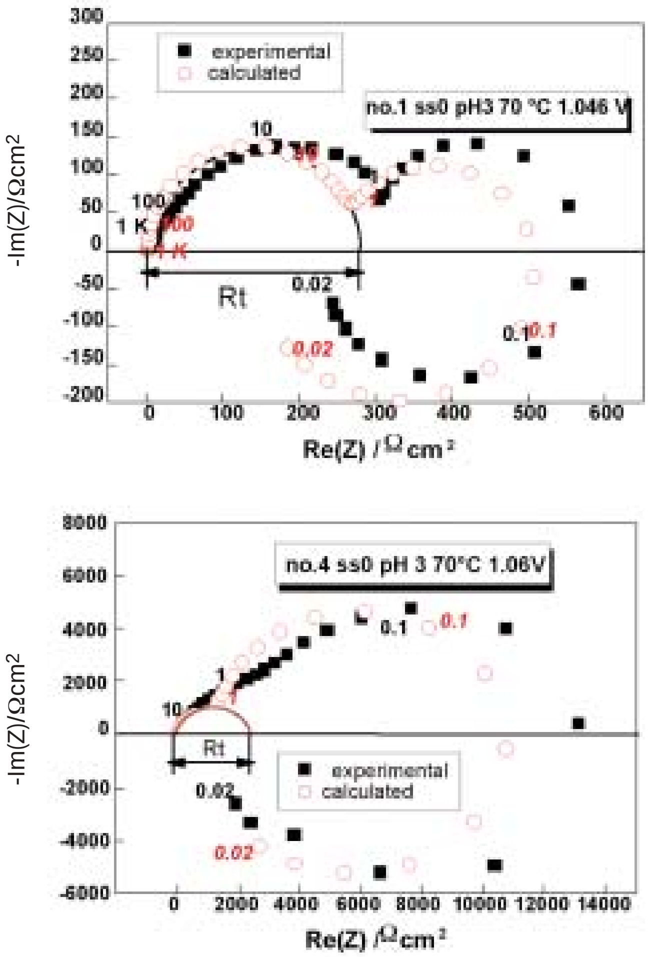

Fig. 5. Experimental and predicted impedance spectra for weld No. 1 (base metal dilution 20%) and No.4 (base metal dilution 40%) in the simulated bleaching solution at two potentials. Parameter is frequency in Hz.

curves) and Fig. 5 (impedance spectra). The figures demonstrate that the proposed model can be used to predict the transpassive dissolution behaviour of high nickel welds.

How to optimise corrosion resistance

As a result of the modelling, a series of computational transpassive corrosion maps were calculated for the welds of 654SMO produced with the nickel- base filler metal OK Autrod 19.81. Examples of these contour maps are shown in the Fig. 7, where the predicted maximum transpassive corrosion rate is expressed as a function of the potential (i.e., the oxidative capacity of the solution) and base metal dilution. According to these results, when the electrode potential is below 0.9 V vs. SHE (corresponding to 0.7 V vs. an external AgCl/Ag electrode), a 30% dilution is calculated to be enough to maintain the maximum transpassive corrosion rate below the 0.1 mm/y value in the tested simulated bleaching solutions.

Based on these model predictions, two experimental filler metals with compositions corresponding to the 30% and 50 % dilution (see Fig. 3) were produced and tested. The transpassive corrosion resistance of the weld ”No. 8 new”, with a chemical composition corresponding to the base metal dilution of 50%, was superior compared with the resistance of the weld “No 7 new”, corresponding to the base metal dilution of 30%. However, this kind of high dilution resulted in a marked reduction in localised corrosion resistance (Table 2).

The corrosion resistance optimisation of the highly-alloyed stainless welds is a demanding task, which requires a knowledge of the operating conditions, as they have a marked effect on filler metal selection. The current results show that a weld of 654SMO should have a good localised and transpassive corrosion resistance in chloride- containing, oxidising environments with the following weld metal composition: Ni < 50%, Fe 15%, Mo 13% and Cr 22%. A high molybdenum content is essential to ensure adequate localised corrosion resistance, although at the same time it catalyses the transpassive dissolution of Cr and Ni. The iron content must be high enough to ensure good resistance to transpassive corrosion.

Summary

A mathematical model was developed to improve our understanding of the way the general corrosion resistance of high-alloyed stainless steel welds can be improved in highly oxidising environments, and to help in the selection of appropriate weld alloying. The validity of the developed electrochemical kinetic model of the dissolution process was checked against a large set of experimental data. The kinetic model was found to reproduce quantitatively the current vs. potential curves and the impedance spectra for the studied nickel-base alloys in the transpassive region. As a result

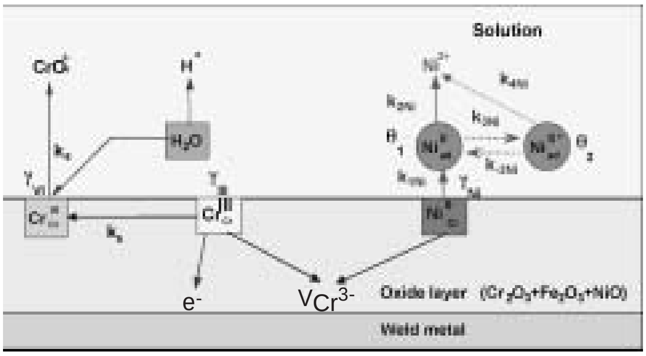

Fig.6. A detailed scheme of the processes occurring at the oxide film / solution interface during transpassive dissolution of nickel-based alloys.

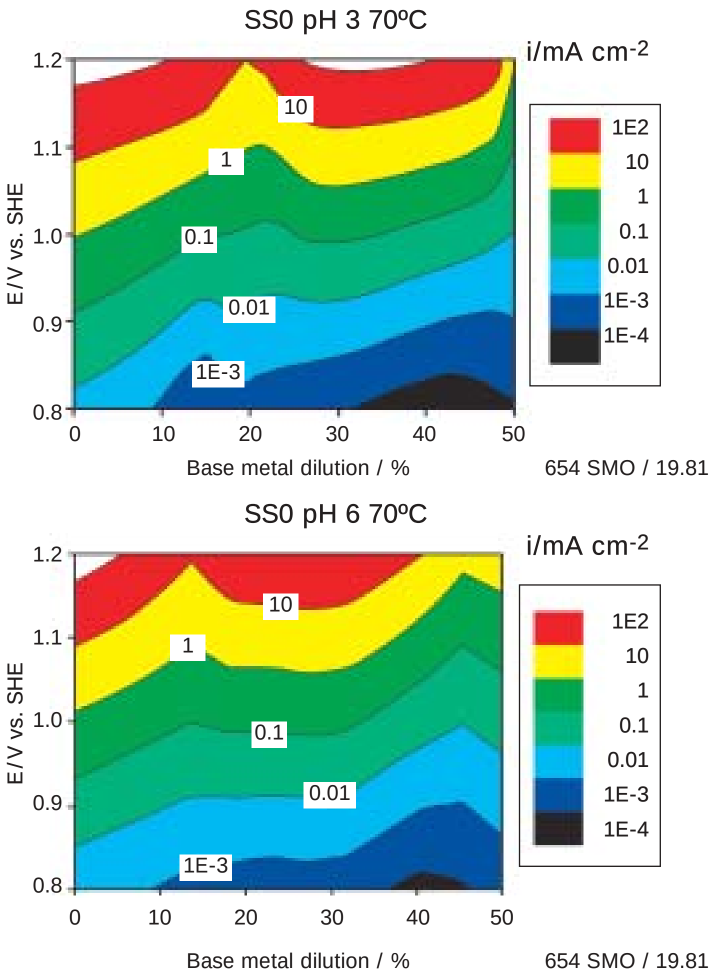

Fig. 7. Dependence of the predicted maximum transpassive corrosion rate (expressed as partial current density for Cr dissolution as Cr(VI)) on the 654 SMO base metal dilution and electrode potential in the simulated bleaching solution at two pH values. A corrosion current of 0.01 mA cm^{-2} is equal to 0.08 mm y^{-1} of corrosion penetration. (Simulated bleaching solutions, 2 g/l $SO_4$2-, 1 g/l Cl-, pH = 3 and 6, T = 70ºC).

Material	No.	Chemical composition %Cr	%Ni	%Fe	%Mo	%N	CPT [ºC]
All-weld-metal samples (AWM)							
Optimised weld 1	7 New	22.2	49.5	12.7	14.0	0.14	>95
Optimised weld 2	8 New	22.5	43.2	19.3	12.6	0.21	<65
Conventional Ni-base filler metal (MIG welding wire)							
OK Autrod 19.81 (filler metal composition)	10	22.5	61.2	0.4	15.5	---	>100

Table 2. Chemical compositions and CPT-values of the developed experimental covered electrodes. The corresponding values of OK Autrod 19.81 are presented for comparison.

of modelling, the composition of the weld metal has been optimised regarding the implementation of a new filler metal with an improved corrosion resistance.

In chloride-containing environments, where good localised corrosion resistance is required, nickel-base filler metals have demonstrated their usefulness. In addition, the welding must be performed with a low heat input to avoid weld cracking and weld imperfections, and to minimise the formation of unmixed zones. In strongly oxidising process environments, like those occurring in ClO_2- bleaching, the weld composition must be optimised in a different way. The alloying elements (Cr, Ni, Mo) that are important to ensure localised corrosion resistance have a detrimental effect on the transpassive corrosion resistance.

A new, experimental, high- nickel covered electrode, with an all weld metal composition of 22.2%Cr-49.5%Ni-12.7%Fe-14%Mo-0.14%N, was developed by ESAB AB. It has better resistance to transpassive dissolution than the traditional Ni-base filler metals. In addition, its localised corrosion resistance was shown to be good in CPT- tests.

Acknowledgements

The National Technology Agency, Andritz Oy, ESAB AB, Kemira Chemicals Oy and VTT Industrial Systems, who are all gratefully acknowledged, have funded this project. The authors would also like to thank the steering committee members Dr. Erkki Pulkkinen (Andritz Oy), Dr. Leif Karlsson (ESAB AB), Mr. Juha Lukkari (ESAB Oy) and Dr. Jari Kukkonen (Kemira Chemicals Oy) for useful discussions.

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CIMTAS, AN INTERNATIONAL PLAYER IN POWER GENERATION AND ENERGY STORAGE

By Ben Altemühl, editor of Svetsaren, Ercan Kaplan, Zeki Yazici and Baran Burat, welding engineers at CIMTAS

In the spring of 2002, Svetsaren visited CIMTAS AS in Turkey, an international fabricator of power plants, power plant components and energy storage. The visit consisted of two parts, the head office in Istanbul, where we interviewed the management about their policies and strategies, and the workshop in Gemlik, some 200 kilometres south of the capital, where we talked in detail with the production staff about recent projects. We decided to highlight the construction on site of two large LNG tanks in 9%Ni steel, which fits in very well with our theme of "advanced materials".

In spite of its success, the project was overshadowed by the tragic death in a car accident of our ESAB colleague Stefan Jakobsson, while he was on duty, assisting CIMTAS with the establishment of the WPSes. CIMTAS management asked us to quote them. "He was a joyful, hard working friend and we deeply share the sorrow of his family and other people that have known him."

Acknowledgement

We thank the CIMTAS management for making this visit possible. We wish to extend special thanks to Nuri Bayezid, purchasing manager, and Ali Berkel, international marketing manager. We would also like to compliment our ESAB representative in Turkey, Erik Sterken, on the constructive partnership that has been built up with CIMTAS in recent years.

CIMTAS

CIMTAS is the principal fabrication unit of ENKA Construction and Industry Company Inc., the largest privately owned international contracting company in Turkey. It constructs anything from single components to complete turn-key installations for power stations, energy storage, petrochemical plants and civil projects, but the nucleus of the factory output is pressure vessels and gas tanks, power and process pipe spools and cooling water piping, plus an increasing number of conical windmill towers.

Located near international deep sea ports, with 41,000m^2 of indoor fabrication shop space and an annual steel handling capacity of 25,000 tonnes, the Gemlik works is well placed to serve international clients with larger projects. It employs some 1,000 workers and 75 engineers and, since its establishment in 1979, it has fabricated more than 250,000 tonnes of steel products.

CIMTAS Gemlik works.

The services include design and engineering, fabrication and erection on site. In 2001 alone, CIMTAS erected 75,000 tonnes of steel at nine individual sites, many of which involved turn-key contracts. The on-site activities comprise petrochemical and power plants, pump and compressor stations, tank farms, cement plants, pipelines and steel bridges. Traditional markets include countries in the region, such as Russia, Kazakhstan, Saudi Arabia, Kuwait, Jordan and Turkey itself, but more and more projects are being secured from Western Europe, the Far East and the USA, as a result of growing international recognition. CIMTAS now constructs regularly for clients such as Bechtel, Framatome-Proser, MHI, GE, Cargill, NEM, CMI, UOP (Europe), GE Hydro, FWI, KTI, Technip, KBR, BP, BASF, UOP(USA), Nuovo Pignone. Quality, in-time delivery and customer satisfaction are central elements in the company philosophy, whereas internally a zero accident target and an environmental protection plan are given high priority using a consistent awareness campaign.

ESAB and CIMTAS

Serving a dynamic fabricator such as CIMTAS calls for the availability of a contact person and nearby stock. The day-to-day business with CIMTAS is handled by ESAB's local dealer Özmetal, which is located in Istanbul and houses a substantial stock of consumables, equipment and spare parts. However, when new solutions are needed, ESAB's representative office acts as an intermediary between CIMTAS and the many resources of ESAB worldwide, based on an understanding of the client's business and needs. In recent years, this has resulted in a mutually satisfactory partnership with knowledge sharing, many improvements and steadily increasing welding and cutting productivity.

The organisation of welding

The Gemlik works employs around 240 welders and three EWEs. Welder education, certification and project training are done internally at the CIMTAS Training Centre, which is well equipped with a representation of the 110 MIG/MAG power sources, 26 single-wire and tandem SAW installations, 70 SMAW units and 150 TIG machines which are used in the workshops. The company has access to its own metallographic and mechanical laboratory.

Apart from windmill towers, the mainstream of projects at the Gemlik works comprises heat recovery steam generator modules and power piping spools, involving a great deal of pipe welding in CMn steel, various creep resistant grades and stainless steel, including advanced grades like P91, as well as nickel alloys.

Base materials are cut and bevelled in the semi-finishing hall and are taken to the various manufacturing halls by separate routes for each project. CNC plasma equipment is used to cut stainless and high-alloy pipe and plate and to cut the branch openings in carbon steel pipes. Various types of oxyfuel cutting equipment, including CNC, are available for products of all kinds.

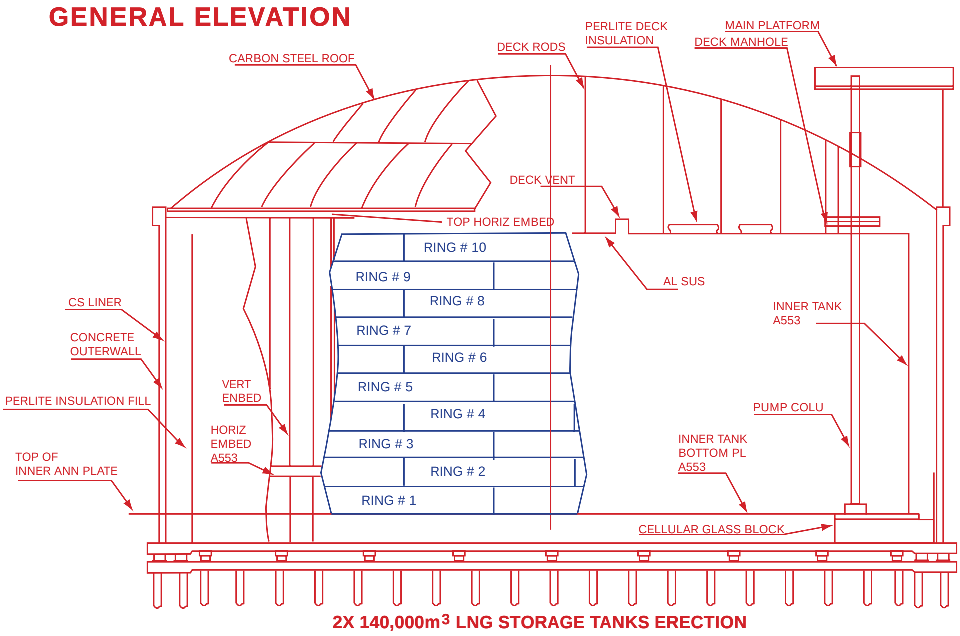
Power piping spools and manifolds are produced in both low-alloyed and stainless steel. In this case, SAW is used for the circumferential welds and the attachment of flanges using ESAB columns & booms, rollers and turntable installations and LAE 800 power sources (Figure 1). Manual TIG (using turntables) and SMAW is used for the numerous branch connections, fittings and flanges with ESAB consumables corresponding to the base materials.

Figure 1. Circumferential welding of a manifold.

Figure 2. A complete ESAB solution for the mechanised TIG welding of stainless pipes.

Mechanised TIG (Figure 2) is used in the stainless piping shop, producing increased TIG productivity at the required weld quality on larger pipe-pipe and pipe-flange connections. The TIG hot-wire process, with a self-developed fixturing and purging device, is used to weld alloyed steel casing panels.

ESAB orbital TIG welding units are used in tube-to-sheet, pipe-to-pipe and header-to-stub welding in the production of heat exchangers, boilers and pipe



Top		
	10 th plate	10.4mm
	9 th plate	10.4mm
	8 th plate	10.4mm
	7 th plate	10.4mm
	6 th plate	11.04mm
	5 th plate	13.52mm
	4 th plate	16.04mm
	3 rd plate	18.45mm
	2 nd plate	20.82mm
Bottom		
	1 st plate	23.14mm

Shell thickness.

Figure 3. 140,000m3 LNG storage tank. The 9% Ni-steel shell is indicated in blue.

pre-fabrication. Orbital MAG welding is used for heavy-wall pipe welding.

LNG storage tanks

In March 2000, CIMTAS started work on the mechanical erection (steel works) of two 140,000 m3 LNG storage tanks in Izmir, Turkey, for Egegaz A.S. in Istanbul, supervised by Chicago Bridge and Iron and inspected by BV. The 31m high and 82m diameter tanks (Fig. 3) consist of a concrete, carbon-steel-lined outer wall and dome roof, an ASTM A 553 type 1 9%Ni steel tank, a suspended aluminium deck type ASTM B 209 5083 and stainless steel piping and stairs. This substantial project lasted until September 2001, with 13 engineers being involved from start to finish and a total of 360 workers at the peak point, 90 of whom were welders. Welding engineers from the Gemlik works were involved temporarily to supervise the welding of aluminium and 9%Ni steel. The site worked three shifts; the midnight to morning shift was reserved for the 100% X-ray control of all the 9%Ni steel welds.

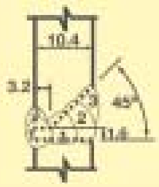
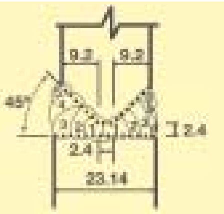
The 9%Ni-steel tank was the most critical job and work here was carried out by qualified, experienced welders contracted from all over Turkey. The "workhorse" for the horizontal welds in the vertical shell was ESAB's Circotech equipment, with A6 tractors using the flux/wire combination OK Flux 10.16/OK Autrod 19.82.

The A6 Circotech is designed for fully-mechanised, double-sided welding, a critical yet economically very attractive method. Before the start of the project, CIMTAS carried out application research on a mock-up stand at the Gemlik works to train the welders and to qualify the welding procedures for double-sided welding without back gouging. It was concluded that it is essential that the root opening remains within 1-4mm. Below 1mm, there is a risk of insufficient penetration and above 4mm slag inclusions and porosity can occur. This means that a very accurate fit-up is elementary during construction welding and a great deal of attention was therefore paid to this aspect. The bonus was welding time that was reduced by more than 50% compared with the single-sided technique. Table 1 shows the X- and V-joint preparations and bead sequences for the double-sided SAW welding, together with the tensile strength and CVN impact toughness obtained from the procedure qualification tests. The tensile test fracture was located in the weld for the V-joints an in the base metal for the X-joint, indicating strength matching weld metal. CVN impact values were well above the minimum value required for the steel. Table 2 shows the welding parameters used for the double-sided welding of the X-joints.

The vertical welds in the tank shell were performed with SMAW, using ESAB OK 92.45, a basic, all-

Figure 4. One of the LNG tanks for Egegaz under construction.

Table 1. Mechanical properties obtained in the procedure qualification tests for the double-sided submerged arc welding with Circotech equipment. The X-joint is used for the lower part of the LNG tank and the V-joint for the upper part. The CVN value is the average of three tests.

	R_m (MPa)	R_p(MPa)	A_5(%)	Fracture Location	CVN (J)	Lat. E.
9%Ni steel according ASTM A553	690-825	>585	>20		>27 at -195ºC	>0.381
	706, 705	n.d	n.d	Weld	weld: 76/-196ºC HAZ: 78/-196ºC	>1
	709, 702	n.d	n.d	Base Metal	weld: 89/-196ºC HAZ: 180/-196ºC	>1

n.d.= not determined

Table 2. Welding parameters for the double-sided SAW with Circotech using OK Autrod 19.82 solid wire. Valid for X-joint.

Pass no.	Process	Filler Metal Class	Filler Metal Dia.	Type & Polarity	Current Amps	Volts	Travel Speed cm/min	Heat Input KJ/mm
1	SAW	ERNiCrMo-3	Ø 1.6	DC - EP	290	25	41	1.06
2	SAW	ERNiCrMo-3	Ø 1.6	DC - EP	290	26	41	1.10
3	SAW	ERNiCrMo-3	Ø 1.6	DC - EP	290	26	59	0.77
4	SAW	ERNiCrMo-3	Ø 1.6	DC - EP	300	26	87	0.54
5	SAW	ERNiCrMo-3	Ø 1.6	DC - EP	300	26	71	0.66
6	SAW	ERNiCrMo-3	Ø 1.6	DC - EP	300	26	83	0.56

position electrode. Both OK Autrod 19.82 and OK 92.45 are nickel-based consumables, with nominal 22%Cr, 9%Mo and 3%Nb classified according to AWS A5.11/5.14: ENiCrMo-3. Table 3 gives the product data for ESAB consumables for welding 9%Ni steel for the three processes, SMAW, GMAW and SAW. They are consumables with a good reputation in this field of welding, providing the high strength and low-temperature toughness levels needed for LNG storage tanks, along with an excellent weldability.

One critical aspect in the welding of the 9%Ni-steel tanks was to keep the interpass temperature below 100°C to avoid the loss of low-temperature toughness properties in the HAZ. The SMAW was critical in this respect, as it involves welds in the PF position, with low travel speeds and large weld pools. The welders were well educated when it came to applying the stringer bead technique and they were also trained constantly to check the interpass temperature using digital thermometers and temperature sticks.

The mechanised SAW of the horizontal welds was less critical, as the Circotech equipment travels the whole 45m circumference of the tank. After each cycle, the weld zone had cooled to almost ambient temperature. In addition, the welding parameters were pre-programmed in the PEH control boxes at the standard settings resulting from the successful qualification tests.

Another practical problem is the occurrence of magnetic arc blow due to the easily magnetising 9%Ni steel. Even though the material was kept away from possible magnetising equipment during handling, this presented a problem in welding. As all the power sources used for SMAW (ESAB LHF 800), SAW with Circotech (LAF 800) and SAW of the bottom plates (LAF 800) are single-wire DC equipment, arc blow had to be controlled by careful demagnetising procedures. There were some initial problems, but the arc-blow phenomenon was soon fully under control.

The deck between the roof and the liquefied gas was made of Mg-alloyed aluminium. CIMTAS used ESAB LAW power sources in combination with OK Autrod 18.16. The components were 50, 25 and 4.76mm in thickness. In the 4.76mm thickness, pure argon was used as the shielding gas, but for the thicker components CIMTAS used Ar/He mixtures to increase the weld penetration and the bead appearance. The air turbulence inside the tank presented a problem, which was overcome by using rolling tents over the welding spots.

The most outstanding feature of the whole project was the spectacular lifting of the 800-tonne dome to a height of 35m inside the tank, by means of pressurised air, with the risk of overturning and rotation. After that, the welders had to connect the dome to the extension plates, while the system remained "on air".

Summary

CIMTAS is a dynamic fabricator in the field of power generation and energy storage, producing anything from single components to turn-key solutions for its international clients. The CIMTAS production site is equipped with state-of-the-art welding and cutting equipment. The company makes full use of ESAB's global resources and support.

About the authors

Baran S. Burat (EWE) joined Cimtas in 1998. He heads the welding department of the Gemlik works and in this position he supervises the welding, the heat treatments, the testing laboratories, R&D and the welders training centre.

Ercan Kaplan (EWE) started at Cimtas in 1982. He is Welding Technology Group Manager at the Gemlik works.

Zeki Yazici (EWE) joined Cimtas in 1981. He is presently Pipe Production Group Manager at Cimtas Pipe Fabrication & Trading Ltd., a subsidiary of Cimtas Steel Construction.

Welding 9% Ni steel

The 9% Ni steel applied for this project is a Q&T type according ASTM A553 Grade 1 (table 1). The microstructure consist of a matrix of fine tempered martensite/bainite, and around 4 % of stable austenite obtained by tempering the steel just above the austenite reformation temperature (around 580ºC). The high nickel ferrite in combination with this small fraction of austenite gives the steel the required toughness at cryogenic temperatures. The hardness of the steel depends on the carbon content, but is normally well below 400HV.

At cryogenic temperatures the UTS of the steel increases, whereas the CVN toughness shows a gradual decrease, without a tough to brittle transition, to levels that are still suited for cryogenic service.

The sensitivity to cold cracking of 9% Ni steel is fairly low, due to the low carbon content (max. 0.08%). In welding, the HAZ shows a limited increase in hardness. Preheating is not necessary up to 50mm plate thickness and a PWHT is not applied, although fabricators do use a slight preheating (40-50ºC) to remove and avoid the formation of condense.

One of the critical aspects of welding 9% Ni steel is to keep the interpass temperature below a level of 150ºC. This has in the first place to do with limiting the thermal cycle as far as possible, in order not to change the microstructure of the HAZ which could lead to loss of low-temperature toughness properties. Normally, fabricators apply a lower interpass temperature in their welding procedures (100-110ºC) to have a practical safety margin.

The second reason for keeping the interpass temperature low is the use of fully austenitic filler materials that can show a tendency of hot cracking, along with welding techniques such as "stringer bead" to avoid the formation of large weld pools. Nickel based consumables with 15-22%Cr and additions of Mo and Nb are a common choice for welding 9%Ni steel, giving the required strength properties and cryogenic toughness. The weld metal strength usually slightly undermatches the parent metal, which is compensated for by over- designing the construction (table 3).

Welding processes commonly used are SMAW, GMAW, SAW and GTAW for thinner sections.

Another problem is the occurrence of magnetic arc blow, due to the easily magnetising 9%Ni steel. This has to be counteracted by using AC power sources and consumables, where possible, or by keeping the steel away from magnetic fields and by applying de-magnetising equipment.

Table 3: Typical chemical composition and mechanical properties of ESAB consumables for 9% Ni steel.

Process	**Type**	**C** (%)	**Mn** (%)	**Cr** (%)	**Ni** (%)	**Mo** (%)	**Fe** (%)	**Nb** (%)	**W** (%)	**R_p** (MPa)	**R_m** (MPa)	**CVN** (J/-196)	**Lat E.** (mm)
SMAW	OK 92.45 (DC)	<0.03	0.4	21	64	9.5	1.3	3.3	-	480	780	50	0.9
	OK 92.55 (AC)	<0,08	3	13	7	6	5	1.3	1.5	460	710	80	>1
SAW	OK Autrod 19.82/ OK Flux 10.16	<0.03	0.25	21	>60	9	-	3.5	-	425	700	80	0.8
GMAW	OK Autrod 19.82	<0.01	0.1	22	bal.	9	0.5	3.5	-	500	800	110	1.0

Stub-ends & Spatter

Aluminium wire from ESAB available in bulk drums

AlcoTec aluminium welding wire is now available in the AlumaPak®, which has a capacity of more than 135kg. This new bulk wire delivery system drastically reduces the downtime otherwise required for spool changes. This has a substantial impact on arc time and thereby on welding productivity.

A special coiling technique with minimum cast and helix assures a perfectly straight wire for problem-free feeding and accurate positioning in the joint, making it highly suitable for mechanised and even robotic applications. No special decoiling equipment is needed. The system uses a reusable plastic cone with conduit and a conduit connector for fast set-up.

AlumaPak is made from sturdy corrugated board with an internal plastic lining and a moisture-resistant coating, protecting the wire from dust and moisture. It comes with lifting straps for use with an optional lifting yoke for easy transport by fork-lift or crane.

The empty AlumaPak can be easily folded flat by hand for efficient storage and is 100% recyclable.

ESAB Coreshield 6 and Coreshield 8 New self-shielded cored wires for structural welding

Coreshield 6 and Coreshield 8 are the latest additions to the line of Coreshield self-shielded cored wires. They have been developed to comply with the stringent FEMA 353 specifications for welding in earthquake-prone regions, such as the United States west coast. They are classified according to AWS A 5.20-95: E70T-6 and E71T-8 respectively. Coreshield 6 is a downhand type, while Coreshield 8 is an all-positional type.

The exceptional feature of these wires is that they combine weld metal strength and toughness with extremely high welder appeal. A smooth and stable arc, low spatter, easy-to-remove slag and low fume production make these wires more user friendly than any other wire in their class. As they are self-shielding, they are also easier to use for applications in the field, including retrofit work.

By developing these wires, ESAB is offering fabricators a welding consumable that allows them not only to comply with strict building codes, but also significantly to enhance their productivity and enable easier welder qualification due to the high welder appeal and ease of use. The reaction to ESAB's new Coreshield wires – from erection and fabrication companies, as well as union organisations responsible for welder training – has been extremely positive, not only in the United States but also in Pacific Rim countries where the product has been introduced.

ESAB INTRODUCES NEW IMPROVED EYE-TECH AUTOMATIC HELMET

The new Eye-Tech 5-13 automatic welding helmet, recently introduced by ESAB, offers significant advantages to the welder in terms of safety, comfort and convenience to help ensure higher welding productivity and quality.

Based on an ergonomic design that incorporates modern, advanced electronics, the Eye-Tech 5-13 embodies all the advantages and reliability of the traditional Eye-Tech helmet, with added features and improvements.

The new Eye-Tech 5-13 can be used for most welding applications, including MIG, TIG and gas welding, as the darkness of the eye shade is continually adjustable between shades 5 and 13. The stylish automatic helmet has the traditional Eye-Tech design but comes in an attractive, heat-reflecting metallic silver finish.

Powered by solar cells, the Eye-Tech 5-13 automatically switches from light to dark in only 0.0002 seconds when an arc is struck, providing the welder with exceptional safety and convenience, coupled with outstanding optical quality.

To perform cutting and grinding operations without removing the helmet, a grinding mode button allows the lens to remain clear for 10 minutes – with a red warning light inside the helmet to remind the wearer when the grinding mode is selected. Comfort is assured thanks to stepless, continuously-variable adjustment for positioning the helmet that allows the operator to obtain perfect balance on the head, as well as optimum viewing angle for reduced fatigue and greater welding accuracy.

CE approved in accordance with EN166/379, the ESAB Eye-Tech 5-13 can be used throughout a wide temperature range of –5ºC to +55ºC, can be fitted with magnifying lenses and an optional fresh air unit and has a total weight of approximately 500g.

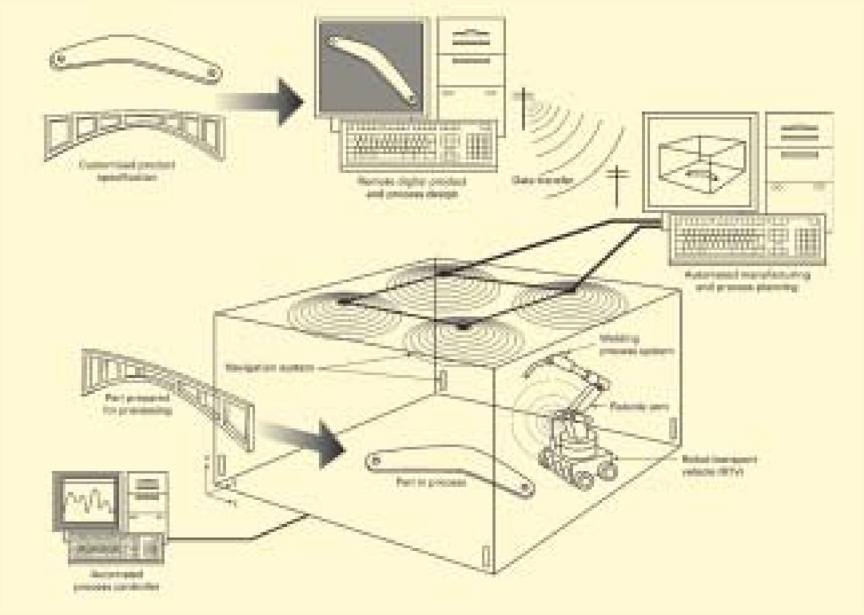


Figure 1. shows the basic layout of the different elements that will have to communicate. The system differs from the current robotised welding installations in that the welding robot moves freely within the production cell. The navigation system detects the location of the part to be welded and its orientation in the cell and navigates the robot to its position for welding. The welding procedure is transmitted by the database of the automated process controller, which recognises the geometry of the workpiece.

ESAB partcipates in NOMAD

NOMAD is a project within the European Commission Framework 5 growth programme. The objective of NOMAD is to produce a fabrication cell based on autonomous robot technology to weld customised structures as efficiently as today's large volume production cells. The duration of the project is 42 months and the total budget of EUR 4.8M is split in 50% EC and 50% partner contribution.
The partners are:
ESAB, Gothenburg, Sweden
Delfoi, Espoo, Finland
IFF, Magdeburg, Germany
Reis, Obernburg, Germany
Robosoft, Biarritz, France
Caterpillar, Gosselies, Belgium
Nusteel, Lympne, UK
TWI, Cambridge, UK
The simulation system consists of IGRIP software, automated robot arm programming, automatic cell calibration, automated weld process planning with welding database, RTV route planning and system monitor and control.
The data transfer, welding position accuracy and system integration are regarded as the toughest challenges in this project.

At the moment, work is being concentrated on the electronic models of the two components to be welded, a bridge part from Nusteel and an excavator arm from Caterpillar. The robot transportation vehicle, RTV, is under construction and will carry all the components needed for welding. At the end of the project, a demonstration cell will be built at Caterpillar and it will be possible to see the results at this demo cell. ESAB's role in the project is to develop an all-positional MAG welding consumable with superior properties for robotised welding using ESAB power sources. In addition, ESAB is participating in the optimisation of the welding procedures.

New contracts signed for friction stir equipment

ESAB continues to be the market leader in Friction Stir Welding. Recently, the FSW team in Laxå obtained three new contracts.

At the end of 2001, SKB in Sweden ordered a FSW installation for its canister laboratory in Oskarshamn, to be used for sealing canisters before the final storage of nuclear waste from Swedish nuclear power plants. Delivery is planned for November 2002.

At the beginning of 2002, a contract was signed with EADS, Ottobrunn, Germany, for a basic ESAB SuperStir™ machine to be used at its laboratory, to be delivered in July.
The third contract was signed during the spring of 2002 with Alenia Spazio in Turin/Italy. This also involves a basic ESAB SuperStir™, but it is equipped with possibilities for circumferential welding and to be able to use the bobbin tool and retractable pin tool technique in the company's laboratory.
S. Antonsson

ESAB Automation North America Up and Running!

It has been almost a year since the green light was given to start the North American Automation Group and we are pleased to report that the venture appears to be a success.

The value package we offer the customer is the "total integration" of the welding project. ESAB's world-leading process technology, combined with the fact that we manufacture all the components, from the filler metals to welding machines to positioning, means we can take responsibility for the weld. This is most important for our customers, as it reduces their risk, while maximising performance.

Our systems are designed to minimise the number of interfaces between the various components. This has tremendous benefits for the customer. Fewer interfaces improve reliability. The cost is reduced, by eliminating the interfaces and cables. What is more, our integrated packages enhance the welding features and performance.

Throughout the USA and Canada, we have delivered several projects, columns and booms, seamers, tandem tractors, positioners, roller beds and many, many components. One impressive project comprised three CaB 460s plus roller beds, which were purchased by DMI in North Dakota, to build windmill towers. Our first beam welder was delivered in June 2002. Our quotation book is large, which should mean plenty of future orders.

One market segment of particular interest is the wind-power business. North America appears to be on the verge of installing a huge number of wind-power plants. We are in discussions with many potential tower suppliers, who are most impressed by our windmill tower technology from Europe. We participated in the American Wind Energy Association (AWEA) trade show, in Portland, in June.

The North-American welding automation group operates from the ESAB Canada plant in Toronto. The plant includes a demo centre, sales and service support, plus a large inventory of automation equipment. From this location, we can conveniently and quickly support all regions of the continent.

The automation group works closely with the standard product and cutting groups. Together, we try to bring the distributor and end-use customer a total welding and cutting package. In doing so, we improve our customers' profitability, while helping ESAB to grow its total North-American business.

We are excited by the early results and confident about long term success!

P.S. A word of thanks needs to go to our Swedish and Finnish teams, who are providing excellent support for the project.

Richard Hadley
General Manager
ESAB Automation North America.

New agent in Australia for ESAB Cutting systems

ESAB Cutting Systems is proud to announce a new agent agreement with Headland Machinery in Australia, a leading supplier of machinery products, software and technical services to Australian manufacturing industry.

Headland Machinery will supply and service the ESAB Cutting Systems line of products. We wish our new partner all the best in this challenging task.

New cutting machines from ESAB

At the Euroblech Fair in Germany, from 22 to 26 October 2002, ESAB Cutting Systems will be launching two new machines.

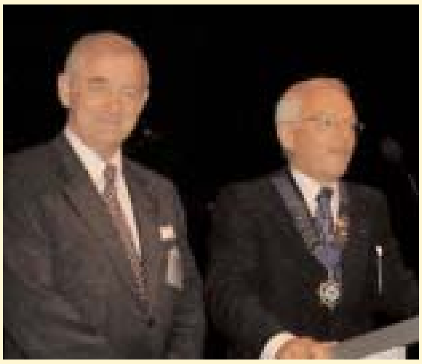
The UXC-P machine is designed for companies with small production needs. It will be equipped with two cutting processes, plasma and oxy-fuel, for cutting plate thickness of up to 50 mm.

The EAGLE machine is specifically designed for plasma cutting, including marking and cutting capabilities with the same torch and consumables. This machine will be equipped with all the latest plasma-related technologies.

Bertil Pekkari new IIW President

During the 55th annual assembly of the International Institute of Welding in Copenhagen (June 23-28), ESAB's technical director and publisher of Svetsaren, Bertil Pekkari, was elected president of the IIW. He succeeds Bevan Braithwaite whose three years-term had expired.

We congratulate Bertil on this nomination.



Bertil Pekkari (right) delivering his maiden speach as IIW President

Repair and maintenance of a new alloyed nodular iron SG APe 771-02

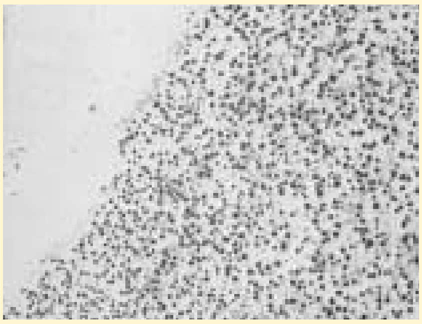


Figure 1. Weld micro structure.

The Swedish engineering bureau APe Allan Persson HAB contacted ESAB about developing a welding procedure for a new cast alloy for press tools for the automotive industry. The aim was to be able to repair surface defects without cracking.

SG APE 771-02 (patent pending) is an alloyed nodular iron with a very high tensile strength (Table 1). The cast tools are rapidly heated to 900°C and immediately quenched in water to produce a hardened zone of approximately 4mm on the surface, with a hardness of around 56HRC, whereas the core remains ductile, with a hardness of 240-280HB. The material has been tested for one million compressions. Other applications for the material include cylinder linings, valve seats and camshafts.

ESAB decided to develop a welding procedure specification at its Gothenburg laboratories, based on the standard MMA electrodes OK 68.82 and OK 84.52.

OK 68.82 (Table 2) produces a ductile duplex stainless steel buffer layer which absorbs the stresses generated by welding and is highly insensitive to the alloying effects caused by dilution with the base material. OK 84.52 in turn provides corrosion-resistant top layers that have the required hardness and resistance to abrasion.

The welding procedure specification stipulates preheating to 350ºC, with the preheated area being 100-150mm larger than the area to be repaired. After welding, the welding zone is cooled slowly to the ambient temperature.

Both parties are satisfied with the result and close teamwork has been established for the further development of the welding procedure.

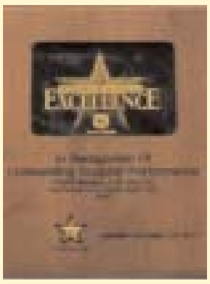
Table 1. Mechanical properties of SG APE 771-02.

$Rp_{0.2}$ MPa	R_m MPa	Compression strength MPa
440-640	700-900	1500

Table 2. OK 68.82/OK 84.52. Mechanical properties and all weld metal chemical composition.

	R_m (MPa)	Rp_{02} (MPa)	A_5 %	CNV J at 20°C	Hardness	C %	Si %	Mn %	Cr %	Ni %
OK 68.82	750	500	23	40	aw 240HV wh 450HV	0,1	1,0	0,8	29	10
OK 84.52	-	-	-	-	aw 50-56HRC	0,25	0,5	<0,5	13	-

ESAB "Hall of Fame" partner for John Deere



ESAB Mexico, S.A. de C.V. is the first Mexican company to receive the "Five Years Hall of Fame" partner classification award from Deere & Co. (John Deere), one of the world's most prominent manufacturers of agricultural, construction and forestry equipment.

In 1997, ESAB Mexico acquired the MAG wire business from Industrias John Deere(IJD), a subsidiary company consisting of three plants located in the northeast of the country. In the same year, IJD launched its "Achieving Excellence" programme, which is based on the company's core values. This programme is a dynamic supply strategy, which focuses on developing long-term relationships with suppliers that share the same commitment as John Deere has to its own customers. ESAB faced the challenge of meeting the required standards of quality, delivery, cost administration and service, resulting in the first "Partner Supplier" nomination at the end of that year. This achievement was repeated in the years that followed, until ESAB reached the classification known as "Five Years Hall of Fame" partner supplier in 2002.

From left to right: Rafael Garcia, Material Services and Export Director (IJD); Luis Lopez Moncada, Achieving Excellence Co-ordinator (IJD); Rafael Manzo, Material Services Manager (IJD); Jesus C. Gomez, MD (ESAB); Ricardo Madrigal, Sales Rep. (ESAB); Sergio Ortega, General Sales Mgr. (ESAB); Juan J. Lopez, Technical Service Mgr. (ESAB); Gerardo Gonzales, Production Unit Leader (ESAB), during the award ceremony.

ESAB CADDY TIG HF GETS ALL NEW POWER PACKAGE

A completely new power package, housed in a familiar rugged body, gives the lightweight, versatile ESAB Caddy Tig HF welding machine increased performance with advanced welding functions for both TIG and MMA welding.

Weighing only 5.9kg, yet providing a welding current of 150A at 30% duty cycle in the TIG mode, the easy-to-use, highly portable Caddy Tig HF is ideal for on-site fabrication and repair and maintenance where access with larger equipment is limited.

Equipped with a choice of lift start and high frequency ignition, the Caddy Tig HF enables the most appropriate start procedure to be selected. The DC supply means that copper, nickel, titanium, mild and low-alloyed steels, in addition to stainless steels, can all be welded, down to a material thickness of 0.5mm.

Advanced TIG adjustments include a menu set-up function for pre-gas time(s), initial current slope-up time(s), final current and post-gas time(s).

A choice of trigger modes includes a setting for two current levels, making manual pulsing possible.

MMA functions include hot-start and arc-force settings. Most metals, including mild and low-alloyed steels, stainless steel and cast iron, can be MMA welded with stick electrodes up to 3.25mm, while electrodes with a diameter of up to 4mm can be used for certain applications.

As with all ESAB equipment, the Caddy Tig HF is designed for rugged use in harsh environments, as it has an IP23-approved enclosure for outdoor operation. An integral dust filter provides protection from the elements and can easily be removed for cleaning.

Getting started is easy with the Caddy Tig HF. A ready-to-use kit is available from ESAB. It includes everything that is needed for welding in one package, such as the Caddy Tig HF machine, a TIG torch, a 1.6mm tungsten electrode, MMA welding and return power cables.

Svetsaren 2/2002

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