Tandem MIG/MAG Welding

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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

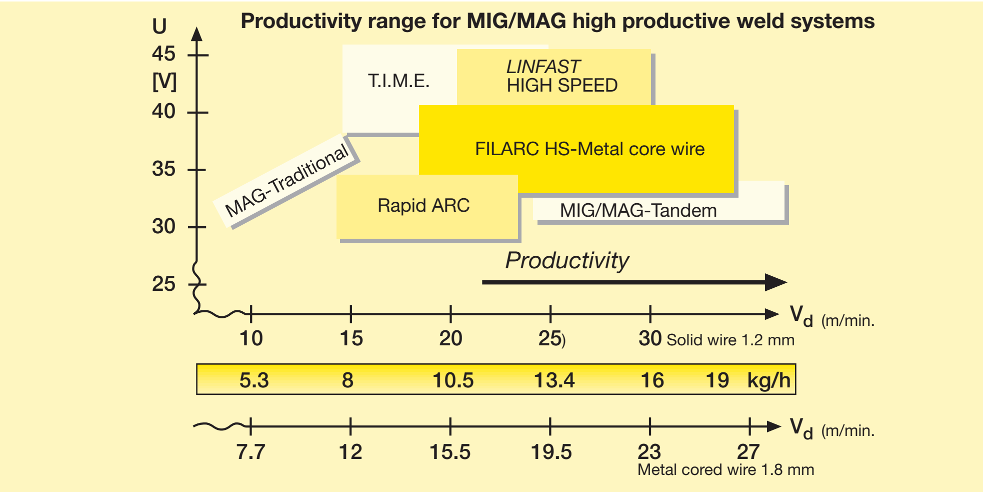

Figure 1. Comparison of different highly-productive MIG/MAG welding systems

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 Kvæerner 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

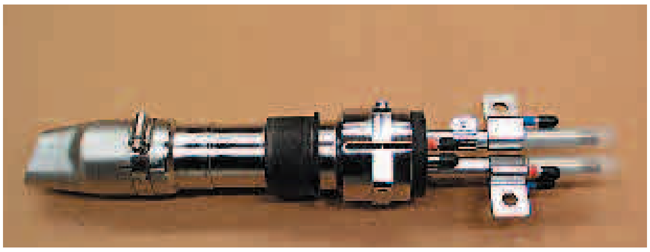

Figure 2: ESAB tandem MAG welding torch 2 x 600 A at 100% duty cycle, wire range from 0.8 to 2.0 mm

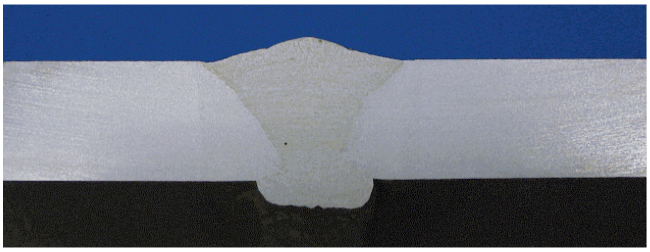

Figure 3: Butt weld will ESAB's tandem welding system with LAF635. Filler material first wire PZR6105R/1.6 and PZR6105R/1.4 second wire. Weld speed 2.5 m/min, weld parameters 550A/128V and 350A/23V. Sheet thickness 5 mm.

- 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.

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

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.

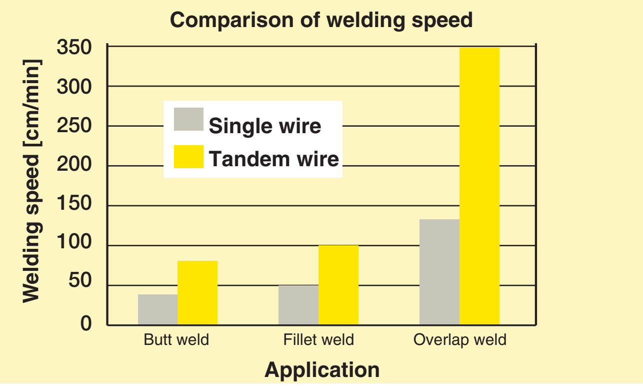

Figure 5. Comparison of the travel speeds for the single-/double-wire applications

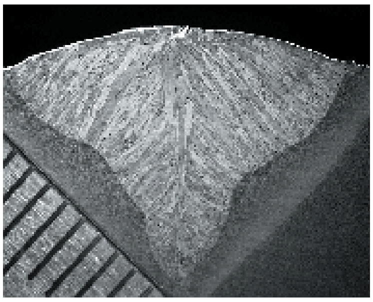

Figure 6. Butt weld with 80% penetration (12 mm plate thickness with no joint preparation). Travel speed 80 cm/min

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% CO_2 + 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% CO_2 + 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.

Arc mode settings	Power source	
	1 – master	2 – slave
Synchronised (same pulse frequency)	Pulsed	Pulsed
Non-synchronised	Pulsed	Pulsed
Mixed	Pulsed	Short arc
Mixed	Pulsed	Spray arc
Mixed	Spray arc	Short arc

Table 1

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/cm^2)

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

	SAW	SAW-TWIN		FCAW FCAW (total current)
Current/A	650	650	145–155	900–1,000
Voltage/V	32	32	22–23	24-28
Welding speed/cm/min	85	80	20	150–235
Heat input/kJ/mm	1.5	1.6	1.0–1.1	1.0–0.65
Deposition rate kg/h	5.6	9.2	2.6	20

Table 2. Results for fillet welds

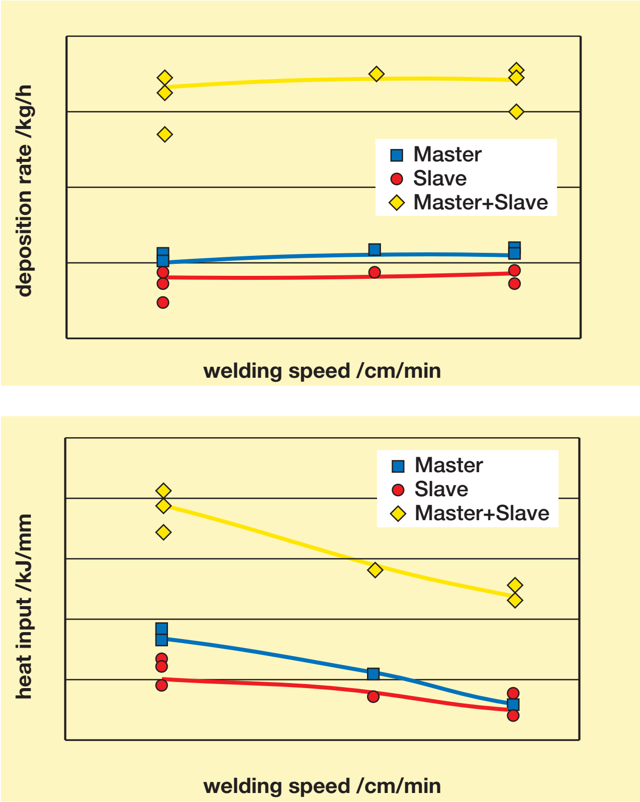

Figure 8 a and b. Deposition rate and heat input depending on the welding speed

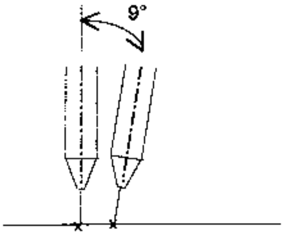

Figure 9. Asymmetrical angle of the contact nozzle

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.

References

Cerwick H.: Tandem MAG welding with the PZ 6105 R, Svetsaren, Vol. 54 No.1 2000, p. 37

Dilthey U. Prof. Dr. et al: Increased Productivity as a Result of Higher Deposition Rate and Higher Welding Speed by using Two-Wire GMAW Processes Welding Institute of Aachen University 1998

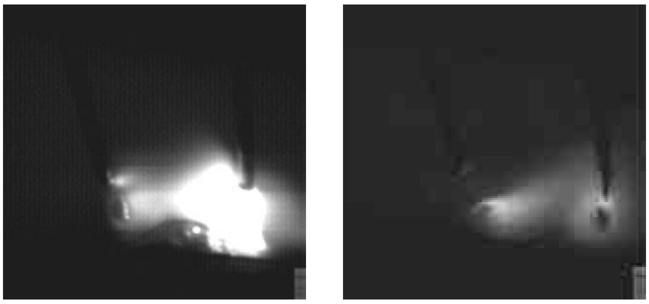

Figure 10. Droplet transfer, a) PPS = 1 ms, b) PPS = 3 ms (which is equal to anti-parallel phase shift)

Ghosh P.K. Ray B.K.: Correlations of Pulse Parameters and Bead Characteristics in Pulsed Current Flux Cored GMAW Process, Welding and Research Lab. Univ. of Roorkee India

Hackl H.: Metall-Inergasschweissen von Aluminiumwerkstoffen, Der Praktiker 1997 (Fronius)

Knoch R.-Nentwig A: Schneller MAG-Schweissen mit mehreren Drahtelektroden; Sonderdruck aus DVS Berichteband 1994; Schweisstechnische Lehr- und Versuchsanstalt München.

Lahnsteiner R.: T.I.M.E. Verfahren- das Hochleistungs-MAG Schweissen mit zwei Drahtelektroden., The T.I.M.E. Process- an innovative MAG Welding Process, Welding Review International 2:1992

Lundin M.: Tandem Wire MAG welding of C-Mn Steels, SIMR Joining Technology Centre, SIMR No IM-2000-549

Rippl P.: Zwei-Draht-Technik: Leistungssteigerung beim MIG/MAG-Schweissen. Kuka Schweissanlagen GmbH., Der Betriebsleiter 1996

Tessin F.: MAG Hochleistungsverfahren ESAB Internal Techn.Information ESAB Solingen 1997

Tusek J.: Raising arc welding productivity, Welding Review International 8:1996

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