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Friction Stir Welding
New technology changing the rules of the game in Al construction

by Lars Göran Eriksson and Rolf Larsson, ESAB Automation & Engineering, Laxå, Sweden

Since its invention by TWI in the UK in 1991 (patent from 1992), the Friction Stir Welding process has been applied in all the major industrial segments using aluminium and aluminium alloys. The process itself and the tool technology have also been further developed for increased welding speed and have been adapted to match different welding tasks.

One major breakthrough is the development of simultaneous welding from both sides of a joint, thereby excluding the need for a backing bar and simplifying the welding of hollow profiles. One special variant of this technology is the bobbin tool design, which can, for example, be used when the backside of the joint is not accessible or to simplify fixturing.

The first FSW applications were straight welds. Subsequent applications include two- and even three-dimensional welding tasks with or without an external axis.

This article briefly presents the tool designs for simultaneous welding from both sides of a joint and summarises applied FSW machines and plants in different industrial segments.

For information about the basic FSW technology and metallurgical aspects, reference is made to articles in Svetssaren Vol. 54, No. 2, 2000, where other references can also be found.

Simultaneous two-side welding
Welding hollow profiles to panels with one FSW welding head of original design meant that the complete panel had to be turned after welding the first side and the other side then had to be welded in the same or a second machine. One of the many advantages of FSW is that welding can be performed in any position using the same welding parameters and the same excellent result can be obtained.

Both of the units that have been installed at Sapa in Sweden have double heads to weld hollow profiles to small panels for the automotive industry, as well as large panels for the roof and side walls of railway wagons, for example.

The double-head system can also be used for the simultaneous welding of butt joints with material thicknesses of up to 30 mm or thereabouts.

The need for rigid fixturing naturally remains in order to keep the parts to be welded in position. The lower head has a firm position in relation to the backside of the fixture (i.e. the workpiece), while the upper head is position or force controlled.
The double-head system applied in a laboratory machine for Tower Automotive in the USA is shown in Figure 1.

The principle of bobbin tool technology is to have both tool drives on the same side of the joint, i.e. the back tool shaft passes through the upper hollow tool shaft and upper tool. Before applying the back tool shoulder, a hole has to be drilled through the workpiece if a run-on tab cannot be used.

Figure 2 shows a bobbin tool in a laboratory set-up. Both shoulders are in position before welding starts. During welding, the two shoulders are pressed against the workpiece surfaces with a set force.

Friction stir welding application

To date, applications in aerospace include the production of fuel tanks for the Delta II and Delta IV rockets at The Boeing Company, USA. The four units that have so far been delivered cover longitudinal welds with a length of up to 15 metres using the conventional technique and circumferential welds using bobbin tools for tanks with a diameter of 2,500 mm.

At Boeing’s central research centre, one machine for longitudinal and circumferential FSW welding and one bobbin tool set-up have been supplied for R&D work and for testing the welding parameters for the four production machines.

The production time for a tank is dramatically reduced and the price difference between FSW and riveting is a factor of somewhere in the region of 1:5. More parts on rockets are being evaluated for future production.

A number of different applications in the commercial and military aircraft Industry are under evaluation; they include carrier beams, floors and whole bodies and wings. Tests are being conducted in the different laboratory machines all over the world.

In shipbuilding, Friction Stir Welding has been established since 1996 in the Marine Aluminium (today Hydro Marine Aluminium) plant that has produced panels and complete structures for fast ferries. Nowadays, the structures above deck on cruise liners are also Friction Stir Welded aluminium panels. These panels can be supplied by either Marine Aluminium or Sapa, Sweden, a company which also has a dedicated panel welding FSW plant, which was delivered in 1999.

The greatest advantages are flat, straight panels (very low distortion) produced in a rational manner.

In the offshore segment, Hydro Marine Aluminium has produced living quarters for oil rigs and is using the FSW method to produce heavy H-beams used in heli decks and other offshore applications.
In rail transport, Hydro Marine Aluminium is welding roofs for inter-city trains for LHB in Germany. Sapa is delivering panels built up from standard-width hollow extrusions for Alstom France.

In the future, other parts of the train body will be produced using FSW, thanks to the lower price of the standard-width extrusions that can be used and joined to any width at the FSW station.

In the automotive industry, there is a great deal of activity in different areas, but as yet there are few installations for series production. Sapa Sweden is producing seat frames in a fully automatic line.

One machine has also been delivered to Tower Automotive in the USA. It is used in the laboratory but will probably be moved into production at a later date.

In the automotive segment, FSW is ideal, thanks to high-quality welds and low production costs.

Examples of ESAB deliveries to segments other than those listed above include the following.

- Plant to Hydro Aluminium Profiles in Norway for the mass production of electrical motor houses. The plant is complete with handling equipment and fixtures. There is one fixture for each motor type and the motor houses are produced in final lengths and

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**Figure 5.** FSW welding gantry at Sapa, Sweden, including two upper and one backside welding head. The picture also shows the material-handling conveyors for feeding in extruded profiles and feeding out straight or curved panels.

**Figure 6.** The rational production of seat frames for cars at Sapa has two side-welding heads. The cycle time is less than one minute. The material-handling robot feeds the station with extruded parts and removes the finished welded parts. By May 2001, this plant had produced more than 400,000 metres of welds.
within the set tolerances for diameter and shape. The plant is equipped with an extra welding station where straight workpieces with a maximum length of three metres can be welded.

- Welding gantry for The Welding Institute, UK, covering a working envelope of 5x8 m at a maximum height of 1.75 m. In this machine, R&D work, test welding and pre-production will be carried out. The gantry is equipped with two welding heads, one high-speed and one heavy-duty head. The machine has a 3D control system permitting 2D welding and, together with an optional actuator, 3D welding is also possible. The gantry is also prepared for a future articulated arm-mounted FSW head.

- Welding gantry for DanStir ApS, Denmark, covering a 3x5x0.6 m working envelope and on five metres of the ten the workpieces can be up to 1.450 mm high. The machine is going to be used for R&D, test welding and pre-production, as well as small series production. The gantry is equipped with a heavy-duty welding head and a 3D welding control system.

- Lab unit co-owned by EADS, France, and Institute Soudure, France. The machine is equipped with a bobbin tool head and manages both longitudinal and circumferential welds. Furthermore, it is equipped for the 3D welding of workpieces with a large radius.

ESAB also has two purpose-built FSW machines, one small exhibition machine that has been on tour around the world and one lab unit for R&D work and for customer tests. The exhibition machine is equipped with fixtures for both longitudinal and circumferential welding. The lab unit has a heavy-duty welding head and is equipped with a powerful hydraulic clamping system to produce realistic test welding. The working length is a maximum of 2 metres.

Conclusion

Friction Stir Welding is a new welding technology that has been applied in rational production within an extremely short space of time. In the future, FSW will continue to expand in every area in which aluminium and aluminium alloys (including lithium and scandium), copper and copper alloys, magnesium and so on are used.

There will also be niche applications in steel and titanium. R&D projects are also ongoing, with the aim of developing new materials that are composed to take advantage of this new non-destructive joining method.

Manufacturers will start to take advantage of the method in their designs.

Equipment and tools will be further developed to meet new demands and will be standardised as the number of machines and units increases. However, there will also be extensive requirements in the future for flexible solutions and special engineering to produce fixturing and rational production solutions.

About the author

Lars Göran Eriksson, MSc Electrical Engineering, joined ESAB in 1973 and has since held different management positions at ESAB within Business Area Automation & Engineering. He is currently site manager at ESAB Laxå in Sweden.

Rolf Larsson, Mech Eng, has more than 20 years experience of the mechanical design of welding machines and plants and is now technical manager at the marketing and sales group, responsible for FSW and resistance welding techniques in Business Area Automation & Engineering, ESAB Laxå. Rolf Larsson holds a number of patents within Friction Stir Welding technology.
Welding spherical tanks made of 9% nickel steel by TISSOT in France. A case story.

by Jörgen Strömberg, ESAB AB, Göteborg, Sweden

Hydrocarbon processing can be defined as the treatment of gaseous hydrocarbons for the production of fuels and chemicals such as plastics, fertilisers and pharmaceuticals.

During processing, transportation and storage, these gases are frequently liquefied to reduce volume. The most impressive welded structures may well be the large LNG storage tanks and the beautiful LNG tankers crossing the oceans.

A number of petrochemical processes are performed in part at subzero temperatures. In ethylene plants, for example, the product is separated at low temperature and equipment may be subjected to temperatures as low as –120°C. Ammonia is separated from synthesis gas at –35°C.

The distillation of liquid air for oxygen and nitrogen production requires temperatures as low as –196°C.

The storage and transportation of liquefied ammonia, propane, butane, ethane, ethylene, methane, oxygen and nitrogen takes place at low temperature.

Table 1 shows the temperatures and materials for storing these gases at atmospheric pressure.

The transportation of methane (LNG) takes place in liquefied form at –170°C.

In process plant of moderate thickness, impact-tested carbon steel is used at temperatures down to -50°C. The corresponding figures for 3.5 or 5% nickel steel are between –50 and –120°C, 9% nickel steel and aluminium or stainless steel down to –196°C and aluminium or stainless below this temperature.

Materials and weldability

Nickel improves quenchability and notch toughness at low temperatures. The optimum microstructure and mechanical properties are obtained by carefully-

<table>
<thead>
<tr>
<th>Gas</th>
<th>Storage temperature °C</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane</td>
<td>0 to –10</td>
<td>Fine-grained carbon steel</td>
</tr>
<tr>
<td>Ammonia</td>
<td>-33</td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>-45 to –50</td>
<td></td>
</tr>
<tr>
<td>Ethane</td>
<td>-90</td>
<td>Ni-alloyed steel, aluminium steel</td>
</tr>
<tr>
<td>Ethylene</td>
<td>-105</td>
<td>or austenitic CrNi steel</td>
</tr>
<tr>
<td>Methane</td>
<td>-162</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>-183</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>-196</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Storage temperature and materials for liquefied gases at atmospheric pressure.

<table>
<thead>
<tr>
<th></th>
<th>ASTM A203 GrE EN 10028-4 12Ni14</th>
<th>EN 10028-4 12Ni19</th>
<th>ASTM A553Gr 1 EN 10028-4 X8Ni9</th>
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<tbody>
<tr>
<td>C max %</td>
<td>0.15</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Mn max %</td>
<td>0.8</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Ni %</td>
<td>3.5</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Rp MPa min</td>
<td>345</td>
<td>390</td>
<td>585</td>
</tr>
<tr>
<td>Rm Mpa min</td>
<td>490-640</td>
<td>530-710</td>
<td>680-820</td>
</tr>
<tr>
<td>Charpy V Joule</td>
<td>&gt;27 -100 °C</td>
<td>&gt;34 -120 °C</td>
<td>&gt;70 -196 °C</td>
</tr>
</tbody>
</table>

Table 2. Typical properties 1) for cryogenic nickel-alloyed steels

1) The properties depend upon the thickness and heat treatment.
Table 3. SMAW electrodes for welding 5% and 9% nickel steels

<table>
<thead>
<tr>
<th></th>
<th>SMAW OK 92.55</th>
<th>SMAW OK 92.45</th>
<th>SMAW OK 69.25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic AC/DC</td>
<td>Basic DC +</td>
<td>Basic DC +</td>
</tr>
<tr>
<td></td>
<td>AWS ENiCrMo-6</td>
<td>AWS ENiCrMo-3</td>
<td>EN 1600 E 20 16 3 Mn LB 42</td>
</tr>
<tr>
<td>C %</td>
<td>&lt;0.08</td>
<td>&lt;0.03</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>Mn %</td>
<td>3</td>
<td>0.4</td>
<td>6.5</td>
</tr>
<tr>
<td>Cr %</td>
<td>13</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>Ni %</td>
<td>70</td>
<td>64</td>
<td>16</td>
</tr>
<tr>
<td>Mo %</td>
<td>6.5</td>
<td>9.5</td>
<td>3</td>
</tr>
<tr>
<td>W %</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nb %</td>
<td>1.3</td>
<td>3.3</td>
<td>N=0.15</td>
</tr>
<tr>
<td>RpMPa</td>
<td>450</td>
<td>480</td>
<td>450</td>
</tr>
<tr>
<td>Charpy V Joule °C</td>
<td>710</td>
<td>780</td>
<td>650</td>
</tr>
<tr>
<td>Lat. Exp. mm</td>
<td>1.0-1.5</td>
<td>0.9</td>
<td>&gt;0.5</td>
</tr>
</tbody>
</table>

(620-730°C) are really critical. Hydrogen-induced cracking can occur in the HAZ or weld metal because of the high hardenability. Using a nickel-based weld metal reduces the risk of cold cracking.

The 5% nickel steels have improved low temperature ductility down to –120°C and also have higher strength than the 3.5% nickel steels and good weldability. They are welded with austenitic CrNi weld metals or with nickel-based consumables.

The 9% nickel steels offer a combination of very high strength and high impact resistance down to -196°C, plus very good weldability, and are welded with nickel-based consumables to obtain adequate strength and ductility. The 9% nickel steels are not usually sensitive to any type of cracking during and/or after welding. Cold cracking in the HAZ has not been reported. The steel displays little or no deterioration in properties with the heat inputs normally used during welding with the procedures described later. The heat input should not exceed 3 KJ/mm and the interpass temperature must be limited to a maximum of 100-150°C. A small increase in hardness is obtained in the HAZ due to changes in the structure by the thermal cycle.

Case history, welding ethylene tanks by TISSOT S.A.

Ethylene is one of the most important gases and it is mainly used to produce recyclable and chloride-free plastics. The transportation and storage of liquid ethylene has been expanding sharply all over the world. This article describes the construction of two spherical ethylene tanks in France in 1999 by TISSOT S.A.

TISSOT S.A. is a French family company in Podensac (Bordeaux close to Sauternes) which specialises in the design and manufacture of pressure vessels and process equipment. The company also has a workshop in St. Nazaire and site maintenance in Petit-Couronne, Alizay, Le Havre and Berre.
In 1999, TISSOT received a contract to construct two spherical ethylene storage tanks to be erected in Berre near Marseille. The volume per sphere is about 1,300 m³ and the minimum service temperature is –104°C. To begin with, the customer (an international chemical company) was planning to make the spheres from 3.5% nickel steel because of the material cost.

TISSOT invited ESAB AB at an early stage to discuss the welding of these spheres and a meeting was also organised with the Belgian steelworks Usinor Fabriques de Fer, which specialises in manufacturing cryogenic nickel steels. After taking account of all the aspects relating to welding, material costs, welding operations, preheating and PWHT, it was concluded that nickel-based or austenitic CrNi weld metal was a reliable alternative.

Five per cent nickel steel is frequently used for ethylene storage tanks.

Having studied all ESAB AB’s references involving welded 9% nickel steel tanks, TISSOT, however, decided to study alternative technical and economical solutions with a base metal of 5% nickel steel and 9% nickel steel. TISSOT discussed a change of base material with the customer, who also became interested
in this proposition, and 9% nickel steel was finally selected.

For these spheres with their high design pressure, 9% nickel steel offered an attractive solution. This also enabled the wall thickness to be substantially reduced due to the higher material and weld strength.

Due to the design of the spheres and the difficulty involved in mechanising the welding, it was decided to use only SMAW welding and welding from both sides. MIG welding would be difficult on site because of the gas shield and the fact that 9% nickel steels are also easily magnetised and create arc blow.

The material thickness was calculated to be between 32.7 to 38 mm and the design pressure is 25 bar.

The spheres are refrigerated and the liquid gas is stored at atmospheric pressure, but the calculation is for safety in the event of cooling failure.

OK 69.25 is an austenitic electrode used for 5% nickel steel and for 316LN chemical/ethylene tankers. OK 92.45 and OK 92.55 are used for both 5% and 9% nickel steels. OK 92.55 is often preferred because welding on AC simplifies the welding of 9% nickel steel. Furthermore, the ductility is higher and the tensile strength is satisfactory. OK 92.45 has the highest strength and offers advantages when welding in the overhead position.

Electrodes are supplied in vacuum-packed plastic boxes which guarantee that the electrodes are dry and do not need to be rebaked before welding.

The electrodes were test welded by TISSOT in their welding shop and OK 92.55 was found to be easy to weld and suitable for positional welding. Welding was required in the 3G, 1G and 2G positions.

The tanks were constructed according to CODAP 95 rev.97/12 (French code for pressure vessels). The highest level of quality was required for the construction.

Welding Procedure Qualification: TISSOT requirements for the properties of the weld and all weld metal were Rp> 430 Mpa, Rm> 680 Mpa and KV (−104°C) > 50 J.

TISSOT decided only to use electrodes with a diameter of 3.25 mm and 4.0 mm. CODAP requires both a transverse prismatic tensile test of the full plate thickness NF EN 895 and a longitudinal cylindrical tensile test, diameter 10 mm, according to NF EN 876 of the weld metal. The welds were to be made in the 9% nickel steel plate in question and with the joint preparation to be used in the production of the spheres. All weld metal tests, including impact tests, are also required.

The WPR of the test welds with the welding parameters used are given in Figure 1 and Figure 2. A summary of the test results can be found in Table 3.

Before the welding of the spheres, a specialist welder from ESAB went to TISSOT in Podensac to assist in the training of all the welders to use OK 92.55 in the relevant types of joint.

The cutting, joint preparation and forming of the plates was done in Podensac and, by using welding manipulators, most of the shop welds to make larger sections were carried out in the 1G position. Spheres were assembled and welded on site without any preheating or PWHT.

Six production control test plates for each sphere were produced and the mechanical characteristics conformed with the code requirements. No magnetic arc blow was detected and these electrodes have been used in AC with a low interpass temperature between each weld run. The weldability was regarded as very satisfactory by the welders.

Acknowledgement

Acknowledgement to Mr Pierre Lameloise QA Manager TISSOT SA and his colleagues for their consent to let us publish this article and for providing valuable information and photos. Also we thank Mr Philippe Varin Product Manager ESAB France for his helpful assistance.

About the author

Jörgen Strömberg, M.Sc has worked for more than 30 years in the welding and Metallurgical Industry of which about 25 years with ESAB. He has also been working in ASEA Material Research Laboratory and in Höganäs Metallurgical Division.
Off to the Caribbean, the largest cruise liner in the world!

by Juha Lukkari, ESAB Oy, Helsinki, Finland

The world’s largest, most beautiful, most luxurious and most expensive cruise liner was delivered to her purchaser, the US shipping company Royal Caribbean Cruises Ltd., on 29 October 1999 at Kvaerner Masa-Yards New Shipyard in Turku.

Order for three ships
In November 1996, Royal Caribbean Cruises Ltd. and Masa-Yards agreed on the objective of building one or possibly two cruise liners at the new shipyard in Turku. The contract for the first ship was signed in January 1997 and the option to buy a second ship became a confirmed order in March 1997. At the same time, an option to buy a third ship was agreed on and it was subsequently ordered in January 1998.

The production of the first ship started in September 1997 and the launch took place on 27 November 1998. Now complete, she is already being used for luxury cruises in the Caribbean. The ship was named the Voyager of the Seas.

The second of the sister ships, the Explorer of the Seas, was delivered in September 2000 and the third, the Adventure of the Seas, will be delivered in the autumn of 2001. The total cost of these three ships is an enormous EUR 1.4 billion (£850 million) and 80% of the materials and labour come from Finland. The family of ships is what is known as an Eagle series.

So the cost of one ship works out at about EUR 0.5 billion (£283 million). The building of the third ship started at the end of August 1999 and her steel work will be ready in December 2000. The direct employment impact of one ship is about 15,000 man-years, the majority of which are being done by Finnish shipyard workers and external small and medium-sized subcontractors.

Huge welding job
If the ship is luxurious, it follows that the welding work is huge. The steel in the ships hull weighs more than 25,000 tonnes and only accounts for about 10% of her total cost. The ship is made up of about 300,000 individual steel components (plates, beams and so on).
welding stations, the stiffener welding station, T-beam manufacturing stations and with tractors. The processes used are single wire, twin-arc wire, tandem and three wire. Most of the wires are solid, but some submerged arc welding is carried out with cored wire.

Some stick electrodes are still required, as the consumption figures show. Electrodes are mainly used for all kinds of outfitting welding.

Standard MAG welding with solid wire is not used at the shipyard and in fact never has been. As welding technology developed, the shipyard moved directly from electrode welding to MAG cored-wire welding; the change mainly took place during the 1980s.

Hundreds of tonnes of aluminium were used on the top decks, which were welded almost exclusively using the MIG process. The aluminium alloys are AA 5083 (AlMg4.5Mn) and AA6082 (AlMgSi1).

The most important and widely used ESAB welding consumables were, in order of importance:

<table>
<thead>
<tr>
<th>Consumable Type</th>
<th>Brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positional, rutile cored wire</td>
<td>PZ 6113</td>
</tr>
<tr>
<td>Metal-cored wire</td>
<td>OK Tubrod 14.12</td>
</tr>
<tr>
<td>Stick electrode</td>
<td>OK 48.00</td>
</tr>
<tr>
<td>Submerged wire</td>
<td>OK Autrod 12.22</td>
</tr>
<tr>
<td>Submerged flux</td>
<td>OK Flux 10.71</td>
</tr>
<tr>
<td>Aluminium wire</td>
<td>OK Autrod 18.16</td>
</tr>
</tbody>
</table>

Cruise liner steel plates are thin

The steel comes from Rautaruukki steel mill in Raahen and the steel is mainly standard NVA grade shipbuilding steel with a yield strength of 235 N/mm². At certain points, a stronger NV36 grade steel has been used. The ship has 18 decks, with 15 in passenger use, and their plate thicknesses generally vary between 5.5 and 6.5 mm. The bottom plate of the hull is 25 mm thick, thinning out to 15 mm towards the top.

The similar ships involved in the order make up a small series and therefore facilitate production in a number of ways: the same job instructions, fasteners, protective canopies and so on, as well as training and experience in general.

Cored wire rules

Cored-wire welding is the most widely used process, as the consumption breakdown shows. The process is already being used almost to its maximum. All the cored wires are welded with shielding gases, either mixed gas or carbon dioxide, so the principal welding process is MAG welding with cored wire. It is performed both manually and by utilising various mechanised carriers (rail-mounted and tractor carriers), other mechanised equipment and robots.

Submerged arc welding is carried out at a number of large work stations and lines, including one-sided
comes under Masa-Yards Technology Unit. It is constantly developing welding and welding processes. Its greatest achievements so far have been made in the development of aluminium welding in LNG tankers, which we have had the opportunity to read about in many trade publications and the media.

The shipyard monitors welding technology development closely and selects any new solutions or processes that are applicable for its operations. Much interest is currently being shown in laser welding in its various forms and in friction stir welding. ESAB also organised a welding seminar at the shipyard in October 1999 which dealt with laser welding and friction welding, of which there is an overview elsewhere in this magazine.

<table>
<thead>
<tr>
<th>Main specifications of the Voyager of the Seas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. length</td>
</tr>
<tr>
<td>Max. width</td>
</tr>
<tr>
<td>Draught</td>
</tr>
<tr>
<td>Max. height</td>
</tr>
<tr>
<td>Gross tonnage</td>
</tr>
<tr>
<td>Ship’s total weight</td>
</tr>
<tr>
<td>Passengers</td>
</tr>
<tr>
<td>Crew</td>
</tr>
<tr>
<td>Cruising speed</td>
</tr>
</tbody>
</table>

Did you know...

The Voyager of the Seas has

- 5,500 fire alarms
- 15,500 seats
- 50,000 m² of carpets = 5 hectares = over 100 basketball courts or 10 football fields
- an ice rink and a full-sized basketball court
- a climbing wall with the top 60 m above sea level
- 757 outside balconies
- the largest cabin of 107 m² with a grand piano
- 65,000 light fittings
- 8 km of neon lights
- about 3,000 books in the library
- 400 game & slot machines
- 31,000 litres of water in her aquaria weighing 56,000 kg
- 3,000 km of electrical cable (compared with the 2,977 m by road from Helsinki via Berlin to Rome (!))
- generator capacity of 110 MW (as compared to the 59 MW power plant in a city with 172,000 inhabitants)
- a length of 311 m, which is equal to a 17-carriage train or four Boeing 747s
- a godmother, the Olympic figure-skating champion Katarina Witt
- the ability to travel sideways at a speed of three knots.

The most expensive day on the ship costs about EUR 1,000 (£630) and even the cheapest one costs about EUR 200 (£115), so cruising does not come cheap. Cruises departing from Miami last one week initially.

Acknowledgements

Many thanks to the management of the shipyard for allowing us to write this article and especially to welding engineer Pasi Hiltunen, who answered all our questions and gave us information about welding the ship.

About the author

Juha Lukkari, M.Sc. (Eng.), joined Oy Esab in Helsinki, Finland, in 1974, after graduating from the Helsinki University of Technology. He has since held different positions and is currently head of technical customer service.
Take advantage of the new magnetic pulse welding process

by Victor Shribman

This innovative solid state “cold” welding process gives you the following benefits:
• Welds stronger than the weaker of the welded metals
• Cold weld in less than 100 msec
• Welds dissimilar metals
• Welds conventionally unweldable materials, such as Al7075.
• No HAZ
• No filler metals, no gases
• A “green” process

Introduction
Magnetic pulse welding is basically a solid state welding process, in which bonding is produced by an oblique, high-velocity collision between the two bodies that are going to be welded. This collision causes a metallic jet to be ejected from the point of impact, carrying with it the contaminated surfaces of both bodies and leaving behind clean, virgin surfaces which are brought together under pressure to form a continuous weld.

The bond that is produced is a true metallurgical bond and is very strong, usually stronger than the weaker of the two materials that are being bonded.

The magnetic repulsion effect used in MPW has been known since the late 1950s, when attempts to use strong magnetic pulses for nuclear research first unveiled the phenomenon of coil shattering.

The process is precisely controllable and repeatable.

The process
The basic principle of the magnetic pulse system is illustrated in Figure 1. A high current is discharged (3) through a coil (2), creating an eddy current (5) in the conductive workpiece (4). Repulsion between the two magnetic forces creates pressure (1) and accelerates the workpiece into a new configuration (6).

The two magnetic fields that are generated strongly repel one another with a force that is proportional to the square of the discharge current. As a result, the workpiece moves away from the coil at very high speed, pushing the metal well beyond its yield strength and into its plastic region. If the conditions are correct, i.e. plate velocity, collision point angle and collision point velocity, the jetting of the surface layers at the collision point occurs, resulting in a weld (see Fig. 3).

---

Figure 1. Basic principles

Figure 2. Magnetic field distribution
The main MPW process parameters are the shock angle $\phi$ and the collision point velocity, $V_c$. Both are governed by the spatial shape of the magnetic field, which governs $V_r$. In this case, Workpiece 1 displays momentary angle $\phi$ relative to Workpiece 2.

**Equipment**

A basic schematic layout of the equipment is shown in Fig. 4. Each operation includes a charge/discharge cycle. When the switch is open, the voltage preset to produce the required energy for the pulse is built up in the capacitor. On closing the switch, current flows rapidly from the capacitor through the operating coil, causing magnetic flux to expand rapidly and radiate from the coil windings.

Figure 5 shows the power source with its coil, which must be close to it to keep the electrical reactance as low as possible.

**Available tubular weld geometries**

Fig 6 shows the geometries used in MPW. They are typically lap joints. To date, work has concentrated on the welding of round, elliptical and rectangular section tube-to-tube and tube-to-bar welds. In theory, MPW can also be used for welding flat areas. However, this type of joint has not yet been developed to a commercial level.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Magnesium</th>
<th>S.Steel</th>
<th>Nickel</th>
<th>Titanium</th>
<th>Steel</th>
<th>Zirconium</th>
<th>Molybdenium</th>
<th>Brass</th>
<th>Copper</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
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<td>Copper</td>
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<td>Aluminium</td>
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<tr>
<td>S.Steel</td>
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<tr>
<td>Nickel</td>
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<td>Magnesium</td>
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</tr>
</tbody>
</table>

Some of the similar and dissimilar materials with numerous dimensions and combinations that may be welded by MPW.
Some applications

A wide range of tubular materials have been joined using MPW technology with the combinations shown above in Table 1. A few examples of them are illustrated by the following figures:

Some metallographic sections of steel-to-steel and aluminium-to-aluminium weld interfaces from welded driveshafts are shown in Figures 11 and 12.

The magnetic pulse welding method is in its infancy stage and the applications shown above will certainly create many new ideas on applications for this revolutionary joining technology. The magnetic pulse welding process can also be used for

- forming
- perforating
- punching
- cutting

which is not covered in this article.

About the author

Victor Shribman is born in N. Ireland. He received B.Sc. (hons.) Mechanical Engineering and a Ph.D. in Metallurgy at The Queen’s University of Belfast, N. Ireland. Mr Shribman has wide experience in the aerospace industry, especially the fields of welding, brazing and plasma coatings.

He has published more than 40 research papers in the fields of explosive welding, magnetic pulse welding, EBW and plasma coatings.

Holds a UK patent in EW.
We've all seen them, haven’t we? The steel expansion strips across the road on either side of concrete bridges. The characteristic sound as you drive over them tells you clearly when you leave the bridge access road for the actual bridge deck. The manufacturer of these expansion profiles achieved a 50% increase in production essentially by using SAW cored wire.

Expansion strips for concrete bridges are made up of several parallel welded profile bars separated from each other by rubber strips. The profile bars are predominantly made of S355J2G3 and have different contours; see Figure 1. These expansion profiles have been made for years by the Corus Mannstaedt-Werke company, a hot-rolling mill at Troisdorf near Cologne, Germany. About 2% of the mill’s 160 000 ton annual output is accounted for expansion profiles for concrete bridges. That’s around 130 kilometres of expansion profiles per year.

Because of the contours of the profile bars they cannot be produced solely by hot rolling. They are made in two parts which are joined from both sides by SAW welding on two continuous welding machines arranged in series. A reinforcement of the weld is not allowed because this would damage the rubber strips. The profile bars are typically 125 mm high, 90 mm wide and 12 to 18 metres long. They usually weigh between 3 and 6 tons.

Growing demand: What to do?

Some time ago, faced with growing demand from the market, from China among other countries, and the resulting increase in the number of different lengths to be produced, the Corus Mannstaedt-Werke had to switch to a welding technology with higher performance and a more reliable welding equipment. The aim was to keep the SAW process and the manufacturing sequence on two continuous welding plants, using two-run-double-side technology.

Welding was done with OK Autrod 12.20 (EN 756 - S2) in diameters 2.5 and 4.0 mm and with OK Flux 10.71 (EN 760 - SA AB 1 67 AC H5). At 680 and 450 A respectively, welding speeds of 80 cm/min were achieved. The welding units had an output of 21 profile bars per shift and operated two shifts per day. Because of unacceptable changes in the seam profile it was not possible to achieve speed increases by increasing the welding current.

After some preliminary experiments in cooperation with ESAB GmbH, Solingen, it was confirmed that submerged-arc welding (SAW) was the most suitable process. Of the various processes, only SAW welding with filler wire electrode could be considered, for reasons of penetration depth, seam forming and maximum welding speed. The company approved the approach and ESAB welded a number of promising samples. The efficiency of the process was evaluated in time and cost calculations.

Figure 1. Expansion profiles for concrete bridges
The SAW cored wire is supplied in drums with a wire weight of 300 kg. For unspooling, the drums are placed on rotating turntables. Corus Mannstaedt-Werke receive the SAW flux in economical BigBags with a capacity of 800 kg. In co-operation with the customer a logistics concept was developed to ensure the automatic, trouble-free supply of welding consumables. Currently ninety-six profile bars are produced on the welding equipment every twenty-four hours.

Implementation

At Corus Mannstaedt Werke, the existing welding equipment were generally overhauled and extended to deal with 16 metre lengths. They were upgraded to the latest state of the art with ESAB components. A6 motors, proven over many years, fully programmable PEH control units and the two LAF 1250 welding rectifiers make up the technical heart of the welding equipment. The entire system is supplemented with GMD tactile seam scanning systems with corresponding motorised supports and a central flux supply with a capacity of 200 litres; see Figures 2 to 4.

With the support of ESAB Solingen, the equipments were run in, parameters were optimised and welders instructed. Initially it was not at all easy for the welders to get used to the more than 65% higher welding speed. All the welders working on these units—which were now operating three shifts—were trained at ESAB. The flow of materials in front and after the welding equipment was also optimised.

The result

Today, to the great satisfaction of the management, the plants are welding at a speed of 135 cm/min; see Figure 5. Thirty-two profile bars are produced per shift, compared with twenty-one before the conversion, a production increase of more than 50% per shift. The 4.0 mm diameter OK Tubrod 14.00S SAW cored wire has proved itself outstanding for this application (AWS A 5.17: F7A2–EC1). It can cover the entire range of parameters, so that there is no need for a second diameter in production. In combination with OK Flux 10.71, high-quality seams with very gentle seam edges are produced at welding currents up to 750 A; see Figure 6.

Welding consumables:

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAW cored wire</td>
<td>OK Tubrod 14.00S</td>
</tr>
<tr>
<td>Diameter</td>
<td>4.0 mm</td>
</tr>
<tr>
<td>EN</td>
<td>–</td>
</tr>
<tr>
<td>AWS A 5.17: F7A2–EC1</td>
<td>(with OK Flux 10.71)</td>
</tr>
<tr>
<td>Flux</td>
<td>OK Flux 10.71</td>
</tr>
<tr>
<td>EN 760:</td>
<td>SA AB 1 67 AC H5</td>
</tr>
</tbody>
</table>

About the author

Martin Gehring works as product manager for consumables at ESAB GmbH in Solingen in Germany since 1994 and focuses primarily on the design of customer-specific systems within SAW and on welding using solid wire and shielding gas.
Aluminium welding in shipbuilding

The manufacture of marine gearbox casings with welding consumables and pulsed current power sources from ESAB

by Dieter Brunnhuber and Helmut Bandt, BuB GmbH, Oberaudorf and Helmut Schmidt, ESAB GmbH, Solingen, Germany

For almost thirty years the company of Brunnhuber und Bandt (BuB GmbH) has been making high value welded constructions of different materials for the construction of plants and apparatus. Some ten years ago, faced with growing demand, BuB was specialising in the construction of gearbox casings of aluminium for high-speed ships.

Manufacture on time and to the correct quality are the virtues that customers appreciate about BuB GmbH. For example, the luxury yacht of Kuwaiti sheikh Aga Khan (Figure 1) relies on its Brunnhuber und Bandt gearbox casing.

With engines that deliver some 49,000 horsepower the yacht reaches top speeds of up to 80 km/h. With this vessel the sheikh won a special award for the fastest crossing of the Atlantic on water. Under the prevailing operating conditions, which are comparable to a race, the welded gearbox casings of AlMg4.5Mn (EN AW 5083) alloy are very highly stressed. Extensive testing of the weld seams after the crossing did not reveal the slightest indication of damage. This speaks highly of the reliability of the yacht and the high quality of the gearbox casings supplied by BuB.

Figure 2 shows the welded construction of a pre-assembled gearbox casing. Even at the planning stage, the manufacture of a casing such as this calls for extreme precision, especially when determining the welding parameters and welding sequences. Finite-element calculations formed the basis for the dimensioning of the casings. Extensive work samples and process tests were needed in order to assess the mechanical engineering properties of the welds. Taking later loads into account, the work samples were subjected to vibration endurance tests. All tests were done by independent institutes.

Naturally, the high standards imposed on the load capacity and quality of the gearbox casings meant equally strict demands on the quality and reliability of the welding technology. After all, seams free from pores and lack of fusion defects had to be produced with very good strength and ductility properties in aluminium parts with wall thicknesses up to 100 mm! A modern pulsed current source, the ESAB multi-function Aristo

Figure 1. Luxury yacht fitted with BuB gearbox casings.

Figure 2. Gearbox casings of AlMg4.5Mn (EN AW 5083).
2000 LUD 450 UW (Figure 3) was therefore chosen to be used for MIG and TIG welding. The ESAB weld metals used OK Autrod 18.16 ø1.6 mm for MIG welding and OK Tigrod 18.16 ø3.2 mm for TIG welding (SG-AlMg4.5Mn, ER5183). The ESAB welding technology used reproducibly delivers the highest seam quality in aluminium welding. Figure 4 shows a cross-section cut through a corner joint.

Metallographical investigations of the welds reveal a perfect structure in both cast and wrought alloys. By using specially modified end crater programs it was possible to produce defect-free seam ends with the ARISTO 2000 pulsed unit. This means that time-consuming and costly reworking could be reduced to a minimum.

Bearing in mind the very close tolerances, especially in the region of the bearing shells, the manufacture of the high value welded construction demands precise observation of the predetermined welding sequences. After welding, the casing parts are heat-treated in a stationary annealing furnace for six hours at 320 °C in a protective gas atmosphere. Distortion due to the release of stresses had to be allowed for when pre-dimensioning the blanks. Subsequent machining was done on a CNC machining centre. Figure 5 shows the upper shell being placed on the lower part with the gears already installed.

High accuracy of fit, especially in the region of the bearing shells, is essential for smooth running of the gearbox and ultimately determines its life. Because of the high quality and the proven service record, there has been a growing demand for ships with gearbox casings from BuB. At present, casings are being manufactured for luxury yachts for Monaco and Spain.

Growing success, much of which is due to high-quality, reliable products from ESAB.

Figure 3. Multi-function welding unit Aristo 2000 LUD 450.

Figure 4. Cross-section cut through a corner seam welded with OK Autrod 18.16.

Figure 5. Assembling the gearbox components.

About the authors

Helmut Schmidt Dipl. Ing. (TU) graduated from the Technical University of Munich (1985) and got a European Welding Engineer diploma at the SLV Munich (1986).

After the studies, he worked in the research department at SLV in Munich. For about ten years Mr Schmidt was responsible for the welding department in a reactor and shipbuilding company. In January 2001 I joined ESAB Germany as a teamleader, with the responsibility for application and sales in Southern Germany.

Dieter Brunnhuber and Helmut Bandt are managing directors in BuB GmbH, Oberaudorf.
Development in welding power source improves weld quality

by Klas Weman, ESAB Welding Equipment AB, Laxå

The history of welding power sources dates back about 100 years. Around this time power sources large enough to supply current for welding became available. At the end of the 19th century, Nikolai Bernados used batteries and a generator driven by a steam-engine for his experiments with carbon arc welding.

The semiconductors of today have revolutionised the design of new power sources. It has now become possible to reduce their weight and size, but the most dramatic changes however, are related to the control technology. The most advanced computer software facilitates both the communication with the user through a control panel, and the optimisation of welding characteristics.

When high performance quality welding is required, it is possible to implement a number of new functions to minimise the risks of welding defects.

ESAB’s New Aristo System is an example of the latest development technology in welding equipment, offering all the functions you need without more complicated settings than necessary.

Design principles

The semiconductors have paved the way for designers to develop and construct new power sources, see Figure 1. The silicon diode used in a welding rectifier was the first such example, followed by the thyristor and the transistor used in modern inverter power sources.

As can be seen in Figure 2, research and development have resulted in more effective designs bringing about the reduction in weight by a factor of ten. The most crucial and important step was the development of the...
welding inverter. The switching technology facilitated
the reduction in the weight and the size of the power
source. In 1984, ESAB developed the first Caddy, a
portable unit weighing only 8 kg.

The reductions in weight and size are the most
obvious changes, but further development indicates
that rapid control of the output current also causes a
radical change in the performance of the equipment.

At ESAB, this aspect of the development is best
represented by the Aristo equipment. The first
generation of the Aristo family was developed in 1988
and introduced a collection of new features.

• Software control of output current and the welding
  process
• Multi-process possibilities – MIG, TIG and MMA
  welding with the same equipment
• The “synergetic lines” optimise the settings/perfor-
  mance for each situation
• Pulsed arc MIG welding
• Feedback control of welding parameters that
  guarantees better accuracy and reproducibility
• Improved welding start and stop functions

Improved weld quality?

Obviously, excellent welding characteristics and better
opportunities to optimise the performance of each
situation would improve the welding quality. The
amount of spatter would be reduced and the general
appearance of the weld will improve. But these are not
the only benefits, it is also possible to create a number
of new functions, due wholly to the electronic control.

The functions in table 1 exemplify the options
available in the advanced welding equipment and assist
the welder in improving the quality and avoiding weld
defects in critical applications.

**Man-to-Machine Communication**

A growing problem, as a consequence of the
development of advanced welding equipment, is the
communication with the user. The more welding
processes and possibilities the machine allows, the more
complex the control panel tends to become.

<table>
<thead>
<tr>
<th>Start of welding</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td></td>
</tr>
<tr>
<td>Creep start</td>
<td>MIG</td>
</tr>
<tr>
<td>Gas pre-flow</td>
<td>MIG, TIG</td>
</tr>
<tr>
<td>Hot start</td>
<td>MIG, MMA</td>
</tr>
<tr>
<td>HF-start</td>
<td>TIG</td>
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<tr>
<td>Lift arc</td>
<td>TIG</td>
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<tr>
<td>Slope up</td>
<td>TIG</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Continuous welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
</tr>
<tr>
<td>Pulsed MIG welding</td>
</tr>
<tr>
<td>Arc length control</td>
</tr>
<tr>
<td>Step-less inductance setting</td>
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<tr>
<td>Synergy lines</td>
</tr>
<tr>
<td>Pulsed TIG</td>
</tr>
<tr>
<td>Slope up</td>
</tr>
<tr>
<td>Arc force</td>
</tr>
<tr>
<td>Feedback controlled parameter settings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Finishing a weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
</tr>
<tr>
<td>Crater filling</td>
</tr>
<tr>
<td>Slope down</td>
</tr>
<tr>
<td>Burn back time setting</td>
</tr>
<tr>
<td>Shake off pulse</td>
</tr>
<tr>
<td>Gas post flow</td>
</tr>
</tbody>
</table>

Table 1. An overview of functions at Start, Stop and Continuous Welding.

The welder does not usually exhibit a great deal of
tolerance for such a high degree of complexity, since
some of these functions may not be required,
depending on the actual situation. For advanced
materials and high performance quality welding every
available function would be appreciated, but in most
cases just a few are necessary.

The new Aristo System, see Figure 3, allows the user
to choose exactly what he requires. There are three
options depending on the welding process, and three
series which provide different degrees of advanced
control. The panels in series 2 are equipped with a few
knobs, series 4 has a display with symbols, while series 3
uses text information in 14 different languages.
The module system
The equipment system for the new Aristo is based on modules. From a few basic modules it is possible to design equipment that can be adapted to suit the specific needs of each customer. Examples of these modules are the power module, a mains voltage transformer, a water-cooling unit, two sizes of wire feed mechanisms, the panels shown in Figure 3, and a number of accessories.

Future development of power sources
It is not difficult to predict that the development of inverter power sources will continue. Small, handy portable power units are requested by craftsmen and for repair and maintenance purposes. The efficiency and consumption of current will be improved, allowing for simple connections even to small fuses. Robustness and durability are also important features, as are protection from dust, moisture and electrical noise.

Regarding the machines for industrial use, the segments for productivity and quality welding, the new ESAB Aristo System is well representative of the state-of-the-art. Here the modular system, the CAN bus communication between units, and the possibility to update software guarantee adaptation to future development.

About the author
Mr. Klas Weman, MSc, has extensive experience in the R&D of arc equipment, power sources and welding processes at ESAB Welding Equipment AB, Laxå, Sweden. He is responsible for training and education and also works as an Associate Professor at the Welding Technology Department at the Royal Institute of Technology, Stockholm.
Many high-efficiency welding methods have been developed and introduced into the market during the past few years. The most successful methods in use today include the MIG/MAG multi-wire and the laser-welding methods.

The most important advantage of laser welding is that the welded workpiece is subjected to extremely little distortion and subsequent straightening operations can therefore be avoided. However, the high investment cost of laser systems makes the method unprofitable for small-scale manufacture. Multi-wire welding is a further development of the conventional MIG/MAG welding process and can be integrated into an existing production line at a low investment cost.

The following article describes ESAB’s newly-developed tandem MAG welding system, together with the result of two independent evaluations made by researchers in Sweden and Germany.

Multi-wire welding
Different multi-wire systems—sold under various names—are today available in the market. Here it should be taken into consideration that multi-wire welding can be performed according to a number of different principles:

• Twin welding (one feeding unit): Two wires are fed by the same feeding unit. Both wires have the same potential and are connected to the same power source.
• Twin welding (two feeding units): Two wires are fed by each one feeding unit. Both wires have the same potential and are connected to the same power source.
• Tandem welding (two feeding units and two power sources): Two wires are fed by each one feeding unit. The wires are connected to each one power source, and the wires are electrically insulated from one another in the welding gun. The wires can have different potentials, and the welding parameters can be set freely for each wire.

In addition to the differences between the systems described above there are also systems, where the distance between the wires is so wide that two from each other more or less separated weld pools are formed.

ESAB tandem MAG welding system
ESAB has developed a new tandem MAG welding system, where the welding parameters for the two wires can be set and where the distance between the wires is relatively small, so that the two wires work in the same weld pool.

There is no question that most efficient method is to set the welding parameters for the two wires individually, as the tasks of the two arcs are different when working in a common weld pool. The leading wire has to do the heavy work of heating the wire and the
base metal so as to form a molten pool, whereas the following wire has to fill up the groove and simultaneously smooth the surface of the weld without causing too much spatter.

The process window appears to be smaller for multi-wire welding than for ordinary MIG/MAG welding. So the welding equipment carrier and the entire installation must be more accurate than that for welding with a single wire.

In order to achieve the optimal welding results, it is important to make sure that the equipment meets the following basic demands:

- Rigid and vibration-free fixation of the welding gun
- High performance in terms of speed and acceleration
- High-performance feed units, guaranteeing safe, smooth wire feed
- Joint tracking systems, guaranteeing invariable welding conditions
- For high-efficiency manufacture with large-scale wire consumption, large wire reels are required or MarathonPacTM (cannot be fitted close to the welding gun, however)

ESAB’s tandem welding system has been developed for heavy-duty welding, where the requirements relating to high duty factors and long welding times are rigorous.

The tandem welding gun is designed to provide excellent cooling of the nozzle and the gas cup. Efficient cooling of the gas cup prevents welding spatter easily sticking to the gas cup.

The insulation of the two separate welding guns is done according to existing standards, guaranteeing no electric flash-over between the two electric systems.

The welding gun can be used for different types of application. The distance between the contact nozzles (the wires) can vary and the advance welding of the vertical position of the rear contact nozzle can be adjusted separately as well.

Filler material PZR6105R/1.6 first wire and PZR6105/R 1.4 second wire

Panel welding at the Kværner Shipyard in Rostock

ESAB’s tandem MAG welding system has been successfully installed at the Kværner Shipyard in Rostock, Germany (for more details see the article in Svetsaren vol. 54 No. 1 2000 p. 37).

Excellent welding results are achieved using the new PZ 6105 R metal-cored wire with welding parameters 450 A for the leading arc and 340 A for the following arc. The mixed gas contains 92% argon and 8% CO2. The wire diameter is 1.4 mm. The weld travel is 120 cm/min, but it can be increased still further if necessary. The total system configuration was:

- two LAF 635 power sources
- two PEH controllers

Figure 2: ESAB tandem MAG welding torch 2 x 600 A at 100% duty cycle, wire range from 0.8 to 2.0 mm

Figure 3: Butt weld with ESAB’s tandem welding system with LAF635. Filler material first wire PZR6105R/1.6 and PZR6105R/1.4 second wire. Weld speed 2.5 m/min, weld parameters 550A/128V and 350A/23V. Sheet thickness 5 mm.

- two A4/MEK wire feed units
- tandem gun

Evaluation of the ESAB tandem system at SIMR in Stockholm

In an ongoing project at the SIMR (Swedish Institute for Metals Research), MAG welding with ESAB’s tandem MAG welding equipment is being studied.

Some results from the first parts of the project in which butt, fillet and overlap joints were performed in mild steel are presented here. The applications came from industry, all currently using single-wire MAG welding (both solid and cored wires depending on the application).

The aim of the project is to evaluate the process by performing a number of application tests. In this case, sufficient joint penetration and quality level should be obtained and the potential for increasing productivity and cost effectiveness should be explored. Furthermore, the project aims to obtain more process knowledge. A preceding literature study only resulted in a few hints on how to set the tandem MAG process.

The following applications are reported:

Application No. 1–butt weld in 12 mm mild steel (position PA): Apart from a process performance test, the opportunity to exclude joint preparation was evaluated (due to a supposed increase in penetration capacity).

Application No. 2–fillet weld in 12 mm mild steel (position PB): A 5 mm weld size with sufficient joint penetration of 2.5 mm has been achieved with a travel speed of 100 cm/min. The determined weld quality level was reached.

Application No. 3–overlap weld in 2.5 mm mild steel (position PA): The weld quality level was achieved with a travel speed of 400 cm/min.
In the conclusions, it is stated that, for all applications, a substantial increase in productivity could be obtained (Figure 5). The rule of thumb sometimes mentioned in literature, "double-wire = double speed", appears to be correct compared with conventional single-wire welding. The welding speed, the weld quality and the process tolerances must, however, be balanced (evaluated for each case).

It is also interesting to note that the tandem MAG welding process has a much higher penetration capacity than single-wire welding (Figure 6).

Conclusions

- The tandem process demonstrates overall potential to reach higher welding speeds and deposition rates, compared with single-wire welding.
- When low and similar wire feed speeds are used for the two wires, the arcs start to oscillate more easily. This supports the tandem MAG welding solution in comparison with twin-wire welding.
- Acceptable weldments can be achieved with multiple and totally different combinations of welding parameters and welding-gun configurations.
- A higher wire feed speed on the front electrode and a process with contracting arcs appears to benefit arc stability with reference to oscillation, but it can also increase spatter.
- A minimum weld pool size appears to be necessary, compared with single-wire welding.
- Synchronised pulsing proved to be beneficial in some of the welding trials where improved control of the weld pool at high travel speeds was achieved.

High speed filming for the analysis of the material transfer in ESAB's pulsed tandem MAG welding system

In tandem MAG welding, the material transfer must be controlled very suitably to obtain a smooth welding result. Different arc modes are used for MIG/MAG welding: dip transfer (short arc), spray arc, pulsed arc and, in the case of tandem MAG welding, all combinations of these modes are possible. However, the two arc processes affect one another and cause disturbances.

The two pulsed arc modes on both wires are an appropriate tool for the adaptation and optimisation of this highly-efficient welding process to match customer requirements.

The main aim of this analysis was to identify process instabilities and improve the process control used for ESAB's tandem MAG welding system which was based on two ESAB LUD 450 W power sources.

The two major tasks were to determine the limits of the pulsed tandem MAG welding process and analyse the material transfer by applying high-speed cinematography. This analysis focused on minimising process instabilities, causing spatter, blow holes, partial arc extinction, rippled welds and so on, by varying the Pulse Phase Shift (PPS) between the pulsed processes on both wires.

For the torch, an asymmetrical set-up of contact tubes with 6°/0° angle to vertical in front (power source 1 - master) and -9°/-6° on the rear tube (power source 2 - slave) was used.

Figure 4: ESAB's tandem welding system at the Kvaerner Shipyard in Rostock

In conclusion, the tandem process demonstrates overall potential to reach higher welding speeds and deposition rates, compared with single-wire welding.
Limits of the tandem MAG welding process
Welding experiments were carried out in relation to the following requirements.(see table 1)

1. Determine the limits of the process use of power sources, synchronised by experimental process control software for different PPS settings.
2. Conduct an experimental analysis and comparison of the different arc modes in the tandem MAG process.

The applications were as follows

**Fillet welding**
- mild steel 8/8 mm thickness
- metal-cored robotic filler wire FILARC PZ 6105 R ø 1.4 mm
- shielding gas 20% CO₂ + Ar, 28 l/min

**Butt welding**
- stainless steel 1.5 mm
- solid filler wire OK Autrod 16.12 ø 0.8 mm
- shielding gas 2% CO₂ + Ar, 28 l/min

The variables were as follows
- Process: wire materials and diameters, gas, welding speed
- Power source: all pulse parameters for master and slave + synchronising: Pulse Phase Shift
- Additional: torch angles; twist angles of both contact tubes; distance to sheet

The results
Compared with other arc welding processes, the results for fillet welds shown in table 2 were obtained.

For the tandem MAG process, the maximum welding speed obtained with the Aristo 450 power source is 235 cm/min for the fillet weld and 400 cm/min for 2 mm stainless steel I-butt welds. In the case of the fillet welds, the maximum achievable deposition rate was 20 kg/h, see Fig. 8. In this case, the power sources reached their power limits with 490 A and 470 A and with a throat thickness of 4.5 mm.

Problems with undercutting can be minimised by using an appropriate torch design and installation accuracy, while spatter can be minimised by optimising the pulse parameters.

Analysis of the material transfer by high-speed cinematography
High-speed film analysis was used to obtain a better understanding of the material transfer and the process behaviour with the emphasis on the effect of the Pulse Phase Shift, PPS, the torch design and the different arc modes.

The set-up was:
- bead on pipe, mild steel 5 mm, Ø 307 mm
- filler wire: 1.2 mm OK 12.51 and OK 14.13
- stick-out: torch 1 = 20. 2 = 21 mm; wire tip distance at worksheet = 9.5 mm
- KODAK camera HS 4540mx with max. 40,500 Fps, CCD chip 256 x 256 pixel
- NIKON zoom lens 70-210 mm, back light: high-performance DC lamp 430 W (106 lux/cm²)

Results and conclusions
The widest achievable parameter box and best welds resulted from a torch design with an asymmetrical angle of the contact nozzles, 0º in front and 9º on the rear one, see Figure 9. Wider distances between the contact tips cause the rear arc to push the melt forward and led to the front arc standing and ending up on top of the weld bead wave.

For a stable tandem welding process in the pulsed mode, synchronisation is indispensable. The main reason for a non-stable process is intensive weld pool wave which causes heavy activity in the built-in arc length control. Using synchronised pulsing, the weld pool wave can be minimised with the optimum at a pulse length (PPS) of 1 ms.

At this rate, a flat, non-waving weld pool stabilises the welding pool. In the case of higher PPS, the weld wave height increases and the process becomes more turbulent, see Fig. 10b). There again, in a non-synchronised pulsed mode, heavy weld pool wave causes short circuiting with spatter initiation. The spatter is mostly caused by incorrect droplet transfer at the rear arc, pushing the droplet horizontally into and through the front arc.

All the other arc mode combinations led to poorer weld results. The spray arc mode on both was a very unstable process. As a result of high arc pressure, there

<table>
<thead>
<tr>
<th>Arc mode settings</th>
<th>Power source 1 – master</th>
<th>Power source 2 – slave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronised (same pulse frequency)</td>
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<td>Pulsed</td>
</tr>
<tr>
<td>Non-synchronised</td>
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<td>Pulsed</td>
</tr>
<tr>
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<td>Pulsed</td>
<td>Short arc</td>
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<td>Pulsed</td>
<td>Spray arc</td>
</tr>
<tr>
<td>Mixed</td>
<td>Spray arc</td>
<td>Short arc</td>
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Table 1

<table>
<thead>
<tr>
<th>Current/A</th>
<th>Voltage/V</th>
<th>Welding speed/cm/min</th>
<th>Heat input/kJ/mm</th>
<th>Deposition rate kg/h</th>
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<td>650</td>
<td>32</td>
<td>85</td>
<td>1.5</td>
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</tr>
<tr>
<td>900–1,000</td>
<td>24–28</td>
<td>150–235</td>
<td>1.0–0.65</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 2. Results for fillet welds
is a high risk of material being pushed out of the melt, whereas, in the short arc mode, heavy melt wave between the two arcs is observed and, in the mixed mode (in front pulsed, rear short arc), a short circuit appears very frequently in the pulsed arc.

It can also be seen from the high-speed film that the arc one wire is blown up by the plasma pressure of the other arc. This appears more frequently with higher PPS during the background phase, probably caused by the high plasma pressure of the opposite arc in the pulse phase. It can therefore be concluded that, in contrast to other available information on the market, with a low PPS, almost in-phase droplet transfer leads to minimum process disruptions and a smooth and regularly sound process with very good welding results.

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**About the authors**

*Herbert Kaufmann*, M. El. Sc. And M. Mech. Sc. Started in ABB Robotics where he was responsible for different departments. In 1988 he joined ESAB automation Inc USA as technical director He came to ESAB Welding Equipment in 1994 as a project manager. Mr Kaufmann is presently working with the Engineering projects department in Laxå.

*Joakim Hedegård*, MSc, Lic tech, EWE, has been working with welding research and education for more than ten years. Presently working as researcher and program manager of the SIMR Joining Technology Centre (SIMR = Swedish Institute for Metals Research).

*Mathias Lundin*, MSc, EWE, has been working with welding research and education at the Royal Institute of Technology. Presently working as technical secretary of the Swedish Welding Commission.

*Sven-Frithjof Goecke*, graduated from Otto-Hahn Gymnasium in Geesthaacht, Germany in 1982. He is now a research associate and project coordinator at the Institute of Low-Temperature Plasma Physics, INP-Greifswald and involved in several University research projects.
Marathon Pac™
Bulk pac for welding wire

by Bernt-Inge Jensen, ESAB AB, Göteborg, Sweden

ESAB’s bulk pack of welding wire, Marathon Pac™, is a familiar product in the market. Few operating interruptions for wire replacement, easy handling and high quality assurance are advantages that have attracted considerable attention all over the world. Marathon Pac™ is the ideal solution for mechanized welding.
When the welding wire is spooled into the drum, it is twisted using a special technique which makes it straight as it exits from the welding gun. The straight welding wire is easy to feed, gives reliable starts and makes contact at the joint with very high precision. All of this contributes to high welding quality with extremely few welding faults.

The Marathon Pac™ drum is made from environmentally friendly corrugated board which is easy to recycle.

Marathon Pac™ is now available in two sizes – one pack with a capacity up to 250 kg and a new, larger pack with a capacity up to 475 kg. Because Marathon Pac™ does not need any decoiling equipment (as the 300 kg spool needs), it takes up little floor space and provides flexible solutions. Marathon Pac™ also protects the wire from dust which can cause operating interruptions.

Trolleys are available for both models, making even the largest pack easy to handle. The wire conduit between Marathon Pac™ and the welding equipment is provided with quick connectors to facilitate wire replacement. Several welding heads can be supplied from a central point. The straight wire in Marathon Pac™ is easily fed through the conduit with a minimum of friction. A wire conduit of up to 12 m in length between the drum and the wire feed unit can thus be used.

- takes up little floor space
- practical accessories
- easily handled
- protects the wire from dust

Marathon Pac™ can be supplied with most types of welding wire for MIG/MAG welding such as unalloyed, low-alloyed, high-alloyed and copper-based solid wires and several types of flux-cored wires.

A Marathon Pac™ Endless version is also available for certain solid wires, which means that the welding station can operate for as long as required in principle without interruption for replacement of the wire – all of which satisfy the increased requirements for more efficient and more reliable production solutions.

Enviromentally-friendly

At ESAB we strive constantly to develop and improve our products, which requires us to adopt an actively environmental approach. In line with our ambition to reduce the load on the environment, Marathon Pac™ is manufactured from recyclable and environmentally-friendly corrugated board coated with a moisture barrier. The empty pack is collapsed simply by hand, making it easy to handle after use. It can then be sent for recycling.

ESAB’s octagonal pack weighs only around one third of the traditional round type of drum. The pack itself thus offers various benefits:

- no large empty drums
- low weight
- moisture-resistant
- environmentally-friendly and recyclable

Better welding quality

The straight welding wire in Marathon Pac™ gives many considerable advantages. Exact positioning in the joint is required: when welding narrow joints, when weaving in coarse material and in conjunction with light gauge welding. The straight Marathon Pac™ wire makes contact at the joint in exactly the right position. This is a requirement for a perfect welding result with good penetration and with no fused edges.
Traditional spool technology gives a wire with a certain cast and helix that can result in a “dog’s tail” effect or a periodic distortion in the welding. The wire will deviate from the centre line, which is associated with a significant risk of welding faults.

With Marathon Pac™ repairs and rejects caused by welding faults are reduced. When you start welding with Marathon Pac™, only the free wire needs to be accelerated. This gives reliable, rapid starts and less wear on the wire feed unit. The risk of welding faults at the start is reduced, and the wire feed unit can keep going for longer without maintenance.

The fact that the wire is protected from dust prevents breakdowns caused by the wire conduit becoming blocked.

**Increased productivity**

With Marathon Pac™, production can be kept running with fewer interruptions for spool replacements. You achieve higher utilization of the welding station – the arc time factor increases.

Experience has shown that Marathon Pac™ reduces the consumption of wearing parts such as contact tips and wire conduits. The loading on the wire feed unit is reduced, which also means reduces the needs for servicing and maintenance of the welding equipment. These advantages can also be utilized in manual welding stations where repeated starts and stops impose a load on the wire feed unit because of the need to get heavy spools accelerated.

Marathon Pac™ thus represents a series of advantages which result in a uniform and more reliable production flow – which has a benefit on profitability.

- fewer spool changes
- reduced maintenance
- increased arc time factor

**Marathon Pac™ gives increased profitability and higher quality assurance**

- **High precision**
  Fewer welding faults
- **Easy to feed**
  Reliable starts, reduced consumption of torch liners and contact tips
- **Dust-protected wire**
  Fewer operating interruptions
- **Complete range of accessories**
  Simple and flexible handling
- **No decoiling stand required**
  Low investment cost
  Takes up less floor space
- **Environmentally-friendly**
  Not bulky
  Recyclable pack
- **Bulk pack**
  Fewer spool changes
  Reduced wire wastage
  Ideal for high production welding

**About the author**

Bernt-Inge Jensen started working at ESAB in Göteborg in 1972. Since 1984 he is Group Product Manager for solid wires.
MIG welding of heat-resistant ferritic steels with cored wire electrodes

By Klaus Blome, ESAB GmbH, Solingen, Germany

As in other areas of industry, the pressure of increasing costs is leading to an increase in the amount of welding with cored wires in the construction of power plants and machinery.

Formerly, however, cored wire electrodes for heat-resistant steels with good welding properties and sufficient mechanical and technological qualities were only available for the PA and PB positions. The main tasks in the development of ESAB cored wires for heat-resistant steels were therefore:

• improvement of the welding properties
• unlimited suitability for welding in constrained positions
• simplified parameter setting with a wider range of adjustability
• increased profitability

Using a proven formulation as a basis, ESAB added chromium and molybdenum to the core alloy to develop a complete range of heat-resistant cored wires, which have since performed excellently in many applications (Table 1).

Advantages of welding with cored wire electrodes

The reasons for the constant growth in the use of cored wires have to do with the specific quality and economic benefits of welding with cored wire electrodes:

• welding costs can be reduced if cored wires are correctly used
• the safe fusion penetration at markedly higher power, comparable with rod electrodes
• the high feed rate made possible by a special manufacturing process
• the low-spatter, easily adjusted arc
• the ease with which the composition of the weld metal can be changed
• the low hydrogen content of the weld metal
• the very good position suitability of the rutile and basic ESAB cored wires
• the good suitability of the basic cored wires for welding root layers, especially at 1.0 mm diameter

Manufacture of the cored wire electrodes

The majority of modern cored wire electrodes are made from a steel strip and a powder mixture. First the strip is formed into a U-shape and filled with the premixed powder in a dosing station. The formulation of the powder mixture is matched to the steel strip, in order to ensure uniform composition of the weld metal. This is especially important with the low- and medium-alloyed materials.

In the next manufacturing operation the filled U-profile is closed to form a tubular cross-section. Depending on the desired degree of filling, a butted or overlapped profile is formed. Butted wires have an average fill factor of 18–20%. Because of their extremely thin steel sheath, overlapped wires may reach a high fill factor of more than 30%, for especially high deposition rates and therefore welding speeds. For technical reasons to do with manufacture, “seamless” filler or tubular wires are mostly limited to a low fill factor of about 12–14%. Their deposition rate (kg/h) or achievable welding speed (cm/min) is therefore lower than that of the other cored wire types. Since the butted and overlapped cored wires can also guarantee a low hydrogen content, as a result of very advanced manufacturing techniques and optimised raw materials, seamless cored wires have lost their final advantage even for use with more demanding steels.

In principle, two different reduction methods are used to achieve the final diameter. Usually, the

<table>
<thead>
<tr>
<th>Type</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
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<td>0.40–0.65</td>
<td>0.020</td>
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</table>

Table 1. Chemical composition of all weld metal as % of basic ESAB cored wires
diameter is reduced by the well-known drawing process. With this process, intermediate annealing is may be necessary, and this may adversely affect both the powder filling and the surface of the wire. The drawing soaps used must be dried at about 280°C before the finished wire is rinsed. One reason for doing this is to reduce the hydrogen content of the weld metal to a reliable level. However, the oxide layer moulding on the surface of the wire prevents current transfer during welding and therefore has a negative effect on the welding properties. Admittedly this can be largely compensated for by adding arc-stabilising elements, which may again raise the hydrogen content.

The processes used in the ESAB works avoid these disadvantages of the drawing of cored wire, which are typical for this method. The ESAB rolling process does not involve the use of drawing agents. The product of this particular manufacturing process is a cored wire with a metallically bright, smooth surface, which is protected only by an extremely thin coating. This film improves the sliding properties of the wire in the hose package and at the same time enhances the current transfer in the contact tubes. Thanks to the “dry” rolling process, very low hydrogen contents in the weld metal can be guaranteed. The optimal current transfer and the high fill factors that can be achieved permit good welding properties together with high profitability.

Selection of the basic formulation

The welding and usage properties of cored wire electrodes are determined primarily by the characteristics of the core. It may contain rutile, basic or predominantly metallic components.

The seam pattern of metal cored wires is quite similar to that of solid wire electrodes with small islands of oxide and silicate on the surface of the seam. However, metal cored wires feature better root suitability in the short arc region and a high profitability in the PA and PB positions at higher currents. Welding in the spray arc region, ie almost spatter-free welding, is possible with metal cored wires with a fill factor of more than 18% from currents as low as 180–190 A. This property means that the cleaning times commonly needed in the welding current range from 180 to 280A when welding with solid wire are considerably reduced.

Owing to their bainitic structure, heat-resistant steels of the CrMo1 type upwards have a relatively high ratio of yield stress limit to tensile strength. They are therefore sensitive to hydrogen-induced crack formation. A further danger arises from the amount of secondary slag inclusions present in the weld metal. They may act as the starting point of cracks and also adversely affect the toughness of the weld metal. The number of micro-inclusions increases with the oxygen content of the consumable.

Because of their higher oxygen content, often more than 400 ppm, introduced by the metallic powder, metal cored wires are therefore unsuitable for welding the heat-resistant ferritic steels.

However, their economic and qualitative advantages compared with solid wires, above all in fully-mechanised processes (eg OK Tubrod 14.11), can in many cases be exploited with the other ferritic steels up to the high-strength S690 (OK Tubrod 14.03).

Like rutile stick electrodes, rutile cored wires are easy to weld with in all positions. In constrained positions, very high deposition rates, up to 3.5 kg/h can be achieved (Figure 1). Because of the heavily ionising effect of the rutile, drop transition takes place exclusively in the spary arc, so welding is almost spatter-free. With the TÜ V-approved rutiles 0.5%-Mo type PZ 6222, it has already been possible to weld easier and cheaper in many applications (Figure 2).

However, the field of application of rutile cored wires for heat-resistant steels is limited by the higher hydrogen and oxygen content of the weld metal compared with basic cored wires. Admittedly the hydrogen content of rutile ESAB cored wires is reliably below 5 ml/100g weld metal, but because of the rutile slag system the mechanical quality figures of basic cored wires cannot be achieved, especially after
subsequent heat treatment or in thick-walled components.

So rutile cored wires can only be used here with small wall thicknesses and in components that do not undergo subsequent heat treatment, or only with short annealing times (Figure 3).

So if the weld metal is to meet the most stringent demands, we are left with the basic formulation.

A feature of basic ESAB cored wires, compared with other cored wires is their unlimited constrained position ability. This applies both to the root of a butt joint and to the filling and covering layers. These ESAB cored wires can be welded with higher parameters than conventional basic wires. This significantly reduces the risk of binding defects, as well as giving a higher performance. In addition, because a higher arc voltage is used, the seam surface is flatter. The convex shape of the seam, which is otherwise common with basic consumables, is avoided. Wetting is better and slag removal is easier.

The basic weld metal provides very high mechanical and technological quality figures even in the heat-treated state and with thick-walled components, for example here on turbine housings with a wall thickness of up to 180 mm (Figure 4). The combination of good welding properties and reliable quality figures makes ESAB basic cored wires especially suitable for welding heat-resistant ferritic steels if high profitability is required in addition to fulfilment of the quality demands.

Factors that influence the hydrogen content of the weld metal

When welding heat-resistant steels, the hydrogen in conjunction with other factors such as the cooling rate and external stresses, may cause cracks to form.

As things stand today, the following factors determine the amount of hydrogen in the weld metal:

• the initial hydrogen content of the weld metal
• the current
• the contact tube distance
• the local climatic conditions

The initial hydrogen content of the basic cored wires mentioned is low, at 2 to 2.5 ml/100g weld metal. This is because the manufacturing process, the components of the filling, and the coating have all been optimised for a low hydrogen content.

Increasing the welding current results in an increase in the hydrogen content. Studies at the ESAB cored wire production facilities in Utrecht (the Netherlands) and Waltham Cross (the UK) and in ESAB Europe’s central laboratory in Gothenburg (Sweden) indicate that an increase in the welding current from 200 to 300 A results in 50% to 100% percent more hydrogen in the weld metal.

An increase in the contact tube distance with the same welding current reduces the amount of hydrogen in the weld metal. Evidently some of the hydrogen in or on the wire is released by the intense pre-heating of the free end of the wire.

Conversely, the hydrogen content falls with small contact tube distances. This must above all be borne in mind when welding in constrained positions.

According to our findings, the local climate has only a minor effect on the hydrogen content of the weld metal in MAG welding. This is because of the protection given by the shielding gas. However, when welding with stick electrodes, the effect is measurable.

The initial hydrogen content of the weld metal is an important parameter. If it can be kept low, as is the case with the basic types mentioned, the result, under European conditions is always a weld metal hydrogen content of less than 5 ml/100g.

Studies on weld metal 10 CrMo 9 10

The purpose is to show, using the example of the weld metal of cored wire PZ6203, that, in addition to the good welding properties, the mechanical and technological properties of the weld metal of cored wire electrodes safely satisfy the requirements.

The duration and level of the tempering temperature may affect the strength at room temperature. Table 2 shows the mechanical quality figures from the tensile test after different treatments. The required characteristics are achieved without difficulty.
The most important strength property which determines use under operating conditions is the creep strength. Tests were done at temperatures of 450 °C and 500°C. Evaluation of the results of /1/ and our own studies in comparison to the base material scatter band in DIN 17175 shows that the results lie in the lower range or just below the scatter band. Comparison with the weld metal of stick electrodes reveals fully equivalent creep strength behaviour. In addition, evaluation of base material results points to an overvaluation of the creep strength behaviour of 10 CrMo 9 10 in the standard /1/; Figure 5.

Some users also demand guaranteed notched-bar impact test figures for heat-resistant steels, for example more than 55 joules at –40°C for 2,5/Cr-1/Mo. These requirements can also be safely met with the basic cored wires.

Summary
ESAB basic cored wire electrodes safely meet the weld metal and welding property requirements for the welding of heat-resistant ferritic steels. These cored wires perform outstandingly when welding in constrained positions and are very well suited for root welding, even on a ceramic weld metal support (backing). Low hydrogen contents in the weld metal can be guaranteed. The cored wires are manufactured in diameters of 1.6, 1.2 and 1.0 mm. This makes it possible to match the heat input to the welding task. They combine excellent mechanical/technological properties with high performance. This ensures that the demand for high quality and reliability combined with high profitability of the welding process can be met.

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Goldschmitz, Peters et al.: Metall-Schutzgasschweißen warmfester ferritischer Stähle mit Fülldrahtelektroden. (Metal-inert-gas welding of heat-resistant ferritic steels with cored wire electrodes) ASTK Aachen, 93

About the author
Klaus Blome obtained an MSc from the Technical University RWTH of Aachen. He joined ESAB Germany in 1990 as a product manager for welding consumables. Between 1992 and 1997, he was international product manager for cored wires at Filare Welding Industries in Utrecht. He returned to ESAB Germany in 1997. Klaus Blome was recently appointed regional sales manager west and key account manager as from January 2001.

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<tr>
<td>CrMo 5 PZ 6204 730-760 min. 590 400 22 120 80</td>
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<tr>
<td>CrMo 1 PZ 6205 675-705 550 - 650 470 21 120 60</td>
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Table 2. Mechanical-technological properties of the pure weld metal of various basic ESAB cored wires after heat treatment

Figure 5. Creep strength of basic cored wire PZ 6203 (FD-03) after heat treatment at 700 and 720 °C compared with base material (GW) and a basic stick electrode (SE-03)
Productive welding solutions with user-related robot manufacturing cells

by E. Schofer, ESAB GmbH, Solingen, Germany

ESAB has taken on the task of satisfying the growing demands of trade and industry for high-grade welding technology by offering a broad range of appliances and units, consumables, services and the process technologies arising from them.

These manufacturing cells are currently less costly and more flexible in use than they were some years ago. Performance has improved and installation and operating costs have fallen. This means that unit costs can be shown to be economic even for small batch sizes. Not wishing to re-invent the wheel, we have once more joined forces with our former partner ABB, in order to offer users production advantages with safe, modular robot systems, using our welding power sources and consumables and above all our process knowledge.

In the marketing of our manufacturing cells, we focus on complete solutions based on standardised function cells or compact stations.

The differently equipped function cells are designed for a permanently allocated working area. With the modular concept, existing design can almost always be used, even for special manufacturing tasks.

At ESAB, mechanisation and automation have been proven technologies for decades. So today, system solutions are available for the integration of welding technology in flexible manufacturing systems, which, with higher productivity, flexibility and product quality, bring greater competitiveness.

ESAB is therefore once again offering welding solutions with selected robot manufacturing cells in central Europe. Here, the emphasis is on the offer of a complete solution, in other words with the appropriate consumables and the necessary process know-how.

ESAB is returning to the market after almost ten years away from automated robot welding. Why?

Here are some of the factors that contributed to the decision:

Nowadays, production must respond quicker and more flexibly to changes in the market. Flexible automation is therefore a stable growth market both in world terms and here in Europe.

There is still a shortage of well-trained welders and there is no obvious indication that this will change.

In recent years the nature of the equipment on offer for automation with robots has shifted towards fully-equipped manufacturing cells.
Modular robot function cells are cheaper than special installations and their design was proven in practice long ago.

As machines and installations become more flexible, mobile manufacturing systems are a sensible addition for a variety of tasks and workplaces. ESAB compact

- Flat seam welds with good bonding
- Round fusion penetration profile
- Simple parameter setting
- Problem-free weld starting
- Good behaviour at the end of welding
- Almost no spatter
- Long service intervals
- Good wire feed properties
- High welding speed
- High feed rate
- Wide field of applications

stations can be moved by fork truck to wherever they are needed. “Plug-and-play” installation helps minimise breaks in production.

The function cells or the compact stations can be equipped to suit the particular requirements. In addition to the robot there are, for instance, various positioners, welding current sources, MIG/MAG torches, torch cleaning units, and so on.

The standard package includes security barriers around the function cells or compact stations, as well as safety equipment. We concentrate primarily on the MIG/MAG process, including pulsed MIG/MAG.

But of course, hardware is not everything. Nowadays, advice on a suitable consumable for the range of use, as well as the recommended process parameters to achieve the required welding and cycle times, are essential for sound production planning and costing.

With our function cells and compact stations, our consumables and our expert advice, we offer a welding solution from a single supplier, giving the customer security in terms of welding technology, production and costs.

Even after installation and acceptance, we do not abandon the user. Experienced application experts and service technicians are always available should the need arise.

ESAB Welding Automation – your partner for flexible manufacturing with tailor-made solutions based on highly standardised components.

About the author

Egbert Schofer graduated from the Technical University of Berlin as a Dipl.-Ing. Mechanical Engineering. He joined ESAB in 1986 and has held several different positions within the area of standard machines and automation. Mr. Schofer is currently the automation director for ESAB’s central region.
ESAB on pole position at Essen show

For the third time in succession ESAB is occupying the prime location in Hall 1 at ‘Schweissen & Schneiden’, the world’s largest welding and cutting exhibition. Moreover one lucky visitor to the ESAB stand will leave the exhibition on the last day with tickets for a fabulous all-expenses-paid trip to the 2002 Monaco Grand Prix.

The exhibition is open for business at Essen from 12th to 16th September. The bald statistics are impressive; with around a thousand exhibitors from over 40 nations distributed over 110,000 sq metres of exhibitions space in 19 hallos, the show’s importance to the welding and cutting community is self-evident. Far from being simply a European event it has grown to attract visitors from all over the world.

ESAB has been open for business for around 100 years and has attended every one of the fifteen ‘Schweissen & Schneiden’ shows. Like the show, ESAB is a worldwide concern with sales offices in 35 countries and 42 manufacturing facilities in 19 different countries.

At an impressive 1,700 sq.m. the ESAB stand will again dominate Hall 1 at Schweissen &Schneiden 2001. This year the Company’s overall focus will be on important markets for welding and cutting products such as shipbuilding, offshore applications, automotive industry, power generation, process industry and the transport and mobile machinery industries.

ESAB will be displaying and demonstrating a wide range of the very latest welding and cutting products including Friction Stir welding equipment, the new Aristo system, which is an intelligent and flexible modular-based range of power sources for MIG/MAG, DC TIG and MMA welding and for cutting the advanced VBA Plasma, Pegasus Laser, Ultrarex and combination plasma and waterjet cutting machines. Together with equipment, ESAB will also be demonstrating products from an ever-increasing range of welding consumables along with their latest economic packaging solutions.

On the stand, ESAB, will also introduce and demonstrate the new revolutionary joining technique – magnetic pulse welding.

In addition, visitors to the ESAB stand will get an overview of the company’s increasingly successful e-business activities, its leadership in the application of technology to product and process innovations, its continued investment in R&D and the growing emphasis on supply chain management.

Many of the new products and processes are described in separate articles in this magazine.

As an added incentive to visit the stand, ESAB is running a daily draw with a unique Formula 1 design Eye-Tech welding helmet as the daily prize. However, on the latest day all entries go back into the hat for the chance to be at the track side in Monte Carlo next year watching the world’s best racing drivers competing in Formula One’s most prestigious race.

In any event, visitors to ESAB at Essen in 2001 are unlikely to go away disappointed. The company’s intention is to put all of its customers on pole position with technology and service that leaves everyone else trailing in their wake.
MechTrac 1500 and 2000 – Components for mechanised welding

MechTrac might very well be the most flexible and fastest way to increase your productivity.

It takes the form of a gantry and can be equipped with A2 welding equipment for SAW or MIG/MAG to create a complete welding station. If the workpiece rotates, other welding methods such as TIG and plasma can be used, depending on the application and handling equipment.

The MechTrac unit is suitable for different types of workpiece that can be covered by a gantry. The gantry offers the opportunity to weld profiles such as I-, T-, or L-beams, columns or tapered beams.

MechTrac is available in two versions, depending on the size of the workpiece. The difference is the width of the gantry—1,500 mm or 2,000 mm between the legs. The length of the legs is the same for both types; 1,500 mm from the top of the rail to the inside of the overhead beam (see the information relating to the operating range on the next page).

The floor-mounted rail can be delivered as standard with a total length of three metres. It can then be extended to match the length of the components. The standard rail is supplied with an end guard which prevents the gantry losing contact with the rail. Other types of rail can be used (see the information relating to dimensions on the next page).

The well-known VEC motor, which is used in many other automation products from ESAB, is used as the driving motor. The gantry can support a maximum of 220 kg, which corresponds to two A2 welding heads, single or twin wire, complete with automatic joint tracking GMD and the OPC flux recovery unit, for example.

The PEH process controller is used with A2 welding equipment, SAW or MIG/MAG. The welding parameters can be programmed swiftly and accurately. When two welding heads are used, one process controller takes control of one welding head and power source, plus the travel speed of the MechTrac. The other controls the second welding head and power source.

To make transport and installation as easy as possible, MechTrac is supplied in component form and can be easily assembled on site.

ESAB’s Sustainability Report 1999 among the 10 highest ranked

In an international evaluation of environmental and sustainability reports, the London-based thinktank SustainAbility has ranked ESAB’s report as one of the top ten in the world. SustainAbility, together with UNEP (United Nations Environment Programme), has ranked 50 reports from several hundred from all over the world.

The areas that have been evaluated include:

- the company’s plans for sustainable development and the management’s understanding of these issues
- structures, systems, processes and objectives for performing undertakings
- whether the report contains background data, results and future objectives
- the applicability, availability and credibility of the information

Since 1999, ESAB has been participating as a pilot company in an international joint venture known as the “Global Reporting Initiative”, GRI, which has been largely funded by the UN. This work is designed to produce global guidelines for reports on the environment, economy and social issues. The GRI will become the generally accepted, broadly adopted worldwide framework for preparing, communicating and requesting information about corporate performance.

Other pilot companies include Ford, Shell, Proctor & Gamble, General Motors and Electrolux.

For more information, or if you want to order the complete report including the CD, please contact ESAB Environmental Affairs or Stefan Larsson, ESAB AB, tel +46 31 509271.
Column and booms in China

The demand for larger sized column and booms has increased significantly in the Chinese market in recent times. The demand for large column and booms was previously mainly in the energy sector for the production of pressure vessels for thick-walled pressure vessels up to 350 mm in thickness. Recently the shipyard industry has started purchasing larger size column and booms. The main reason for the use of these column and booms is the production of submarines.

In 2000, the largest column and boom built by ESAB was supplied, an MKG type purchased by Bohai Shipyard in China. The working range of this column and boom is 12.5 x 10 m, with having an overall height of some 16 metres. The welding equipment mounted on this MKG is A6-G welding heads for MIG/MAG welding equipped with LAF630 power sources. The welding heads in this case are equipped with extended contact tubes to enable welding of larger sized stiffener rings.

In addition, ESAB has started implementing a new technology on the joint tracking systems for the column and booms. Previously the joint tracking systems were restricted to the size of the slide cross which normally had a working range of 300x300mm. Now ESAB has started implementing a control system which uses the whole column and boom as a slide cross. The fine positioning is still done by the traditional 300x300 mm slide cross but a course positioning system to adjust the whole column and boom is now being implemented. This system requires an inverter control for the actual boom hoisting system.

The new concept of large column and booms with an extremely large working range in terms of joint tracking has attracted the interest of shipyards in China, leading to a number of large contracts in Hulodao and Wuhan. The reason for the new demand is that the shape of the submarines built, is not centric - they have an oval shape, resulting in a need for a joint tracking system that can handle variations of up to two metres.

The ESAB solution with the extreme-sized column and boom combined with a very accurate joint tracking system covering the whole working range of the column and boom has broadened the use of the MIG/MAG welding process, clearing the way for the production of large vessels in the shipyard industry.

A new brochure dealing with welding processes for mechanisation is now available

It focuses on MIG/MAG welding with solid wires, flux-cored wires, aluminium wires and SUB-arc welding. The brochure analyses the advantages, potential and limitations of each process, together with applications suitable for the processes, using different types of mechanisation equipment.

This brochure can also be used as a educational document for initial training.
Fluxes for high-speed welding

When it comes to high speed welding, ESAB has two very interesting products in its SAW range OK Flux 10.45 and OK Flux 10.83. They both have their advantages when welding mild steels where low or no impact requirement is acceptable.

OK Flux 10.45 is a special purpose acid slightly manganese alloying fused flux designed for high speed welding of clean thin sheet metal plate up to 5.0 mm. in thickness.

Sound, undercut free welds can be produced at speeds up to 500 cm/min. with good slag removal and a good bead surface appearance.

The slag is very fluid, which makes OK Flux 10.45 the perfect selection for copper-backed thin sheet lap- and butt joints. Being a fused flux it is virtually non-hygroscopic and will only pick-up surface moisture if exposed.

Applications include water heater tank seam welds and tube to tube welds in heat exchangers.

OK Flux 10.83 is an acid agglomerated silicon and manganese alloying aluminate rutile flux, designed for single-pass high-speed/high- productivity welding of carbon steels up to 25 mm.

Butt, lap, and fillet welds are well washed and free from undercut even at speeds up to 305 cm/min.

It is primarily used with DC single and twin wire systems at currents up to 1300 A. OK Flux 10.83 is recommended for high speed welding of I and box -beams, spiral and longitudinal water and sewage line pipe, storage tanks, LPG bottles, heat exchange panels and rail cars.

With their high Si content, OK Autrod 12.22/12.23 are the preferred wire selections for high-speed fillet welding.

### Some typical welding parameters

<table>
<thead>
<tr>
<th>OK Flux 10.45 Weld type</th>
<th>Plate thickness mm</th>
<th>Wire mm</th>
<th>Amps</th>
<th>Volt</th>
<th>Travel speed cm/min</th>
<th>Comments</th>
<th>Polarity</th>
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<tbody>
<tr>
<td>Butt weld</td>
<td>2.0</td>
<td>2.5</td>
<td>400-500</td>
<td>21-22</td>
<td>380-510</td>
<td>Cu Backing+</td>
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<tr>
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<td>2.5</td>
<td>400</td>
<td>24</td>
<td>320</td>
<td>Cu Backing+</td>
<td></td>
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<tr>
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<td>600</td>
<td>27</td>
<td>190</td>
<td>Cu Backing+</td>
<td></td>
</tr>
<tr>
<td>Lap weld</td>
<td>1.5-3.0</td>
<td>2.5</td>
<td>550</td>
<td>28</td>
<td>320</td>
<td>15% off vert.+</td>
<td></td>
</tr>
<tr>
<td>Lap weld</td>
<td>3.0-5.0</td>
<td>3.0</td>
<td>550</td>
<td>28</td>
<td>190</td>
<td>15% off vert.+</td>
<td></td>
</tr>
<tr>
<td>Burn-through</td>
<td>1.5-3.0</td>
<td>2.5</td>
<td>450</td>
<td>26</td>
<td>320</td>
<td>Cu Backing+</td>
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<tr>
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<td>700</td>
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<td>220</td>
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<th>OK Flux 10.83</th>
<th>Plate thickness mm</th>
<th>Wire mm</th>
<th>Amps</th>
<th>Volt</th>
<th>Travel speed cm/min</th>
<th>Comments</th>
<th>Polarity</th>
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<td>Horiz. fillet</td>
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<td>2x2.0</td>
<td>1000</td>
<td>24-25</td>
<td>200</td>
<td>Web-to-flange+</td>
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<tr>
<td>Horiz. fillet</td>
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<td>1150</td>
<td>25-26</td>
<td>250</td>
<td>Web-to-flange+</td>
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<tr>
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<td>2x2.0</td>
<td>1240</td>
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<td>305</td>
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<tr>
<td>Butt weld</td>
<td>3.0</td>
<td>2.5</td>
<td>500</td>
<td>25-27</td>
<td>320</td>
<td>Cu Backing+</td>
<td></td>
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</table>

Welding automation speeds up production of wind mill towers

Safety, cleanness and renewability are fundamental concepts in today’s energy debate. Wind power energy without doubt satisfies the demands in this respect.

When it comes to the manufacturing of the wind mills that generate the electricity, ESAB can make a strong contribution with tailor-made turnkey solutions for the production of the steel towers supporting the rotors and generators.

This rapidly growing energy sector has necessitated an increase and improvement in machinery facilities, and interest has focused on high-productivity welding equipment in order to reduce door-to-door times.

From the bending machine or buffer (not illustrated on the layout), a shell is placed in one of the 10T roller beds to position it for internal and external longitudinal submerged arc welding carried by the CaB 460 column and boom. While one shell is being welded in one roller bed, another shell is prepared in the other roller bed set. This procedure definitely increases the arc time factor. In addition, each shell at the end of a tower section has a mounting flange. The flanges are also welded to these shells at this station.

At the next station, a head and tail stock positioner, a sub-arc welding head for internal circumferential welding and one CaB 460 column and boom for external circumferential welding are integrated. In addition, there is a support roller bed and a rounding jig to complete this station. The tower section is built up here until it reaches its full length. The first shell with the flange is clamped into the withdrawn tail stock, while the second shell is clamped into the head stock in a corresponding manner. The two shells are tightened by pushing the movable tail stock towards the head stock, whereupon tack welding takes place. The ESAB A2 welding head carried by the support arm performs the internal welding, and finally the external circumferential welding is performed by the A6 head of the CaB 460 station. Step by step, the tower grows, as one shell after another is added, until the last shell with its flange completes the tower section. In order to maintain the roundness of the gradually extended tower, a rounding jig adapts the tower ends, using hydraulically operated pressure arms with rollers, in order to make them fit the shells that are added. Taken as a whole, this is an advanced piece of equipment for high productivity and consistent weld quality.
ESAB has developed matching composition, high strength, metal cored wires suitable for the GMAW girth welding of supermartensitic pipelines. OK Tubrod 15.53 and OK Tubrod 15.55 offer productivity benefits and excellent side-wall penetration and produce high quality welds with satisfactory mechanical properties when used with realistic fabrication welding procedures.

Welding of supermartensitic stainless steel pipelines

Supermartensitic stainless steels are rapidly becoming a practical and economical alternative for flow line applications in the oil and gas industries. The supermartensitics (also called low-C/13Cr stainless steels, weldable 13Cr martensitic stainless steels or super 13Cr steels) are 12-13 %Cr martensitic steels with a very low C content (<0.015%) and an Mo content of up to 2.5% (Ref. 1). They offer sufficient corrosion resistance for sweet and mildly sour environments, in combination with high strength and good low-temperature toughness. Supermartensitic steels are also ideal for field welding, where preheating and long-term PWHT are impractical (Ref. 1).

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

ESAB has developed matching composition, metal cored wires (MCW) that are ideal when it comes to meeting the new strength requirements for supermartensitic pipes. The OK Tubrod 15.53 & 15.53S wires are recommended for steels with up to 1.5%Mo, whereas OK Tubrod 15.55 & 15.55S should be used for steels with a higher Mo content. OK Tubrod 15.53 & 15.55 are produced with a diameter of 1.2 mm and have been developed for GMAW and mechanised GTAW, the ‘S types’ are designed for the SAW process and come in a diameter of 2.4 mm. The weld metal is designed for use in the as-welded, tempered or quenched and tempered condition, depending on toughness and hardness requirements (see product data for further information).

This paper gives an example of the orbital narrow gap girth welding of supermartensitic pipes in the PG-H-L000 position (5G-down) and describes a test on a 60º V-joint in the PA position (1G). It is shown that supermartensitic consumables can be used with realistic fabrication welding procedures to produce high quality welds with satisfactory properties.

Orbital narrow gap MCW 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. The torch rotates around the circumference of the pipe using a mechanism which is commonly referred to as a welding head or bug. The term is misleading, however, when referring to equipment using the GMAW/FCAW processes. If the pipe is in the horizontal position, welding is done 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).

GMAW welding with solid wire is done both double up and double down. Flux cored arc welding is only performed using the double-up technique because of the possibility of slag entrapment when welding downhill. MCWs, however, only form small isolated silicate islands on the solidified weld bead. They are removed by brushing between passes or are simply welded over, as they will re-melt and float to the weld pool surface. This feature allows MCWs to be used for welding double up as well as double down. For all-position welding with an MCW, a pulsing power source must be used to guarantee proper droplet transfer and weld pool control.

With an appropriate 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 narrow J-groove geometry. The joint geometry is narrow enough to allow each pass to bridge from wall to wall without oscillation, except for the capping layer where slight weaving is necessary to complete the last layer.

Controlling defects
Orbital or mechanised pipe welding equipment has been used in the cross-country and marine pipeline industries for almost 30 years. Virtually all pipeline welding has been performed using the short-arc GMAW process for all passes, using narrow gap joint geometry. Downhill welding with solid wires is attractive because it allows high travel speeds and thereby shorter arc times, but it has a propensity to produce side-wall fusion defects. In addition, a simple CV power source, which cannot control the process optimally, is used and this may lead to excessive spatter or insufficient penetration. Many pipeline owners are reconsidering permissible defects when using the new supermartensitic materials. Although conventional short-arc GMAW is being used, alternatives to reduce the defect and repair rate, while maintaining the high speed of double-down solid wire welding, are being sought.

Metal cored wires provide the answer
MCWs provide an impressive solution to the problem. When used with a pulsed arc power source, the welding process is precisely controlled and provides a more tolerant welding technique than solid wire. MCWs ensure reliable side-wall fusion and sufficient penetration into the parent material. ESAB has formulated a family of matching composition supermartensitic cored wires (see product data), including the 2.5%Mo type, OK Tubrod 15.55. When used with an appropriate welding procedure, these consumables produce a high quality weld deposit with a low-carbon martensitic microstructure.

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 (Ref. 2). A narrow J-groove was selected for use without root gap (Figs. 1 & 2). An expanding clamp with copper backing shoes was used to ensure precise pipe alignment and uniform root bead penetration.

Orbital pipe welding requires a machined bevel on the end of the pipe. Portable bevelling equipment is available from numerous suppliers in order rapidly to machine a precise bevel in a fabrication shop or at a field work site. Machining a narrow J-groove requires no additional time as compared to a conventional V-joint with an angle of 30° or 37.5°.

The Pipeliner System, manufactured by Magnatech, was used for the trials. It consists of a welding head mounted on a track or band, sized to the specific pipe outer diameter (OD). The welding head rotates the torch around the pipe and manipulates the torch, with capabilities for programmed torch weave or oscillation, and provides motorised adjustment of contact tip to workpiece distance. The wire feeder is mounted on the welding head using a 5-kg spool for precise wire delivery.

The Pipeliner System was interfaced with an ESAB Aristo LUD320W power source. This is a synergic type of 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 new formulation ESAB cored wire (OK Tubrod 15.55 with a diameter of 1.2 mm). Samples of 322 mm (12-inch) 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 1 and Ref. 3). Figures 3 and 4 illustrate the smooth bead appearance of the weld cap and the excellent side-wall fusion. MCWs deposit high quality welds with good penetration, due to the stability of the arc and the very fine droplet transfer without spatter. For the filling layers, weaving was not necessary in order to obtain reliable side-wall fusion, 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 efficiently with MCWs in narrow J-groove geometry. The new range of supermartensitic MCWs is now available and wires can also be delivered in relatively small quantities.

Weld properties

The weld metal toughness and strength were determined in house by preparing a tensile bar and 5 ISO-V Charpy specimens transverse to the weld (Ref. 3). The tensile bar (21.1x12.9mm) broke in the pipe material at 900 MPa, showing that the weld metal clearly over-matched the pipe material. Impact toughness was tested at –40ºC in the as-welded condition and after a short PWHT at 600ºC. 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 (Ref. 4). The measured range of 285–350 ppm correlates well with the observed impact toughness, according to earlier studies (Ref. 4), suggesting that there is potential to further increase toughness by improving the gas shield. This is possible by using a special nozzle in combination with a small designed gas cup or a 100% inert gas.

Additional tests performed at TWI (Ref. 5) were in line with the above findings. Cross-weld tensile testing resulted in the fracture of the parent steel. The all-weld metal yield strength was 680 MPa and the tensile strength 923 MPa after PWHT at 637ºC for five minutes. Impact toughness was measured as an average of 47 J at –46ºC after PWHT at 651–661ºC for five minutes. Four-point bend sulphide stress cracking (SCC) testing for 30 days in slightly sour (10 mbar H2S) formation water and condensed water indicated no susceptibility to SCC.

High productivity welding in downhand position

For applications where the welding can be performed in the PA position (1G), by rotating the pipe sections that are going to be joined, it is interesting to investigate the opportunity to increase productivity. One obvious approach is to reduce the number of passes required to fill the joint, which will, however, inevitably increase the heat input. An initial trial with an MCW with a larger wire diameter of 1.6 mm was performed to see whether this is a realistic approach and to see how the pipe material and weld metal are affected by heat inputs higher than those normally used for supermartensitics.

A 2.5%Mo supermartensitic pipe with 255 mm OD and 13 mm wall thickness was welded in only three passes – one GTAW root pass and two GMAW fill passes, (Table 2) with a heat input of approximately 2.8 kJ/mm. The chemical composition of the weld metal and parent material of the simulated production weld are presented in Table 3.

<table>
<thead>
<tr>
<th>Pass</th>
<th>Position (A)</th>
<th>Amperage (V)</th>
<th>Wire feed (cm/min)</th>
<th>Welding speed (cm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root</td>
<td>12/4 o’clock</td>
<td>210</td>
<td>18.8</td>
<td>9.3</td>
</tr>
<tr>
<td>Fill 2,3,4</td>
<td>12/4 o’clock</td>
<td>215</td>
<td>21.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Cap*</td>
<td>12/6 o’clock</td>
<td>140</td>
<td>18</td>
<td>3.0</td>
</tr>
<tr>
<td>Root</td>
<td>4-6 o’clock</td>
<td>178</td>
<td>17.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Fill 2,3</td>
<td>4-6 o’clock</td>
<td>175</td>
<td>17.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Cap*</td>
<td>12-6 o’clock</td>
<td>140</td>
<td>18</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*Slight weaving

Table 1. Typical welding parameters: Shielding gas 99.5% Ar/0.5% CO2. No backing gas (welding against copper backing). Total welding time 14 minutes.
Weld microstructure and mechanical properties

The weld produced in the PA position was defect free and had a largely martensitic microstructure (Fig. 5). Weld metal strength was clearly over-matched, as evidenced by a cross-weld tensile test fracture in the parent material, and ductility was sufficient to pass bend testing (Table 4). Maximum hardness was below 330 HV10 and the impact toughness in the as-welded condition was 75 J at –20°C. Good toughness and comparatively low hardness can clearly also be obtained for relatively high heat inputs and large weld beads. It is therefore encouraging to note that high productivity welding procedures might offer advantages in terms of improved toughness as well.

Supermartensitic welding consumables

The development of matching composition supermartensitic welding consumables and welding procedures is still progressing. However, it is obvious that this concept offers a number of advantages in terms of properties, productivity and the opportunity to perform a PWHT when desired. Another advantage that is often overlooked, compared with duplex or superduplex consumables, is that a martensitic weld metal microstructure is expected for all levels of dilution with the parent material. It is therefore only a matter of time before supermartensitic consumables become the preferred choice in the welding of supermartensitic stainless steel.

Acknowledgements

The authors would like to extend their gratitude to NKK Europe Ltd, Weldtech and Valk IPS for their valuable contribution to the successful evaluation of the new supermartensitic consumables.

References


<table>
<thead>
<tr>
<th>Joint/ Interpass Heat input</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>position temp. (°C)</td>
<td></td>
</tr>
<tr>
<td>Heat input (kJ/mm)</td>
<td></td>
</tr>
<tr>
<td>Wire: OK Tubrod 15.55, Ø 1.6 mm</td>
<td>60°V/ PA</td>
</tr>
<tr>
<td>Shielding gas: Ar (GTAW)/ Ar + 0.5%CO₂ (GMAW)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Welding conditions for pipe welding of 12Cr-6.5Ni-2.5Mo pipe material (Ø 255 mm, t= 13 mm) in PA position (1G)

<table>
<thead>
<tr>
<th>Pipe/ Weld C</th>
<th>N (ppm)</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
<th>O (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>0.010</td>
<td>87</td>
<td>0.17</td>
<td>0.50</td>
<td>12.3</td>
<td>6.6</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td>Weld</td>
<td>0.009</td>
<td>135</td>
<td>0.31</td>
<td>2.0</td>
<td>12.5</td>
<td>7.0</td>
<td>2.2</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Table 3. Chemical composition (wt.%) of pipe material and weld metal.

Table 4. Mechanical properties of girth weld (consumable: OK Tubrod 15.55) in a 2.5%Mo supermartensitic pipe (Ø 255 mm, t= 13 mm).

<table>
<thead>
<tr>
<th>Impact toughness (J)</th>
<th>Cross-weld tensile strength (MPa) Rm</th>
<th>Maximum hardness (HV10) Weld metal HAZ t=10 mm</th>
<th>Face bend Ø 3 x t, 120°</th>
<th>Side bend Ø 4 x t, 180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60°C</td>
<td>-40°C -20°C +20°C</td>
<td>895*</td>
<td>323</td>
<td>326</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Fracture in parent material
Product data—supermartensitic metal cored wires

MCWs depositing a martensitic 13%Cr-type, Mo-alloyed, extra-low carbon weld metal. Designed primarily for welding supermartensitic steels (also called low-C 13Cr stainless steels, weldable 13Cr martensitic stainless steels and super 13Cr steels). 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 a higher Mo content. The weld metal is designed for use in the as-welded, tempered or quenched and tempered condition, depending on toughness and hardness requirements.

Higher CO₂ content can be used but will increase weld metal C content and hardness.

GTAW: Ar or Ar+He mixtures

SAW flux: OK Flux 10.93

Wire diameters:
OK Tubrod 15.53 & OK Tubrod 15.55: Ø 1.2 mm for GMAW and GTAW.
OK Tubrod 15.53S & OK Tubrod 15.55S: Ø 2.4 mm for SAW.

Shielding gas:
GMAW: Ar+30%He or Ar+0.5%CO₂. Gases with a higher CO₂ content can be used but will increase weld metal C content and hardness.

GTAW: Ar or Ar+He mixtures

SAW flux:
OK Flux 10.93

Typical chemical composition (wt.%) of all-weld metals.

<table>
<thead>
<tr>
<th>Wire C</th>
<th>N</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5% Mo, metal cored wires:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK Tubrod 15.53*</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.8</td>
<td>1.2</td>
<td>12.5</td>
<td>6.8</td>
<td>1.5</td>
</tr>
<tr>
<td>OK Tubrod 15.53S**</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.8</td>
<td>1.1</td>
<td>12</td>
<td>6.8</td>
<td>1.5</td>
</tr>
<tr>
<td>2.5% Mo, metal cored wires:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK Tubrod 15.55*</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.4</td>
<td>1.8</td>
<td>12.5</td>
<td>6.7</td>
<td>2.5</td>
</tr>
<tr>
<td>OK Tubrod 15.55S**</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.5</td>
<td>1.6</td>
<td>12</td>
<td>6.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Consumables</th>
<th>Impact toughness (J)</th>
<th>Tensile strength (Mpa)</th>
<th>Hardness (HV10)</th>
<th>Welding method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-40°C</td>
<td>20°C</td>
<td>$R_{p0.2}$</td>
<td>$R_{m}$</td>
</tr>
<tr>
<td>1.5% Mo, metal cored wires:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK Tubrod 15.53/Ar</td>
<td>&gt;100</td>
<td>&gt;110</td>
<td>700-850</td>
<td>950-1050</td>
</tr>
<tr>
<td>OK Tubrod 15.53/Ar+30%He</td>
<td>&gt;401</td>
<td>&gt;50</td>
<td>700-850</td>
<td>950-1050</td>
</tr>
<tr>
<td>OK Tubrod 15.53S/OK Flux 10.93</td>
<td>&gt;301</td>
<td>&gt;35</td>
<td>700-850</td>
<td>950-1050</td>
</tr>
<tr>
<td>2.5% Mo, metal cored wires:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK Tubrod 15.55/Ar</td>
<td>&gt;100</td>
<td>&gt;110</td>
<td>700-850</td>
<td>950-1050</td>
</tr>
<tr>
<td>OK Tubrod 15.55/Ar+30%He</td>
<td>&gt;401</td>
<td>&gt;50</td>
<td>700-850</td>
<td>950-1050</td>
</tr>
<tr>
<td>OK Tubrod 15.55S/OK Flux 10.93</td>
<td>&gt;301</td>
<td>&gt;35</td>
<td>700-850</td>
<td>950-1050</td>
</tr>
</tbody>
</table>

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

About the authors

Leif Karlsson. Ph.D. Senior Expert in welding of stainless steels at the ESAB central Laboratories in Göteborg, Sweden. He joined ESAB in 1986 after graduating from Chalmers University of Technology, Göteborg, with a masters degree in Engineering Physics in 1981 and finishing his Ph.D. in Materials Science in 1986. At ESAB he has been working with R&D on highly alloyed weld metal devoting much time to duplex stainless weld metals. He is currently holding a position as Manager Research Projects. Solveig Rigdal, M.Sc. and EWE, is working as a development engineer in the department for Automatic Welding Consumables within R&D in ESAB. She graduated in chemistry from the University of Göteborg in 1974 and joined ESAB in 1982.

Michael Goldschmitz (52), B.Sc. Metallurgy, is development engineer cored wires for ESAB Europe, and is located in Utrecht, The Netherlands. He was nominated Senior Expert by The ESAB Group in 1995. Presently, he is involved in several development projects concerning stainless steel cored wires.

John van den Broek (52), is product manager stainless steel cored wires and related products for ESAB Europe, and is located in Utrecht, The Netherlands. He joined ESAB in 1996, after having worked as a welding consultant for the TNO Research Institute in The Netherlands.
Aluminium welding within the automotive industry

Moving forward with weld quality – welding equipment characteristics and technical training

by Tony Anderson, AlcoTec Wire Corporation, USA

Without doubt, the use of aluminium within the automotive industry and the development of aluminium welding technology are both continuing to expand. The continued developments of aluminium within this industry can be primarily attributed to this material’s many desirable physical characteristics.

Aluminium provides its users with the opportunity to utilize a material which has comparatively light weight, high strength, versatility of both extruding and casting, and excellent corrosion resistant characteristics. When we consider this material’s physical properties, in conjunction with the continually developing environmental issues, such as improving fuel efficiency and superior recycling capabilities, it becomes perfectly understandable why it is increasingly becoming the popular choice of engineers and designers for a variety of automotive applications. With the advancement of aluminium within this industry, we have seen both the need for developments within the area of welding equipment used for this somewhat specialized material, and also, the increased demand for technical training in aluminium welding technology.

Fig 1. Typical non structural automotive application.
Equipment Characteristics

When considering the developments in aluminium welding equipment, the friction stir welding of aluminium has probably been the most publicized in recent welding journals and has attracted much attention. The friction stir welding process has many unique and exciting characteristics when used to make certain joints in aluminium alloys. However, friction stir welding is somewhat limited in its application and, while excellent for some components, does not have the versatility of some of the other welding processes. This discussion shall be directed toward the development and use of one of the more traditional methods of welding aluminium, the Gas Metal Arc Welding (GMAW) or alternatively named Metal Inert Gas (MIG) welding process. This process has been used for the welding of aluminium for many years. Historically, the first aluminium welding operations were of a non-structural nature, performed on heat exchangers, radiators, cooling systems, and their associated components. Considerations for this type of welding have been primarily to consistently produce welds with minimum leakage rates. Procedure development has revolved around the use of high silicon content filler alloys with minimum consideration for strength characteristics with much emphasis placed on fluidity and the ability to seal weld joints in thin material. More recently, there have been major moves toward the fabrication of structural components such as engine cradles, front and rear suspension frames, drive shafts and wheels.

These welded components can often be subjected to dynamic loading in service and, consequently, can be susceptible to fatigue. Structural welded joints of this nature require very different considerations when developing welding procedures and maintaining welding quality that is acceptable for their service conditions. The requirement for higher integrity in structural welded joints in aluminium, along with the recognition of some unique characteristics of aluminium which can produce certain welding discontinuities, has promoted the necessity for a better understanding of welding equipment characteristics. Some of the inherent problems associated with the MIG welding of aluminium and the production of high integrity structural welds, when compared with the welding of steel, are: feedability, incomplete fusion at the start of a weld, and crater or termination cracking at the ends of the weld.

**Feedability:** This is the ability to consistently feed the spooled welding wire when MIG welding, without interruption, during the welding process. Feedability is probably the most common problem experienced when moving from MIG welding of steel to MIG welding of aluminium. Feedability is a far more significant issue with aluminium than steel. This is primarily due to the difference between the material's mechanical pro-
Steel welding wire is rigged, can be fed more easily over a further distance, and can withstand far more mechanical abuse when compared to aluminium. Aluminium is softer, more susceptible to being deformed or shaved during the feeding operation, and, consequently, requires far more attention when selecting and setting up a feeding system for MIG welding. Feedability problems often express themselves in the forms of irregular wire feed or as burn-backs (the fusion of the welding wire to the inside of the contact tip). In order to prevent excessive problems with feedability of this nature, it is important to understand the entire feeding system and its effect on aluminium welding wire. If we start with the spool end of the feeding system, we must first consider the brake settings. Brake setting tension should be backed off to a minimum. Only sufficient brake pressure to prevent the spool from free-wheeling when welding has stopped is required. Electronic braking systems and electronic and mechanical combinations have been developed to provide more sensitivity within the braking system. Inlet and outlet guides, as well as liners, which are typically made from metallic material for steel welding, must be made from a non-metallic material such as nylon, to prevent abrasion and shaving of the aluminium wire. Drive rolls have been developed, often with U-type contours with edges that are chamfered and not sharp, that are smooth, aligned, and provide correct drive roll pressure. Excessive drive roll pressure can deform the aluminium wire and increase friction drag through the liner and contact tip. Contact tip I.D. and quality are of great importance. We are seeing the availability of contact tips made specifically for aluminium welding, which have smooth internal bores and the absence of sharp burrs on the inlet and outlet ends of the tips which can easily shave the softer aluminium alloys.

Aluminium welding wire is used in both push and pull feeder systems; however, limitations are recognized dependent on application and feeding distance. Push-pull feeder systems for aluminium have been developed and improved upon to help overcome feeding problems and may be used on more critical/specialized operations such as robotic and automated applications. More recently, the planetary drive push-pull system (ESAB Mongoose System) has become popular for aluminium welding, providing an extremely positive feeding system capable of delivering aluminium wire over greater distances with minimum burn-back problems.

The author conducting training in aluminium welding technology at the AlcoTec Training school.

**The Hot Start Feature:** Aluminium has a thermal conductivity about 6 times that of steel, and because of this ability to rapidly conduct heat away from the weld area, there has always been an inherent problem, particularly when starting a weld on this material. It is not uncommon to experience incomplete fusion at the start of an aluminium weld because of the material's high thermal conductivity. One method which can now be used to help overcome this problem, particularly on thicker sections of aluminium used in structural applications, is the use of equipment that has a hot start feature. This feature may allow the user to program the weld starting current characteristics independently from that of the general welding current parameters, thus providing the user with the ability to start the weld with a higher current density for a predetermined period before moving to the general welding conditions for the remainder of the weld. This allows the use of a higher heat input at the beginning of the weld that can help to overcome the dramatic heat sink associated with this material prior to the weld area becoming heated by the welding operation. The result of this technique is to eliminate, or significantly reduce, the probability of incomplete fusion at the start of the weld, and thereby improve the life expectancy of welded components subjected to high stress or fatigue loading.

**Crater Fill Feature:** Other characteristics of aluminium which can provide welding problems are associated with its thermal expansion, which is about twice that of steel, and its shrinkage on solidification, which is 6% by volume. This can increase both distortion and weld crater size. One common concern when welding aluminium is crater cracking or, what is sometimes called, termination cracking. When MIG welding with conventional equipment, once the trigger of the welding gun has been released, the arc is extinguished, and no additional filler metal is added to the weld pool to fill the crater. Consequently, if no further precautions are taken, a large crater will be left which will have a higher probability of cracking. Craters can be serious defects, and most welding standards require them to be filled and free from cracks. Run-off tabs, or other methods of locating weld craters on scrap material away from the
weld, are not usually practical. However, if the weld pool size can be reduced before the arc is fully extinguished, the resulting crater may be very small or almost eliminated and, consequently, the weld may be free from cracks.

In the past a number of welding techniques have been used in an attempt to reduce this termination problem. Reversing the direction of travel at the end of a weld, increasing travel speed to reduce crater size, and providing suitable build-up and removing the crater area flush with the weld surface by mechanical means, are some of the methods which have been used. These methods are often difficult to control, require specialized training, and are not always successful in their objective. More recently, welding equipment has been developed for aluminium welding which has a built-in crater fill feature. This feature is designed to terminate the weld in a gradual manner by decreasing the welding current over a predetermined period as the weld is completed. This feature may be adjustable to enable the user to select the most favorable termination conditions, thereby preventing a crater from forming at the weld termination. Tests have shown this crater fill feature to be extremely user friendly and very effective in eliminating the crater cracking problem.

Other equipment features which may be significant:

**Slow Run-In Start:** This feature is desirable under circumstances that require precision starting characteristics to minimize start-up fusion defects and provide a starting profile that is acceptable when the weld overlaps at termination. It is also desirable to prevent wire-base contact problems (example, bird nesting) at the start of a weld when high feed rates are incorporated, particularly when using the softer aluminium filler alloys.

**Burn-Back Control:** This feature is desirable when the accurate and consistent positioning of the welding wire, in relationship to the completed weld, is required. When used with the crater fill option, the wire is effectively separated from the puddle, and it leaves a sharp end in preparation for the next weld start. It is particularly useful with those manufacturing procedures that require consistent restarting capabilities.

The need for technical training in aluminium welding technology:

The advancement of aluminium in the automotive industry, along with its increased use within the welding fabrication industry in general, has certainly promoted the development of specialized welding equipment design. Correspondingly, the increased use of aluminium welding has promoted the demand within industry for technically competent aluminium welding personnel. The need for welding engineers, technicians, inspectors, supervisors and welders who have experience and technical training in aluminium welding technology has increased. Unfortunately, because aluminium welding has traditionally represented such a small part of the overall welding industry, personnel with such qualifications have been difficult to find. Many of the universities and technical institutions, which have been involved in welding education, have neglected detailed instruction in aluminium welding technology. Consequently, it is not uncommon to find formally trained welding engineers with very little, if any, experience or in-depth training within this field.

In order to help remedy this problem, and in recognition of the need for technical training and support for those manufacturers who have moved into the aluminium welding industry, AlcoTec Wire Corporation provides specialized training in aluminium welding technology. AlcoTec is located in Traverse City, Michigan, U.S.A., and is recognized as both a world leader in the manufacturing of aluminium welding wire, and the ESAB Aluminium Welding Center of Excellence. AlcoTec’s staff of metallurgical, welding, and quality engineers present numerous training courses that combine their many years of aluminium manufacturing experience with a knowledge of the industry equipment, specifications and quality requirements. Training courses, which have been developed over many years, are designed to incorporate both the theory and practical hands-on approach to the welding of aluminium alloys.

Moving forward with weld quality:

In order to successfully improve both aluminium welding quality and productivity, it is important to understand the many features of today’s welding equipment, and how they may assist us in achieving our objectives. We must use these available features to reduce the probability of rework or defective welding and enhance our welding efficiency. It is also important to evaluate our human resources to ensure that we have technically competent welding engineering personnel. We must utilize technical training, when necessary, in order to develop our technical skills and promote the successful development of welding quality and improve manufacturing efficiency.

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**About the author**

**Tony Anderson** is Technical Services Manager of AlcoTec Wire Corporation, MI, USA. Mr Anderson is the Chairman of the American Aluminium Association Technical Advisory Committee for Welding and Joining, and Vice Chairman of the American Welding Society (AWS) Committee for D1.2 Structural Welding Code – Aluminium.
Several methods have been developed to increase the deposition rate of the single-wire process. This article reports on the deposition rates of these SAW process variants.

Submerged arc welding has a manifold deposition rate compared with MMA and MAG welding. There are also highly-productive process variants with deposition rates of up to 50 kg/h and more.

Single-wire SAW process

A basic SAW process is a single-wire process:
- single wire (1-wire)
- current: DC+
- wire diameter: 1.2-6.0 mm
- wire electrode: solid wire
- contact tip distance (stickout): 20-40 mm

The deposition rate depends on the welding current and electrode diameter, as shown in Figure 1. A smaller diameter with the same current produces a higher deposition rate than a larger diameter because of higher current density. Needless to say, the current range for a larger diameter involves higher currents and therefore also higher deposition rates. A smaller diameter wire produces a more deeply penetrating and narrower weld bead than a larger diameter wire. One possible application for small diameter wires could be a reduction in heat input with the same deposition rate when welding steels sensitive to high heat inputs.

A diameter of 4.0 mm is generally the most frequently used diameter. One good rule of thumb for 4.0 mm wire is 13 g/A h; with a welding current of 900 A, this results in a deposition rate of 11.7 kg/h.

Example 1: Effect of wire diameter on current density
- Welding current: 400 A
  - 1.2 mm: 354 A/mm²
  - 1.6 mm: 199 A/mm²
  - 2.0 mm: 127 A/mm²
  - 2.5 mm: 81 A/mm²
  - 3.0 mm: 57 A/mm²
  - 4.0 mm: 32 A/mm²

Example 2: Effect of wire diameter on deposition rate
- 4.0 mm (650 A): 7.5 kg/h
- 3.0 mm (650 A): 8.6 kg/h (=+ 15 %)

Example 3: Effect of a small diameter wire on heat input
- application: filling a 6 mm deep groove with an angle of 90°
• weld metal: 2.83 kg/m
• welding speed for filling (cm/min):
• 100xdeposition rate (kg/h) : 60xweld metal (kg/m)
• 4.0 mm wire:
  • welding current: 700 A
  • welding speed: 52 cm/min
  • heat input: 30 kJ/cm
  • deposition rate: 8.9 kg/h
• 1.6 mm wire:
  • welding current: 470 A
  • welding speed: 48 cm/min
  • heat input: 19 kJ/cm
  • deposition rate: 8.2 kg/h

Improving productivity in SAW
Productivity can be illustrated by following formula:

\[ \text{Welding time} = \frac{\text{Weld metal}}{\text{Deposition rate} \times \text{duty cycle}} \]

There are several ways of improving productivity (e.g. reducing welding time):
• increasing the deposition rate (kg/h):
  • high productivity processes
• improving the duty cycle:
  • several arrangements of work and workplaces
  • manipulators
  • welding instructions
  • automatic welding, e.g. ABW welding and so on
• decreasing weld metal (kg) in a groove (e.g. reduced weld metal volume):
  • narrow gap welding

There are several high-productivity process variants for basic single-wire welding:
• welding using DC-:
• welding using long stickout
• welding using cored wire
• welding using metal-powder feed
• welding using cold-wire feed
• welding using twin wires (twin arc welding)
• welding using two wires (tandem welding)
• three-wire welding
• and so on
• different combinations of the above-mentioned variants:
  • twin-wire welding using cored wires
  • tandem welding using metal-powder or cold-wire feed
  • and so on

Deposition rate and impact toughness
Many engineers may think that any increase in productivity is automatically associated with higher heat input and reduced impact toughness. However, this is not the case. In SAW, it is possible to achieve a higher deposition rate with no significant increase in heat input using most of the process variants referred to in this article. This results in the retention of good impact toughness in welded joints.

Only exception is tandem welding. Tandem welding can also be performed with a fairly low heat input if a higher welding speed is used than in single-wire welding.

In recent years, many developments have been made in structural steels and consumables to enable them to tolerate a higher heat input during welding, without impairing impact toughness.

SAW using DC-
In normal circumstances, submerged arc welding is applied using DC+ (DCEP) because it produces good penetration and reproducibility. If the electrode is made negative (DC-, DCEN), the deposition rate is increased significantly, because of the cathodic heating of the wire, Fig. 2. This increase in deposition rate is achieved without any additional capital expenditure. An arc voltage about two volts higher for 4.0 mm diameter wire than that usually used for DC+ at the same current is necessary.

![Fig. 2. Effect of electrode polarity on deposition rate (diameter: 4.0 mm and stickout: 30 mm)](image)

There is a reduction in penetration of between 20% and 30% when using DC- compared to DC+. This is not usually so significant, except when specific root penetration is required, but it has to be taken into account in welding procedures. It is used quite little in butt welding.

The increased bulk of deposited metal resulting from the higher deposition rate with DC- should be accommodated by increasing the welding speed rather than by allowing the bead to become thicker.

In surfacing welding, both characteristics of DC- are very beneficial, because a higher deposition rate reduces the welding time and less penetration means less dilution.

SAW using a long stickout
Usually a stickout in SAW is of 20–40 mm and it is dependent on a wire diameter. Wire burnoff rates can be increased significantly by increasing the electrical extension, Fig. 3, but this results in less penetration. This
extension is usually called stickout, measured from the contact tip to the work, although, to be strictly accurate, it should be the distance from the contact tip to the root of the arc. This is not a bad approximation, however, because the arc is usually buried beneath the plate surface.

The wire protruding beyond the contact tip is heated by resistance heating (IR effect). The degree to which the wire is preheated produces an increased burnoff rate with an increased deposition rate.

With a long stickout, the wire becomes soft from resistance heating and the end of the wire tends to wander. It is therefore necessary to provide an insulated guide for the hot wire. The maximum stickout is about 150 mm for 4.0 mm wire. If long stickout and DC- are combined, the deposition rate almost doubles compared with DC+ and normal stickout.

Example 4: Deposition rate with DC- and long stickout
- 4.0 mm: DC+, 700 A and 30 mm
- 9 kg/h
- 4.0 mm: DC-, 700 A and 120 mm
- 18 kg/h

It is not known exactly how much welding with a long stickout is used; it may be very little in butt welding. In surfacing, this variant is again very useful as DC- above, due to the higher deposition rate and less penetration.

SAW using cored wire
A cored wire can also be used instead of a solid wire in SAW, in the same way as it is used extensively in MAG welding. As current density determines the burnoff rate of the wire, the deposition rate with the cored wire is higher than that with solid wire, Fig. 4. Only the outer steel shell (“tube”) conducts electricity, not the filling material which consists mainly of mineral materials. The increase is about 20–30%.

Using cored wire is a very simple and easy way to increase the deposition rate in SAW without any additional equipment and without any increase in heat input. A cored wire can also be used in other high-productivity process variants to increase their deposition rates still further. At the present time, there is a large range of different cored wires in the ESAB consumables range.

Tests in the following example were conducted with the same parameters as the existing procedure (case A) but also with a higher welding current and travel speed (case B). Tested with the same parameters, thicker beads are deposited because of the increase in deposition rate. An arc time reduction of 21% is obtained. At a higher welding current, while selecting a travel speed to produce the required bead thickness, arc time is reduced by 27%. The mechanical properties show that this does not lead to any loss of excellent low-temperature toughness.

Example 5: Use of cored wire
- plate thickness: 40 mm
- groove type: 45°-half V
- root run: MMA
- diameter of wire: 4.0 mm
- solid wire: 650 A, 30 V and 41 cm/min
- heat input: 28 cm/min
- number of runs: 25
- total arc time: 35 min/m
- A: The same heat input as with solid wire
- cored wire: 650 A, 30 V and 41 cm/min
- heat input: 28 cm/min
- number of runs: 20
- total arc time: 29 min/m
- B: The same number of runs as with solid wire
- cored wire: 750 A, 32 V and 58 cm/min
- heat input: 25 kJ/cm
- number of runs: 25
- total arc time: 27 min/m

SAW using metal-powder feed
In conventional SAW, only a small part of the available arc energy is used to melt the filler wire. The remainder is dissipated in melting the flux and the parent metal, as well as superheating the molten weld pool. So there is
extra energy in the arc cavity to melt additional filler metal. Remarkable improvements in deposition rates can be obtained by the addition of metal (iron) powder to single- and tandem-wire processes, Fig. 5.

Two methods of powder feed have been developed and they involve either the addition of metal powder to the weld pool ahead of the flux burden  the forward-feed system, or the addition of metal powder via the wire using magnetic attraction  the wire-feed system. The feed system utilises conventional submerged arc equipment with metered feed equipment for metal powder. The typical rates for feeding metal powder are 5–6 kg/h for single-wire welding and 6–8 kg/h for tandem-wire welding.

Example 6: Metal-powder feed
- single wire welding: 4.0 mm (700 A: 8.9 kg/h)
- powder feed: 7 kg/h (= + 70%)
- tandem wire welding: 4.0 mm+4.0 mm (2x700 A: 19.1 kg/h)
- powder feed: 8 kg/h (= + 50%)

Metal-powder feed is used fairly extensively in the offshore industry, for example, to increase process productivity without any degradation in the mechanical properties of the weld metal.

Metal-powder feed can also be used in conjunction with the twin-wire process and deposition rates in excess of 20 kg/h have been achieved.

Example 7: Metal-powder feed in the twin-wire process and an increase in productivity
- twin wire welding: 2x2.4 mm
- welding current: 900 A
- deposition rate: 14 kg/h
- welding speed: 70 cm/min
- metal powder feed: 7.5 kg/h
- total deposition rate: 14 + 7.5 kg/h = 21.5 kg/h
- heat input: 29 kJ/cm

SAW using cold-wire feed

Last year, ESAB introduced some very simple equipment (A6-SCW kit) for cold-wire feed, a process called synergic cold-wire SAW. It offers a unique opportunity to increase the deposition rate by up to 100% compared with single-wire welding, Fig. 6. The cold wire is fed in synergy (e.g. with the same wire-feed speed) with the normal arc wire into a weld pool where it melts. Because the wire feed speeds are the same, the arc and cold wire ratio always remains constant after a suitable wire diameter is selected.

The SCW process eliminates the risk of overdosing the filler metal. The risk of moisture pick-up, which can occur with metal powder, is also eliminated by the SCW process. The SCW process can be used in an endless variety of combinations with solid and/cored wires, single-wire, twin- and tandem-wire welding. According to users, the first experience is very promising.

Example 8: Feeding cold wire and an increase in productivity
- arc wire: 4.0 mm
- current: 700 A
- deposition rate: 8.9 kg/h
- + cold wire 2.5 mm: 3.5 kg/h
  = + 39%
- + cold wire 3.0 mm: 5.0 kg/h
  = + 56%
- + cold wire 4.0 mm: 8.9 kg/h
  = + 100%

Fig. 5. Effect of metal powder feed on deposition rates in single-wire process (DC+, 4.0 mm, stickout: 30 mm and powder feed: 70% of a wire feed, e.g. 50–130 g/min)

Fig. 6. Effect of cold-wire feed on deposition rate (DC+, diameter: 4.0 mm and stickout: 30 mm)

Fig. 7. Effect of twin wire on deposition rate (DC+, stickout: 1.2 mm and 1.6 mm: 20 mm, 2.0 mm: 25 mm and 2.5-4.0 mm: 30 mm)
The cold wire can be either trailing or leading, depending on the penetration and build-up requirements. It is very easy to use and can be also put on and off very easily during welding.

**SAW using twin wire**

Twin-wire welding is also called twin-arc welding. In this variant, two wires are connected to the same power source. For twin-wire welding, a standard SAW machine is equipped with the double drive rolls and contact tips suitable for feeding two wires simultaneously instead of a single wire. The twin-wire process produces considerably higher deposition rates than the conventional single-wire process using large diameter wires, Fig. 7. It offers deposition rates that are 30-50% higher.

This increase in deposition rate can be attributed primarily to the increase in current density and the increase in resistance heating of the smaller diameter wires and hence the higher burnoff rate. The wires are of small diameter (1.2–2.5 mm). In order to achieve higher deposition rates in the twin-wire process, the diameter of the wire should be less than 70% of the diameter of the comparable single-wire process.

**Example 9: Current density in single-wire and twin-wire process**
- single wire (4.0 mm) and 600 A: 48 A/mm²
- twin wire (2x2.0 mm) and 600 A: 95 A/mm²

The other aspect of this process is that high welding speeds are possible, due to the longer weld pool. Moreover, the current capacity of the twin-wire process is higher than that of the one-wire process, as can be seen in Fig. 7.

---

**Fig. 8. Effect of cored wires in the twin-wire process on deposition rate (DC+)**

**Fig. 9. Effect of tandem welding on deposition rate (DC+/AC, 4.0 mm/4.0 mm and stickout: 30 mm). The total current is the sum of the current of each wire.**
Example 10: High-speed fillet welding with twin wire
- fillet weld (PB): 3.5 mm
- plate thickness: 6 mm
- wire diameter: 2x2.0 mm
- welding current: 800 A
- arc voltage: 33-34 V
- welding speed: 160 cm/min

The twin-wire process is mainly used in fillet welding where very high welding speeds can be achieved. However, it can also be used successfully for butt welding and will produce deposition rates in excess of 15 kg/h. In the twin-wire process, cored wires can be also used to enhance uniform deposition rates, Fig. 8.

SAW using two wires

In two-wire welding, which is frequently also called tandem welding, each of the two wires is connected to its own power source and is fed simultaneously by its own feed unit. The lead arc, which is operated at high current (normally in DC+) and low voltage, produces high penetration, while the trailing arc uses lower current (normally in AC) to smooth and finish the weld bead profile. AC is normally used in the second wire to avoid the arc blow effects of the magnetic attraction of close arcs. The lead arc is normally slightly trailing and the second arc slightly pushing. The wires used in tandem are normally of large diameter (3.0-6.0 mm).

The deposition rate obtained in tandem welding is about twice that of single-wire welding, Fig. 9.

Needless to say, the additional capital expenditure is quite high for tandem welding, as double sets of equipment are required. Tandem welding is widely used in heavy industry, e.g. shipbuilding, offshore, beam production and pipe mills. Tandem welding is not only restricted to thick plates, but it is also suitable for thinner plates and the fast welding of small fillet welds.
Example 11: Tandem welding for one-sided welding of thin plate
- Plate thickness: 6 mm
- Groove: I groove with gap of 1 mm
- Backing: glass-fibre band + copper
- Tandem welding: DC+/AC
- Welding head no 1 (vertical): DC+, 3.0 mm, 800 A, 30 V
- Welding head no 2 (pushing): AC, 3.0 mm, 625 A, 33 V
- Distance between heads: 20 mm
- Welding speed: 2 m/min
- Heat input: 14 kJ/cm

In conjunction with tandem welding, other highly-productive variants can be used to increase the deposition rate still further; they include cored wires, metal-powder feed and cold-wire feed. Twin wire can also be used in the second head (trailing head) instead of single wire.

Example 12: Fillet welding using tandem welding with cored wires and twin wire in the second head
- Fillet weld (PB): 5.5 mm
- Tandem welding: single wire+twin wire
- Wire electrode: metal cored wire
- Welding head no 1: DC+, 3.0 mm, 450 A and 27 V
- Welding head no 2: DC+, 2x2.4 mm, 800 A and 32 V
- Distance between heads: 50 mm
- Welding speed: 120 cm/min
- Deposition rate: 6 kg/h+14 kg/h = 20 kg/h
- Heat input: 18 kJ/cm

Narrow gap SAW
Narrow gap welding represents a totally different route to higher productivity when welding thick plate. The main advantage of all narrow gap welding techniques is the reduced weld metal volume. SAW can also be used for narrow gap welding. The deposition rate is generally fairly low, similar to that of single-wire welding, about 5–7 kg/h. In recently-developed ESAB narrow gap tandem welding, the deposition rates can be as high as 15 kg/h. Narrow gap welding requires some extra equipment, including a special welding head.

In narrow gap SAW, parallel-sided joint preparation is normally used with a gap of approximately 20 mm, with two beads deposited on each layer using single-wire or tandem-wire techniques. This technique is generally regarded as more reliable and practical than the single-run-per-layer technique.

The main drawback of any narrow gap process is the additional equipment cost, as well as the tighter preparation and fit-up tolerances. It is of the utmost importance that the preparations are done correctly, so that the correct root gap is obtained, and that mismatch and misalignment of the joint are kept to a minimum.

General comparisons based on arc times have been made between the narrow gap process (DC+) and conventional SAW joint preparations using single and tandem wires, both with and without metal-powder feed, as well as cold-wire feed, Fig. 10.

The narrow gap process results in shorter total arc times, above approximately 50 mm, compared with a standard single-wire procedure, above approximately 70–80 mm, compared with a metal-powder or cold-wire feed process, and above approximately 100 mm, compared with the normal tandem-wire process.

References
The deposition rate curves in the figures are based on the following references:
Figs. 1, 2, 3, 7 and 9:
Figs. 4 and 8:
- OK Tubrod product brief, Esab Group (UK)
Figs. 5 and 6:
- Based on a weight of additional filler metal added to the single-wire process
Fig. 10:
- Mathematical calculations based on a joint cross-sectional area and deposition rate

Summary
Some people may feel that the SAW process should already have been pensioned off, as it is more than seventy years old and does not offer any potential or developments for heavy industry. They may also suggest that newer processes, such as beam welding, should be used.

This is not at all the case! SAW is still in good condition and provides the best productivity for the heavy welding industry. Significant improvements in deposition rates can be achieved using many high-productivity SAW variants, such as cored wire, metal-powder or cold-wire feed, twin wire and tandem wire, Fig. 11.

About the author
Juha Lukkari, M.Sc. (Eng.), joined Oy ESAB in Helsinki, Finland, in 1974, after graduating from the Helsinki University of Technology. He has since held different positions and is currently head of technical customer service.
Flash Butt Welding
Old welding technology – state of the art in special applications

by Lars Göran Eriksson and Johnny Sundin, ESAB Welding Equipment, Laxå, Sweden

The flash butt welding method was invented and developed during the 1930s and was used in many different applications because of its productivity and reliability in achieving a good and consistent welding result. Some of its original applications were replaced by friction welding, in applications where the parts that were going to be joined could be rotated, and arc welding, when this method was required by classification authorities.

However, flash butt welding is still the state of the art in some specific applications and it is also being introduced in new applications. This article presents some of these applications and gives technical details relating to the way a modern control system can overcome some drawbacks this welding method has compared with other methods.

The flash butt welding process
Flash butt welding is one of the resistance welding processes, i.e. the energy transfer to the parts that are going to be joined is mainly provided by resistance heat in the parts themselves. The shape of the sectional area can be circular, oval, quadratic, rectangular or irregular. The section area can be between 200 mm and 30,000 mm in production applications, but even larger section areas can be considered.

The surfaces of the workpieces are positioned end to end. As a general rule, the flash butt welding process is sub-divided into pre-heating, flashing and upsetting. In addition, pre-flashing before pre-heating can be used to handle problems when the two surfaces to be joined are

Figure 1.
A typical flash butt weld from a railway rail
not parallel. After upsetting, controlled post-heat treatment can be used.

The removal (trimming) of excess material after upsetting is often part of a totally integrated process.

Pre-heating is carried out under low welding pressure. When the welding joint has been heated to a certain temperature, flashing commences and the surface material is burned off, resulting in even, clean joint surfaces.

After the pre-set flashing, upsetting starts and presses the two surfaces together with high force to produce a good joint. The flash consisting of molten and oxidised material is removed by trimming and the joint itself is pure and consists of a thin joint line in the middle of a heat affected zone. A typical joint from a flash butt welded rail is shown in Fig 1.

Machine development

During the past few decades, standardised machines designed conceptually at a very early stage have been developed into customised equipment, where standardised modules are used for the power electrics, the hydraulics and the computerised control system. The same controller is used for all machine sizes. In the following part of this article, some of these special customised machines are described.

Joining of billets in rolling mills

In the endless welding rolling process, developed jointly by the well-known rolling mill supplier, Danieli & C., Italy, and ESAB Engineering in Laxå, Sweden, flash butt welding was the welding process that was selected because of the extremely short cycle time available for welding and trimming the billets coming from the heating oven before entering the first stand in the rolling mill. The welding machine was developed by ESAB. The other parts of the system were developed by Danieli.

The machine is based on a totally new design concept where space and weight saving was one of the design criteria. The welding time is extremely short and, as a result, the electric power and the hydraulic and mechanical forces are impressive. Special attention has been paid to the harsh environment in which the machine operates. The billets are heated up to around 1,050°C in the oven for the rolling process itself. This is also necessary for the extremely short welding process. Pre-heating is not needed and flashing begins as soon as the two ends to be joined come in contact.

The machine can be moved by a rack-and-pinion drive in a controlled manner with the same speed as the first rolling stand. Using this system, the continuous rolling of long bars or wire can be performed. Several of these systems have been delivered to Asia, Europe and North America. The machine in the flashing sequence is...
shown in Figure 2 and a typical weld sequence diagram can be seen in Figure 3.

Rail joining
Flash butt welding in stationary machines has been used for many years to weld railway rails to sections of up to 420 metres. For the further joining of the rail on site, flash butt welding has also been used to some extent.

Modern stationary machines, like those shown in Figure 4, are DC machines with automatic aligning features and a built-in trimming device.

To comply with the demands imposed on a machine designed to be installed in rail welding trains, ESAB has developed an AC machine, specified together with the French company Geismar, which is a well-known supplier of rail processing equipment and also acts as a turn-key supplier of complete stationary and movable rail welding projects. Figure 5 shows this machine at final assembly at the ESAB Laxå Plant.

Chain making
Flash butt welding is the welding method used in chain production for rod diameters from around 16 mm and up to the largest sizes. When it comes to the details relating to modern mining chain production, reference is made to the article in Svetsaren No. 1/93.

For chain with rod diameters of above 24 mm, it makes good financial sense and it is also advisable from a quality point of view to manufacture chain in a continuous process, i.e. to use the heat needed to bend the rod in the welding sequence as well. Energy is saved, quality is improved and productivity is substantially increased compared with systems with separate bending and welding lines.

All stud chain (anchor chain) is manufactured in continuous production from cut rods, through heating devices, bending, welding, trimming and stud pressing. Ship chain is manufactured in lengths of 27.5 m, which is a design parameter for the chain-handling system.

The different machines are placed in four positions around a rotating table and a rotating chain transport system, a so-called carousel arrangement.

Offshore platform chain is manufactured to more or less any length and modern plants have facilities to do this without separate joining stations.

Other applications for flash butt welding
Flash butt welding should be considered for butt weld joints if high productivity with good weld quality and a robust process is needed. Examples other than those described above include the welding of anodes in aluminium smelters (reference to article in Svetsaren No. 3/95), the joining of T-profiles at shipyards, strip joining in rolling mills and the joining of pipes in the production of industrial and power boilers, for example.

Process control
The flash butt welding controller (FWC) type ZVUQ-1 can control all types of flash butt welding. The control unit is housed in a cabinet that stands directly on the floor, separate from the machine. It is built around a microprocessor, which controls both the welding sequence and the auxiliary functions of the machine.

The processor executes a complete welding sequence (a welding program) containing all the parameters needed for the successful handling of the welding cycle. The programming phase is an easy-to-learn procedure using interactive man-machine communication. A virtually unlimited number of welding programs can

Figure 4. Stationary flash butt welding machine for railway rails
Figure 5. Welding machine for the rail welding of trains under assembly at ESAB Laxå before delivery to Geismar, France, for installation in a rail welding train
naturally also be saved on floppy discs for back-up purposes.

The complete welding program contains parameters for:
- Physical dimensions
- The pre-flashing step
- The pre-heating step
- The final flashing step
- The upsetting step
- The trimming step (optional)
- The annealing step (optional)

The controller displays the main parameters during the welding procedure and also records these parameters for subsequent investigation. The recording system stores the welding records on a hard disk or directly on a central computer somewhere in the plant network, where each weld can be stored for subsequent quality assurance follow-up.

Apart from the recording above, there is also another type of recording in which a number of interesting “extreme values” are extracted from each weld and then plotted against “weld no.” With this latter type of recording, it is very easy to study trends for certain parameters. This is very valuable for quality assurance work and also for planning the maintenance of the machine. Saved recordings can also be printed on a printer.

Testing flash butt welds
The process controller described above has the option of discovering possible weld defects caused by any malfunction that can be identified in the process itself, including electric current, flashing and upsetting length, press forces and cycle times.

Flash butt welding is a robust process that can be controlled and supervised in a reliable and accurate manner. As weld defects of the porosity and crack type do not exist, non-destructive testing methods are of limited value.

Flash butt welding is used in many critical applications and different test methods are employed. Anchor chain is test-pulled to specified loads, rail joints are tested mechanically at regular intervals and boiler tube joints are tested by selecting test samples for examination also at regular intervals.

In special cases, welds are tested using non-destructive testing methods to discover crack indications or impurities. Some poor bonding (kissing bonds or grey spots) cannot be discovered by NDT, but the same problem can also occur with other welding methods.

Conclusion
Flash butt welding is a reliable, well-proven welding method which will continue to be the best process for a number of metal joining tasks when the section area is above 200 mm or thereabouts. New machine and control technologies will open new application areas, as well as improving quality control, and should simplify the present test procedures.

About the author
Lars Göran Eriksson, MSc Electrical Engineering, joined ESAB in 1973 and has since held different management positions at ESAB within Business Area Automation & Engineering. He is currently site manager at ESAB Laxå in Sweden.

Johnny Sundin, MSc Electrical Engineering, joined ESAB in 1982 and has been R&D manager within ESAB welding engineering operations for both standard machines and engineering. He is now responsible for project management within Business Area Automation & Engineering.
Electroslag strip cladding for corrosion resistance

by Dipl.-Ing. R. Paschold, ESAB GmbH, Solingen, Germany

The resistance electroslag cladding process with strip electrodes (RES-cladding) is widely used for producing corrosion resistant clad layers by welding on mild or low-alloyed steels. Very common are milled and sintered strips for stainless austenitic or Nickel-based claddings. The choice of the welding flux and the welding parameters is not only influencing the deposition rate and the dilution from the base material in a certain amount. This paper describes several technical and economical details that should be taken into consideration by the user of the RES-cladding process.

1. Introduction

The electro-slag strip-cladding process is increasingly used for the production of corrosion resistant overlays in equipments for the offshore- and process- industries. Since it has been developed in the early seventies, the technical and economical advantages of this process have resulted in more widespread use compared to that of submerged arc strip cladding.

2. Principle of RES-Cladding

Resistance Electroslag Cladding belongs to the resistance welding processes and is based on the ohmic resistance heating (IR) in a liquidized electro-conductive slag. The heat generated by the molten slag pool melts the surface of the base material, the strip electrode dipping in the slag and the flux.

Compared to SAW-strip cladding the flux supply is different. The welding flux is only supplied on one side in welding direction (Fig. 1). Normally the flux height is between 20 and 35 mm. The temperature of the slag pool is about 2,300°C and it is emitting visible light and infrared radiation. The resulting thermal load makes it necessary to water-cool the trailing contact jaw. Because of the higher welding currents to be transferred, the welding heads for RES-cladding are more heavily built than welding heads for SAW-strip cladding (Fig. 2).

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

- Increased deposition rate by 60 to 80%
- Only half of the dilution from the base material through less penetration (about 10–15%)
- Lower arc Voltage (24–26 V)
- Higher Amperage and current density (About 1,000–1,250 A with strips of 60 mm width, corresponding to 33–42 A/mm²)
- Increased welding speed (50–100% higher), resulting in a higher area coverage in m²/h
• Comparable heat input in the base material
• Lower flux consumption (0.5–0.8 kg/kg strip)

In addition the solidification rate of the RES weld metal is lower, improving the degasification and the resistance to porosity. Oxides can rise easier out of the molten pool to the surface; the overlay metal is cleaner from a metallurgical point of view and less sensitive to hot cracking and corrosion.

3. Consumables for RES-Strip cladding

3.1 Welding Fluxes

The RES-process requires a slag pool with an Ohmic resistance behaviour. In comparison to SAW cladding the electrical conductance must be remarkably better to avoid arc flash, which is recognized as a disturbance of the process. Basic fluxes, consisting mainly of Fluorspar, deliver a slag with the properties of hot conductors, repressing arc break out effectively [1]. The principle ingredient of fluxes for RES-strip cladding is calcium fluoride (Fluorspar, CaF_2), where the basicity according to Boniszewski is 4–5.

With increasing proportion of CaF_2 the electrical conductance of the slag increases, the resistance and the resulting generation of heat is decreasing. The dilution and the deposition rate at similar welding parameters are decreasing consequently. Furthermore the viscosity of the slag is lower with higher CaF_2-contents of the flux. The molten pool of a more fluid slag is wider and not as deep. This can be an advantage for cladding with strip alloys of high viscosity like Nickel and Cobalt alloys. The wetting is improved and the weld bead is of greater width and less thickness. Its surface is very smooth with a shallow slope. This is also connected to the lower temperature of solidification and the increased length of the fluid slag pool. Especially for cladding with Nickel alloys the lower dilution rate is of advantage, because the lowest possible Fe-content of the weld metal is normally aspired for the best possible corrosion resistance of the cladding. Compared to a three-layer cladding using SAW often a two-layer RES-cladding is of similar or better corrosion resistance.

<table>
<thead>
<tr>
<th>Welding Flux</th>
<th>CaF_2-Content</th>
<th>Electrical Conductivity</th>
<th>Solidification</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK Flux 10.10</td>
<td>64%</td>
<td>middle</td>
<td>middle</td>
</tr>
<tr>
<td>OK Flux 10.11</td>
<td>70%</td>
<td>high</td>
<td>slow</td>
</tr>
<tr>
<td>OK Flux 10.12</td>
<td>60%</td>
<td>low</td>
<td>fast</td>
</tr>
</tbody>
</table>

Table 1. Content of Fluorspar and typical properties of welding fluxes for RES-cladding.

OK Flux 10.10 is a universal flux, which can be combined with strips of stainless steel, or nickel based alloys. In comparison, OK Flux 10.11 is used for cladding with higher welding speed and for special alloys with bad wetting behaviour. OK Flux 10.12 delivers a fast freezing slag, best suitable for cladding of cylinders and rollers. The lower the diameter of the cylinder, the more difficult is the holding of the molten slag pool on the top, especially with slow freezing slag.

Fig. 3. Self-lifting slag of OK Flux 10.10, combined with a sintered strip of Super-Duplex steel (OK Band 11.88).

But one of the most important requirements to all welding flux for RES-cladding is the slag detachability (Fig. 3). This is also valid for Niobium-stabilized cladding alloys and Nb-alloyed Nickel strip electrodes.

3.2 Strip Electrodes

For cladding with standard alloys the application of rolled, solid strip electrodes is very common. Since one melted heat consists of 40–60 tons normally, the production of solid strips is limited to standard alloys like austenitic steels and the most common Nickel based welding alloys. The productions of special alloys in small batches invoke high expense resulting in high costs and long lead times. On the other hand the stiffness and ductility of solid strips are of advantage for the internal cladding of pipes and pressure vessels of smaller diameters.

In the last few years the production of sintered strip electrodes has successfully been accomplished. The advantages of sintered strips are:

- Alloys that are impossible or difficult to produce by melting and rolling (like Cobalt alloys) can be produced as sintered strip electrode.
- Sintered strips are also available in small heats and as tailor-made alloys for special applications.

To compensate the dilution from the mild or low-alloyed base material in the first layer of RES-claddings, over-alloyed strip electrodes are used. Compared to SAW-cladding the dilution of the RES process is lower and the over-alloying of the strip for the first layer is not as high. To produce a single layer cladding with a weld metal composition of 19.9 Nb/347, for SAW, a strip of type S 23 12 Nb (EQ309LNb) is selected (Table 2, 3). For RES-cladding the type chosen is S 21 11 Nb. The choice of the suitable strip composition has to be done in respect to the expected and acceptable content of A-Ferrite in the weld metal. In some applications over-alloyed strips made for SAW are used for RES-cladding variants with higher dilution. Deeper penetration with higher dilution from the base metal can be found in RES-cladding processes with high welding speeds combined with high currents.

4 RES strip cladding with increased efficiency

4.1 Objectives

The efficiency of the RES strip cladding process with common welding parameters and width of the strip is remarkably higher than that of SAW cladding. But for
Table 2. Solid strip electrodes for RES-cladding (other grades are available on request).

<table>
<thead>
<tr>
<th>designation</th>
<th>Classifications according to Strip composition (typical) [%]</th>
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<tbody>
<tr>
<td></td>
<td>EN 12072, DIN 1736 W.-Nr. AWS A5.9, 5.14 C Si Mn Cr Ni Mo Nb</td>
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<tr>
<td>OK Band 11.61</td>
<td>S 19 9 L</td>
</tr>
<tr>
<td>OK Band 11.62</td>
<td>S 19 9 Nb</td>
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<td>UP-NiCr20Nb</td>
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Table 3. Sintered strip electrodes for RES-cladding (other grades available upon request).

<table>
<thead>
<tr>
<th>designation</th>
<th>Classifications according to Strip composition (typical) [%]</th>
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<tr>
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<tr>
<td>OK Band 11.97</td>
<td>UP-NiCr20Nb</td>
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</table>

some years now there are tendencies of increasing it still further. This necessity becomes stronger with the growing pressure of competition in the welding market. Up to now there are three different ways, which are successful or seem to be promising:

- Cladding with strip electrodes of larger width,
- Process variants with extended stick out,
- Increased travel speed with special fluxes.

4.2 Strip electrodes of increased width

To increase the cladding efficiency (cladded area per period of time), wider strips than those commonly used are applied for the cladding of large areas on pipe plates or in large pressure vessels. Normally 90 mm wide strips are then applied (Fig. 4). Applications with strips of up to 250 mm in width are also known to have been utilized [2].

Using strips wider than 60 mm raises the technical requirements of the welding equipment. Special strip welding heads and very powerful welding power sources are needed. Often an additional magnetic field control system is required to improve the bead appearance by neutralization of the magnetic blow effect. The increasing depth of the HAZ with increasing strip width has also to be taken into consideration.

4.3 Extended stick-out

Normally a stick out between 30 and 40 mm is used for RES-cladding. To increase the deposition rate of the process, the stick-out can be increased within certain limits. According to the $I^2RT$-method known from GMAW, the rising preheating of the strip electrode is connected to higher deposition rates.

Taking into account that austenitic solid strips possess a high electrical resistance. When exceeding certain limits of welding current or stick out the strip...
will fuse within the exposed strip length [4]. Because of their composition of metal powders, sintered strips have a better electrical conductivity. The stick-out can variably be increased (up to 90 mm). This to take advantage of the increased deposition rate by I²R-preheating.

This requires special welding heads giving the strip a better stability by putting it into a shape. The strip can be formed to an U-shape using special driving rolls and contact jaws. Often highly fluoride fluxes with increased electrical conductivity of the slag are used for cladding with extended stick out. Additionally power sources supplying the required high currents and magnetic steering units are needed. Corresponding to the increased deposition rate the welding speed can be increased by up to 30%. The dilution from the base metal decreases. This is useful for claddings with Nickel alloys with limited permissible ferrous content to decrease the number of the layers needed.

4.4 Fluxes of high conductivity
The composition of the welding flux influences the conductivity, the solidification range and the viscosity of the molten slag. To increase the cladding speed at corresponding high welding currents, fluxes producing a slag of high electrical conductivity and low viscosity are used to avoid disturbances of the electroslag process.

Fig. 8 shows the RES-cladding process at a speed of 45 cm/min using OK Band 11.66 (60x0,5 mm) and OK Flux 10.11 during tests for a research project at the welding institute ISF Aachen in Germany. At a welding current of about 2,500 Amps the deposition rate is about 56 kg/h.

5 Corrosion resistance
5.1 Features of RES-claddings
Compared to the corresponding steels, available in quenched or cold rolled condition, RES-claddings show partly higher corrosion rates, but lower than those of SAW-claddings. To estimate the suitability of a welded overlay for certain corrosion conditions, the qualification by cladded specimens in corrosion tests has to be recommended. The reasons for the lower corrosion resistance of welded overlays compared to similar steels are the coarse-grained structures of weld metals and especially the precipitations of intermetallic phases. Intermetallic phases can occur during the relatively long cooling time and also during the post weld heat treatment (stress-relieving), which is required sometimes.
5.2 Ferrite content in austenitic claddings
To be resistant against hot cracking, the austenitic standard strip electrodes (OK Band 11.61, 11.62, 11.63, 11.71, 11.72, 11.73 etc.) are alloyed to produce a weld metal containing a certain amount of Δ-Ferrite.

Frequently the content of Δ-Ferrite is limited by the rules of the chemical and petrochemical industry to maximum of 8% (or to be between 2 and 8%). With higher concentrations a ferritic lattice at the grain boundaries may occur, which impairs the corrosion resistance and the ductility of the welded overlay. At higher operating temperatures or during the post weld heat treatment (as required by the European pressure vessel and ASME-codes), Carbides can precipitate to the ferritic lattice and sigma phase will be found. Sigma phase mainly lowers the toughness and can lead to inter-granular corrosion. Consequently the adjustment of the Δ-Ferrite content in the weld metal is of utmost importance. The biggest influence on the resulting ferrite content greatly involves welding speed, which also affects the dilution of the base material. If a very low travel speed is used with overalloyed strip during cladding of the first layer, the result would be a very low dilution but at the same time acquiring an unacceptable high content of ferrite. Welding speed is not only an economical factor but also a metallurgical one. With strip electrodes like OK Band 11.71, 11.72 and 11.73 / 60x0,5 mm for electroslag cladding, welding speeds of 18 to 20 cm/min are selected as usual parameters (about 1,200 Amps and 24 Volts). If the requested thickness of the overlay is more than 5 mm, a second layer with another strip (OK Band 11.61, 11.62 or 11.63) is recommended instead of cladding a single thick layer with high ferrite content.

6. Applications

6.1 Austenitic cladding of a separator

Fig. 9 shows a dished end of a condenser/separator for the petrochemical industry. A single layer cladding on 35 mm thick mild steel P355NL1 (TStE 355, 1.0566) with a weld metal of type 316L/1.4430 was specified. To meet the low-carbon-limit (C 10,03%), the carbon content of the overalloyed strip had to be very low.

Because of availability a sintered strip is available (OK Band 11.49) with C=0,008% was chosen. At a dilution of about 13% the Carbon content of the weld metal was measured to 0,025%, the ferrite content as welded to about 8 FN.

The welding parameters: 650A, 24V and 18 cm/min. The stick-out was 40 mm, the overlap 8 mm and the produced thickness of the overlay about 4,5 mm. The other sections have been cladded with OK Band 11.49 in 60x0,5 mm at about 1,250 Amps.

6.2 Cladding of a tube plate

Fig. 10 shows the surface of an RES-cladded tube plate for a chemical reactor. It is cladded in two layers with solid (OK Band 11.95) and sintered (OK Band 11.97) strips of type “Inconel 82“ (NiCr20Nb, 2.4806). To acquire decreased dilution from the base material the welding current and the travel speed has to be limited to a lower level compared to steel strips.

6.3 Cladded reactor

In Fig. 11 a cross section is shown, RES-cladded using similar welding parameters but with OK Band 11.92,
which is of type „Inconel 625“ (NiCr21Mo9Nb, 2.4831). The depth of the HAZ, the overlapping zone and the coarse-grained weld metal are a good example. The uneven shape of penetration is typical for RES-claddings with Nickel-alloys.

![Fig. 11. Cross-section of an Inconel 625-cladding.](image)

Fig. 11. Cross-section of an Inconel 625-cladding.

has been developed for overlaying of cylinders and rollers of smaller diameters (OK Flux 10.12). So-called high-speed-fluxes with a wider solidification range like OK Flux 10.11 produce a slag of low viscosity and high conductivity, which is suitable for increased travel speeds or decreased penetration. Depending on the welding parameters the choice of the alloy of the strip electrode and of the welding flux are important for the quality of the overlay. For single layer claddings and the first layer of multi layer claddings with over alloyed strip electrodes the welding parameters are of importance and the acceptable content of \(\Delta\)-ferrite has to be taken into consideration carefully. A low as possible dilution from the un- or low-alloyed base material is not desirable if over alloyed austenitic steel strips are used. This could lead to high ferrite contents injuring the corrosion resistance and toughness of the overlay weld metal. On the contrary a lowest possible dilution should be aspired in cladding jobs with Nickel-based strip electrodes.

8 References


7 Concluding remarks

The electroslag strip cladding process with solid or sintered strips of dimensions 60x0,5 and 30x0,5 mm is widely used today for producing corrosion resistant welded overlays. Process variants with improved cladding efficiency based on increased deposition rate have been developed, which raise special requirements of the power sources, strip welding heads and also welding fluxes. Several fluxes with different characteristics are available, suitable for a wide range of different application fields. Beside universal fluxes like OK Flux 10.10, a flux with relatively fast solidifying slag

![Fig. 12. Cladding job at the dish-end (10CrMo9-10) for a chemical reactor with OK Band 11.92 (60 x 0,5 mm) in two layers at 1,000 Amps, 24 V, 17 cm/min.](image)

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Welding in the chemical industry

by G. Kaulich and P. Kaißer, ESAB Solingen, Germany

The chemical industry manufactures a wide variety of products, ranging from chemicals, fertilisers, pharmaceutical products via plastics and greases to cosmetics, to name but a few. These products are made in reactor, pressure vessels, boilers or columns, processed in agitators and transported through pipe systems.

Many of the products made, their intermediate products or the media required for their manufacture are corrosive and call for suitably resistant materials. This is why the chemical industry is the typical field of application for chemically-resistant steels, formerly known as corrosion-resistant or simply stainless steels. These steels are used by firms that build apparatus and pipework or by suppliers of the necessary production plants, and welding plays an important role in this.

Particular attention should be paid to the physical properties of austenitic CrNi and CrNiMo steels. Stainless Cr steels are of only minor important here. The fact that their thermal conductivity is lower than that of unalloyed steels may lead to overheating of the material. Their higher coefficient of thermal expansion encourages the creation of stresses and/or distortion. This calls for appropriate welding parameters. Many welding processes that are very important where ordinary structural steels are concerned therefore tend to be under-represented when it comes to the welding of chemically resistant steels.

The purpose of this article is to investigate the suitability of individual welding processes for use in the construction of chemical plants, and to highlight and clarify with application examples the special demands they place on welding technology and the welding equipment.

Materials and welding consumables
Table 1 lists the major chemically-resistant steels conforming to EN 10088-1. They can be subdivided into conventional CrNi and CrNiMo steels, fully austenitic Cr steels are of only minor important here. The fact that their thermal conductivity is lower than that of unalloyed steels may lead to overheating of the material. Their higher coefficient of thermal expansion encourages the creation of stresses and/or distortion.

<table>
<thead>
<tr>
<th>Material No.</th>
<th>Alloy type</th>
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Table 1. The main chemically-resistant steels to EN 10088-1
steels, also known as super-austenites, and ferritic-austenitic duplex steels.
The first group contains the standard austenites, known for and proven over many years. They possess an austenitic structure, but may also contain a small percentage of ferrite.

The second group, the super-austenites, are higher-alloyed materials with an extremely low carbon content. Some of them are alloyed with copper. Nitrogen stabilises the structure and reduces the tendency for the precipitation of intermetallic phases, which may adversely affect the resistance to corrosion. Because of their higher chromium and nickel content, as well as the additional alloying elements and the stable-austenitic condition of the structure, they can also be used under extremely corrosive conditions, above all where ferrite fractions in the structure of conventional steels might lead to selective corrosion.

The third group has a two-phase structure made up of about 50% each of ferrite and austenite. This makes them especially resistant to stress corrosion, which may occur in lyes or in media that contain chlorine if the material is subject to tension stresses, for example after welding.

It is a basic rule that chemically-resistant steels must be welded with consumables of the same or a similar type. ESAB has developed a wide range of welding additives for these groups of steels [1]. Table 2 lists suitable welding consumables for the major base materials.

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>MMA</th>
<th>MAG</th>
<th>TIG</th>
<th>FCW</th>
<th>SAW</th>
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<td>OK Tigrod</td>
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* OK Flux 10.93
** OK Flux 10.16

Table 2: Allocation of suitable welding consumables according to Table 1

Thoughts on the suitability of chemically-resistant steels for welding
The smallest difficulties are to be expected with conventional austenitic steels. With correctly balanced Cr/Ni equivalents, they harden ferritically first, undergoing conversion to austenite later as they cool down. Their susceptibility to solidification cracking is therefore very low. However, because of their low thermal conductivity, thermal congestion may cause areas of overheating, which reduce the toughness and corrosion-resistance of steels. These materials should be welded with low heat input, in other words with a low welding current and/or a high welding speed.

Super-austenites are prone to solidification cracking because of their austenitically-stable structure. They must therefore be welded relatively “cold”, with low currents and small weld pools. Thin melt runs are preferable to broad pendulum layers. On the other hand, it is important to bear in mind that the shrinkage increases with every layer, above all at right angles to the weld seam. In chemically-resistant steels this is encouraged by the high coefficients of thermal expansion. A reasonable compromise should therefore be aimed for as regards the number of layers to be applied.

Duplex steels are well suited for welding. The joints are not in danger of solidification cracking. However, under certain conditions, duplex steels are prone to cold cracking. A low hydrogen content in the base metal should therefore be aimed for.

To ensure good toughness and corrosion properties, the following instructions must be observed [2].
• Cooling after welding should not be too rapid in the region affected by heat. The gap energy must therefore be high for thick materials and low for thin materials (less than 5 mm).
• The buffering temperature should not go above 150°C for thin materials and 180°C for thicker materials.
• To ensure the desired two-phase structure in the weld metal, the nickel content of the welding consumables must be higher than that of the base materials.

Using the different fusion welding processes with the corresponding current sources and equipment
The factors that govern the choice of welding process

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>MMA</th>
<th>MAG</th>
<th>TIG</th>
<th>FCW</th>
<th>SAW</th>
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<tr>
<td>Steel type/ W. Nr.</td>
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<td>Autrod</td>
<td>OK Tigrod</td>
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* OK Flux 10.93
** OK Flux 10.16

Table 2: Allocation of suitable welding consumables according to Table 1
are material thickness, shape of joint, degree of mechanisation to be used, welding position and often the material to be welded as well.

Digital current sources are being used more and more in the chemical industry. The advantage of this type of current source is that its control characteristics are not dependent on the hardware used (transformers, chokes, etc.). Instead the welding is controlled by software. This leads to a marked improvement in the stability of the arc and the reproducibility of the welding results.

**Manual arc welding (MMA)**

Manual arc welding with stick electrodes is still used relatively frequently in the construction of chemical plant, compared with other fields of manufacture. Among the reasons for this is that it results in a high-quality seam and that the seam surfaces show relatively little oxidation compared with MAG welding, for instance, so that there is less need for follow-up work in the form of grinding, brushing or pickling, which can soon cancel out the advantages of mechanised MIG/MAG welding. These oxide skins must in any event be removed before the component goes into service, since they reduce the resistance to corrosion in this region. This applies to the face in contact with the product, mainly the inside of containers and pipes. Externally they are removed mainly for reasons of appearance.

Nowadays, the electrodes used are predominantly rutile-coated stick electrodes. Compared with electrodes with a basic coating, these provide good slag removal and smooth seam surfaces (Figure 1). This is especially the case with fillet welding. As well as normal electrodes there are also core-stick-alloyed high-performance electrodes with enhanced feed rate.

The main current sources used nowadays are inverters with primary clocking. In addition to their outstanding welding characteristics, they offer many supplementary functions such as hot start und anti-stick effect. Figure 2 shows the manual arc welding in the construction of a chemical plant. Tubular reinforcements are being welded to containers.

**Tungsten inert gas welding (TIG)**

At least in terms of the number of instances of its use, this is the welding process most widely used in the chemical industry. Manual TIG welding is often used for root welding. The fact that the supply of weld metal is independent of the current makes this process superior to any other for this purpose. However, because of the low feed rate, the remaining layers are often applied by other processes, for example by manual arc welding.

A frequent application of mechanised welding on chemically resistant pipes is TIG orbital welding [3].

Pulse welding with pulse frequencies of up to about 10 Hz is used for this welding process, because it gives better pool control, combined with good fusion penetration. The fact that successful root welds can be reproducibly made with very low constriction, ie a sag of less than 0.1 mm, is a particularly important factor here. This is especially important in “piggable” pipes, which must be accessible to an internal cleaning device for regular cleaning (Figure 3). TIG orbital welding is always done gapless.

The pipes are often prefabricated with welded-on fittings in the form of bends, flanges or tees by means of orbital welding. The pipework systems are then welded together on site using this process. TIG orbital welding
is also used to weld pipes into tube plates, a frequent practice for heat exchangers or reactors in the chemical industry.

A typical application for TIG orbital welding in this field of industry is pipework for various process lines. Figure 4 shows TIG orbital welding being used to make connections in an assembly of this kind.

Metal inert/active gas welding (MIG/MAG welding)

Inert gas welding is seldom used for the group of materials dealt with here, so that we are by definition mainly concerned with MAG welding. Formerly, argon/oxygen mixtures with 1–5% oxygen were used for this. One consequence of this, however, was that the seam surface itself and the adjacent regions were heavily oxidised, which meant a lot of subsequent work to remove these oxide layers before the component could be put into a service [4].

The use of gases containing CO₂ is problematic, because the carbon monoxide given off on disassociation of carbon dioxide leads to carburisation of the weld metal, reducing its resistance to corrosion. However, small fractions of CO₂ do not cause problems. For some time now, argon with 2.5% CO₂ has been successfully used for welding chemically-resistant steels. On top of improved fusion penetration, there is the further advantage that the seam suffers less oxidation than with argon/O₂ mixtures. Reservations about the use on stainless steels of the three-component gas Ar+5%O₂+5%CO₂ introduced for welding unalloyed steels have recently been set aside. A further drawback of MAG welding is the risk of flank and layer bonding defects. Although this risk is smaller here than with unalloyed steels, because of the lower thermal conductivity, the poor detectability of such defects by non-destructive material testing methods means that such defects may go undetected. For this reason, the internal works standards and construction regulations of various chemical companies in Germany prohibit the use of this process. The drawbacks described has so far prevented wider use of the MAG process in the construction of chemical plants.

Flux-cored wire welding (FCW)

Flux-cored wire for welding chemical-resistant steels and in the form of slag-carrying wires. All the cored wires in the ESAB range belong to the group of gas-shielded cored wires, meaning that they are used in MAG welding. Unlike solid wires, they can be melted under argon gas mixtures with a higher CO₂ content of 18%, for example, some of them even under pure carbon dioxide. Carburisation of the weld metal is a less important factor, especially with slag-carrying wires. With these types, there is significantly less oxidation of the weld metal surface and the regions close to the weld, eliminating a major drawback of MAG welding with solid wire. The higher feed rate that this makes possible and the reduced risk of bonding defects are further advantages that could lead to wider use of this process in chemical plant construction.

Submerged-arc welding (SAW)

There is still a widespread belief that submerged-arc welding is only suitable for joining heavy-gauge plates. Plates upwards from 3 mm thick can indeed be joined on one side, with backing for the molten pool. With stainless steels, position/counter-position welding fluxes as an I-shaped butt joint is possible at material thicknesses of about 5–10 mm. Beyond that, the edges of the workpieces must be chamfered to form a Y– or DY–seam.

For submerged-arc welding of stainless steels there are special fluxes which either metallurgically reduce the chromium melting loss or even prevent it
completely by chromium supports. The latter outcome is only possible with agglomerated welding powders.

The SAW process gives very smooth run surfaces, from which it is easy to remove the oxide coating. Since the process is only used on a fully mechanical basis, a high level of investment is necessary. It can only be used for long, continuous longitudinal seams or for circular welding. Most applications are therefore to be found in the welding of circular seams on large vessels. Figure 5 shows SAW welding on a vessel for chemical processes.

Another field of application for the SAW process in the construction of chemical plants is the plating of surfaces by SAW strip surfacing. This process can be used on components of unalloyed or low-alloyed construction steels to make the side in contact with the product corrosion-resistant by applying layers of high-alloyed steel.

Other processes
A further process used in chemical plant construction is plasma welding. Here, the keyhole technique is used to weld longitudinal seams of vessel courses of CrNi steel to 3–6 mm thick plates in one layer, including the circular seams.

Because of its better performance, electro-slag strip plating is gradually beginning to replace SAW plating in vessel construction.

Forming when welding
It has already been mentioned that the oxide coatings that form on and beside the seam owing to corrosion must be removed by brushing, grinding or pickling before the component is used. However, this is often impossible in the inside of small-diameter vessels or pipes. In such cases the oxide coatings must be prevented from forming by using protective gas to displace the oxygen from the inside of the components. In addition to argon itself, argon/hydrogen mixtures are also suitable for this purpose. If the materials to be welded permit, less expensive gases such as nitrogen or hydrogen/nitrogen mixtures may also be used for this. Since these gases have a positive effect on the underside of the root by their cooling action, they are called forming gases.

Result:
The particular physical properties of austenitic CrNi steels and the severe demands placed on them in chemical plant construction, call for welding processes, that take these features into account.

For fusion welding, therefore, the processes that have proven themselves here in particular are manual arc welding, TIG welding and the SAW process. The chemical industry also places severe demands on welding equipment, in order to reproducibly achieve defect-free connections. One might go so far as to say: “Here, the best is just good enough”.

Bibliography:

About the authors
Günter Kaulich is product manager for mechanized welding TIG, PLASMA and Robot. He has been working at ESAB GmbH Solingen since 1970 in different positions.

Peter Kaifer joined ESAB GmbH Solingen in 1994 and works as a junior product manager for TIG and MMA.
Laser welding – will it have any significant impact on welding?

by Herbert Kaufmann, ESAB Welding Equipment AB, Laxa, Sweden

For some time now, laser cutting has been a generally used manufacturing method and ESAB is one of the world’s leading suppliers of laser cutting machines. Laser cutting equipment is manufactured and sold by ESAB-Cutting in Karben, Germany.

The laser cutting technique has reached a very high level of perfection and the subsequent treatment of cut-out pieces can be almost excluded.

While the laser cutting technique is a recognised manufacturing method, the laser welding technique has developed somewhat more slowly. Most laser welding applications are currently found within the automotive industry and modern vehicle bodies are largely joined together using laser welding. Another regarding laser welding. At the present time, ESAB can offer complete laser welding plants and perform test welds on behalf of customers.

Laser welding is mainly performed using two different types of laser:

- ND:YAG laser up to 4 kW where the laser beam is transferred from the laser resonator to the welding optics through a fine optical conductor (often used for the robotic welding of thin materials and aluminium welding).
- CO$_2$ laser up to 20 kW where the laser beam is transferred via a lens/mirror system from the laser resonator to the welding optics (used for welding thick materials up to 20 mm).

The greatest advantage of laser welding is that very high welding speeds can be attained and distortion is very rare as the heat input is low. One major difficulty when it comes to laser welding, however, is that gaps cannot be accepted in the weld joint. Even a gap which is only some tenths of a millimetre wide causes the weld material to sink and this has a negative impact on the tensile properties of the welded joint.

In order to avoid this disadvantage, the pure laser welding method has been combined with different traditional welding methods, such as MIG, TIG or plasma welding (laser hybrid welding). By adding filler material to the laser welding process, satisfactory weld joints can be produced, even if the gap is wide and not uniform. The heat input increases in laser hybrid welding by some 30% compared with pure laser welding, but in overall terms this is only 10% of the heat input that is normally used for other types of welding. The properties of the weld material also improve slightly using the laser hybrid process.

The heat input is always a gauge of the distortion that can be expected after the welding operation. As the heat input for laser welding is extremely low, the expected distortion of the welded piece is some 10% of what is usually produced in submerged arc welding, for example. Large pieces—up to 20 m in length—can
therefore be manufactured with great accuracy. This will definitely revolutionise the shipbuilding industry in particular when it comes to the production of ships panels and decks.

It would be generally true to say that the welding properties of laser welding are always superior to those of conventional welding. This applies particularly to the welding of high-tensile steels, which are being used increasingly in cars but also in telescopic cranes and other heavily-loaded structural elements.

Test welds with Weldox 960 have shown that yield point limits of more than 1,000 Mpa can be achieved with the laser welding method. All the fractures occurred in the base metal (fracture lengthening by more than 20%)!

In tests of the laser hybrid process, ESAB has obtained very good welding results. Multi-layer welds in thick material have also been successfully performed using this method.

The principal advantages of laser welding can be summed up as follows:

- High welding speeds (2 – 10 m/min, depending on the laser power and the plate thickness)
- Lower heat input means low distortion rate (10% of what is usual with conventional methods)
- Simplified welding of high-tensile and special steels (narrow heat-affected zone)
- Very little or no subsequent treatment of the piece (the weld looks like a TIG weld)
- The geometry of the joint can be chosen freely (3-D welding with robots is, for example, possible)
- Weight reduction as a result of the more efficient utilisation of the material (complete penetration regarding fillet joints, for example)
- High productivity and uniform weld quality

The disadvantages of laser welding are:

- High investment cost
- Higher joint preparation cost
- Special safety requirements

Vehicle parts are a good example of products that are suitable for welding with laser, but it is also appropriate for the longitudinal and spiral welding of tubes (material thickness up to 15 mm) which are currently welded using MIG or SAW (submerged arc welding). Parts which are usually TIG welded, like hot-water containers, tube pieces and valves in different materials, can be suitably welded using YAG lasers at very high welding speeds.

In order to obtain optimal profitability using the laser welding process, the total flow through the manufacturing unit must also be studied, so that the high productivity obtained as a result of the higher welding speed does not result in stoppages at a later stage in the manufacturing chain. The manipulation of the part at the welding station should also be made more effective so as to reduce the set-up times at the same rate as the welding time. Lasers also offer attractive manufacturing solutions, as cutting, welding and marking operations can be combined in the same production line. In the manufacture of tubes, for example, plates can be cut to the exact initial dimensions before the bending operation and can then be ready welded in the same equipment after the tube has been given the shape of the final blank. Should joint preparation be necessary, this can also be done in the same equipment.

The accuracy of the laser machine must be top class. The machine must also be able to work at high welding speeds and high acceleration and must be installed in a vibration-free environment. As the weld joint is very narrow—generally not visible to the naked eye—special equipment offering top-class reliability must be used for tracking the joint.

The gas shield for the welding process is often a mixture of helium and argon, sometimes with a small CO₂ content. Special laser gases are also available nowadays. At plants with CO₂ lasers, the beam path between the laser resonator and the welding optics must be set under pressure using a special gas consisting of a mixture of nitrogen, carbon dioxide and helium.
short wavelength normally requires the whole plant be designed as a closed production cell with windows made of special materials. The personal safety requirements at a CO\textsubscript{2} laser plant are easy to fulfil as plexiglass can be used in screens and windows.

The laser welding process can easily be mechanised and production can be supervised using a comprehensive production control system. Due to the great accuracy of laser welding and the insignificant need for subsequent treatment, the door-to-door time of the product can be considerably reduced.

Laser welding is definitely going to be a welding process that is in great demand in the future.

References


About the author

Herbert Kaufmann M.Sc. E.E. and M.Sc. M.E. joined Esab Automation Inc in the USA in 1988 as Technical Director, and moved to ESAB Laxå in 1994. At present he is a project leader within engineering operations at ESAB Welding Equipment in Laxå. He was previously responsible for the development of arc-welding robots at ABB.