HIGH-SPEED®-Welding, a MAG high performance process with a future

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1 Introduction

To be able to keep up with the pressure of international competition, the producers of products which are weld-intensive are forced to optimise their production processes constantly to improve productivity.

The key to achieving this is the application of technologies with a future and increasing the economy of existing production methods. ***HIGH-SPEED***®- welding is a process which combines both these methods. Modern power source technology makes it possible to stretch conventional MAG welding far beyond what were its performance limits for practical applications, thus creating an interesting high performance process.

The increase in the deposition rates and welding speeds also open up completely new fields of application for ***HIGH- SPEED***® - welding which currently have been mainly the preserve of Submerged arc welding.

2 Performance characteristics of *HIGH- SPEED*® - welding

2.1 Process principle

The high performance MAG process ***HIGH- SPEED***® makes it possible to weld wire electrodes with a speed of up to 30 m/min. The material transfer from electrode to workpiece takes place in the spraytransfer range. With this two different transfer modes are characteristic:

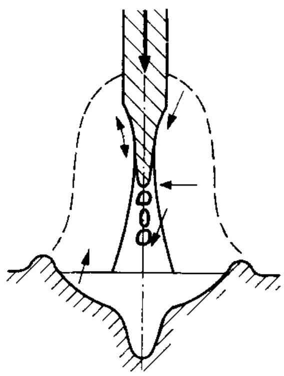

Fig. 1, Stream transfer.[1]

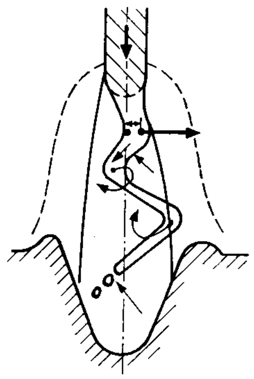

Fig. 2,. Rotary transfer [1]

The stream transfer, Fig. 1 and rotary transfer, Fig. 2.

The axial stream transfer at high current intensities is characterised by the conical electrode tip from which the plasma flow disperses in a trapezium. The high plasma pressure generates a penetration profile in the workpiece with a typical narrow, deep core and a flat, trough-shaped edge zone [1], Fig. 3.

The usual distance between contact tube and base material is about 15 - 20 mm.

Rotary transfer, by contrast, takes place with the formation of long, liquid columns on the melting electrode. As a result of very high current intensity and a large length of free wire raises the temperature at drop formation so high that the wire melts without the influence of the arc [1].

In this case the distance from the contact tube to the base material is between 25 and 35 mm. Because of the strong longitudinal magnetic field these fluid columns rotate about their axis of symmetry and spread the arc column conically [1].

The droplets are transferred radially to the base material and generate a relatively flat and wide penetration, Fig. 3.

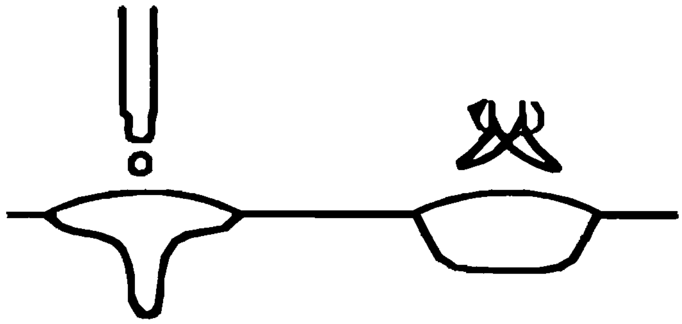

Fig. 3, Penetration profiles of the conventional spray arc (left) and rotary spray arc (right) [2].

2.2 Wire electrodes / Shielding gas combinations and Working Range

The ***HIGH- SPEED***® -welding process is intended for wire electrode diameters of 1,0 and 1,2 mm. Smaller wire diameters are less suitable because of their lower feed stability at high wire-feed rates. Larger wire diameters are excluded for rotary transfer because the high temperature necessary at the point of droplet formation to produce rotation cannot be achieved with sensible wire stickouts [1]. To ensure a stable welding process, the wire electrode should be layer wound and display a consistently good gliding performance. The wire / shielding gas combinations are made up from solid and flusecored wires and standard, two component gasses. The range of applications encompasses Mild and fine-grained steels with a yield strength of up to 500 N/mm^2.

Whilst mainly mixed gasses containing Carbon Dioxide are used in the range of conventional spray arc (Stream Transfer), rotary spray arc (Rotary Transfer) is achieved mainly under gas mixtures containing Oxygen. The reason for this lies in the characteristics of Argon- Oxygen mixtures, which generate a longer liquid column in the material transfer of the melting electrode [4] and thus favour the rotation. By comparison, the Argon- Carbon Dioxide mixtures require higher arc voltages [4] and shift the working range of spray transfer to higher current intensities.

The standard gasses of 82% Ar + 18% CO_2 and 92%Ar + 8% CO_2 extend the stability range of the conventional spray arc [3] with solid wires of 1,0 mm diameter up to wire feed rates of about 24 m/min, and with 1,2 mm diameter up to about 23 m/min wire feed speed.

Rutile cored wires and basic cored wires with 1,2 mm can be welded with up to 30 m/min wire feed speed by contrast without any transition to rotary spray arc transfer [5].

A standard gas mixture of 96% Ar + 4% O_2 is used to utilise the working range of rotary transfer. The use of this shielding gas reduces the transition zone between conventional and rotary spray arc [3] and stabilises the latter with wire feed speeds from about 23 m/min, Fig. 4.

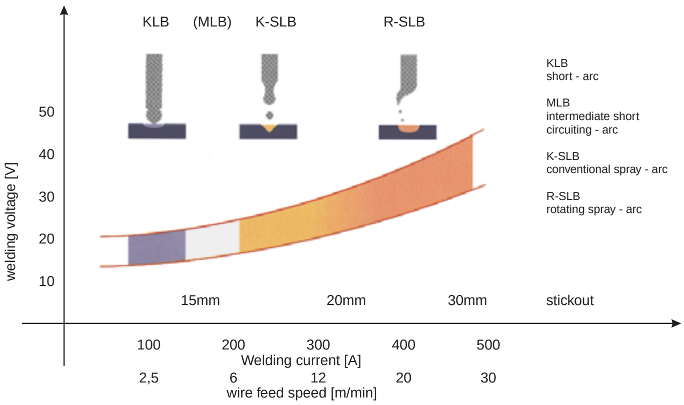

Fig. 4, Types of arc and their power ranges. [2]

Wire feed rates of up to 30 m/min are achieved with both 1,0 mm and 1,2 mm solid wires.

2.3 Requirements for the Power Source and the Equipment

The *integral inverter* ***MIG 500 HIGH- SPEED***® power source, Fig. 5, is designed as an inverter power source for MAG high performance welding with 500A/60% duty cycle (400A/100% duty cycle).

Further, MIG/MAG standard and pulse welding, TIG DC welding and Manual Metal Arc welding modes are also available. This combination of welding processes is made possible by an inverter power module. The advantages of the inverter are the comparatively small unit size, the high degree of efficiency, the insensitivity to mains power fluctuations and thus the high level of reproducibility of the welding parameters [6]. The power source control takes place on the one-knob principle (Synergic). The electrical power and the wire feed speed are adjusted steplessly with one knob along a programmed characteristic. The arc length can also be corrected. The system comprising inverter and control gives the arc the capacity to react very fast to various influences in order to keep the power parameters constant independently of the cable lengths in the welding power circuit [6].

The "***PROGRESS 4***" control panel, Fig. 6, ensures simple operation of the power source.

Fig.5, Welding power source *integral inverter* ***MIG 500 HIGH- SPEED***®.

It gives the user the possibility of establishing and storing welding programmes. Different operating points can be called with the torch trigger which firstly give a safe start with reduced power (P1) to prevent starting faults, and secondly permit a defined slope down of the welding power at the end of the weld seam to fill the end crater (P4),Fig. 7.

What is more, the user can activate a lower power setting at any time during welding by pressing the torch trigger which makes it possible to weld around corners in the job, for example (P3).

The wire feed unit is an important component. The tacho-controlled 4 roller wire feed with high starting torsion and pull through capacity guarantees stabile wire feed speeds up to 30 m/min.

The welding torch used must also be able to withstand the high thermal loading. Its design and construction requires water cooling not only of the contact tube but also of the shielding gas nozzle.

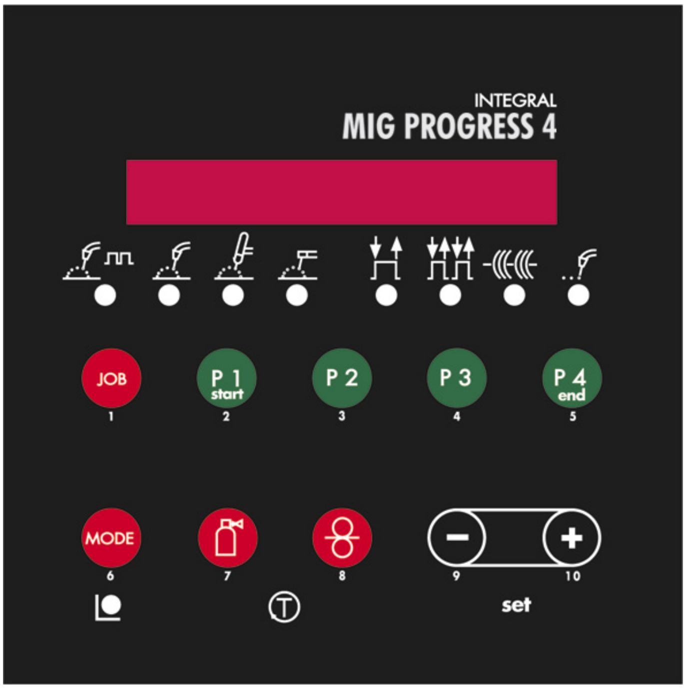

Fig. 6, User Interface ***„PROGRESS 4"***.

A contact tube stand-off ensures adequate shielding gas cover for the weld seam even with large wire stickout.

For manual applications wire feed speeds of up to about 23 m/min in the conventional spray arc range are achieved. Above this full mechanisation or automation is advisable. The power source is able to serve both variations.

What is more, it is possible to undertake a weld data documentation at any time using the serially connected monitoring and data gathering software Q-DOC 9000, Fig 8.

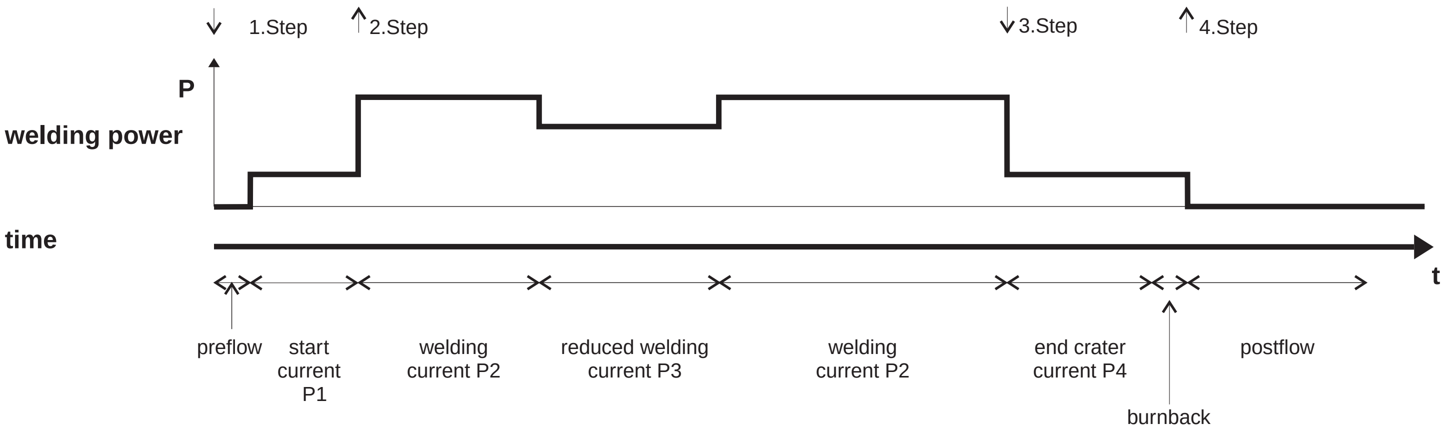

Fig. 7, Program run of the User Interface ***„PROGRESS 4"*** of ***HIGH-SPEED®***.

3 Technical Welding Tests- Research Report of the Technical Welding Training and Research Institution Mecklenburg- Vorpommern (SLV)

3.1 Testing Method

To extend the practical applications, particularly of the rotary spray transfer, the SLV in Rostock carried out a wide range of welding tests under an order from EWM High- Tech Precision Schweißtechnik GmbH on the subject: "Testing the influence of various shielding gases when changing the welding parameters for MAG high performance welding with rotary spray arc" [7].

The aim was to establish the optimum welding parameters and peripheral conditions for practical welding. The starting point was the good characteristics of the rotary spray arc, the under-cut free transitions from base metal to the weld seam and the high melting rate in gravity position (PA).Particular attention was paid to the welding gases as their costs play a decisive role in economical practice [8]. With this in mind, it seemed logical to compare standard two component gases with a three and four component gas (T.I.M.E-Gas).

Keeping the basic settings:

- **Welding power source:** *integral inverter* ***MIG 500 HIGH- SPEED®*** from EWM High- Tech Precision Schweißtechnik GmbH
- **Base metal:** St 37,t = 20 mm, St 52-3, t = 12 mm
- **Filler material:** G3Si1 (Union K 52 T), ∅ 1,0 mm and 1,2 mm
- **Torch approach angle:** 10^0 lancing
- **Welding position:** gravity position (PA)
- **Welding speed:** 0,5 m/min

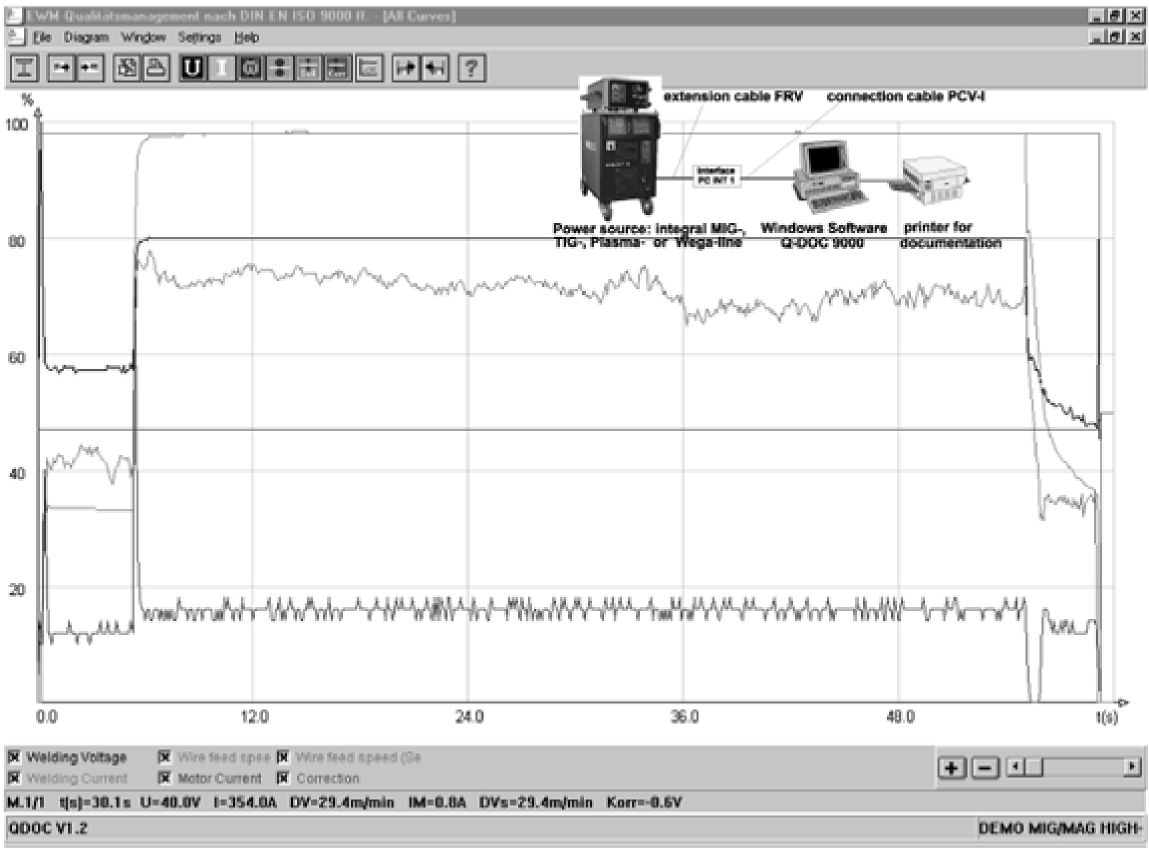

Fig. 8, Graphical representation of the welding parameters with ***HIGH- SPEED®*** welding.

The following shielding gases:

- **T.I.M.E.- Gas**
  (65% Ar + 26,5% He + 8% CO_2 + 0,5 O_2)
- **Two component gas**
  (96% Ar + 4% O_2)
- **Two component gas**
  (92% Ar + 8% CO_2)
- **Three component gas**
  (72% Ar + 20% He + 8% CO_2)

were tested.

A fillet weld was welded in the PA position (gravity position) with mechanised torch guidance. To investigate the large number of test parameters systematically without raising the number of tests to unnecessary heights a factor plan was used.
The first test series had the factor type 2^4.
The welding parameters varied as follows:

Wire diameter	1,0 mm
U_s	28V / 42V
V_{Dr}	23m/min / 27m/min
Contact tube distance	28 mm / 32 mm
Shielding gas quantity	22 l/min / 28 l/min T.I.M.E.- Gas

and

Wire diameter	1,2 mm
U_s	44V / 48V
V_{Dr}	26m/min / 30m/min
Contact tube distance	29 mm / 33 mm
Shielding gas quantity	22 l/min / 28 l/min T.I.M.E.- Gas

The influence of the shielding gas quantity was seen in the form of arc wandering. This could be minimised at high flow-rates. As increasing the shielding gas flow rate above 25 l/min brought no further recognisable improvement, that value was adopted for all tests. This reduced the further test sequence to a 2^3 - factor plan.

The following variations in the welding parameters:

- **Voltage**
- **Wire feed speed**
- **Contact tube distance**

were applied to each wire diameter and each shielding gas.
The visual evaluation criteria for the welding tests were the rotation of the arc, the process stability and the external weld appearance (smooth weld-seam surface, no under-cut, flat seam).
The maximum welding speed which could be achieved was evaluated on this basis (in 0,1 m/min steps).
Recording of the welding parameters took place with the assistance of the EWM documentation software Q- DOC 9000.
Macrosections were mainly used for the evaluation of the internal weld quality.
Additional hardness tests to the Vickers method over the weld seam (DIN 1043-1) for the samples considered best completed the MAG high performance welding evaluation [7].

3.2 Test Evaluation

The welding technical results of these tests clarified the influence of various shielding gases on the MAG high performance process. In this the two component gas of 96% Ar + 4 % O_2 was found to be the optimum shielding gas. Very good welding results can already be achieved with relatively low voltage value for rotary spray arc.
The arc rotation was clearly the best in a comparison of the four gases.

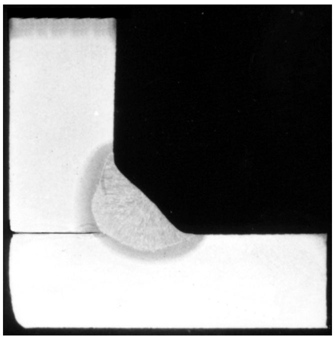

Fig. 9,
Etched section through a fillet weld, specimen 406, chap. 3.2.1,.

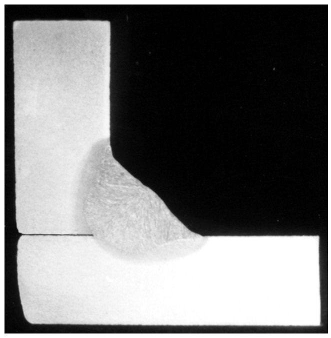

Fig. 10,
Etched section through a fillet weld, specimen 302, chap. 3.2.1.

Welding speeds of up to 0,5 m/min were achieved without undercut or arc wander occurring Figs. 9 and 10.

When welding with T.I.M.E.- Gas the rotary spray arc only came with high voltage values. The dependence upon the contact tube distance was the least here.. Welding speeds of up to 0,7 m/min were achieved.

The three component gas (72% Ar + 20% He + 8% CO_2) also only achieved a rotary spray arc with 1,0 mm wire diameter with high values for the voltage.
The 1,2 mm wire diameter gave good high performance weld results, of only in the conventional spray arc range. The welding speed achieved was 0,7 m/min.

The 92% Ar + 8% CO_2 two component gas proved to be only conditionally suitable for welding wire of 1,0 mm diameter with a rotary spray arc, as a stable welding process was only possible in a small process window. With 1,2 mm wire the rotating spray arc could only be achieved with absolutely optimum welding parameters. The welding speed was 0,6 m/min. Good results were especially achieved in the conventional spray arc range.

An area was seen for the contact tube distance which ensured reliable arc rotation. This condition was fulfilled with 25 mm or more stickout.
It was noted, especially with the two component gases, that a larger contact tube distance is needed with increasing wire feed speed to achieve a stable welding process with a rotary spray arc.

Weld porosity only occurred with the tests with T.I.M.E.- Gas and with three component gases which contained Helium. A dependency upon particular parameters, such as the contact tube distance or voltage, could not be seen.

To sum up it is to be noted that the 96%Ar + 4%O_2 two component gas is judged to be the best of the shielding gases tested here for MAG high performance welding with rotary spray arc. Both the weld process stability and its insensitivity to parameter fluctuations make the use of this gas interesting bearing in mind the availability of the gases and their costs [7].

3.2.1 Welding Parameters Investigated

The welding parameters in Table 1 gave the highest possible welding speeds with optimum weld seam formation for the wire/ shielding gas combination concerned [7].

3.2.2 Hardness Tests

The selected weld samples, Table 1, were subjected to hardness tests, Fig. 11.

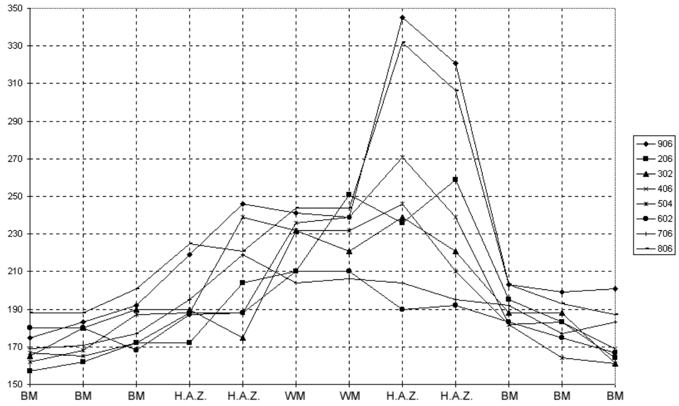

Fig.12, test result hardness course to Vickers (HV5)

The heat affected zone (H.A.Z.) and the weld metal (WM) are of decisive significance in determining the characteristics of the weld joint.

A hardness of 350 HV is a critical value for many accreditation bodies. This hardness occurs particularly with abrupt cooling conditions.

The very high values for both current and voltage combined with the comparatively low welding speeds in this process brings a great deal of heat into the component, so that no high hardness values can occur.

	Gas	Wire Ø [mm]	U_s [V]	I_s [A]	WFS [m/min]	Gas flow [l/min]	Contact tube distance [mm]	Sample	Welding speed [m/min]
1.	T.I.M.E: 65%Ar + 8%CO_2 + 0,5%O_2 + 26,5%He	1,0	42	326	23	25	28	906	0,6
2.	T.I.M.E: 65%Ar + 8%CO_2 + 0,5%O_2 + 26,5%He	1,2	48	500	26	25	29	206	0,7
3.	96%Ar + 4%O_2	1,0	42	385	23	25	28	406	0,4
4.	96%Ar + 4%O_2	1,2	48	500	26	25	33	302	0,5
5.	92%Ar + 8%CO_2	1,0	42	342	27	25	32	504	0,4
6.	92%Ar + 8%CO_2	1,2	48	486	26	25	33	602	0,6
7.	72%Ar + 8%CO_2 + 20%He	1,0	42	334	23	25	28	806	0,5
8.	72%Ar + 8%CO_2 + 20%He	1,2	48	500	26	25	29	706	0,7

Table 1. Welding Parameters for the Test Welds.

The material hardness was tested with the aim of finding the area of greatest hardness and to draw conclusions about the predicted material behaviour from the hardness value [9].

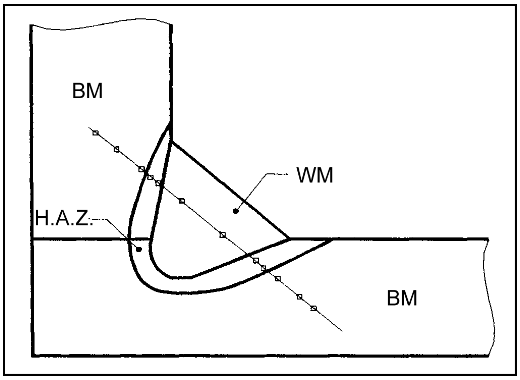

Fig. 11,position hardness indents

All hardness values measured were well below the critical value of 350 HV, Fig. 12, [7].

3.2.3 Structural composition and mechanical properties

Macro- and microsections of the weld metal and Heat Affected Zone were prepared for the complex analysis of the weld seam structure.

For this purpose welds on St 52-3 and on a TM- Steel with reduced Carbon content, L36TM (t=12mm), were prepared. The chemical composition of the material is shown in Table 2.

The welding parameters for samples 406 and 302 were used. They represented the combination of parameters with which an optimum welding process could be ensured in the tests.

	C	Si	Mn	P	S	Cr	Ni	Mo	V
ST 52-3	0,140	0,440	1,410	0,011	0,015	0,052	0,001	0,020	0,003
L36TM	0,090	0,430	1,400	0,011	0,0007	0,023	0,026	0,005	0,001

Table 2. Chemical Composition of the base materials

The appearance of the microstructure of the St 52-3 H.A.Z. and a calculation of the cooling time ($t_{8/5}$) with the WELDWARE consulting system showed a good agreement.

With the welding samples tested a maximum hardness of 178 HV5 was measured in the H.A.Z.. The deviation below the calculated hardness values can be explained in the fact that the weld samples were under-dimensioned so that the rapid heat conduction into the solid workpiece did not occur because of the high heat input.

List of mechanical properties

ta (s)	HV (HV30)	Rp0.2 (MPa)	Rm (MPa)	A (%)	Z (%)
4.0	328	687	904	13.0	44.9
5.0	315	659	873	14.1	46.4
6.0	305	636	849	14.9	47.6
7.0	296	617	828	15.6	48.6
8.0	289	602	811	16.2	49.5
9.0	283	588	796	16.7	50.2
10.0	278	576	783	17.1	50.9
11.0	273	566	771	17.5	51.4
12.0	269	557	760	17.9	51.9
13.0	265	548	751	18.2	52.4
14.0	262	541	742	18.5	52.8
15.0	258	534	734	18.7	53.2
16.0	256	527	727	19.0	53.6
17.0	253	522	721	19.2	53.9

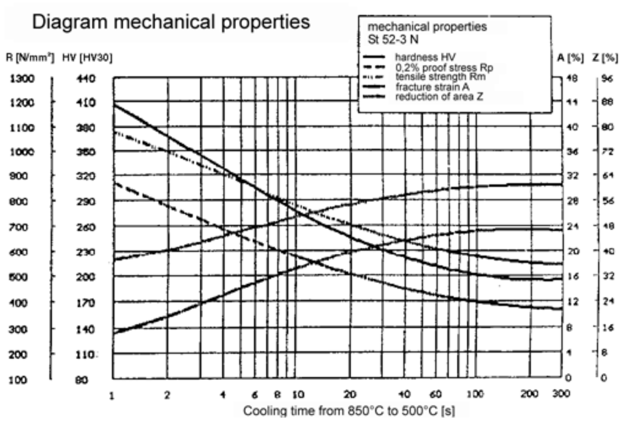

Fig. 13, Mechanical properties of ST 52-3 as a function of cooling time $t_{8/5}$

The hardness values measured converged with those calculated with WELDWARE. The value for the welded samples was about 270 HV5, WELDWARE calculated a value for a cooling time above 10 s of less than 278 HV. A cooling time range ($t_{8/5}$) of about 10-20 s gives expected mechanical values which achieve a good toughness with adequate strength, Fig. 13.

Cooling times over 10 s were given with these welding parameters with a welding speed of about 0,4 m/min.

The thermo-mechanically treated steel L36TM gives a hardness of below 251 HV for the cooling time of over 10 s calculated by WELDWARE on the basis of the welding parameters. This value is valid for 3-dimensional heat conduction, i.e. for the critical case of welding solid components.

Evaluation of the microsections showed not Martinsitic proportion, evidence that the cooling time had to have been over 12 s. That allows the mechanical properties show in Fig. 14 to be predicted.

It demonstrates that the ***HIGH- SPEED***® welding of thermo-mechanically treated steels, characterised by a low Carbon content, can be carried out without any problems [7].

List of mechanical properties

ta (s)	HV (HV30)	Rp0.2 (MPa)	Rm (MPa)	A (%)	Z (%)
4.0	302	700	850	12.8	49.5
5.0	289	666	815	14.1	51.3
6.0	278	639	786	15.0	52.6
7.0	270	617	763	15.8	53.8
8.0	263	598	744	16.5	54.8
9.0	256	582	727	17.0	55.6
10.0	251	569	713	17.5	56.3
11.0	246	557	701	18.0	57.0
12.0	242	546	689	18.3	57.5
13.0	238	537	679	18.7	58.0
14.0	235	528	670	19.0	58.5
15.0	232	521	662	19.3	58.9
16.0	229	514	655	19.5	59.3
17.0	227	507	648	19.7	59.6

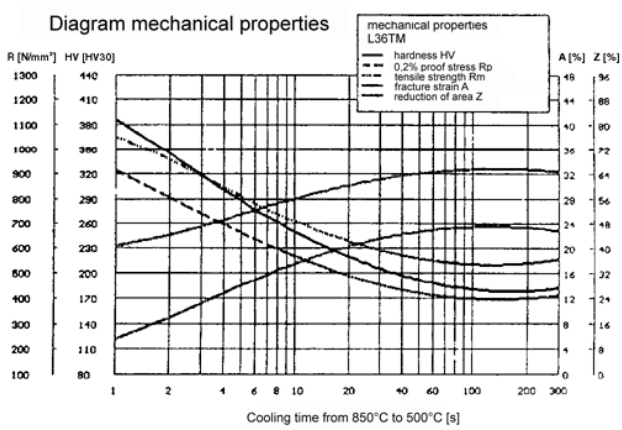

Fig. 14, Mechanical properties of L36TM as a function of cooling time $t_{8/5}$

4 Practical experience and Prospects

The area of application for the MAG high performance welding process ***HIGH- SPEED***® is determined automatically by the higher welding speed with conventional spray arc welding with small and medium material thicknesses.
The rotary spray arc finds its main application with medium to high material thicknesses.
The high deposition rate can be applied primarily in the gravity position. The flat seam shape and the reliable side wall fusion qualify this process for use with components subjected to dynamic loading.
Thus the MAG high performance welding represents a true alternative to submerged-arc welding. Wherever no submerged arc unit is available or where the space needed for it cannot be made available because of design constraints, the use of this process merits consideration.
Further, the *integral inverter* ***MIG 500 HIGH- SPEED***® power source is more flexible than a submerged arc welding unit because of its smaller size and its additional programmes for manual welding. A practical example from a steel-working factory will demonstrate this.
There 20 mm thick flat bars are welded onto a box section with 10 mm wall thickness. The material is St 52-3; the weld preparation for the longitudinal seam is a V.
In the past this welding application was solved by fully automatic MAG welding. The purchase of a submerged arc power source was intended to improve the economy of this process as a single run would replace the three previously needed.
As this product does not need to be made all the time, the investment calculation must, of course, take the machine utilisation and the complete range of parts to be welded in the works into account. The ***HIGH- SPEED***®- machine has a clear advantage.

	Old	New	Saving
Number of passes	**3**	**1**	**2**
Wire feed speed	**10 m/min**	**26 m/min**	
Welding-speed	**0,46 m/min**	**0,40 m/min**	
Total welding time	**6,5 min**	**2,5 min**	**4 min**
Average gas use	**15 l/min**	**25 l/min**	
Total gas use	**97,5 l**	**62,5 l**	**35 l**
	Old	**New**	**increase**
Deposit rate	**5,3 kg/h**	**13,7 kg/h**	**8,4 kg/h**

Table 3. Comparison of MAG and ***HIGH- SPEED***®- welding based on 1m of weld seam, wire diameter: 1,2mm.

Table 3 shows a comparison of the “old“ and “new“ welding processes based on 1 m of weld seam.
In this case 1,2 mm wire electrode of SG2 quality was welded under a shielding gas mixture of 96% Ar + 4%O_2 with a wire-feed speed of 26 m/min with a rotary spray arc.
The saving of shielding gas and working time through the increased deposition rate is the basis for the economical application of MAG high performance welding.

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