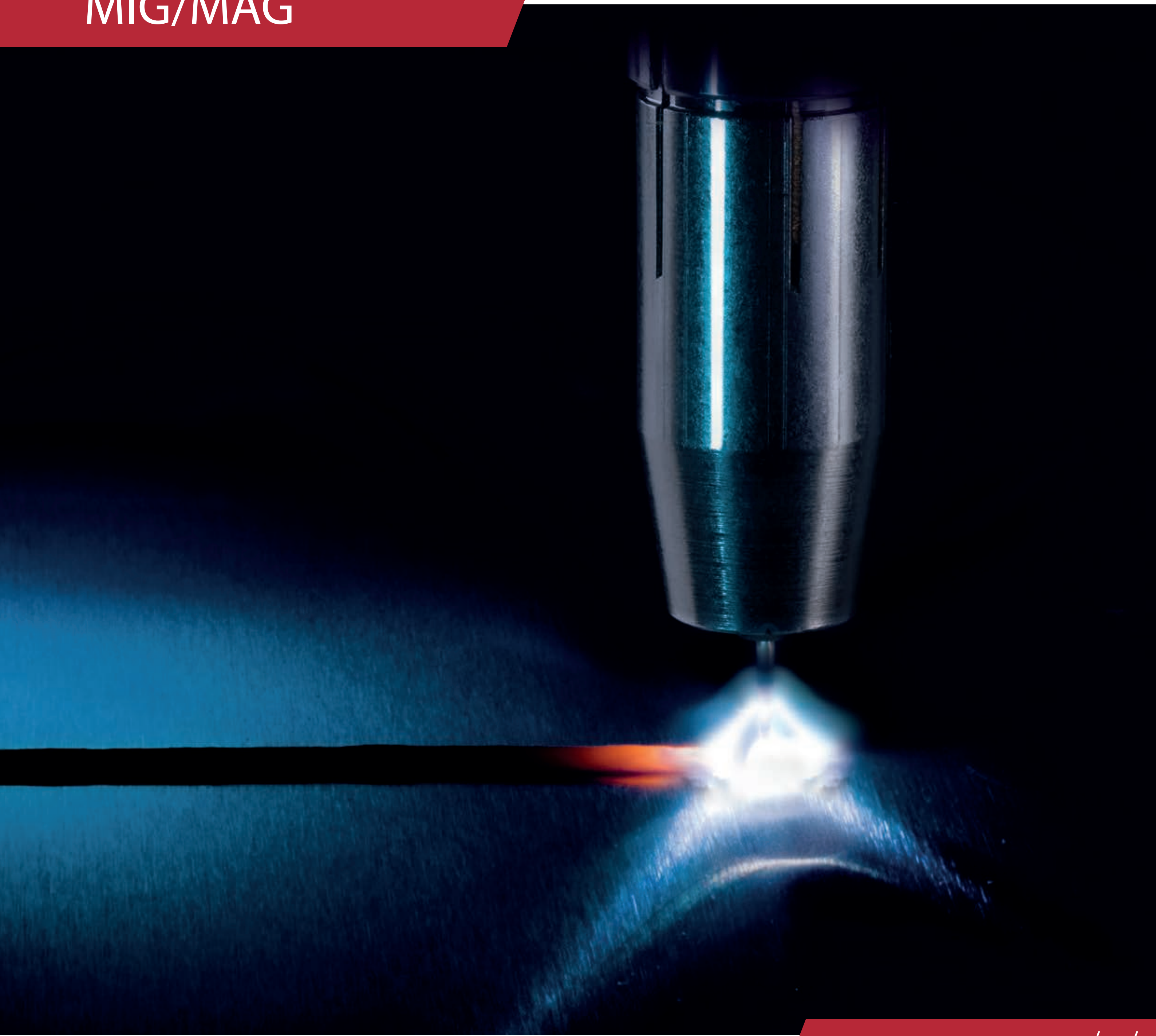
WE ARE WELDING

Welding Dictionary

MIG/MAG



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1. Foreword

MIG/MAG welding (Figure 1) is one of the more recent arc welding procedures. It originated in the USA, where it was first used in 1948. It arrived in Europe shortly afterwards. MIG/MAG welding initially used inert gases such as helium and argon, which only contained small amounts of active constituents (e.g. oxygen). The procedure was therefore shortened to S.I.G.M.A. welding (Shielded Inert Gas Metal Arc). In Russia, from 1953 on, with carbon dioxide (CO_2) an active gas was used for welding instead of expensive, inert gases. This was possible because high-alloy wire electrodes were now also available. They compensate for the greater burn-off during the hotter active gas welding and ensure material quality.

MIG/MAG welding is very popular today in almost all metal processing branches, from the trades to large industrial operations. It is already partially mechanised and can also be used fully mechanised or automated with little effort. This brochure explains the specific characteristics of the procedure and provides information on its appropriate application.

2. The procedure

2.1 General information

As defined in EN 14610, in Europe the valid generic term for all arc welding procedures where a wire electrode is melted using shielding gas is “gas-shielded metal-arc welding” (process no. 13). The generic term formerly used in Germany was metal gas shielded arc welding. The standard explains the procedure as follows: “An arc burns between the workpiece and the melting wire electrode”. Depending on the type of shielding gas used, it is further subdivided into metal inert gas welding (MIG), process no. 131, if inert gases (e.g. argon, helium) are used, and metal active gas welding (MAG), process no. 135, if active gases (mixed gases, e.g. argon mixed with CO_2 or O_2) are used.

Figure 1: Manual MIG/MAG welding

Additional variants in EN 14610 are flux cored wire welding with an active gas constituent (process no. 136) and flux cored wire welding with inert gas (process no. 137).

In MIG/MAG welding (Figure 2), a wire electrode (5) is fed from the spool by a wire feed motor and electrically contacted and

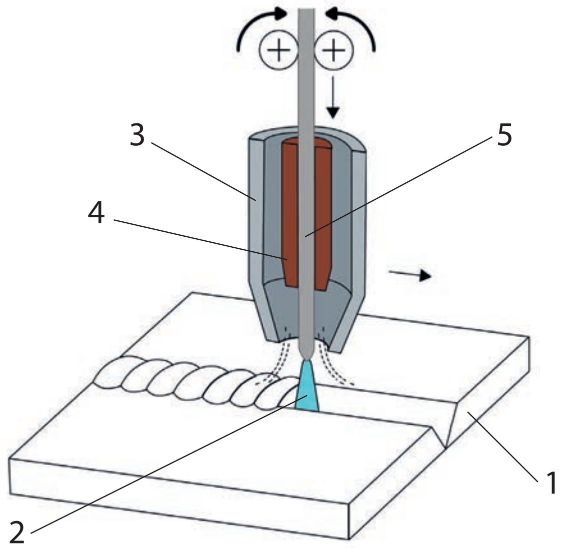


Figure 2: Metal gas shielded arc welding (MIG/MAG) principle

fed through the contact tip (4) immediately before it exits the welding torch. The arc (2) can thus burn between the wire electrode end and the workpiece (1). The shielding gas flows from the shielding gas nozzle (3), which concentrically encloses the wire electrode. The arc and the weld metal are thus protected from the atmospheric gases oxygen, hydrogen and nitrogen. In addition to its protective function, the shielding gas has other purposes. It determines the composition of the arc atmosphere, affects its electrical conductivity and therefore the welding characteristics. In addition, the shielding gas affects the chemical analysis of the resulting weld metal through the pick-up and burn-off processes. Therefore, it also has a metallurgical effect.

2.2 Current type

MIG/MAG welding is carried out using direct current, sometimes in a pulsed form, with some more recent exceptions. Here, the positive pole of the power source is on the electrode (wire tip) and the negative pole on the workpiece. A few flux cored wires (e.g. self-shielded flux cored wires) are welded with reverse polarity. More recently, alternating current with special characteristics is also used for very special applications, e.g. for MIG welding on very thin aluminium sheets.

3. Filler metals and auxiliary materials

3.1 Wire electrode types

Wire electrodes for MIG/MAG welding of unalloyed steels and fine-grained steels are standardised in EN 14341. The standard classifies eleven types of welding wires according to their chemical analysis. It also contains types of welding wire that are only common in other European countries. Of the compilation given in Table 1 for unalloyed steels, G2Si1, G3Si1 and G4Si1 grades are primarily used in Germany. They contain increasing quantities of silicon (Si) and manganese (Mn) in the order given. The respective average percentages are 0.65 to 0.9% silicon and 1.10 to 1.75% manganese. For fine-grained steels, grades G4Mo, G3Ni1 and G3Ni2 are also used (Figure 3).

EN 17632 contains flux cored wire electrodes for welding these steels. Depending on the composition of the filler, rutile types, basic types and metal powder types are differentiated (Figure 4). In addition to flux cored wires for MIG/MAG welding, EN 17632 also standardises self-shielded flux cored wires, which are welded without any additional shielding gas. Wire electrodes for welding creep-resistant steels

Table 1: Example wire electrode

EN 14341

Wire electrode — **G 46 2 M G4 Si 1**

- Table 1a — 46
- Table 1b — 2
- Table 1c — M
- Table 1d — G4 Si 1

Table 1a

ID for strength and elongation properties of the weld metal			
ID	**Minimum yield strength[1] (N/mm²)**	**Tensile strength (N/mm²)**	**Minimum elongation at break [2] %**
35	355	440–570	22
38	380	470–600	20
42	420	500–640	20
46	460	530–680	20
50	500	580–720	18

[1] The lower yield strength (R_{eL}) applies. If the yield strength is not clear, 0.2% ($R_{p0.2}$) should be used.
[2] Measuring length is equal to five times the sample diameter.

Table 1b

Code for impact energy	
Code	**Temperature for minimum impact energy 47 J (°C)**
Z	No requirement
A	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

Table 1c

Code for shielding gas	
Code	**Meaning**
M	If the classification has been carried out with the shielding gas EN 439-M2, mixed gas without helium.
C	If the classification has been carried out with the shielding gas EN 439-C1, carbon dioxide.

Table 1d

Code for the chemical analysis of wire electrodes									
Code	**Chemical analysis in % (m/min) [1], [2], [3]**								
	C	**Si**	**Mn**	**P**	**S**	**Ni**	**Mo**	**Al**	**Ti and Zr**
G0	Any additional agreed composition								
G2Si1	0.06–0.14	0.5–0.8	0.9–1.3	0.025	0.025	0.15	0.15	0.02	0.15
G3Si1	0.06–0.14	0.7–1.0	1.3–1.6	0.025	0.025	0.15	0.15	0.02	0.15
G4Si1	0.06–0.14	0.8–1.2	1.6–1.9	0.025	0.025	0.15	0.15	0.02	0.15
G3Si2	0.06–0.14	1.0–1.3	1.3–1.6	0.025	0.025	0.15	0.15	0.02	0.15
G2Ti	0.04–0.14	0.4–0.8	0.9–1.4	0.025	0.025	0.15	0.15	0.05–0.2	0.05–0.25
G3Ni1	0.06–0.14	0.5–0.9	1.0–1.6	0.02	0.02	0.8–1.5	0.15	0.02	0.15
G2Ni2	0.06–0.14	0.4–0.8	0.8–1.4	0.02	0.02	2.1–2.7	0.15	0.02	0.15
G2Mo	0.08–0.12	0.3–0.7	0.9–1.3	0.02	0.02	0.15	0.4–0.6	0.02	0.15
G4Mo	0.06–0.14	0.5–0.8	1.7–2.1	0.025	0.025	0.15	0.4–0.6	0.02	0.15
GG2Al	0.08–0.14	0.3–0.5	0.9–1.3	0.025	0.025	0.15	0.15	0.35–0.75	0.15

[1] If not specified: Cr ≤ 0.15, CU ≤ 0.35 and V ≤ 0.03. The percentage of copper in the steel plus coating may not exceed 0.35%.
[2] Individual values in the table are maximum values.
[3] The results must be rounded to the same decimal place as the specified values given in ISO 31-0, Appendix B, Rule A.

Figure 3: MAG welding in rail vehicle construction

are standardised in EN 21952; flux cored wire electrodes for these steels are standardised in EN 17634. The wire electrodes range from the molybdenum alloy version to wires with 1%, 2,5%, 5% and 9% chromium and the wire electrode with 12% chromium. Additional alloying elements are vanadium and tungsten. Flux cored wire electrodes are available with a chromium constituent up to 5%.

Wire electrodes for welding stainless and heat-resistant steels are standardised in EN 14343; flux cored wire electrodes for these steels are standardised in EN 17633. The standards classify additives for martensitic/ferritic chromium steels, austenitic steels, ferritic/austenitic steels and fully austenitic high corrosion-resistant steels as well as special and heat-resistant types.

A corresponding European standard is available for wire electrodes for welding aluminium and aluminium alloys: EN ISO 18273.

3.2 Technical delivery conditions for wire electrodes and flux cored wire electrodes

Wires, rods and wire electrodes for gas shielded arc welding are produced by cold drawing, flux cored wire electrodes also by cold rolling or folding in certain manufacturing processes.

Standardised diameters and permissible limit sizes for wire electrodes and flux cored wire electrodes can be found in EN 544. The diameters range from 0.6 mm to 4.0 mm. The most common diameters of solid wires for MIG/MAG welding are 0.8 mm, 1.0 mm, 1.2 mm and 1.6 mm. The flux cored wires usually start at a diameter of 1.0 mm. However, they are also used in greater diameters such as 2.4 mm or 3.2 mm.

Unalloyed and low-alloy wire electrodes are generally used with a copper-plated surface. The copper plating

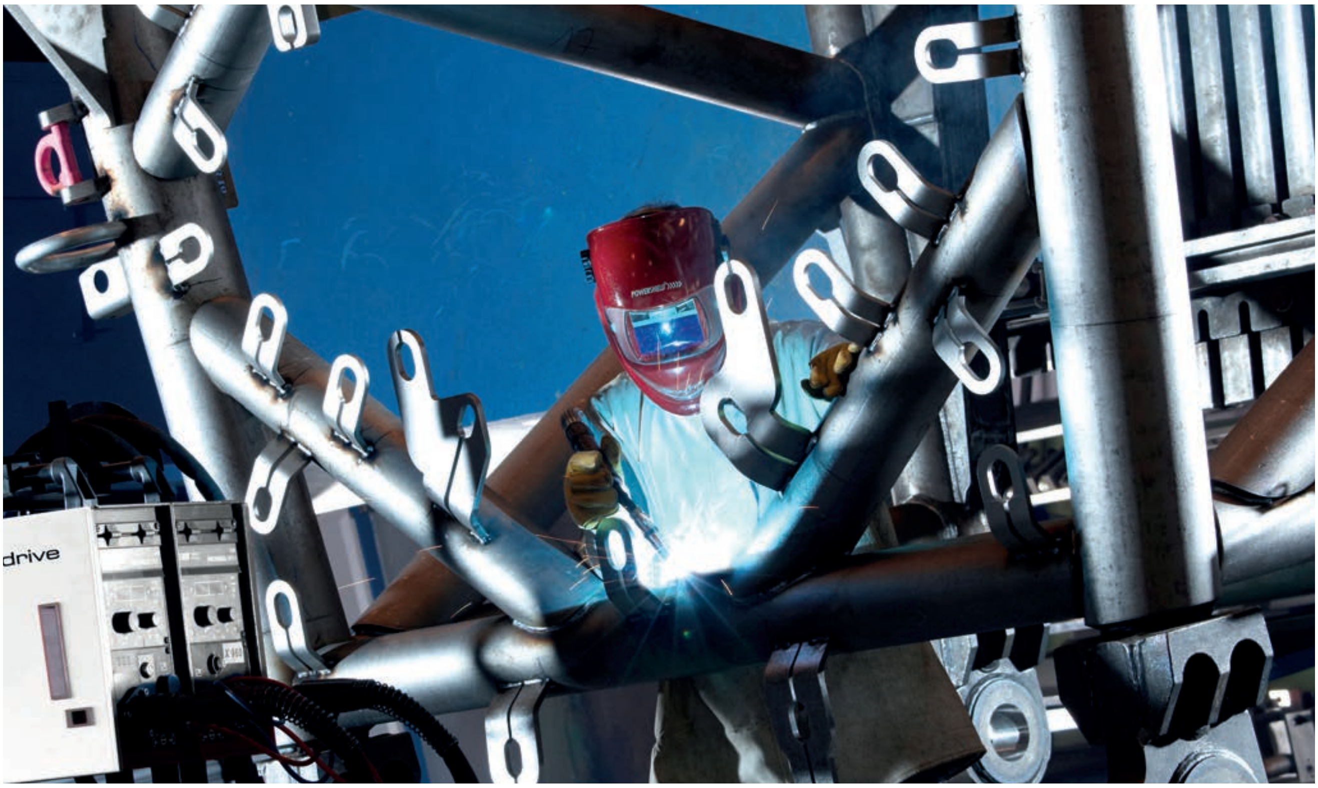


Figure 4: Gas-shielded metal-arc welding of high-tensile steels in crane construction using flux cored wires

serves to protect against corrosion, reduces sliding resistance during feeding and improves the current contact. Flux cored wire electrodes can only be copper-plated if they have a closed coating without an air gap. High-alloy wires cannot be copper-plated galvanically or in the pool. They are supplied with a bare white surface. Aluminium welding wires with a bare surface are also used. Because drawing agents can be pressed into the soft surface of the aluminium, which can subsequently lead to pore formation during welding, shaving is performed on quality wires before finishing.

Wire-type welding consumables for gas shielded arc welding are supplied on plastic, mandrel or wire spools. Large packing drums such as drums are also available.

Further information: EWM welding consumables manual

3.3 Shielding gases

Shielding gases for MIG/MAG welding can be found in EN 14175. All shielding gases for arc welding and cutting are standardised in this standard. The shielding gases are divided into seven groups and additional subgroups (Table 2).

Group R contains argon-hydrogen mixtures which have a reducing effect. In addition to argon and helium, the gases in Group R1 are used in TIG and plasma welding, while gases in subgroup 2, which have a higher hydrogen content (H) are used in plasma cutting and backing (purging gases).

The inert gases are collected in Group I, including argon (Ar) and helium (He) as well as argon/helium mixtures. They are used in TIG, MIG and plasma welding as well as for backing.

The large M group, which is further subdivided into M1, M2 and M3, combines mixed gases for MAG welding. Here, too, there are three or four subgroups in each group. The gases are ordered from M11 to M33 according to their oxidation behaviour. M11 is slightly oxidising, M33 is the most strongly oxidising. The main constituent of these gases is argon. Oxygen (O_2) or carbon dioxide (CO_2), or oxygen and

Table 2: Classification of shielding gases for arc welding and cutting (EN 14175)

Short designation [1]		Components in volume percent						Common application	Remarks
Group	ID number	Oxidising		Inert		Reducing	Inert		
		CO_2	O_2	Ar	He	H_2	N_2		
R	1			Rest [2]		> 0 to 15		TIG, plasma welding, plasma cutting, backing	
	2					> 15 to 35			
I	1			100				MIG, TIG, plasma welding, backing	Inert
	2				100				
	3			Rest	> 0 to 95				
M1	1	> 0 to 5		Rest [2]		> 0 to 5		MAG	Slightly oxidising
	2								
	3		> 0 to 3						
	4	> 0 to 5							
M2	1	> 5 to 25							
	2		> 3 to 10						
	3	> 0 to 5							
	4	> 5 to 25	> 0 to 8						
M3	1	> 25 to 50							
	2		> 10 to 15						
	3	> 5 to 50	> 8 to 15						
C	1	100							Strongly oxidising
	2	Rest	> 0 to 30						
F	1						100	Plasma cutting, backing	Inert
	2					> 0 to 50	Rest		Reducing

[1] If components are added which are not listed in the table, the mixed gas is designated as a special gas and by the letter S.
[2] Argon can be substituted up to 95% by helium.

carbon dioxide (three-component gases), are mixed as active components.

In the range of gases used for MAG welding, Group C includes pure carbon dioxide and a carbon dioxide/oxygen mixture. However, the latter is not important in Germany. The gases in Group C are the most strongly oxidising because the CO_2 decomposes at the high temperature of the arc. Here, large quantities of oxygen are produced in addition to carbon monoxide.

Table 3: Designation example for a wire/shielding gas combination compliant with EN 440

ID for strength and elongation properties of the weld metal			
ID	Minimum yield strength N/mm²	Tensile strength N/mm²	Minimum elongation at break %
35	355	440–570	22
38	380	470–600	20
42	420	500–640	20
46	460	530–680	20
50	500	560–720	18

ID for the impact energy of the weld metal	
ID	Temperature for minimum impact energy 47 J (°C)
Z	No requirements
A	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

EN 440 – G 46 3 M G3Si1

Designation example for a wire/shielding gas combination compliant with EN 440

Finally, group F comprises nitrogen (N) and a nitrogen/hydrogen mixture. Both gases can be used in plasma cutting and purging. In addition to the oxidation behaviour, the electrical and physical properties within the arc and thus the welding properties change with the composition of the gas. By adding helium to the argon, the energy transfer in the arc process and the heat input into the workpiece are changed, among other things. This leads to a more energy-rich arc and therefore to improved penetration characteristics.

If active components (O_2, CO_2) are added to mixed gases, finer droplets are formed when the wire electrode melts and the weld pool displays improved flow properties, among other things. Energy transfer within the arc is also increased. This results in improved penetration characteristics: The finger-shaped penetration in the middle of the seam, typical of argon-rich shielding gas, widens with active gas constituents.

According to a rule of thumb, the necessary shielding gas flow rate of a MIG/MAG system is 10 to 12 litres/minute per millimetre of wire diameter. Welding torches with small gas nozzle openings require a slightly lower gas flow rate, torches with large nozzle openings require a slightly higher rate. Because aluminium tends to oxidise during MIG welding, the flow rates are set somewhat higher, and even noticeably higher for Ar/He mixed gases, due to the low density of helium.

The pressure of the gas available from the bottle or ring line is initially reduced. The set flow rate can be read off a manometer, which is adjusted together with a damper, or on a flow meter with a float. Modern welding machines are sometimes fitted with electronic gas control valves. The influence of the shielding gases on the welding process will be discussed in more detail later in the description of the different types of arcs.

3.4 Weld metal properties

When choosing a welding consumable for unalloyed steels and fine-grained structural steels, the main aim is to also achieve the properties of the parent metal in terms of strength and toughness in the weld metal. Here, EN 14341 offers assistance. Similar to stick electrodes, a designation system exists from which the minimum values of yield strength and elongation at failure can be taken as well as the strength and impact energy of the weld metal. The designation system is illustrated in Table 3.

In the example used here, a G3Si1 wire electrode is welded under a mixed gas (M). This welding consumable has a minimum yield strength of 460 N/mm^2 (“46”), a tensile strength of 530 to 680 N/mm^2 and a minimum elongation of 20%. Impact energy of 47 Joule is achieved at a temperature of -30 °C (“3”). A similar system is also used to characterise flux cored wire electrodes in EN 17632.

For creep-resistant steels, corrosion-resistant and heat-resistant steels and aluminium materials, the rule applies that the weld metal should be alloyed as closely as possible to the parent metal to be welded or slightly higher in order to achieve the required material properties. For wire electrodes and flux cored wire electrodes of creep-resistant, corrosion-resistant or heat-resistant steels, information about the minimum yield strength, tensile strength, elongation and impact energy values of the weld metal can be found in a table in the relevant standards. However, these values are not components of the designation system.

A wire electrode for MAG welding the creep-resistant steel 13CrMo4.5 has the EN 21952-compliant designation EN 21952 – G CrMo1Si.

A wire electrode for MAG welding the corrosion-resistant CrNi steel with the material number 1.4302 has the following designation compliant with EN 14343: EN 14343 – G 19 9 L.

The designation of a wire electrode for MIG welding the material AlMg5 is EN 18273 – G AlMg5Mn.

Further information:
EWM welding consumables manual

4. Edge preparation

4.1 Groove shapes

Figure 5 shows the most important groove shapes used for MAG welding steel.

Because the process shows such good penetration characteristics, seams with root faces (butt welds, single-Y and double-Y butt welds) can be welded using larger sheet thicknesses without gouging, compared to MMA welding. Where greater material thicknesses are used, it is advisable to gouge from the back to avoid errors. The root face thickness depends on the relevant current.

Because aluminium materials dissipate heat better, larger included angles of 70 to 90 degrees are advisable.

4.2 Applying the fusion faces

In the case of unalloyed and low-alloy steels, edges of the parts to be joined are usually bevelled by oxyacetylene cutting. High-alloy steels and the metals that are welded using the MIG process (e.g. aluminium) can be melt-cut using the plasma jet.

The oxidation that occurs during thermal cutting does not necessarily need to be removed. However, it may still be necessary in special cases. The characteristics of aluminium as a material in this regard are discussed in more detail elsewhere.

Mechanical machining of the fusion faces can also be recommended where there are special requirements and low tolerances. This applies particularly to pipe butt joints. The modern possibilities of precision plasma cutting or laser beam cutting come into play in mechanised production.

4.3 Weld pool backing

When working manually, the welder observes the welding process and can achieve a uniform root pass by setting the correct current, the position of the welding torch in the groove and the welding speed, even if the air gap varies. In the case of fully mechanised welding, on the other hand, all variables, from the weld joint geometry and the air gap used to the correct welding parameters with welding speed and deposition rate, must be selected appropriately. In order to make root welding easier, weld pool backing is often used in mechanised welding (Figure 6).

If the root gap does not vary excessively, root faces can serve as natural weld pool backing, e.g. for butt or single-Y joints (internal weld pool backing). Depending on the root face thickness, the parameters when welding the first pass must be selected such that the root face is not completely melted. The remainder of the root face can then be included when welding the backing run, with or without gouging.

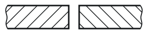
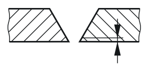
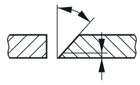
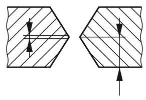
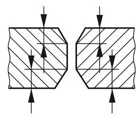
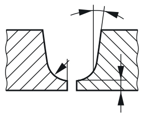
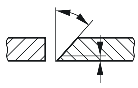
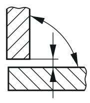
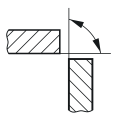
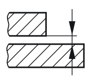
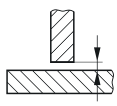
Groove shapes compliant with EN 9692-1		
Joint type	**Thickness of workpiece (mm)**	**Sketch**
Butt weld	one-sided 3–8 two-sided < 8	
Single-V butt weld	one-sided 3–10 with backing run 3–40	
Single-Y butt weld	one-sided 5–40 with backing run > 10	
Double-V butt weld	two-sided > 10	 
U-weld	one-sided > 12 with backing run > 12	
Single-V butt weld	one-sided 3–10 with backing run 3–30	
Fillet weld T-joint	one-sided > 2	
Fillet weld corner joint	one-sided > 2 two-sided > 3	
Fillet weld lap joint	one-sided > 2	
Fillet weld double fillet weld	two-sided > 2	

Figure 5

Artificial (external) weld pool backing consist of metal, for example. Copper is used for most metals and alloys; the backing must not be melted. Ceramic backing is now also available in numerous variants as weld pool backing. The backing is used to prevent the weld metal from suddenly sagging at critical points. This way the molten metal is caught, and a correct root bead is formed. The weld pool backing also forms the underside of the root pass. It is usually provided with a groove for this purpose.

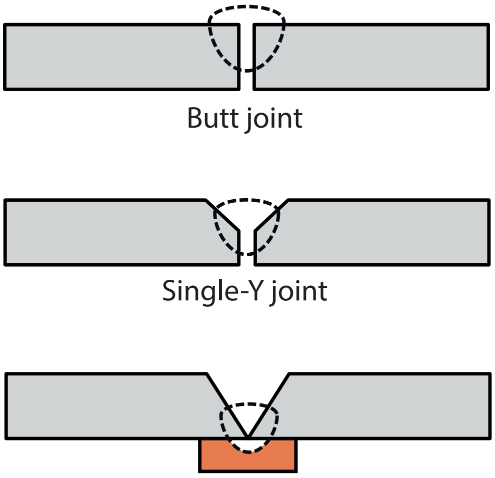


Figure 6: Typical groove shapes and weld pool backing for mechanised gas-shielded metal-arc welding

4.4 Purging

By purging we refer to the addition of shielding gas at the rear of the seam. This prevents the highly heated material from being directly exposed to the atmosphere (oxidation). This is generally indispensable for TIG and MIG/MAG welding, so that the root does not need to be gouged again. Purging is frequently unnecessary when MAG welding root passes. This depends on the material used.

Purging prevents, or at least reduces, the formation of oxidation and discolouration on the back of the root. This is important when welding corrosion-resistant steels, for example, because the oxidised areas of the welded joints become more susceptible to corrosion. After welding, it may be necessary to remove them by brushing, blasting or pickling.

When welding pipes, the ends of the pipes are blocked; the purging gas must flow into the interior in a controlled manner. When welding sheet metal, it flows out of the openings in the weld pool backing.

Argon or an argon/hydrogen mixture can be used as purging gas. In many cases, however, the inexpensive Group F purging gases in EN 14175 can be used. These consist of a hydrogen/nitrogen mixture, for example. Even pure nitrogen can be used for purging, under certain circumstances.

5. Welding machines

MIG/MAG welding machines consist of the power source, the control and the wire feeder with hose package and welding torch. They can be used as compact machines or decompact machines with an external wire feeder for various applications.

In the compact machine (Figure 7), the power source, control and wire feeder are all included in one casing. The operating radius corresponds to the length of the torch hose package, generally 3 to 5 metres. Accordingly, compact machines are generally used at permanent workplaces, e.g. in welding booths or on production lines.

On decompact machines (Figure 8), the wire feed mechanism is located in a separate casing and is connected via an intermediate hose package to the power source and the control. The wire feeder can be transported to the workpiece. This allows the operating radius to be extended by up to 40 metres compared to the compact machine. Universal machines are therefore generally deployed at moveable workplaces and on construction sites. Figure 9 shows the MIG/MAG multiprocess inverter pulse welding machine Titan XQ puls with Expert 2.0 control in the power source and HP-XQ control in the wire feeder.

5.1 Power sources

The task of the power source is to supply the welding process with the necessary electrical energy. This includes reducing the high grid voltage to values that are safe and useful for welding; at the same time, the high current required is made available. Because only direct current is used for MIG/MAG welding, with a few exceptions, only rectifier machines or inverters are used as power sources.

The welding rectifier consists of the mains transformer and a downstream rectifier set (diodes). While the transformer converts the high voltage and low current of the mains grid into electrical power with low voltage (10 to 50 V) and high current (50 to 500 A), the rectifier set converts the alternating current or three-phase current supplied by the transformer into direct current.

Different currents and voltages are required for different welding tasks. The power sources must therefore be adjustable. On simple MIG/MAG welding machines, tappings of the turns on the transformer are switched using a step switch.

Figure 10 shows a schematic diagram of a step switch controlled machine.

Figure 7: Compact, step switch controlled MIG/MAG welding machine with integral wire drive

Figure 8: Decompact, step switch controlled MIG/MAG welding machine with separate wire drive and water cooling

Figure 9: Titan XQ MIG/MAG multiprocess inverter welding machine

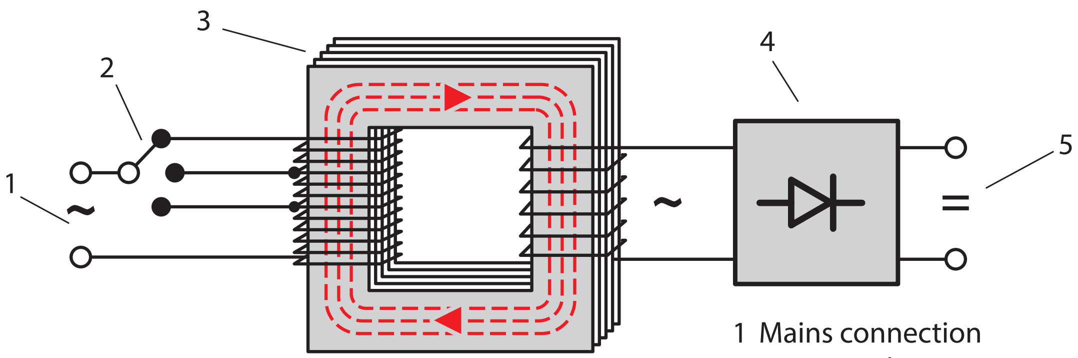
By incorporating more or fewer turns of the primary coil, the transformation ratio of the transformer changes and with it the voltage on the secondary side.

In the case of slightly more complex power sources, the current in the rectifier section is adjusted using a controllable rectifier (known as thyristors). Figure 11 shows a schematic diagram of such a machine.

By controlling the thyristors accordingly, more or less large proportions of the AC half-waves are used. As a result, the welding voltage changes. This relatively simple technology is now obsolete.

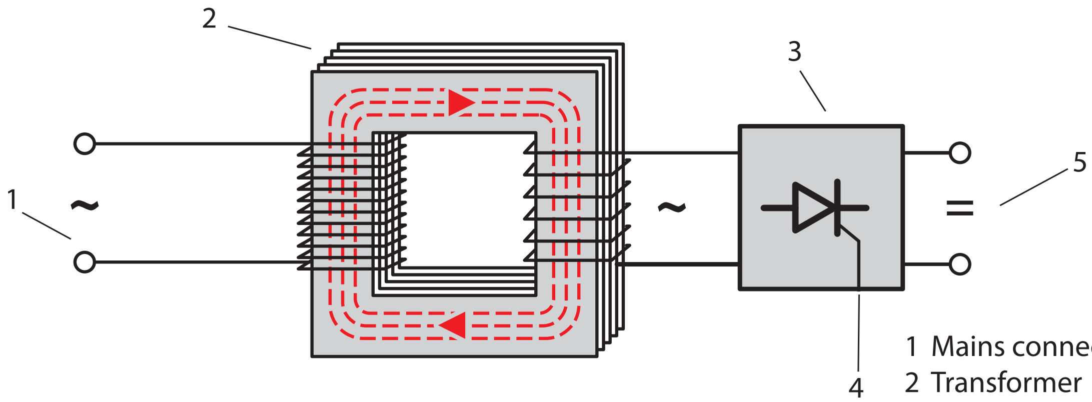
More modern MIG/MAG machines are equipped with inverters as power sources. The inverter is an electronically controlled and regulated, primary-switched power source. After using analogue and secondary-switched electronic power sources for decades, development now concentrates on these primary-switched machines. They utilise a completely different working principle than conventional power sources (Figure 12).

The power supplied by the electrical mains grid (voltage, current, 50 Hz) is first rectified using a set of diodes and then



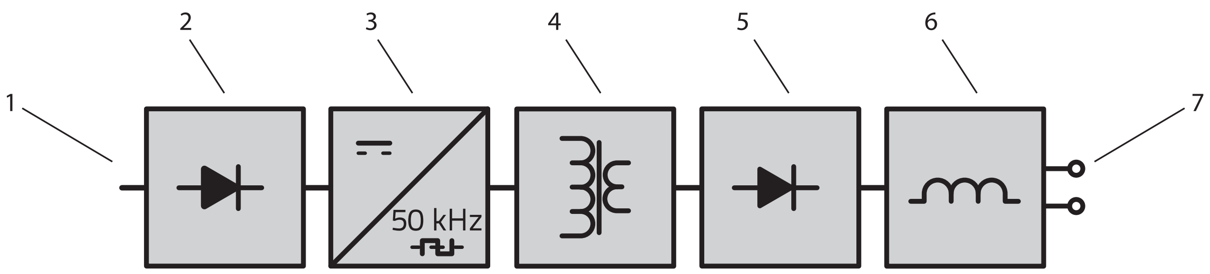
1 Mains connection
2 Step switch
3 Transformer
4 Rectifier
5 DC output

Figure 10: Welding power source schematic with step switch control



1 Mains connection
2 Transformer
3 Thyristor set
4 Control electronics
5 DC output

Figure 11: Schematic of an infinitely adjustable welding power source with thyristor control



1 Mains connection (50/60 Hz)
2 Primary rectifier (diodes)
3 AC unit (transistors)
4 Medium frequency transformer
5 Secondary rectifier (diodes)
6 Medium frequency choke
7 DC output

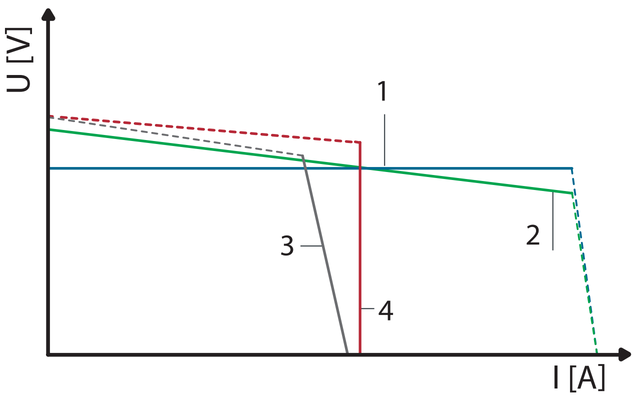
Figure 12: Block diagram of a modern inverter power source

divided into short blocks by fast switching. This switching is performed by fast-working electronic switches, the IGBT transistors.

The first transistorised inverters work with switching frequencies of around 20 kHz. In the meantime, with more developed transistor switches, frequencies of up to 100 kHz are possible.

After quickly switching the power on the primary side, it is transformed to the power required on the secondary side at a high current and low voltage. An approximately rectangular AC voltage is created downstream of the transformer, which is subsequently rectified again (diodes). The high switching frequency keeps the required mass of the transformer, which operates at high frequency, very small; it is strongly dependent on the switching frequency. This makes it possible to manufacture lightweight power sources with high efficiency.

In modern welding machines, numerous functions that are achieved in conventional power sources using conventional electrical components such as resistors, chokes, capacitors and switches are now electronically solved by the control. The control of these power sources is therefore at least as important as the power unit. To adjust the output power, for example when using with



1 Constant voltage characteristics
2 Flatly falling characteristics
3 Steeply falling characteristics
4 Constant current characteristics

Figure 13: I–V characteristics

switched sources, the ratio between the on/off times with the lowest losses is changed. The ratio of the on/off times is cyclically altered by the control in order to generate pulsed current profiles. In a similar manner, the current can be ramped up or down as required when the welding process is started and stopped.

Inverter technology made possible the precisely regulated power source, which had long been in demand for welding technology. As a control device, an electronic controller continuously measures welding current and voltage and compares these values with the specified nominal values. If the current actual values change, e.g. due to undesirable changes in the welding process, the control corrects this within a few microseconds (typically 0.1 ms). In a similar way, the short-circuit current in the welding process can be limited to reasonable values. The technology described here results in significantly better efficiencies with minimal open-circuit losses and very good inverter device cos φ (phi).

In the simplest case, the electrical behaviour of the welding machines (power sources) discussed here is characterised by the shape or position of the machine's I–V characteristic. This can be a constant voltage characteristic or what is known as a constant current characteristic. In between these, any other form of I–V characteristic, from flatly falling to steeply falling is possible (see diagram in Figure 13). This description, also referred to as the "static characteristic of the source", has an important influence on the operation and stability of each and any arc process.

5.2 Wire feeders

In the wire feeder, the wire electrode moves at a selectable speed towards the arc process by means of wire feed rolls. It is drawn from the spool and pushed through the hose package. The welding torch is located at the end.

The rotating speed of the wire feed rolls is driven by an infinitely adjustable DC gear motor.

In modern machines that allow a controlled welding process, the motor speed, and thus the wire feed speed, is measured by a speed sensor and precisely controlled regardless of the load.

In MIG/MAG welding, wire feed speeds between 1 and 20 m/min are common – depending on the wire diameter – with high-performance variants moving up to 30 m/min.

The wire feed mechanism must handle the surface of the wire electrode with care. The wire feed rolls must therefore have a sufficiently large diameter to prevent excessive surface pressure on the wire surface.

Compared to a 2-roll drive, the wire can be conveyed with less contact pressure and still slip-free in 4-roll drives. In the case of 4-roll drives, all the rollers are frequently interlocked and driven together by a (powerful) motor.

Figure 14 allows a look into a wire feeder with 4-roll drive. This results in a 3-point support of the wire circumference between the rollers, which is gentle on the surface while offering optimal traction. Knurled rollers are often used for flux cored wire and U-groove rollers are used for soft wires (Figure 15).

Careful handling of the wire surface is important because abraded wire particles (metal particles) are conveyed into the hose package and may thus clog it after a short

Figure 14: Modern wire feeder with 4-roll drive

time. Increased metal abrasion also occurs when the wire feed rolls are worn or damaged. Their condition must therefore be regularly checked. New wire feed rolls must be free of burrs on and in the grooves.

The pressure of the wire feed rollers is adjustable and must be selected depending on the wire type according to the machine manufacturer's information (scale on the pressure sleeves).

5.3 Hose package and welding torch

The hose package that connects the MIG/MAG welding torch to the welding machine or wire feeder contains all the necessary supply lines: the welding current lead, the shielding gas supply, the wire feed hose and the control cable assembly. On machines designed for higher currents, the cooling water supply and return are also included.

In water-cooled welding torches, the current lead is within the water return. The line cross-section is therefore smaller and the hose package lighter and more flexible than for welding torches without water cooling. When welding unalloyed and low-alloy steel, the wire guide hose consists of a steel liner. If wire electrodes made of chrome-nickel steel as well as aluminium and other metals are used, a wear-resistant plastic hose (e.g. Teflon) is employed. Plastic guides have a more favourable coefficient of friction than steel. Control signals can be sent from the welding torch to the controls through the control cable assembly. The torch trigger is located on the torch grip and can be used to control the necessary welding functions.

Figures 16 to 18 show some common welding torch types. Curved welding torches (Figure 16) are most commonly employed. They are lightweight, and the arc generally reaches the weld location easily. The welding torch in Figure 17 offers a special technology with the remote control integrated in the handle.

An additional welding torch type is the push/pull torch (Figure 18). With the push/pull drive, a wire feed motor mounted in the torch handle pulls the wire electrode, while the drive, which is located in the machine, pushes the wire into the hose package. This allows even soft and thin wires to be fed safely. A push/pull drive is also frequently employed in robot systems and in mechanised welding machines in order to be able to safely transport the wire electrode over long distances. Both drives must be synchronised using electronic means.

e.g. UNI rolls for Ø 1 mm to 1.2 mm with V-groove (blue/red): for stainless steel, steel

e.g. Ø 1 mm with U-groove (blue/yellow): for aluminium

e.g. Ø 1 mm with V-groove, knurled (blue/orange): for flux cored wire

Figure 15: Drive rolls with differing groove geometries

Figure 16: Standard MIG/MAG welding torch for manual welding

Figure 17: MIG/MAG welding torch with integral display

Figure 18: MIG/MAG welding torch with push/pull drive and exchangeable torch neck

These days, small-scale, powerful wire drive systems installed on the robot wrist are used in robot systems; they feed the wire electrode directly from a wire drum via a low-friction conveying path and without additional drive technology.

Figure 19 shows a cross-section through a modern welding torch.

Because of the high peak currents (400 A to 600 A), current transfer from the contact tip to the wire electrode is not uncritical. Reliable contacting, and thereby an interference-free and reproducible welding process, is only possible if the wire has a bare, metallic surface and – due to its curvature ("shape") or by measures on the torch side – is pressed against the contact tip inner bore ("forced contact"). In the event of interferences at this point, the wire movement is usually blocked briefly and irregularly, thus significantly affecting the welding process.

5.4 Control

A number of functions can be set on the welding machine's control. For example, you can move between non-latched and latched operation. In addition, a wire electrode creep speed when igniting and a burn-back time of the arc when the welding is ended can be defined. The adjustable, low speed of the wire electrode during ignition makes the ignition process safer because the arc, which at the beginning still burns weakly on the cold material, is not immediately smothered by the wire pressing from behind. The defined burn-back time prevents the electrode from sticking in the end-crater. To achieve this, wire feeding is switched off slightly earlier than the welding current. However, if the burn-back time is excessively long, the wire can burn back to the contact tip and stick there. An additional program can prevent an excessively large droplet, which would interfere with re-ignition, from remaining

Greater contact tip and screw base cross-sections ensure optimal heat dissipation under high loads.

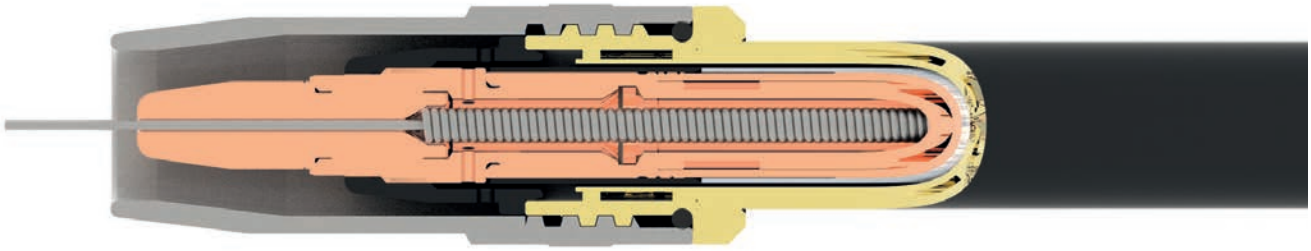


Figure 19: Cross-section through MIG/MAG welding torch head

at the end of the wire after welding has ceased. Here, the droplet formed on the wire immediately before welding is ended is detached by a current pulse. Modern MIG/MAG systems also allow the current to be ramped up at the beginning and reduced correspondingly at the end of the weld.

A further function, called soft start technology, ignites with a low current and reversing wire movement, making a low-spatter and reliable process start possible.

Using what is known as process switching between types of arcs with increased or reduced heat input, welds can be implemented and designed in a variety of different ways.

The welding circuit in the leads between the machine and the arc location has specific values for ohmic resistance and inductance. They depend on the cable length, cross-section and geometry of the installation and may change the current and/or voltage curve shapes and thus the welding results. Modern machines are capable of determining the resistance and inductance values and of compensating for their influence. This ensures reproducible welding results.

The latest generation of inverter welding machines can work on mains voltages in an extended range around the nominal voltage of up to -25%/+20% and thus facilitate operation at different deployment locations. Changes in the mains voltage within this range have no effect on the welding process.

Thanks to modern electronics, the machines are highly efficient during welding and consume little energy in idle phases. To achieve this, these machines switch off the cooling circuit pump and the machine fan when they are at a standstill for a long time, so that energy consumption in standby assumes very low values.

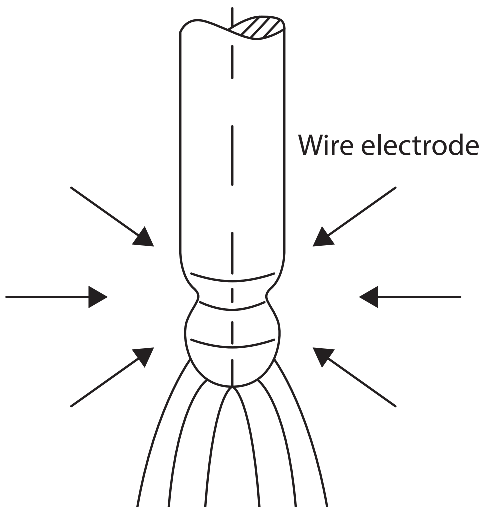
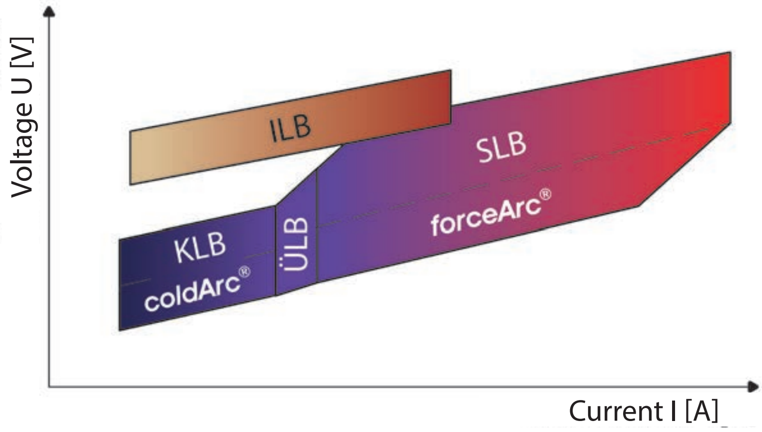


Figure 20: Schematic of pinch effect [1]



ILB = Pulsed arc
KLB = Short arc
ÜLB = Transitional arc
SLB = Spray arc

Figure 21: Location of the working areas

The electronic log-on function can prevent unauthorised personnel from starting the machine or changing the defined parameters.

In critical applications, welding data should be continuously recorded and certain parameters monitored. This data can be stored together centrally in a network of numerous active welding machines. The microcomputer systems in modern welding machines are capable of this (see ewm Xnet).

Further information:
www.ewm-group.com/sl/brochures

6. Material transfer during MIG/MAG welding

6.1 Arc ranges

Depending on the specified welding parameters and the shielding gas used, different material transition forms, the arc operating states, occur in MIG/MAG welding. Here, both physical phenomena such as surface tension and viscosity of the molten metal, gravity and plasma flow as well as electrical forces such as the Lorentz force are involved. The latter electromagnetic force, in particular, has a dominant influence on droplet transitions that occur in free fall. The Lorentz force, here also referred to as the pinch effect, results from the surrounding magnetic field and is a force directed radially inwards (Figure 20). It constricts the molten end of the electrode and "pinches" individual drops from it.

DIN 1910-4 differentiates and describes the arc types listed in Table 4.

The typical material transition forms at uniform current occur in part in the lower power range, i. e. at low currents and voltages, and in part in the medium or upper power range.

Figure 21 schematically shows their position in the I–V diagram.

The pulsed arc is available across a very broad power range.

6.2 Short arc

The short arc occurs in the lower power range at low currents and arc voltages. Not only does its name indicate that this is a geometrically short arc, it is also referred to as a short(-circuit) arc because of the nature of the droplet transfer. Figure 22 shows the different droplet transfer stations.

Under the influence of the heat from the arc, a small droplet (a) forms at the end of the electrode, which, thanks to the short arc and

Table 4

Arc types compliant with DIN 1910-4	
Name	**Material transfer**
Spray arc	ultrafine to fine droplets > practically short circuit-proof
Long arc	coarse droplets > not short circuit-proof
Short arc	fine droplets > in short circuit
Pulsed arc	Adjustable droplet size and frequency > practically short circuit-proof

caused by the wire movement, soon comes into contact with the weld pool. A short circuit occurs: The arc extinguishes (b). The droplet is absorbed by the weld pool as a result of the surface tensions. The arc subsequently ignites again at regular intervals (c). This process is repeated at irregular intervals, depending on the shielding gas used, approximately 20 to 100 times a second. During the short circuit phase, the current increases with a delay. Because of the small size of the droplet, the short-circuit phase is short and there are no excessive current spikes. Using conventional power sources, the rate of current increase is limited to reasonable values by an adapted choke in the welding circuit. This way, following the short circuit, the arc is re-ignited softly and without significant spatter formation. In inverter welding machines, the electronic open-/closed-loop control (software) flexibly prevents the current from increasing excessively in the droplet short circuit.

The short arc is a relatively “cold” process with low electrical power conversion, low penetration and viscous molten metal. It occurs under all welding shielding gases and is particularly suitable for welding root passes, thin sheets and in positional welding.

6.3 Long arc (100% CO_2)

The long arc occurs in the medium and upper power range when welding with pure CO_2 or mixed gases with high CO_2 content. Large-volume droplets and increased spatter ejection are characteristic. The deep penetration reduces the risk of lack of fusion in certain applications.

The long arc is rarely used in Europe.

6.4 Spray arc

With argon and argon-rich mixed gases, the arc envelops the lower electrode end at the contact with the droplet, allowing the pinch effect to optimally develop if the current is sufficient. The end of the wire is constricted; individual drops are detached from the electrode (Figure 23).

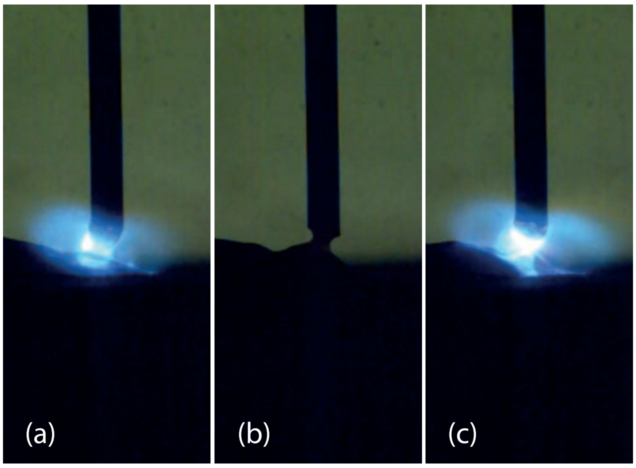


Figure 22: Droplet transfer in short arc

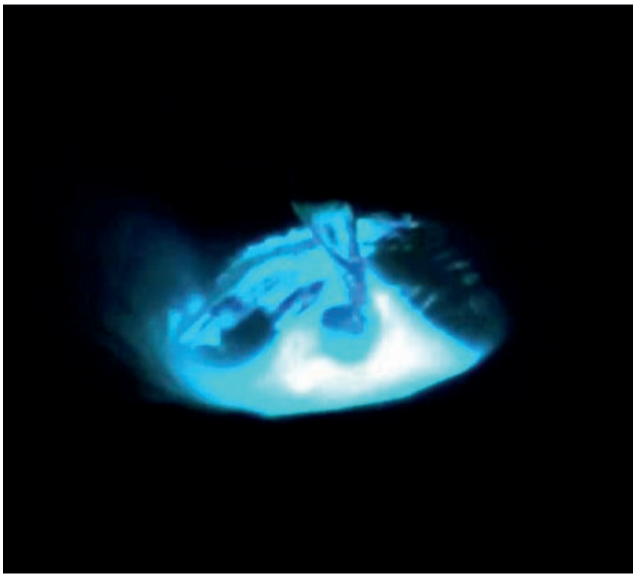


Figure 23: Droplet transfer in spray arc

Here, material transfer is short circuit-proof and low-spatter.

The spray arc occurs with argon-rich shielding gases in the upper power range. With this type of arc, a large, hot weld pool forms, normally making the process unsuitable for positional welding (PC–PF, Figure 25).

6.5 Transitional arc

The transitional arc occurs between the short arc on the one hand and the spray or long arc on the other. A mixed material transfer, partly in short circuit, partly in free fall, is typical for this. Spatter increasingly forms in this range, even with argon-rich mixed gases. The heat input and penetration depth are in the mid-range between the processes discussed above (Figure 24). This arc is avoided where possible.

6.6 Pulsed arc

A characteristic of the pulsed arc is a rapid, regular change between phases with high and phases with low power, which is forced by the power source.

Depending on the "modulation" (closed-loop control instead of "control principle") of the power source, the parameters for this arc operating mode are the wire feed speed, the basic current or the basic voltage, the pulse current or the pulse voltage, the pulse duration and the pulse frequency. As Figure 26 shows, one droplet detaches from the electrode tip in the pulse phase under the influence of the pinch effect, provided the parameters are selected correctly. This results in a regular welding process with fine droplets and low-spatter.

The pulsed arc can be used over almost the entire power range and is also suitable for positional welding at low and medium currents.

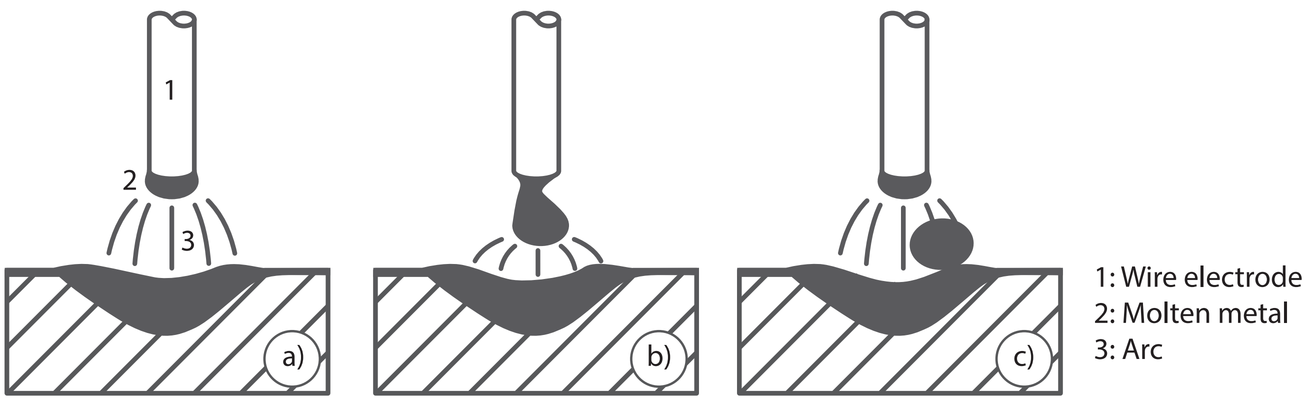


Figure 24: Droplet transfer in transitional arc

6.7 Special forms of material transfer

In addition to the standard arc types described above, special forms, that have only come to the fore in recent years, also exist.

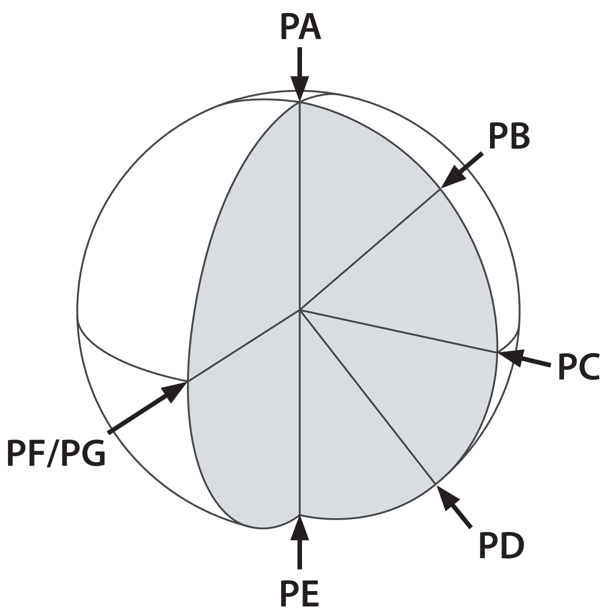


Figure 25: Welding positions in accordance with EN ISO 6947

At currents that are higher than those of the conventional spray arc – that is, at wire feed rates of more than 18 m/min for 1.2-mm wire, for example – the high-performance spray arc occurs under mixed gases. However, this is accompanied by such a deep penetration, even cutting under certain circumstances, that it can lead to faults in the seam.

If the stick-out and the voltage are increased, the arc begins to rotate in this power range and the penetration widens. The rotating arc is used when the aim is to increase the deposition rate. The rotating arc is also used if the welding speed for filler and cover passes on butt welds and fillet welds needs to be increased on thick-walled components. The risk of pore formation as a result of gas turbulence is high; the process should be used with great caution.

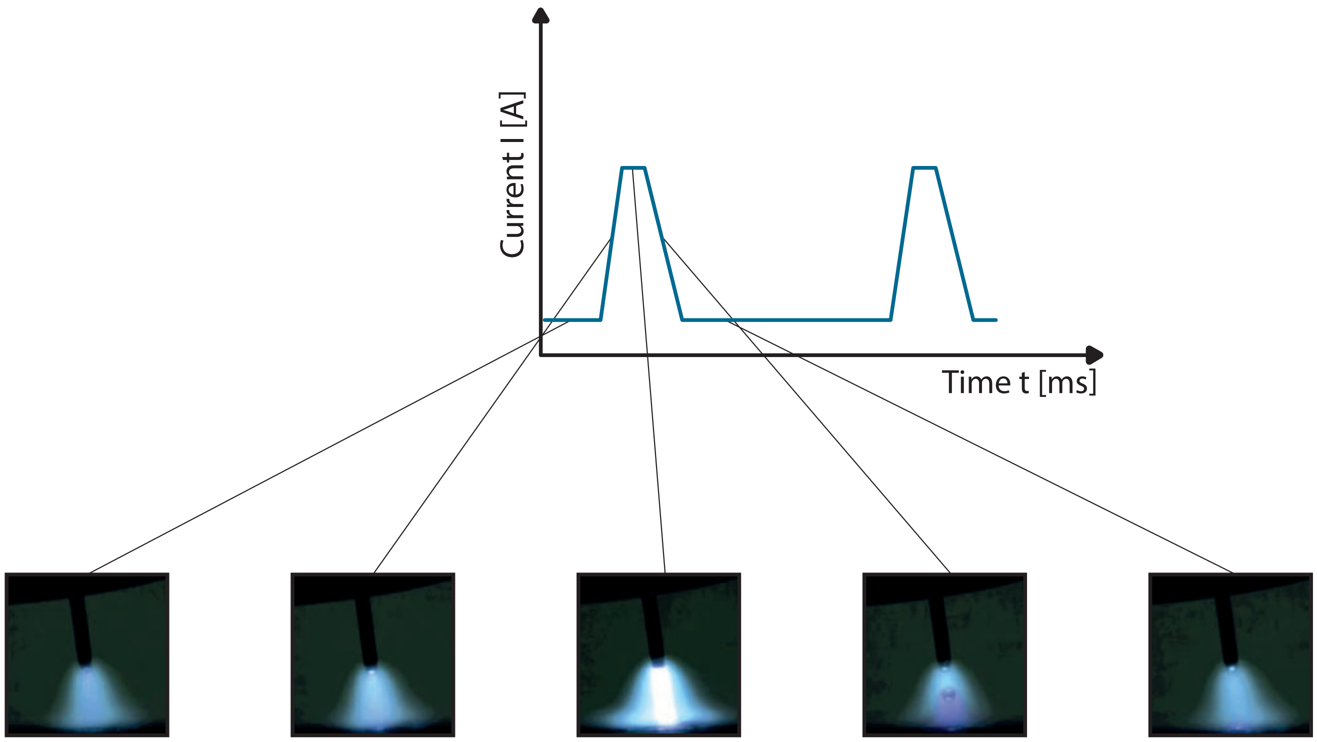


Figure 26: Droplet transfer in pulsed arc

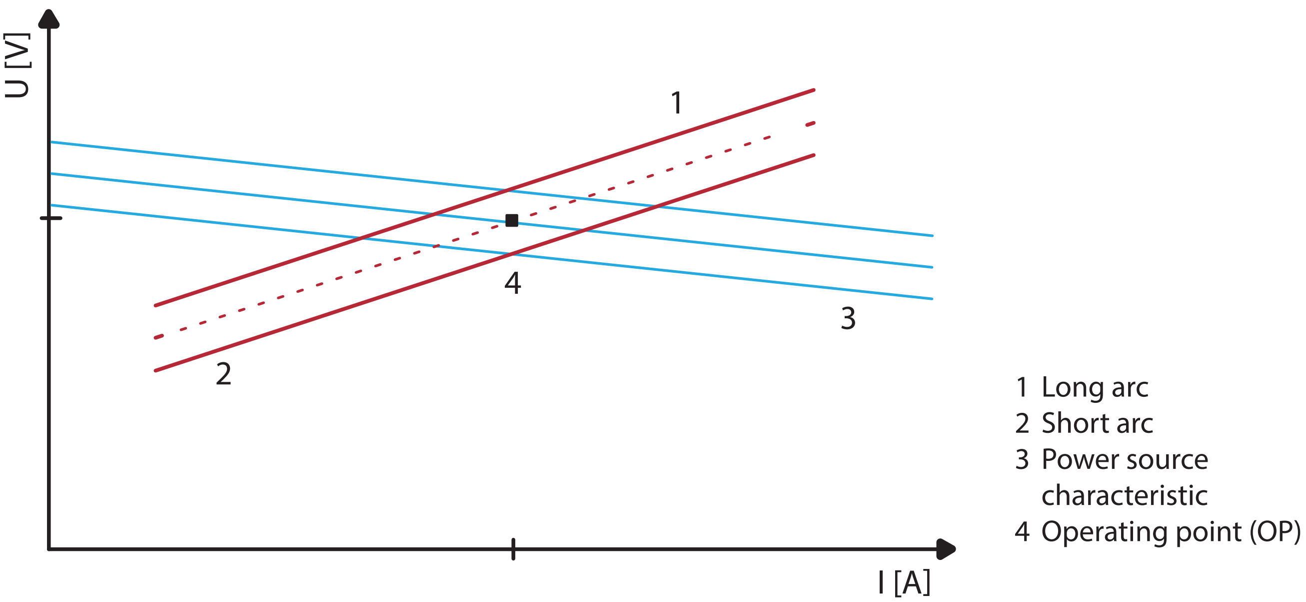


Figure 27: Arc ranges for MIG/MAG welding

The high-performance short arc is a process with a material transfer in the typical short-circuit transition area. It occurs at currents in the conventional spray arc range, but at a significantly lower arc voltage.

With some exceptions, the high-performance MIG/MAG welding variants discussed here are only used in fully mechanised welding.

7. Setting the welding parameters

7.1 Setting on conventional welding machines

In contrast to MMA welding and TIG welding, two adjustment processes are necessary for MIG/MAG machines. This is explained using the example of the relatively simple settings on a step switch controlled machine (welding rectifier).

Constant voltage sources or – in most cases – those with a flatly falling I–V characteristic are used for MIG/MAG welding. The approximate voltage required is therefore selected by setting a specific characteristic (step) on the welding machine's coarse and fine step switches. Together with a suitably defined wire feed speed, a favourable arc length is achieved. Figure 27 shows how the position of the operating point changes when the settings of the power source and the wire feed speed are changed.

The operating point (OP) is the intersection between the defined power source characteristic and the arc characteristic. It is characterised by the current Is(OP) and the voltage Us(OP). If the wire feed speed is increased, the arc is shortened, and the operating point moves to the right on the source characteristic – the current increases. If the wire feed speed is reduced, the OP moves to the left instead. The required current can thus be specified via the wire feed potentiometer. However, the arc is shortened as a result of the higher wire feed speed. To prevent it from becoming too short, the voltage must be simultaneously increased.

For a higher voltage, a higher characteristic must be set on the step switch; if a lower arc voltage is desired, a lower characteristic must be set. The source characteristics usually fall. This means that if one required parameter is adjusted, the other also changes slightly. This mutual influencing is only absent in constant voltage sources (horizontal power source characteristic).

For optimal welding conditions, the arc may be neither too short nor too long. Droplet short circuits and therefore spatter often occur if the arc is too short. The short circuits can be recognised by a typical backfiring noise emanating from the arc. As the length of the arc increases, the risk of ambient air entering the arc area also increases. This in turn increases the risk of pores and undercuts, among other things. The welder can recognise the excessively long arc optically and from the hissing noise of the arc. The range of favourable operating points runs approximately diagonally through the I–V diagram. This is the working area where welding should be performed.

Figure 28 shows the working areas for an Si/Mn alloy steel wire electrode and two different mixed gases.

All operating points within the sketched working area lead to favourable welding conditions. Operating points below this range mean excessively short arcs, operating points above lead to excessively long arcs. The working areas always apply only to a specified combination of wire electrode and shielding gas type.

When welding with pulsed arc technology, the material transfer is largely free of short circuits. At low and medium currents, the range limits shift here to somewhat higher arc voltages.

7.2 Synergetic settings for welding processes

The operation of modern welding machines is becoming increasingly difficult due to the variety of functions and parameters. However, the welding parameters can be very easily set on modern MIG/MAG machines.

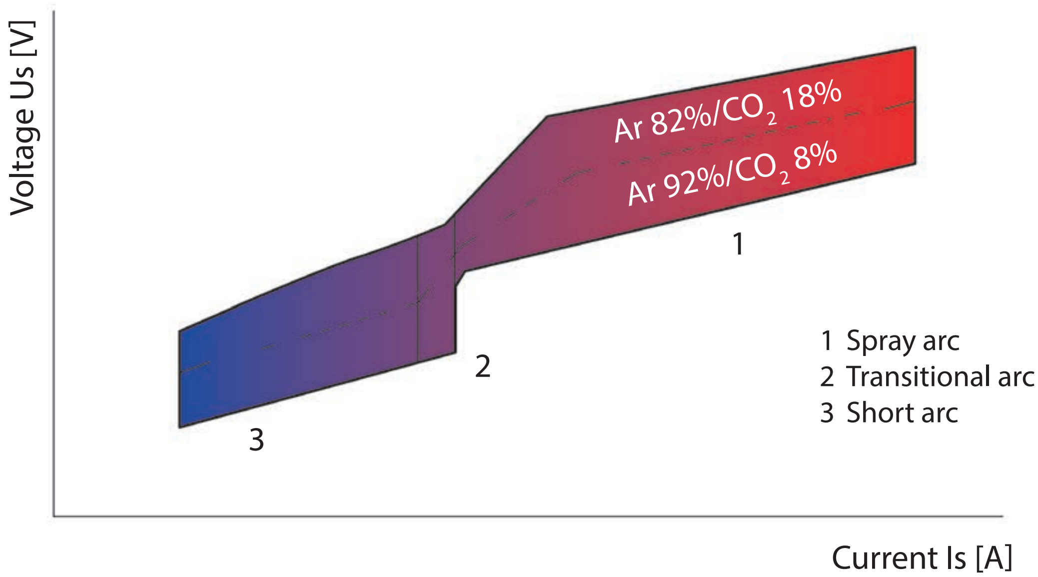


Figure 28: Working areas for two argon mixed gases

This development began decades ago with the so-called "one-knob operation", in which the power, by means of an infinitely adjustable source (voltage) characteristic, and the wire feed speed could be adjusted appropriately at the same time by simply turning a rotary knob. A certain amount of correction to the operating point was possible via an optional second knob.

In the meantime, it has become the standard for many MIG/MAG machines, such as the EWM multiprocess machines Titan XQ, Phoenix puls, Taurus Synergic S or Picomig Synergic/puls (Figure 29), that the intrinsically complicated setting of modern machines is much simpler. The ideal "working characteristics" for the most frequent welding tasks are stored in the machine. The machine operator only defines the so-called JOB using the touch buttons or by selection in the corresponding menus. This includes the material to be welded, the required wire diameter, the material of the wire or the welding consumable and the shielding gas used. This calls up the pre-programmed, ideal working characteristic for the welding task ("synergic characteristic"). The power can now be infinitely adjusted using a potentiometer/voltage correction (in volts). A correction button is available for individual requirements for the most favourable arc length. Figures 30 and 31 show controls of modern welding machines. They allow numerous additional settings.

7.3 Stabilisation/control of MIG/MAG processes

MIG/MAG arc processes are not intrinsically stable: The feed speed of the wire electrode and the voltage must always be the same. Only in this way can a balance between stick-out and the arc length be maintained. To

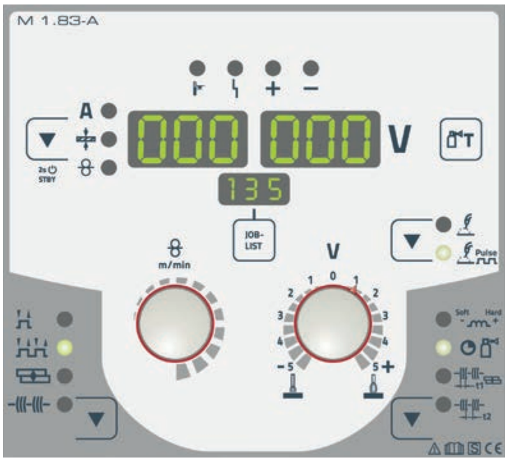


Figure 29: Picomig control

achieve this, certain conditions must apply: The wire feed speed is usually held constant during MIG/MAG welding (see section on wire feeders). If the welding machine supplies the arc process with a stable voltage – that is, constant voltage behaviour or a flatly falling I–V characteristic (see Figure 27) – a "simple" arc process itself (e.g. in spray arc operating mode) can balance the stick-out and keep the arc length stable. External interferences, e.g. caused by changes in distance, may not be completely eliminated, but the welding process remains fundamentally stable.

This is illustrated in the following diagram (Figure 32): The arc process characteristic shifts to the right in the I–V diagram as a result of a change in the distance between the welding torch and the workpiece (a -> b); a new operating point OP2 is created with an increased welding current. The higher current leads to a greater wire deposition rate. In turn, this causes the arc to become longer. It forms a new equilibrium with the shorter stick-out. If the original distance between the welding torch and the workpiece is reached again (b -> c), an equilibrium between the wire and arc length is achieved as in (a). The operating point is once again at OP1.

Figure 30: Control of a synergy-programmed MIG/MAG machine (high-tech)

Figure 31: Control of a synergy-programmed MIG/MAG machine (standard)

The compensation processes described take place in the tenths of a second range. The process is referred to in welding technology (not entirely correctly) as "internal regulation" or (better) as "internal self-balancing".

On the other hand, if the welding machine has a steeply falling or constant current characteristic as used in other welding procedures (e.g. TIG), a stable MIG/MAG process is not possible. There can be no, or only an insufficient, change in the current I.

Short interruptions in the arc caused by droplet transfers in the short circuit (between the wire tip and the weld pool), as they occur in the "short arc" and "transitional arc" processes, for example, are compensated by an adapted choke (inductance). This prevents the current in the welding circuit from increasing excessively; the welding process is not disturbed (see Figure 32). If the distance shortens, the process may react with more frequent droplet transfers, and if the distance increases, with fewer. The process therefore remains stable as long as the changes in distance do not occur suddenly.

Stabilisation is more complicated when arc welding using pulse technology (see Figure 26), because the basic phases must be operated at low power with controlled current across a steep characteristic. This dispenses with stabilisation in these phases. In many cases, the (short) pulse phases are operated with a controlled voltage using a flat characteristic. This allows the process-internal stabilisation to work.

This simple stabilisation method fails at low pulse frequencies with long basic phases without stabilisation just as with non-ferrous wire materials. Instead, the entire pulse process is operated under a controlled current: It runs across steep source characteristics in all phases. However, the balance between stick-out and arc length must then be established using a complex, electronically assisted control system. This technology continuously measures current and voltage and uses information from the welding process. In doing so, it utilises an arc model. The average welding current is adjusted in a suitable form depending on the results of the measurement. This counteracts unintended changes in the process.

The parameters of this arc model depend on materials, shielding gases, operating modes, working areas and many other influencing factors. The welding machine manufacturers determine these parameters with great effort in their laboratories and incorporate them in the microcomputer-based electronic systems (also see Section 7.2 – Synergic programming).

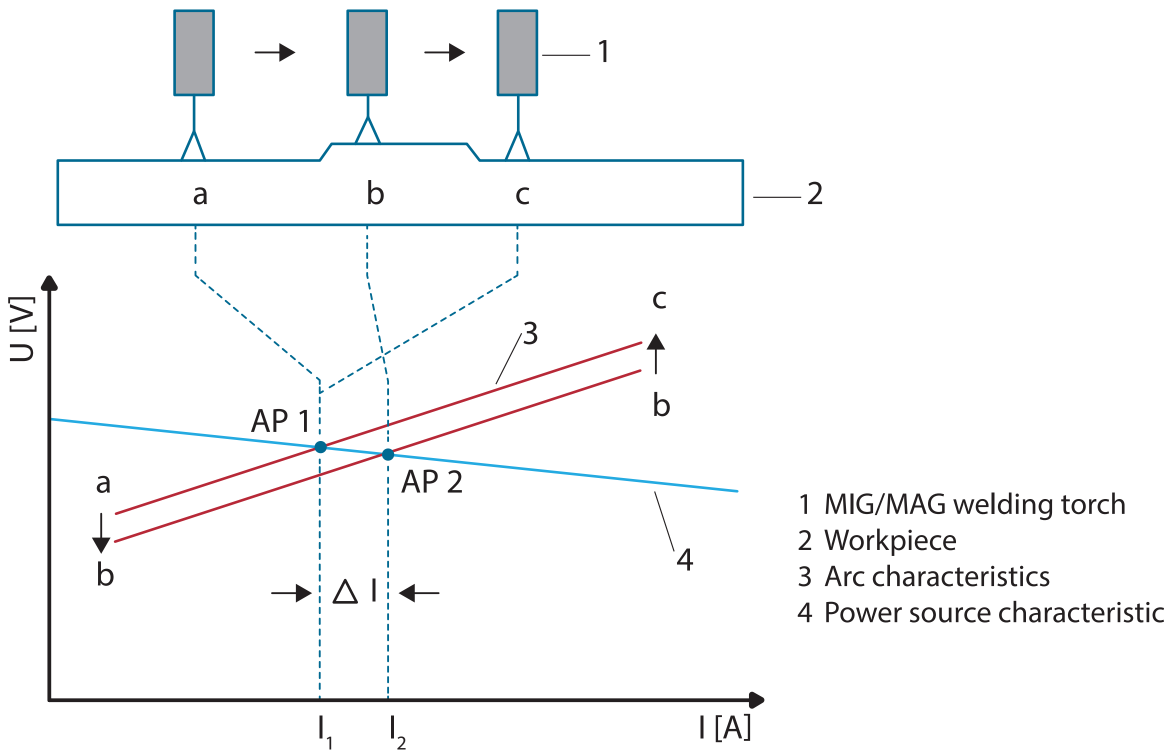


Figure 32: Arc length stabilisation (delta I control)

8. Carrying out welding

The MIG/MAG welder requires good training, both in practical welding and in the special theoretical aspects of the method. They are described below:

8.1 Arc ignition

If the torch trigger is actuated, the wire electrode starts to move (at a reduced speed, so-called "wire creep speed"). At the same time, the current supply is started, and the shielding gas begins to flow. A first contact is made when the wire tip touches the workpiece surface, through which a high current flows immediately. Material is heated at the point of contact as a result of the high current density at the tip of the electrode. This is the requirement for arc formation. When the arc is stable, the machine automatically switches to the preselected wire feed speed. Modern welding machines support the required, repeatable sequence of the critical ignition process using electronics.

Ignition should normally not take place outside the weld and, where possible, only in locations that are subsequently melted. Cracks may form at ignition points that are not welded over.

Occasionally, the optimal ignition process described above fails and multiple ignitions in rapid succession result, with backfiring noises and flying wire pieces. This is a clear sign of errors in the following areas: thick, oxidised ball on the end of the wire, poorly conductive workpiece surface, loose contacts between workpiece and earth connection, defects/interruptions in the welding cables or welding torch leads, incorrectly selected welding parameters or incorrectly selected wire creep speed (if manually adjustable). An unsuitable wire electrode contact in the contact tip of the welding torch, e.g. due to wear, among other things, may lead to ignition difficulties.

8.2 Torch guidance

The welding torch is tilted in the direction of welding by around 10° to 20° and can be backhand or forehand (Figure 33). The distance between the stick-out and the workpiece, i.e. the between the lower edge of the contact tip and the start point of the arc, should be about 10 to 12 times the wire diameter [mm]. If the welding torch is tilted

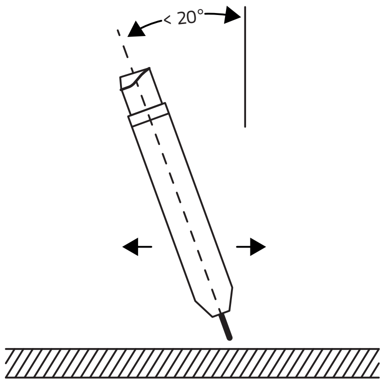


Figure 33: Setting the welding torch in the welding direction

excessively, there is a danger that air will be injected into the shielding gas, thus creating faults. Forehand welding is generally used when welding with solid wires; backhand welding is used with slag-forming fluxcored wires. A slight backhand motion is normally used in the PG position. Vertical down welding (position PG, vertical down) mainly occurs with thinner sheets. On thicker sheets, there is a risk of lack of fusion owing to weld metal running ahead. This lack of fusion caused by weld metal running ahead may also occur in other positions if welding is performed at too low a welding speed. Wide weaving movements should therefore be avoided wherever possible, except in the PF position (vertical upwards).

8.3 Ending the welding process

At the end of the seam, the arc must not be suddenly shut down and the welding torch removed. With thicker sheets, in particular, deep end-craters can form in large-volume runs. It is therefore better to slowly withdraw the arc from the pool or to specify an end-crater filler program if the welding machine used allows this. A specific shielding gas post-flow time should be specified to allow the last molten weld metal remaining to solidify under the shielding gas coverage. However, this is only effective if the welding torch is also held for a time at the end of the seam.

8.4 Welding parameters

The lower material thickness limit for using the MIG/MAG process with steel is around 0.5 mm and with aluminium materials around 1 mm.

Root passes and thin sheets are generally welded using the (advanced) short arc process or in the lower pulsed arc power range. For filler, final and backing runs on thicker sheets, spray or pulsed arcs at a higher power range are specified.

Guide values for suitable welding data for welding butt and fillet welds can be taken from Tables 5 to 9.

The current and voltage values used by the welder for information purposes can be read from the integral measuring instruments. During pulsed welding, the display instruments show the (arithmetic) mean of the current and welding voltage. This results from the pulse and basic phases at the specified pulse frequency. The tables can therefore also be used as guide values for pulsed MIG/MAG welding. If no measuring instruments are installed, it may be possible to work with external measuring instruments.

Table 5

Guide values for MAG welding butt welds on unalloyed and low-alloy steel. Wire electrode: G3Si1/G4Si1 – Shielding gas: Mixed gas M2.1 – Data after [1] and [2]									
Plate thickness mm	Groove shape	Included angle °	Root gap mm	Position	Wire electrode dia. mm	Wire feed m/min	Current Ampere	Arc voltage Volt	Pass
1.0	I	–	0	PA	0.8	3.8	70	18	1
2.0					1.0	4.3	125	19	
			1.5	PG	0.8	7.1	130		
4.0			2.0	PA	1.0	4.8	135		
			2.5	PG		5.4	160	20	
6.0	V	50	2.0	PA		4.3	125	19	
						8.4	205	22	2
				PG		4.7	130	19	1
						5.4	170	20	2
8.0				PA	1.2	3.1	135	18	1
						8.1	270	28	2
									3
				PF	1.0	3.7	100	17	1
									2
10.0			2.5	PA	1.2	3.2	135	19	1
						9.0	290	28	2
									3
				PF	1.0	4.5	120	18	1
									2
15.0			3.0	PA	1.2	3.2	130	19	1
						9.2	300	29	2
									3
									4
									5
				PF		3.2	130	19	1
						4.2	160	20	2
									3
20.0				PA		3.8	140	19	1
						9.5	310	29	2
									3
									4
									5
									6

Table 6

**Guide values for MAG welding butt welds on stainless CrNi steel 1.4541.
Wire electrode: G 19 9 L – Shielding gas: Mixed gas M1.2 – Data after [2]**

Plate thickness mm	Groove shape	Included angle °	Root gap mm	Position	Wire electrode dia. mm	Wire feed m/min	Current Ampere	Arc voltage Volt	Pass
1.0	I	–	0	PG	0.8	4.0	70	15	1
2.0			1.5	PA	1.0	3.5	100	16	
			2.0	PG		4.0	105	17	
4.0			2.5	PA		4.3	115		
6.0	V	60	2.0			3.4	95	15	
						10.0	200	26	2
8.0						4.4	110	16	1
						10.0	200	26	2
									3
12.0					1.2	3.0	110	17	1
						8.0	250	28	2
									3
									4

Table 7

**Guide values for MIG welding butt welds on aluminium materials.
Wire electrode: GRAlMg5 – Shielding gas: Argon – Welding position PA – Data after [1] and [2]**

Plate thickness mm	Groove shape	Included angle °	Root face thickness mm *)	Wire electrode dia. mm	Wire feed m/min	Current Ampere	Arc voltage Volt	Pass
2.0	I	–	2.0	0.8	5.0	110	20	1
4.0			4.0	1.2	3.1	170	22	
6.0	Y	70	1.5	1.6	6.0			
8.0					6.8	220	26	2
10.0		60	2.0		6.2	200		1
					6.0	170	24	2
					7.2	230	26	G
12.0			1.5	1.2	13.7	240		1
					12.2	220		2
					15.6	250	28	G

*) without gap between root faces G = Backing run

Table 8

<table>
<tr><th colspan="7">Guide values for MAG welding butt welds on unalloyed and low-alloy steel. Wire electrode: G3Si1/G4Si1 – Shielding gas: Mixed gas M2.1 – Data after [1]</th></tr>
<tr><th>Throat thickness mm</th><th>Position</th><th>Wire electrode dia. mm</th><th>Wire feed m/min</th><th>Current Ampere</th><th>Arc voltage Volt</th><th>No. of passes:</th></tr>
<tr><td rowspan="2">1.0</td><td>PA/PB</td><td rowspan="4">0.8</td><td rowspan="2">3.8</td><td rowspan="2">65</td><td rowspan="2">17</td><td rowspan="10">1</td></tr>
<tr><td>PG</td></tr>
<tr><td rowspan="2">2.0</td><td>PA/PB</td><td>7.3</td><td>130</td><td>19</td></tr>
<tr><td>PG</td><td>7.1</td><td>100</td><td>20</td></tr>
<tr><td rowspan="2">3.0</td><td>PB</td><td rowspan="3">1.0</td><td>10.6</td><td>215</td><td>23</td></tr>
<tr><td>PG</td><td>9.0</td><td>210</td><td>22</td></tr>
<tr><td>4.0</td><td>PA/PB</td><td>10.7</td><td>220</td><td>23</td></tr>
<tr><td>5.0</td><td rowspan="2">PB</td><td rowspan="2">1.2</td><td rowspan="2">9.5</td><td rowspan="2">300</td><td rowspan="2">29</td></tr>
<tr><td rowspan="2">6.0</td></tr>
<tr><td>PF</td><td>1.0</td><td>4.7</td><td>115</td><td>18</td></tr>
<tr><td rowspan="2">8.0</td><td>PB</td><td>1.2</td><td>9.5</td><td>300</td><td>29</td><td>3</td></tr>
<tr><td>PF</td><td>1.0</td><td>4.8</td><td>130</td><td>19</td><td>2</td></tr>
<tr><td rowspan="2">10.0</td><td>PB</td><td rowspan="2">1.2</td><td>9.5</td><td>300</td><td>29</td><td>3</td></tr>
<tr><td>PF</td><td>4.2</td><td>165</td><td>19</td><td>2</td></tr>
</table>

Table 9

<table>
<tr><th colspan="7">Guide values for MAG welding butt welds on stainless CrNi steel 1.4541. Wire electrode: G 19 9 L – Shielding gas: Mixed gas M1.2 – Data after [2]</th></tr>
<tr><th>Throat thickness mm</th><th>Position</th><th>Wire electrode dia. mm</th><th>Wire feed m/min</th><th>Current Ampere</th><th>Arc voltage Volt</th><th>No. of passes:</th></tr>
<tr><td rowspan="2">2.0</td><td>PB</td><td rowspan="2">0.8</td><td>6.5</td><td>100</td><td>17</td><td rowspan="6">1</td></tr>
<tr><td>PG</td><td>7.0</td><td>110</td><td>18</td></tr>
<tr><td rowspan="2">3.0</td><td>PB</td><td rowspan="3">1.0</td><td>9.0</td><td>200</td><td>24</td></tr>
<tr><td>PG</td><td>8.8</td><td>195</td><td>22</td></tr>
<tr><td>4.0</td><td rowspan="3">PB</td><td>10.4</td><td>220</td><td>26</td></tr>
<tr><td>5.0</td><td rowspan="2">1.2</td><td rowspan="2">8.0</td><td rowspan="2">250</td><td rowspan="2">28</td></tr>
<tr><td>6.0</td><td>3</td></tr>
</table>

Normal calculation of the energy per unit length Es = Us · Is · eta/vs [kJ/mm] from the above-discussed mean values leads to significant faults in pulse and short arc processes; voltage drops across the welding cables must also be taken into consideration. Only the correct electronic power calculations, as offered in the EWM Multimatrix and Titan XQ welding machines, provides error-free information for all process types and systems. The thermal efficiency data, for example for MIG/MAG processes, are adopted at 0.8 across the board in welding technology; there are minor differences, depending on the selected process type (see EN 1011-1).

If the energy per unit length is determined, so-called t8/5 measurements may return better results in order to determine the what may be the critical heat input when welding heat-sensitive materials. These measurements are usually relatively easy to perform: The duration of the temperature drop in the seam (heat-affected zone, HAZ) from 800 °C to 500 °C is determined using a thermocouple measuring system. The material suppliers provide information on recommended durations in their data sheets, which – depending on the sheet thickness and weld seam geometries – lead to favourable microstructure and strength conditions (type 5…20 s).

On the basis of a multidimensional heat propagation analysis, modern welding machine controls can determine t8/5 values and display them after the end of welding (e.g. EWM Titan XQ puls with Expert-XQ-2.0 control).

Further information:
https://www.ewm-group.com/en/titan-xq.html

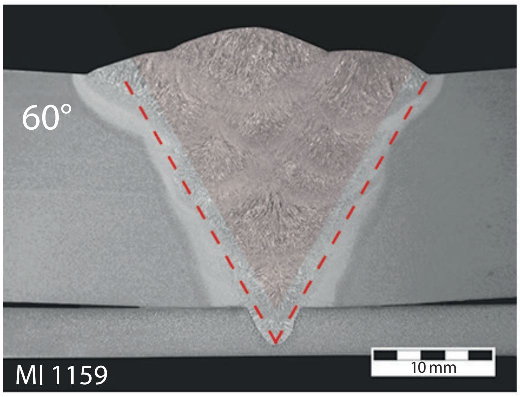
8.5 New procedures and processes

a) The pulsed arc welding process

Cyclic switching from low arc power to high arc power in the millisecond range results in synchronous droplet detachment. The method can be used from low through medium to high wire feed speeds, whereby the pulse frequency is varied between 20 Hz and 400 Hz (pulses per second).

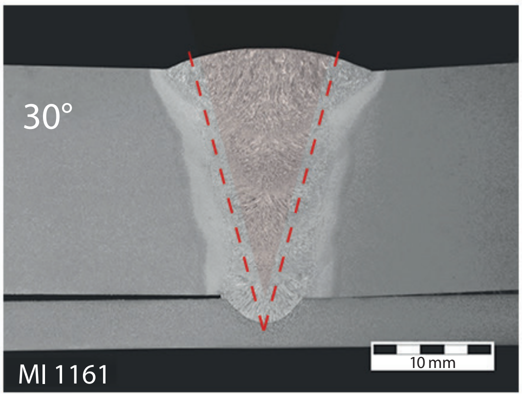
The open- and closed-loop electronics guarantee stable arc characteristics through all ranges. Argon-rich shielding gases must be used when welding unalloyed steels (> 80% Ar).

Standard spray arc



11 runs

forceArc® XQ



5 runs
50% shorter welding time
MI 1161

Figure 34: Comparison of single-V butt welds using the standard method with EWM forceArc technology (t = 20 mm)

Thanks to the superPuls technology, uniform seams on thin aluminium sheets and bead ripples on thick sheets are equally possible.

The synergy programs stored in the welding machines make setting and operating simpler, cleaner and low-spatter.

Further information: Machine catalogue, www.ewm-group.com/en -> EWM arc film: Pulsed arc Alu

b) The EWM forceArc XQ/forceArc puls XQ welding processes

General designation compliant with DVS MB 0973-1: Modified spray arc

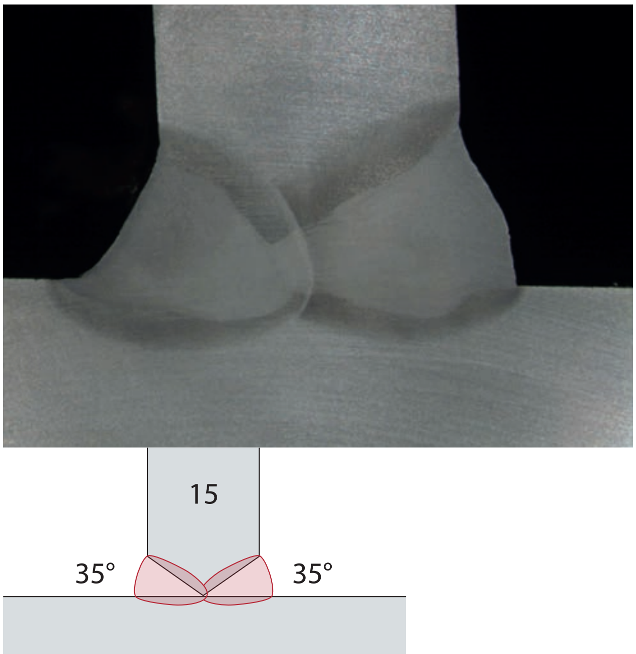
As already described above, the spray arc function can achieve high deposition rates at high wire feed speeds. The associated high currents ensure favourable penetration; however, great heat is usually unintentionally input into the workpiece here. This brings disadvantages in terms of energy per unit length and distortion. If modern electronics and advanced process control are employed, the arc length and thus the heat input can be significantly reduced at higher currents. Penetration depth values are therefore high. Such a process using a "forced arc" can penetrate unusually deeply with material sheet thicknesses and excellently captures the sidewalls. Rapid control interventions by the electronic control system prevent the heavy spatter formation that normally occurs with short arcs.

The images in the EWM MIG/MAG product overview (https://www.ewm-group.com/en/innovation-research/mig-mag-welding-procedure.html -> forceArc) clearly show that much narrower grooves (30° instead of 60°) can be mastered in seam preparation with the deep penetration and the directionally stable arc; root and sidewall fusion are excellent. Considerably fewer passes must be made. Welding time is shorter – halving is possible – considerable material savings are made and there is less distortion due to the lower heat input (Figure 34). (-> Quotes from the forceArc website discussed above)

There are fewer undercuts and less spatter thanks to the short arc. Stick-out length changes are electronically corrected; particularly long wire ends in tight grooves are mastered.

The typical deep penetration when welding fillet welds on thick sheet metal leads to particularly favourable connection cross-sections without critical edge notches, as are required for structures that are subject to high dynamic loads.

The images in the EWM "forceArc" product overview discussed above also show the unusually deep penetration on fillet welds with a greater material thickness. In this way, full connections can be safely achieved on seams welded on both sides (Figure 35).



S355, 15 mm, included angle: 35°

Figure 35: Full penetration thanks to deployment of forceArc technology

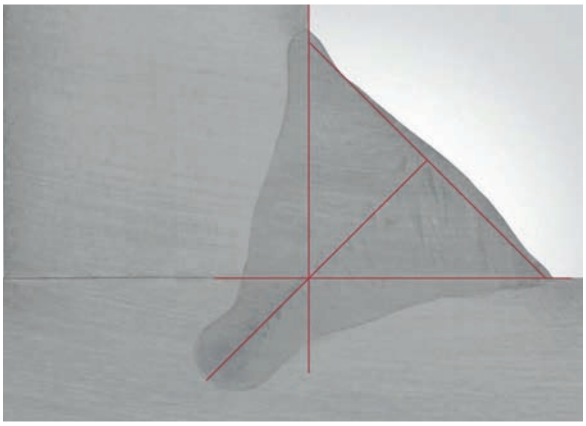


Figure 36: Throat thickness and penetration with forceArc puls

The forceArc process can be used with unalloyed, low-alloy and high-alloy steels as well as with high tensile strength fine-grained steels and can be used manually or in automated processes.

In the forceArc puls variant, controlled heat can be introduced for a comparatively longer arc. This is useful, for example, when welding cover passes so that the sidewalls flow smoothly with little seam curvature. Figure 36 shows an example application. (https://www.ewm-group.com/en/innovation-research/mig-mag-welding-procedure.html -> forceArc puls).

c) The coldArc XQ/coldArc puls XQ welding processes

General designation compliant with DVS MB 0973-1: Controlled, low-spatter short arc.

The short arc is short-circuited during the material transfer from the wire to the weld pool and thus has a low heat input (Figure 22). Arc burning phases alternate cyclically with short-circuit phases. In the coldArc process, the up-slope in the arc short circuit is limited by the electronic control technology (EWM Rapid Current Control Technology). The short circuit is resolved by separating the fine bridge of liquid metal. However, this leads to a peak power that inevitably creates spatter due to its high plasma pressures. The coldArc XQ process suppresses this critical power peak with great technical effort within the welding machine and thus reduces spatter ejection to a minimum. This makes the process valuable for visible welds.

The extremely low heat input reduces distortion and discolouration. Large root gaps can be excellently bridged with the colder weld pool. Positional welding or MIG brazing are considerably easier.

The coldArc XQ process can be used with unalloyed, low-alloy and high-alloy steels as well as with high tensile strength fine-grained steels and can be used manually or in automated processes.

Moreover, additional controlled heat can be input using the coldArc puls XQ variant. This allows the seam to be better wetted or widened, e.g. for intermediate and cover passes in the transition zone.

The machine switches automatically between coldArc XQ and coldArc puls XQ when Positionweld is turned on, facilitating outstanding and straightforward welding in the vertical up position, without using the “Christmas tree technique”.

Further information: https://www.ewm-group.com/en/innovation-research/mig-mag-welding-procedure.html

d) The rootArc XQ/rootArc puls XQ welding processes

The heat-minimised, directionally stable short arc works in the low power range and is ideal for root welding in different positions. With the introduction of the new RCC (Rapid Current Control) inverter technology, the rootArc XQ welding process has been optimised once again. The arc is powerful and directionally stable and melts the edges of the workpiece well. It bridges the gap perfectly, reliably encompasses the sidewalls and is ideal for root welding in any position.

Compared to the MMA and TIG methods, welding can be carried out at higher speeds; the deposition rate is also higher. The weld surface is flat and smooth, saving finishing work. If necessary, the heat input can be increased through superimposing pulses (superPuls). Among other things, the torch trigger can be used to switch between the two versions in the running process. This welding process is employed in both manual and mechanised applications.

Further information: https://www.ewm-group.com/en/innovation-research/mig-mag-welding-procedure.html

e) The superPuls welding process

General designation compliant with DVS MB 0973-1: Combined process variants

It is useful to combine different processes if a demanding welding task cannot be optimally solved with one process. Two different processes can be selected using the superPuls function; the welding machine alternates rhythmically between the two processes and between two power levels.

In the case of coldArc XQ and pulsed arc technology, the pulsed arc phase generates the necessary heat to melt the seam fusion faces in positional welding. The subsequent short arc phase allows the ensuing weld pool to quickly solidify.

Among other things, this results in highly uniform bead ripples, extremely beneficial in aluminium welding, low heat input and simple seam modelling. Vertical-up welds can be very easily mastered. The switching parameters are automatically adapted proportional to the process power.

f) Positionweld

Positionweld combines the tried-and-tested EWM processes for reliable penetration and uniform seam appearance in positional welding: when welding upwards, the welding torch can be held straight, without using the “Christmas tree” technique. This allows faster welding with less heat input. Parameters do not need to be elaborately identified; welding power only needs to be adapted to the respective material thickness.

Further information: https://www.ewm-group.com/en/innovation-research/mig-mag-welding-procedure.html

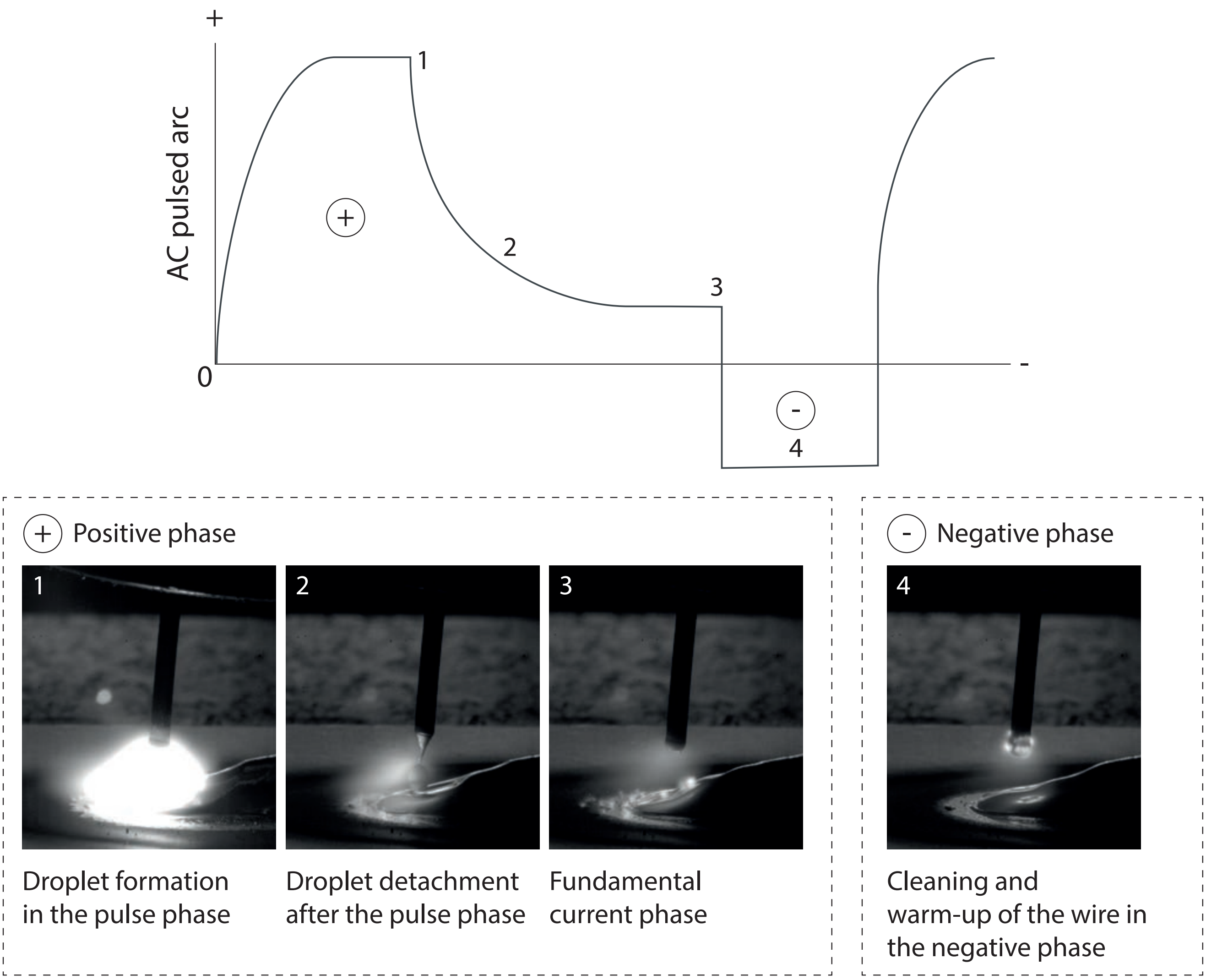
g) EWM wiredArc – Welding with constant penetration

The changes in distance between the welding torch and the workpiece, which are particularly unavoidable in manual MIG/MAG welding, lead to a noticeable change in current in the classic processes by changing the stick-out length (free wire end). As the distance increases, the welding current decreases significantly and the penetration depth becomes smaller. The seam quality is at risk. EWM wiredArc helps to compensate for undesirable changes in current through active, electronic intervention in the wire feeder. The penetration depth is therefore kept constant for components with areas that are difficult to access, where a change in distance is unavoidable.

Further information: https://www.ewm-group.com/en/innovation-research/mig-mag-welding-procedure.html

h) The acArc puls XQ welding process

In the acArc puls XQ welding process, the polarity switches between positive (pulse) and negative during the process. This is made possible by the fast digital current control employing the new EWM RCC (Rapid Current Control) inverter technology.



The acArc puls XQ welding process

Because the polarity changes between the workpiece and the welding wire, the heat is transferred from the material to the filler material. The heat at the workpiece is minimised. This allows even thin aluminium sheets to be perfectly welded. In addition, air gaps are very easily bridged.

The principle (see Figures 1–4 above): The droplet forms in the positive pulse phase and detaches just before the subsequent fundamental current phase. During the negative phase, the wire is cleaned and preheated. The next droplet is detached in the subsequent positive phase.

In addition to welding fume emissions and burn marks, magnesium oxides are also greatly reduced. The result is clean, shining welds. The acArc puls XQ welding process is employed in both manual and automated fields.

i) The MIG/MAG tandem welding process

To increase performance, a GMAW tandem welding process has been in use for years. Here, two GMAW processes are arranged closely behind one another within a large (oval) welding torch. The two circuits are electrically isolated from each other and are supplied by two power sources and two wire drives. This welding procedure can only be operated fully mechanised or automated, e.g. by using robots. This enables particularly high welding speeds to be achieved on thin sheets and high deposition rates on thick sheets. The procedure can be used in both steel and aluminium welding.

8.6 Mechanisation options

In semi-mechanical MIG/MAG welding, filler material and shielding gas are already added mechanically; the arc length is also controlled automatically. Only the welding progress movement is performed manually. Full mechanisation is easily possible: The welding torch is clamped and moved on a carriage at welding speed across the workpiece. Alternatively, the welding torch is suspended stationary and, for example, an axis-symmetric component in a positioner beneath the welding torch is moved. The uniform movement essentially guarantees high and reproducible seam quality. However, the welding torch tip must be precisely guided in the real groove with the aid of suitable measures (Figure 37).

The MIG/MAG process is also suitable for difficult mechanisation tasks, if several welding torches weld a single workpiece simultaneously, for example. It is not for no reason that MIG/MAG welding is the procedure that is by far the most frequently used for arc welding with industrial robots.

Figure 37: Fully mechanised GMAW orbital welding

Further information: Welding Accessories Catalogue, https://www.ewm-group.com/en/downloads.html

9. Occupational safety

In accordance with the requirements of the Hazardous Substances Regulations and the current technical occupational safety status for welding, the generated welding fumes must be extracted.

The use of modern, innovative EWM welding processes can significantly reduce the emission of harmful welding fumes.

Scientific studies show that the digitally modified, innovative coldArc®, forceArc® and forceArc puls® processes reduce welding fume emissions significantly and minimise hazards for welders and operators. These findings are also relevant regarding the German Building Trade's Employers' Liability Association Information Sheet 593 – Harmful substances during welding and related processes (BGI 593 – Schadstoffe beim Schweißen und bei verwandten Verfahren).

The coldArc® process develops up to 75% fewer emissions for the same deposition rate than the short arc process (Figure 38). forceArc® can reduce emissions by up to 40% as a result of the greater weld fume deposition on the workpiece surface (Figure 39).

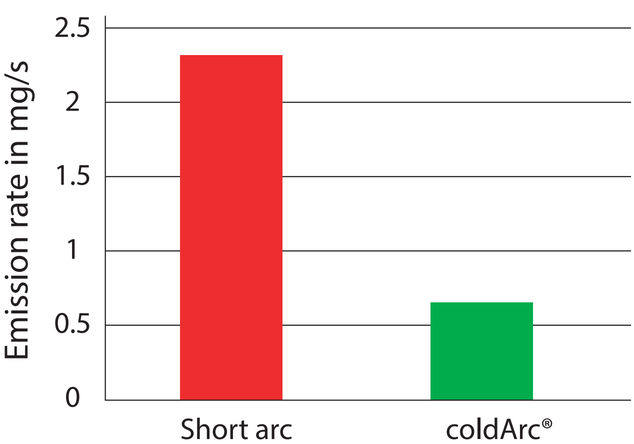


Figure 38: coldArc® emission rate

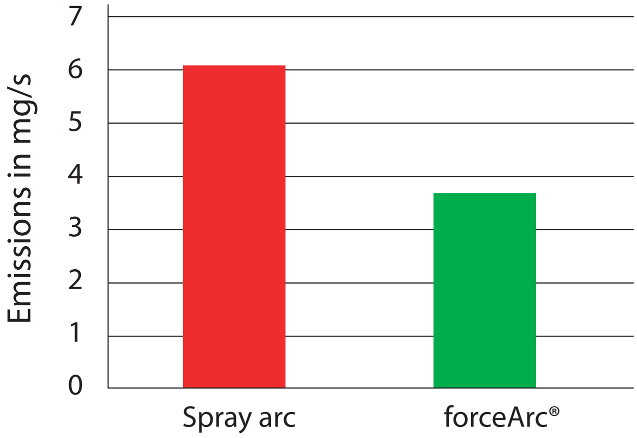


Figure 39: forceArc® emissions

With forceArc puls®, the emission rate when welding high-alloy (CrNi) steel drops to a rate 4.5 times lower than with the pulsed arc (Figure 40) – an important contribution to protecting the welder's health.

The welder must also protect himself from the radiation from the arc and from electrical hazards. The MIG/MAG welder generally wears a head shield against the infrared and intense ultraviolet radiation, which keeps both hands free. The welding safety glass is integrated in this protective screen. The filters are standardised compliant with EN 169. There are various protection levels that must be permanently legible on the glass. In MIG/MAG welding, filters with protection levels from 8 to 15 are used, depending on the current applied. Level 8 is one of the lower currents; 15 is assigned to the higher currents.

The ultraviolet radiation is harmful to the skin even after only short exposures. Protective clothing must therefore cover the entire body.

The greatest electrical hazard is presented by the open circuit voltage. This is the highest voltage that is supplied by the switched-on power source between the connection sockets when the arc is not burning. After the arc is ignited, the voltage is much lower, for MIG/MAG welding, for example, between about 15 and 40 volts. According to UVV VBG 15, power sources for direct current in normal operation may have a peak open circuit voltage value of 113 volts max. For AC systems that are used for MIG/MAG welding in special cases, this value is also 113 volts.

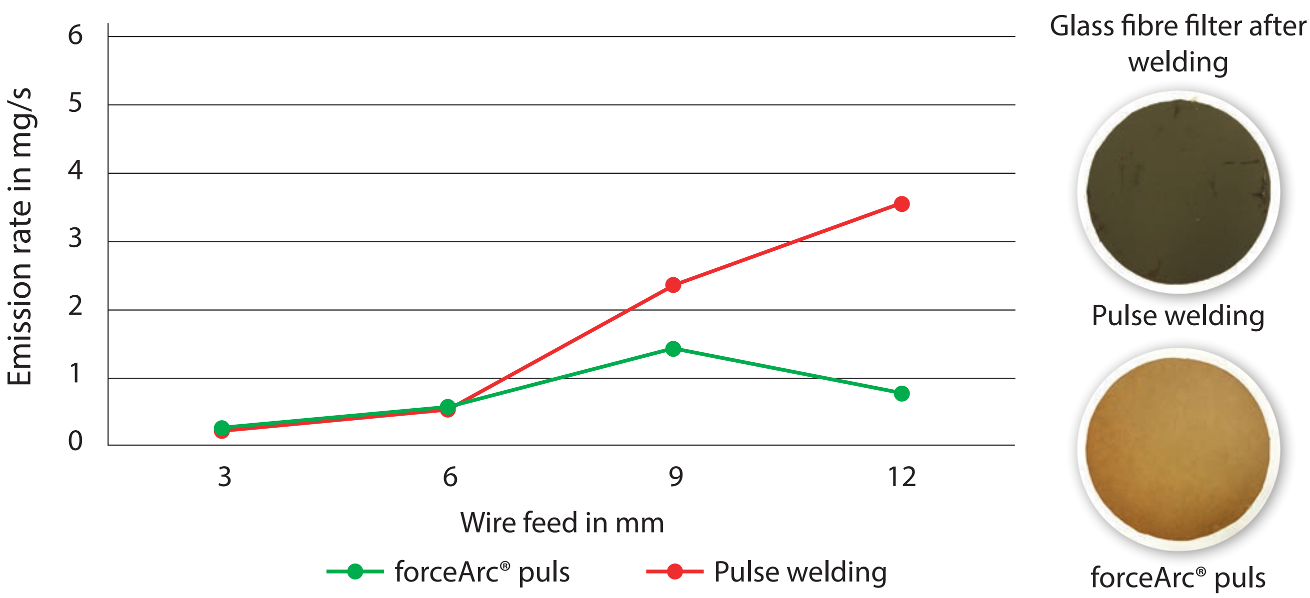


Figure 40: Emission rates depending on wire feed on forceArc puls® and pulse welding

Figure 41: MAG welding in steel construction

However, the root-mean-square value is limited to 80 volts max. If there is an increased electrical hazard, such as when welding in confined spaces or on large iron masses, reduced values for alternating current apply (e.g. a peak value of 68 volts and a root-mean-square value of 48 volts). More recent power sources that meet this demand have an "S" mark compliant with EN 60974-1. Older power sources, in contrast, may still be marked with "K" (direct current) or "42 V" (alternating current). The welder's most effective protection against electric shock is by wearing undamaged leather welding gloves, well-insulated work clothes and appropriate footwear.

The welder should be aware that, after starting the welding machine, the open circuit voltage (> 60 V) and the working voltage (15 ... 40 V) are applied to the wire electrode and the contact tip during welding. The wire spool and the drive in the wire feeder also carry this voltage. In welding operations, spatter that penetrates the gas nozzle can establish a connection between the contact tip and the gas nozzle in unfavourable cases. This means it is live. If the gas nozzle then makes contact with the component connected to ground, a destructive short-circuit current can be the result.

In the majority of cases there is a connection between the component that is connected to ground and an earthed system (protective earth PE). If the live wire tip now makes contact with any metal parts of the surrounding system, a high current driven by the welding machine flows, which has an immediate destructive effect. Protective earth systems are at great risk here and must be examined regularly by a qualified electrician at welding workstations!

10. Characteristics of various materials

As previously mentioned, the MIG/MAG process is suitable for welding a wide range of materials. The following is a list of some of the special characteristics of the different materials.

Figure 42: MIG aluminium welding

10.1 Unalloyed and low-alloy steels

Unalloyed and low-alloy steels are welded using mixed gases M1, M2, M3 or, more rarely, using pure carbon dioxide (Figure 40). However, on account of the lower spatter formation, especially in the upper power range, mixed gases predominate in Europe. These steels can generally be welded in good quality using the MAG process.

High carbon grades form an exception, such as E 360 (formerly St 70), with approximately 0.45% carbon. The large process penetration causes the weld metal to absorb a relatively large amount of carbon by mixing. This then presents a hot-cracking risk. All measures that reduce penetration and therefore also mixing, can provide a remedy here. This includes low current intensities and welding on forward-travelling weld metals. Care must be taken in terms of the risk of lack of fusion.

Pores in the weld result from various causes, such as air introduced through insufficient shielding gas coverage, outgassing from contamination or residual moisture in the workpieces. Pores are prevented if the shielding gas quantity is correctly adjusted.

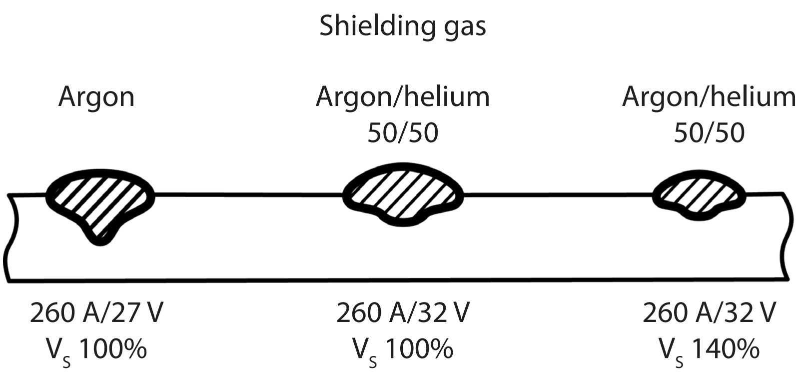


Figure 43: Penetration profile for different shielding gases. Material: AlMg3, wire Ø. 1.6 mm

Spatter in the shielding gas nozzle or process instabilities should be avoided. They can lead to swirling of the shielding gas flow and thus to pores. Using carbon dioxide as a shielding gas makes the process less susceptible to pore formation: In the case of mixed gases, the sensitivity is reduced as the CO_2 content increases. Individual pores are not generally critical. Larger accumulations should be avoided (also see DVS MB 0913).

10.2 High-alloy steels and nickel-based alloys

In principle, this material group can also be welded well using the MIG/MAG process. The shielding gases used for high-alloy steels are argon/oxygen mixtures with 1–5% oxygen (M11) or argon with CO_2 content up to 2.5% (M12). A significant disadvantage when welding corrosion-resistant steels is the oxidation, which remains on and next to the seam after welding. They must be completely removed by brushing, pickling or blasting before the component is put into operation, because they impair the corrosion resistance. The cleaning effort for MAG welded seams is greater than that for MMA welding. Here, the slag cover prevents oxygen from coming into contact with the weld surface even at higher temperatures. Part of the economic advantages of partly mechanised welding can therefore be lost owing to the amount of clean-up work required. Mixed gases containing CO_2 are more favourable in this respect than those containing O_2. As a result, they are increasingly used. However, if the proportion of carbon dioxide in the shielding gas is too high, the gas that breaks down in the arc leads to carburisation and oxidation of the weld metal and thus to lower corrosion resistance. The allowable CO_2 content is therefore limited to 5% max.

Figure 44: MAG welding of a lorry trailer

Figure 45: MAG welding a CrNi steel hopper

Any overheating must be avoided when welding corrosion-resistant steels. Here, chromium carbide is excreted, which can make the steel brittle and more susceptible to corrosion. Over-alloyed filler material can compensate for this effect. Heat input therefore needs to be controlled and it may be necessary to allow the workpiece to cool down by including intermediate cooling breaks. With materials in the fully austenitic steels groups, “cold” welding also prevents hot cracks.

Because austenitic steels do not embrittle under the influence of hydrogen, a few percent of hydrogen can also be added to the argon to increase performance (increase the welding speed). However, the H_2 content should not be more than 5% owing to the risk of pore formation. In contrast, duplex steels, a two-phase microstructure of austenite and ferrite, form more cracks with hydrogen.

Nickel-based alloys are generally MIG-welded using argon. In the case of pure nickel and some alloys, low levels of hydrogen additives can reduce the surface tension and thus improve the seam formation.

10.3 Aluminium and aluminium alloys

Aluminium materials are always MIG-welded (Figure 42, page 42).

Argon (100%) is generally used as the shielding gas. Because aluminium dissipates heat very easily, the addition of helium is particularly effective here. As previously noted, helium improves heat input into the workpiece, among other things. Penetration is deeper and wider, as shown schematically in Figure 43 (page 42).

Where deeper penetration is not needed, e.g. when welding thinner sheet metal, welding can be performed more quickly. Because the material conducts heat easily, thicker aluminium cross-sections need to be preheated. The warmer weld metal thus has more time to degas, which ensures sufficient penetration and reduces the susceptibility to pores. When using helium-containing shielding gases – levels of 25% or 50% are common – only slight preheating is necessary, or no preheating at all if the wall thickness is low. This partially compensates for the higher price of helium-containing gases.

The high-melting oxide skin can easily be eradicated on the pool in MIG welding, because the positive pole is on the electrode (cathodic cleaning). It is nevertheless advisable to remove the oxide layers from the workpiece immediately prior to welding by scraping or brushing, because they are hygroscopic and therefore carry hydrogen into the weld metal. In addition to injected air, hydrogen is the primary cause of pore formation when welding aluminium materials. If the aluminium is molten, hydrogen can be relatively easily dissolved in it. In the solid state, on the other hand, the gas is practically insoluble in metal. If no pores are to be formed, then any hydrogen absorbed during welding must therefore leave the weld metal before solidification. This is not always possible, especially on thicker cross-sections. Moisture on the workpieces is particularly harmful in a cold environment. In the case of greater wall thicknesses, entirely pore-free seams cannot therefore be achieved in aluminium materials. The beneficial effect of preheating has already been mentioned.

With Si contents of around 1% or Mg contents of around 2%, AlMg and AlSi alloys tend to form hot cracks during welding. Avoid this alloy range when selecting the filler material. Wire electrodes with an alloy content one degree higher usually perform better than electrodes of exactly the same type.

10.4 Other materials

In addition to the previously discussed materials, copper and copper alloys are MIG-welded to a significant extent. Owing to its high thermal conductivity, pure copper needs a relatively high level of preheating in order to avoid lack of fusion.

The weld metal of bronze wires, e.g. those made from aluminium bronze or tin bronze, has good sliding properties. It is therefore used for surfacing sliding surfaces. In these welds on ferrous materials, penetration must be kept low by taking appropriate measures, because iron has a low level of solubility in copper. It is included in the weld metal in the form of small spheres and thus reduces the usage properties.

MIG brazing has similar conditions. For example, this process is used to join galvanised sheets in automobile construction. Silicon or tin bronze wire electrodes are used as filler material. Zinc vaporisation is reduced as a result of the low melting point of these bronzes. Fewer pores are created, and the protection provided by the zinc coating is retained right up to near the seam and on the back of the sheets. Here, too, there should be no penetration into the steel material, if possible. When brazing, the bond should only be made by means of diffusion and adhesion forces. This is achieved by adapting the welding parameters and using a special torch position so that the arc burns only on the molten weld pool.

11. Application of MIG/MAG welding

11.1 Production branches

According to recent statistics, the proportion of the process among all arc welding procedures is approximately 80%.

There are almost no branches of industry in which MIG/MAG welding is not used. The main areas of application are vehicle construction, where motor vehicles, locomotives and rail vehicles are fabricated, for example. Aluminium is also increasingly used here. Moreover, it is also used in steel and bridge construction, shipbuilding and mechanical engineering. High-tensile steels are increasingly being used in crane and excavator construction. The MAG process is particularly suitable for this because the weld metal has a low hydrogen content. Therefore, no cold cracks occur. MAG welding is somewhat underrepresented in boiler, apparatus and pipe construction. Because of the excellent quality demanded of the weld metal, basic stick electrodes are often welded here, or work is performed using the submerged arc procedure.

However, not only in industry but also in the trades there is barely a workshop that does not use MAG welding. This applies to automotive workshops as well as metalworking shops and small steel construction companies.

11.2 Application examples

Finally, a few selected application examples should clarify the appropriate use of the MIG/MAG process.

Figure 41 (page 41) shows the use of MAG welding in steel construction. Fillet welds or double bevel seams are used at the corners of beams, as can be seen in the image. On longer beams, butt welds must also be welded transversely to the main direction of loading. They must be especially fault-free; this is separately specified.

Figure 44 (page 43) shows the use of MAG welding on a steel lorry trailer. The wire feeder was mounted on a movable boom arm to allow the welder to easily reach all the points to be welded.

The ewm Xnet quality management software is used in modern EWM welding machines to ensure the quality of the welds. This allows comparisons between nominal and actual values. This is shown in Figure 45 (page 44), where MAG welding is employed on a CrNi steel hopper.

To ensure that the relatively soft aluminium wires are fed without difficulty, welding is carried out here using a push/pull drive.

12. Welding processes

12.1 Overview

a) Welding unalloyed and low-alloy steel

- Root welding —— rootArc® XQ
- Welding filler passes and cover passes —— forceArc puls® XQ
- Welding fillet welds with deep penetration —— forceArc puls® XQ
- Welding using 100% CO_2 —— coldArc® XQ/rootArc® XQ

b) Welding unalloyed, low-alloy and high-alloy steel

- Welding full-penetration fillet welds —— forceArc puls® XQ
- Positional welding without using the "Christmas tree" technique —— Positionweld
- Welding with consistent penetration and consistent power —— wiredArc® XQ/wiredArc® puls XQ

c) Welding and brazing of unalloyed, low-alloy and high-alloy steel and galvanised sheet metal

- Welding and brazing thin sheet metal —— coldArc® XQ

d) Welding high-alloy steel

- Welding filler passes and cover passes —— forceArc puls® XQ

e) Welding aluminium and aluminium alloys

- Welding aluminium and aluminium alloys —— pulsed arc XQ
- Positional welding without using the "Christmas tree" technique —— Positionweld
- Welding aluminium lap welds —— acArc puls XQ
- Welding aluminium fillet welds —— acArc puls XQ + Positionweld

f) Surfacing

- Cladding, hardfacing

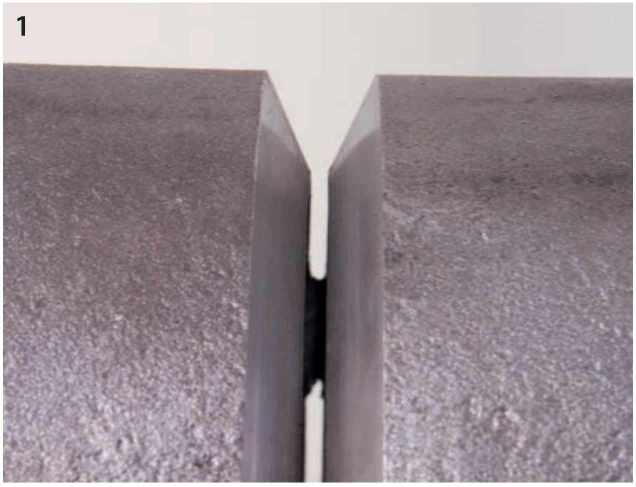
12.2 Root welding of unalloyed and low-alloy steel

Welding process: rootArc® XQ

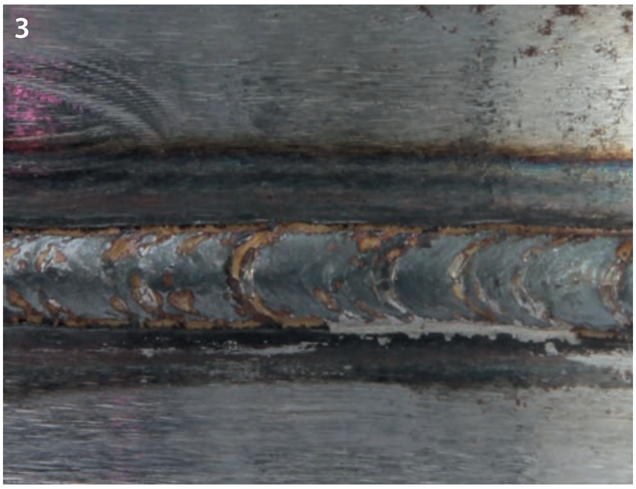
Advantages:

- Perfect gap bridging
- Excellent root formation and sidewall fusion
- High arc force for root welding in all positions
- High welding speed and deposition rate compared to TIG or MMA welding
- Low-spatter process
- Rapid digital control of the process, easy to guide and control
- Uses standard welding torches without additional wire movement
- Welding even with long hose packages without additional voltage measuring leads thanks to RCC power module (Rapid Current Control)
- For manual and mechanised applications
- Flat, smooth weld surface and virtually spatter-free process for reduced finishing work

Root welding in PC position with air gap, without backing

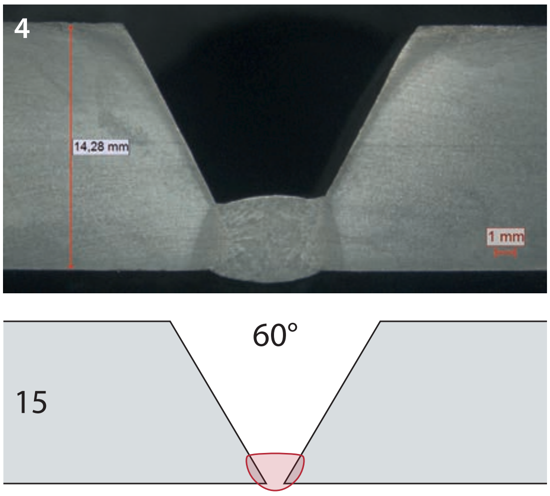


Weld preparation of root welds on pipes, 60° included angle with 3 mm air gap



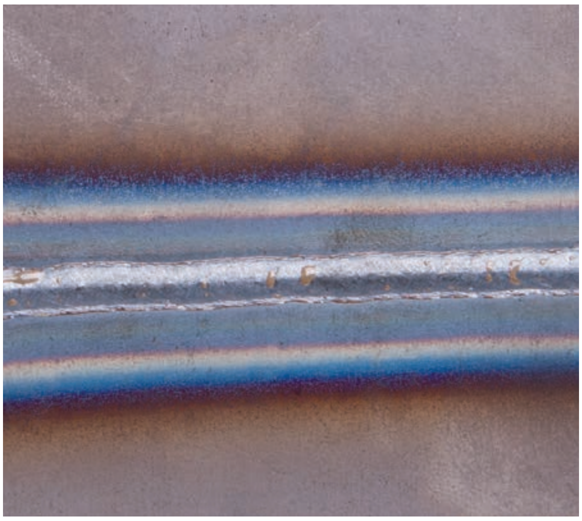
Root

Front view

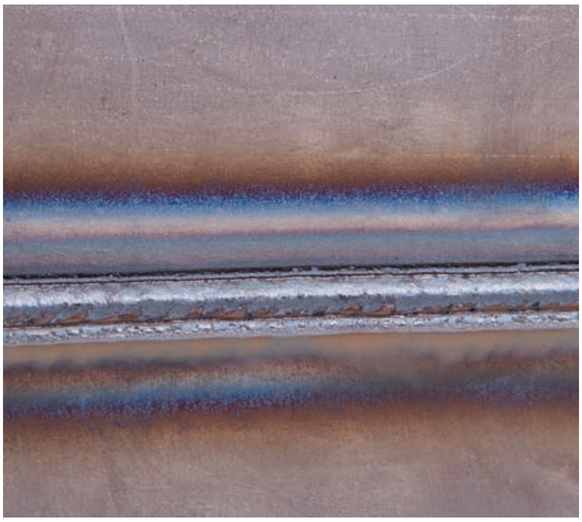


Pipe welding, wall thickness :15 mm, included angle: 60°

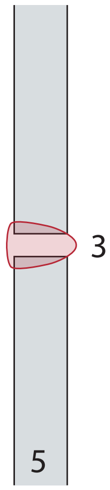
Root welding in PC position with air gap, without backing (t = 5 mm)



Front view

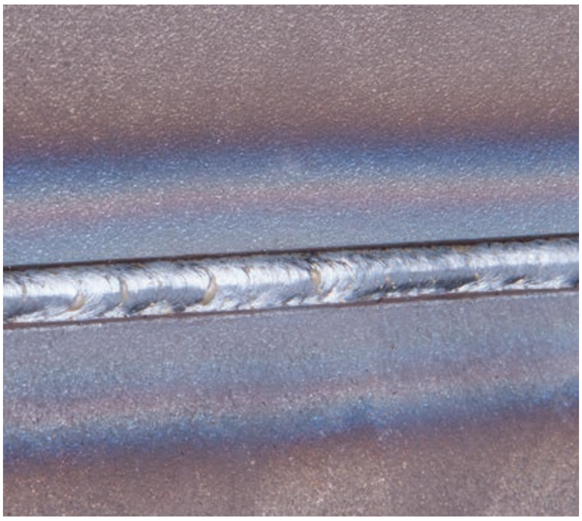


Root

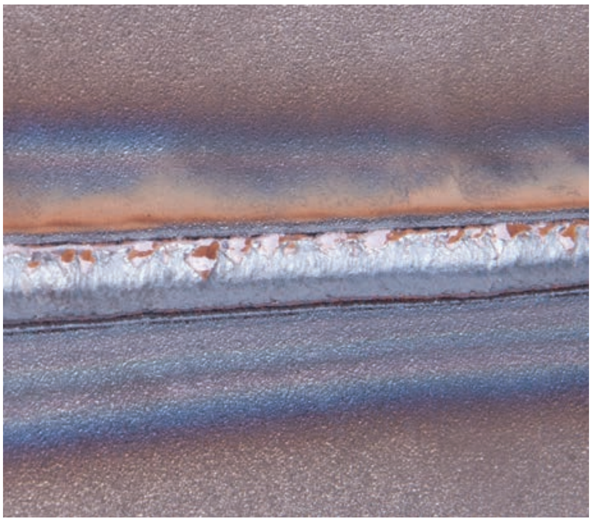


Material thickness: 5 mm
air gap: 3 mm

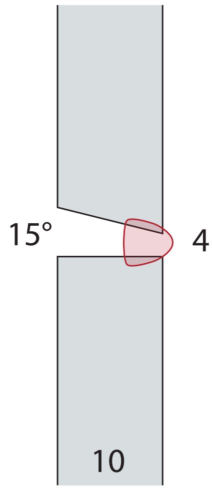
Root welding in PC position with air gap, without backing (t = 10 mm)



Front view



Root



Material thickness: 10 mm, one-sided bevel: 15 degrees, air gap: 4 mm

12.3 Welding filler passes and cover passes in unalloyed and low-alloy steel

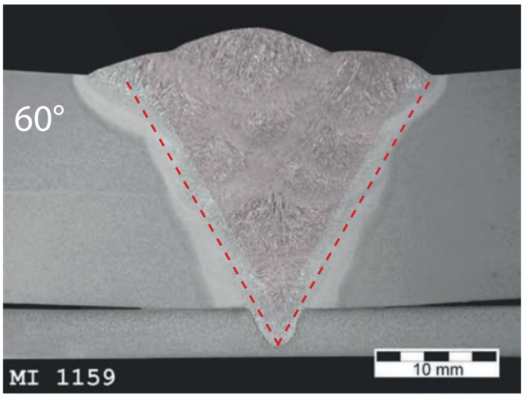
Welding process: forceArc puls® XQ

Advantages:

- Easy to learn, even for inexperienced welders, thanks to rapid digital control of the process, virtually spatter free, reduced undercuts
- Deep penetration for excellent root and sidewall fusion
- Modified, heat-reduced, directionally stable pulsed arc
- Enables weld volumes to be reduced, potential for over 50% reduction of welding times in production, manual and automated
- Perfect welding even with very long stick-outs
- Excellent gap bridging even in high power ranges
- Excellent wetting of the material surface, smooth weld surface even on heavily oxidised or soiled sheet metal
- Qualified by welding procedure test (process no. 135), compliant with EN ISO 15614-1

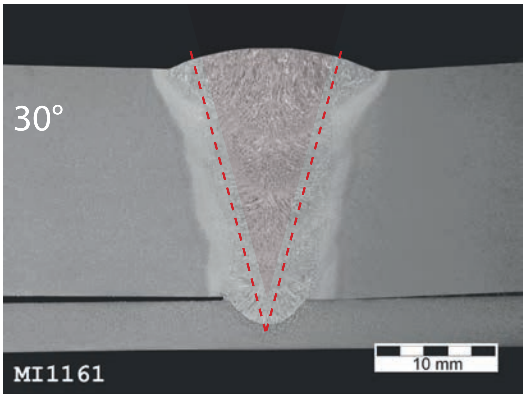
Welding with reduced seam volumes has been tested and confirmed multiple times by independent institutes. The EWM forceArc® XQ and forceArc puls® XQ welding processes allow welding times to be reduced by up to 50% compared to standard spray arc processes. The reduced included angle saves resources without changing the mechanical and technological properties.

Standard spray arc



11 runs

forceArc® XQ

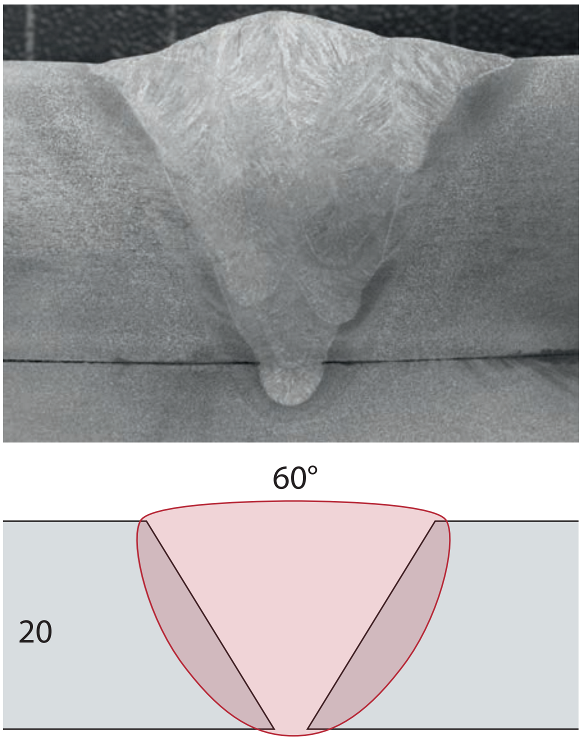


5 runs
50% shorter welding time

Unchanged mechanical/technological properties

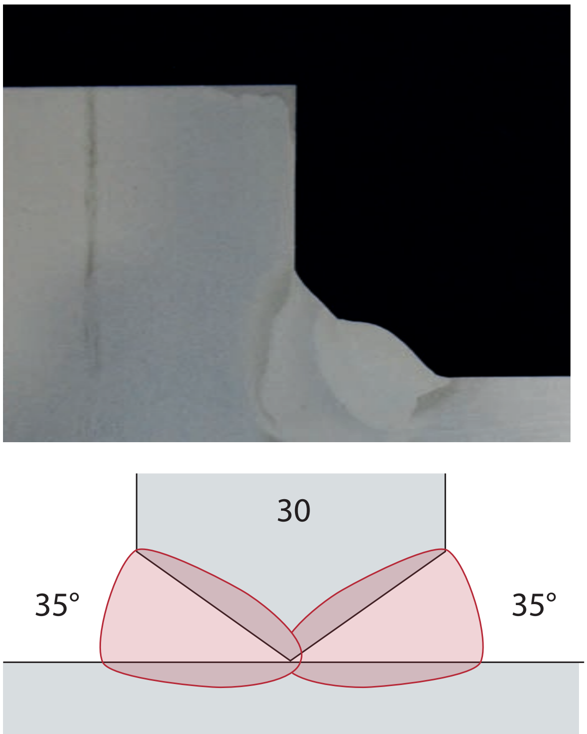
A complete technical report documenting all the advantages can be found online at the following link: www.ewm-group.com/sl/fachbericht

Full penetration, one-sided butt joint with reduced included angle

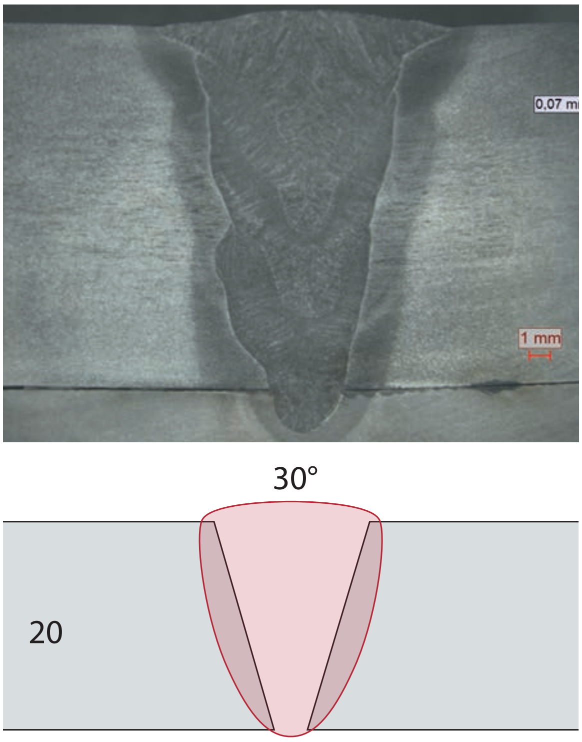


S355, 20 mm, included angle: 60°
9 weld beads, standard spray arc

Full penetration,
T-joint welded on both sides

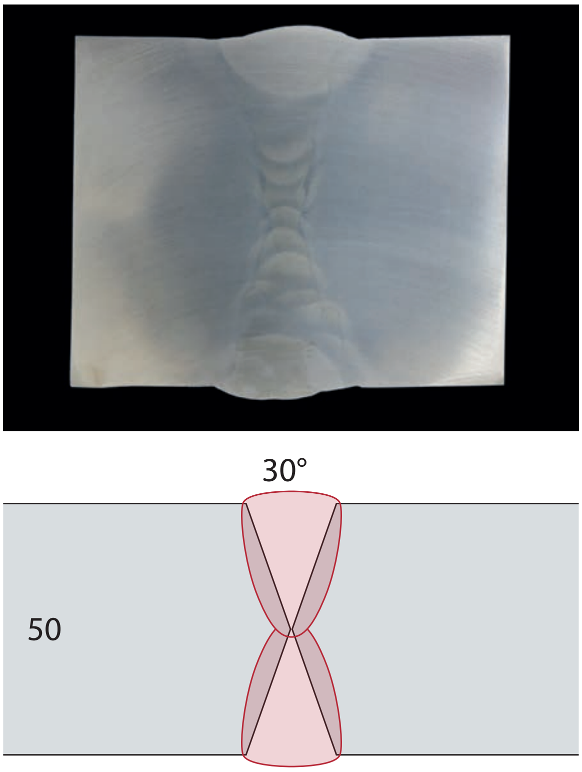


S235, 30 mm, included angle: 35°
8 weld beads



S355, 20 mm, included angle: 30°
4 weld beads, forceArc puls® XQ

Full penetration,
butt joint welded on both sides



S355, 50 mm, included angle: 30°
15 weld beads

12.4 Welding fillet welds with deep penetration on unalloyed and low-alloy steel

Welding process: forceArc puls® XQ

Advantages:

- Reduced number of welding passes for fillet welds
- Deep penetration for excellent root and sidewall fusion
- Modified, heat-reduced, directionally stable spray arc
- Perfect welding in narrow grooves, even with very long stick-outs
- Rapid correction of alterations to stick-out lengths, reliable processing of stick-out lengths up to 40 mm
- Forces transferred to the interior of the component by deep penetration, seam volume reduced by large effective seam thickness compliant with EN ISO 17659:2005-09, reduced heat input into the component
- Qualified by welding procedure test (process no. 135), compliant with EN ISO 15614-1
- Rapid digital control of the process, easy to learn and directly applicable regardless of torch angle

Additional information
www.ewm-group.com/sl/forcearctitan

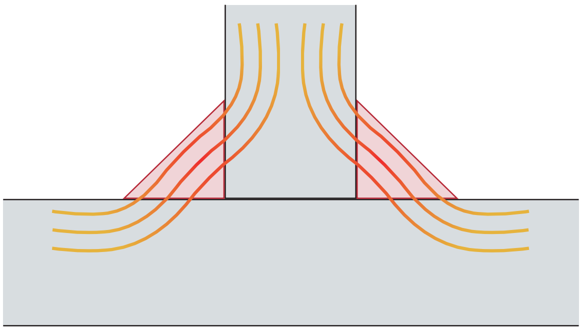
Energy savings

Reduced production time (welding, finishing work)

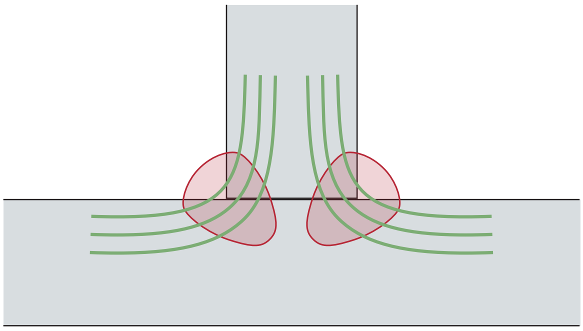
Reduced material costs

Reduced welding fume emissions

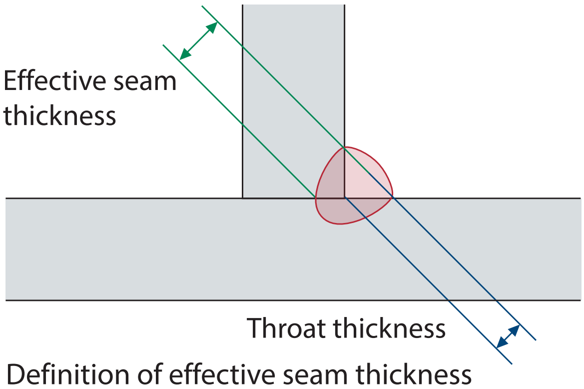
Welding with deep penetration compliant with EN 1090
By taking the effective seam thickness of fillet welds into account, the forceArc puls® XQ process enables single-pass welds up to throat = 8 mm to be created as opposed to throat = 5 mm in processes without deep penetration.



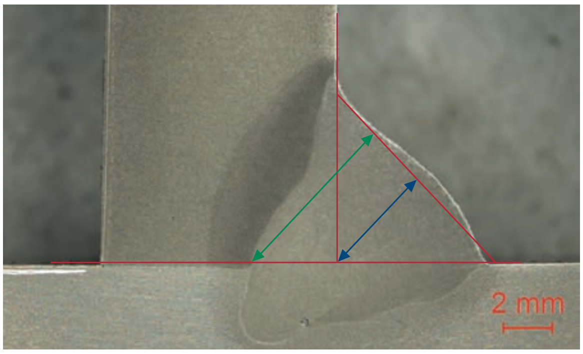
Flow of force in standard fillet welds



Improved flow of force thanks to deep penetration

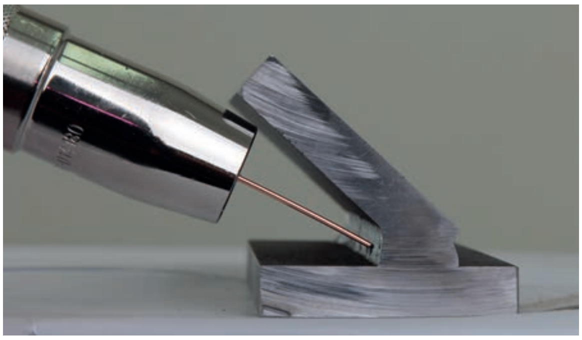


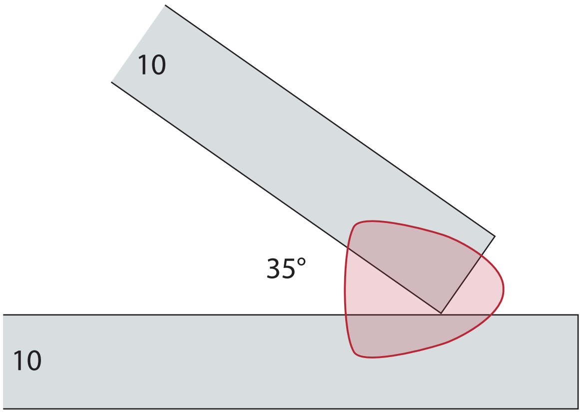
Definition of effective seam thickness compliant with EN ISO 17659:2005-09



S355, 10 mm, effective seam thickness of 8 mm compliant with EN ISO 17659:2005-09

Welding with deep penetration and long stick-out





Material thickness: 10 mm, included angle: 35°

12.5 Welding with constant penetration and constant power on unalloyed, low-alloy and high-alloy steel

Welding processes: wiredArc® XQ/ wiredArc® puls XQ

Advantages:

- Welding process with consistently high penetration depth regardless of alterations to the stick-out
- Virtually spatter-free welding results thanks to rapid digital control of the welding process
- Digital process control supplies a consistent welding current
- The energy per unit length and heat input remain virtually consistent despite changes to the stick-out
- Ability to reduce the seam's included angle and therefore the weld seam volume
- Flat, even weld surface and virtually spatter-free process for reduced finishing work
- Easy to learn and to control

Standard

Alteration of the stick-out causes the penetration depth to change in standard welding processes (Figure 43). In particular, welding with an increasing stick-out length can cause the weld root to be insufficiently fused (lack of fusion).

wiredArc XQ

With EWM wiredArc XQ (Figure 44), the penetration remains consistent when the stick-out is altered. The innovative control keeps the welding current and the heat input virtually consistent.

12 mm stick-out | 30 mm stick-out

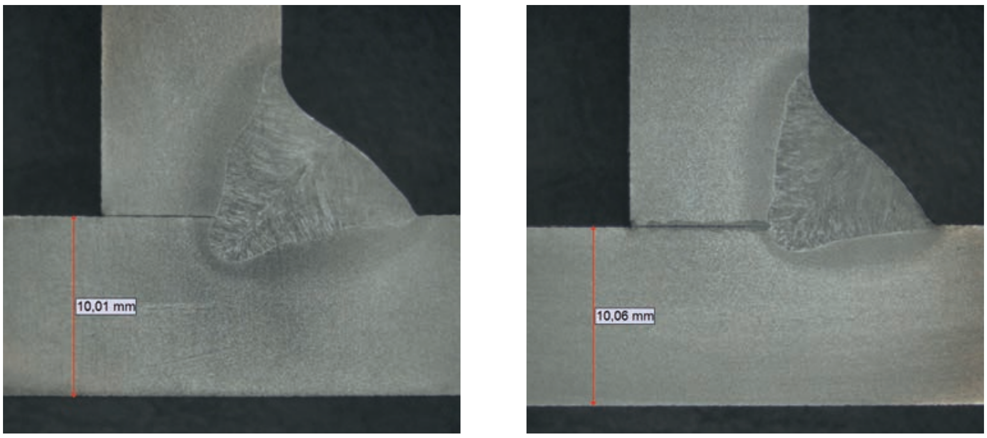


Figure 43: Standard welding process

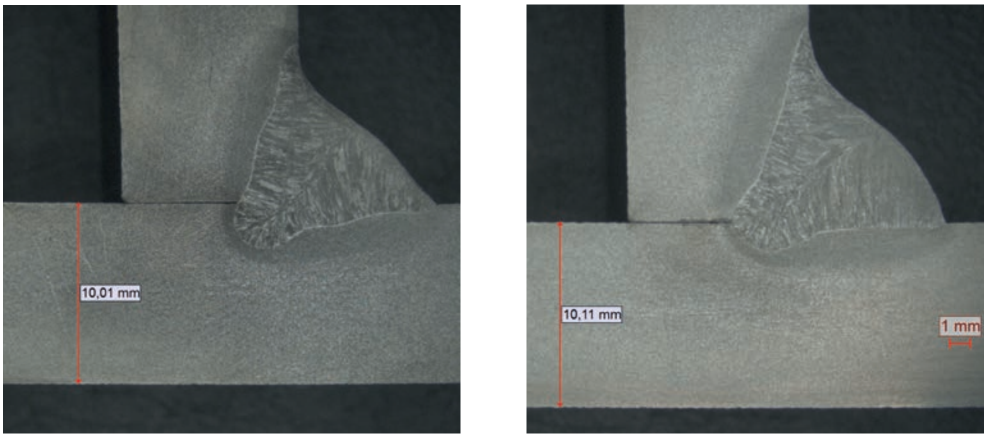


Figure 44: wiredArc XQ

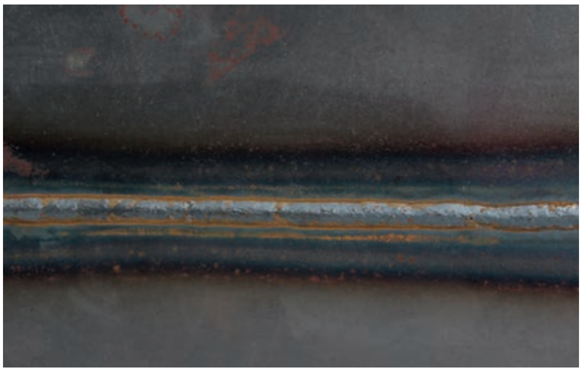
12.6 Welding using 100% CO_2 on unalloyed and low-alloy steel

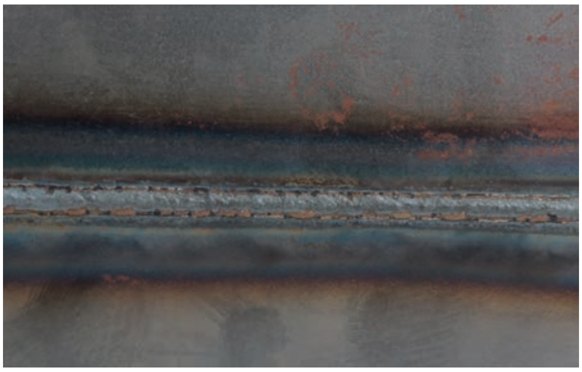
Welding processes: coldArc® XQ/ rootArc® XQ/Standard

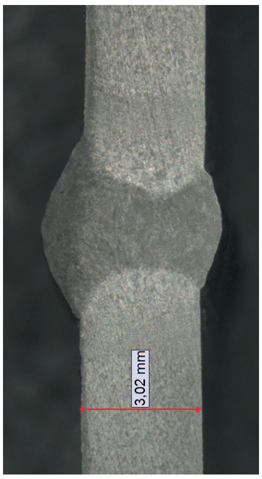
Advantages:

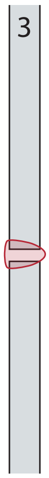
- Digital process control for low-spatter droplet transfer thanks to the RCC power module (Rapid Current Control)
- Rapid process control thanks to the use of the latest microelectronics
- Minimised weld spatter similar to mixed gas
- Welding even with long hose packages without additional voltage measuring leads thanks to RCC power module (Rapid Current Control)
- Easy to guide and control

Root welding in PC position with an air gap and without weld pool backing



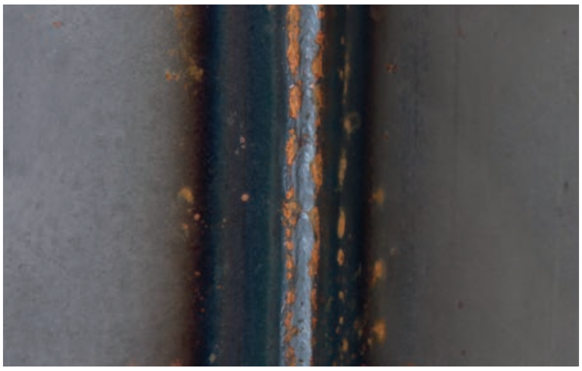


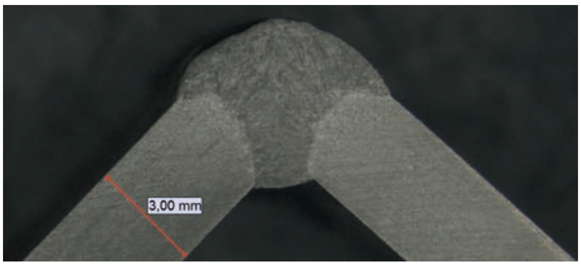


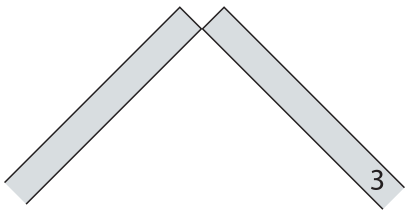


S355, material thickness: 3 mm, using G3Si1 1.2 mm diameter at 100% CO^2

Root welding in PA position with an air gap and without weld pool backing







S355, material thickness: 3 mm, using G3Si1 1.2 mm diameter at 100% CO_2

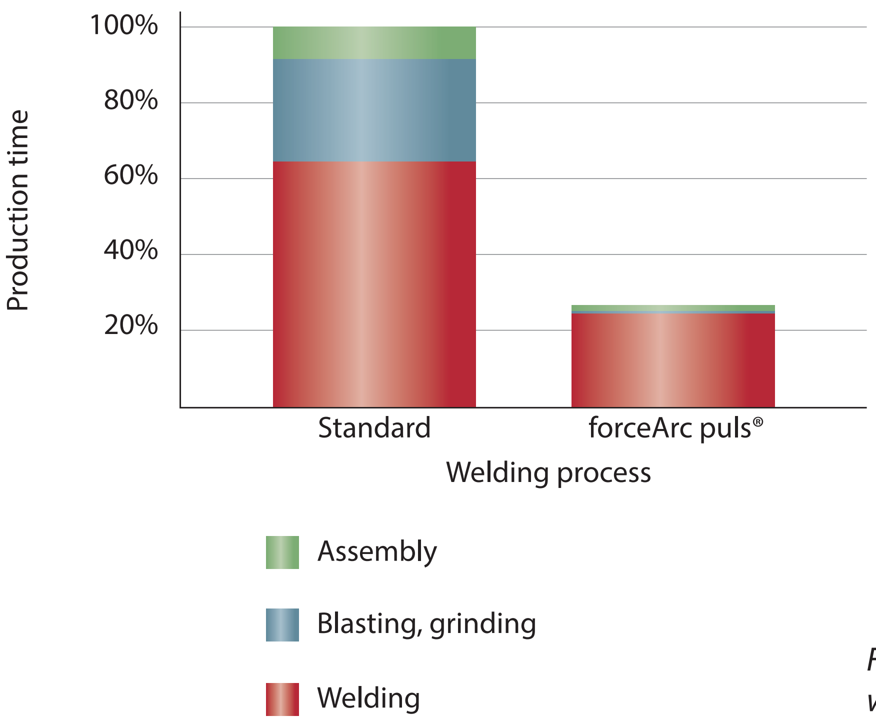
12.7 Welding full-penetration fillet welds on unalloyed, low-alloy and high- alloy steel

Welding process: forceArc puls® XQ

Advantages:

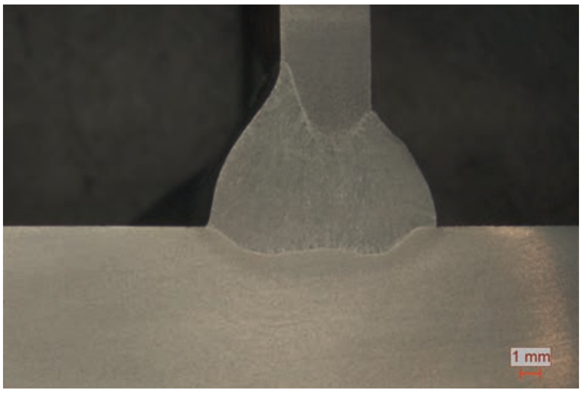
- Good gap bridging even in high power ranges, easy to learn and directly applicable
- Considerably reduced welding fume emissions compared to pulsed arc welding
- Reliable full penetration even without air gap, therefore good for fitting work
- Enables included angles to be reduced thereby reducing weld seam volumes, lowering the number of runs and significantly lowering costs
- Double-sided full-penetration welds on butt joints or T-joints without grinding or gouging the transverse root side
- Deep penetration for excellent root and sidewall fusion
- Good process stability when welding on the weld pool even at small included angles
- Perfect welding even with very long stick-outs
- Even in tight and narrow grooves with very long stick-outs
- Rapid correction of alterations to stick-out lengths, reliable processing of stick-out lengths up to 40 mm

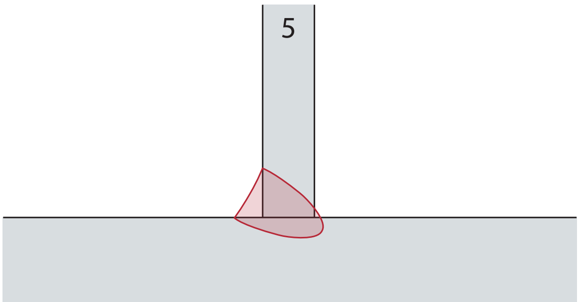
Time saved by using forceArc puls® XQ in production



Further information
www.ewm-group.com/sl/savings

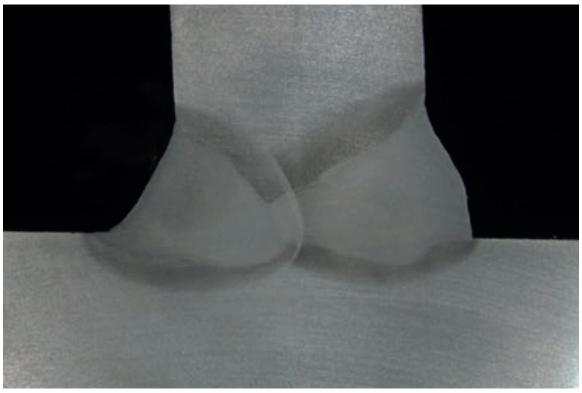
One-sided fillet weld

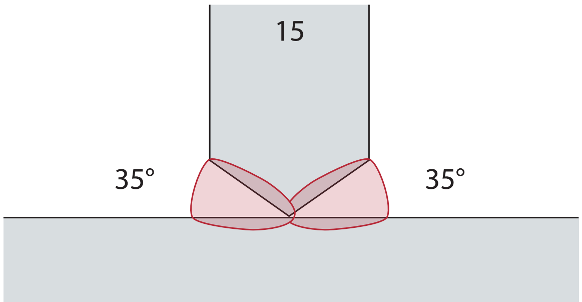




S355, 5 mm on 10 mm

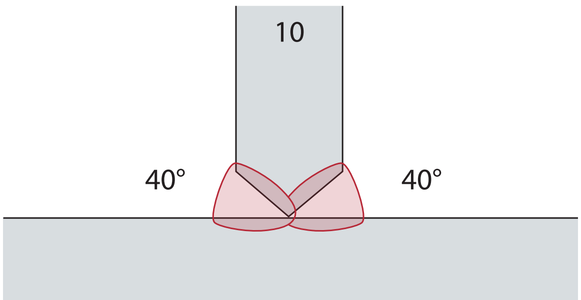
Full penetration, welded on both sides





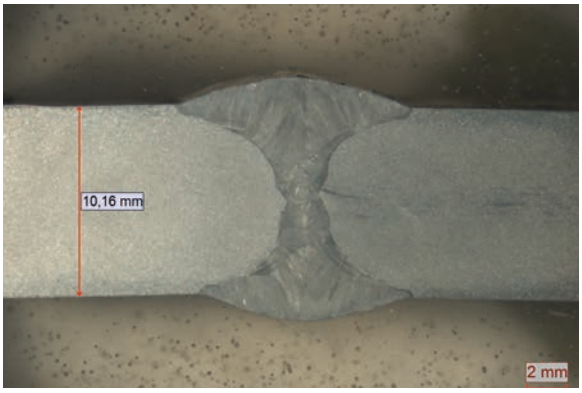
S355, 15 mm, included angle: 35°

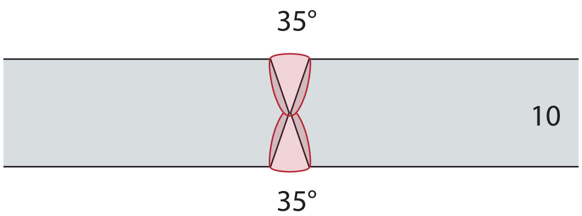
Full penetration, welded on both sides



1.4301, 10 mm, included angle: 40°

Full penetration, welded on both sides





1.4301, 10 mm, double-sided full penetration on a butt joint with an included angle of 35°

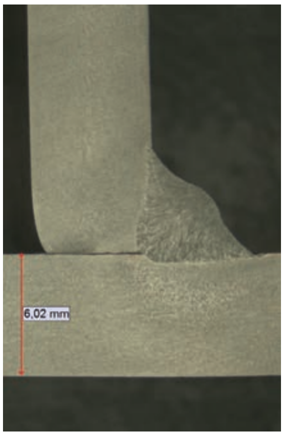
12.8 Positional welding without using the “Christmas tree” technique on unalloyed, low- alloy and high-alloy steel

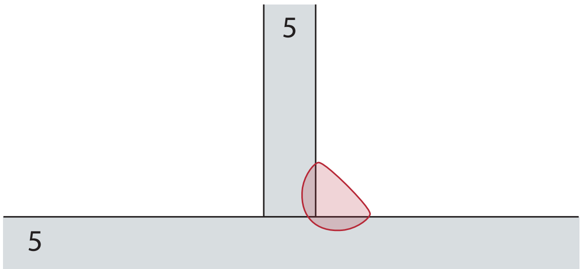
Welding process: Positionweld

Advantages:

- High welding speeds compared to the traditional “Christmas tree” technique
- Concentrated, digitally modified pulsed arc
- Virtually spatter-free welding results thanks to rapid digital control of the welding process
- Optimum, ex-works configured switching between low and high welding power
- Heat-reduced process with low arc power and energy per unit length
- Flat weld surface with even ripples and virtually spatter-free process for reduced finishing work
- Easy to set and easy to guide

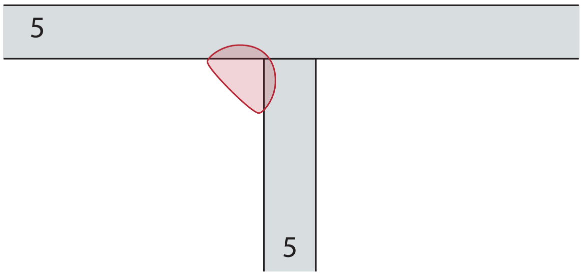
Vertical-up weld, straight torch guidance without using the "Christmas tree" technique





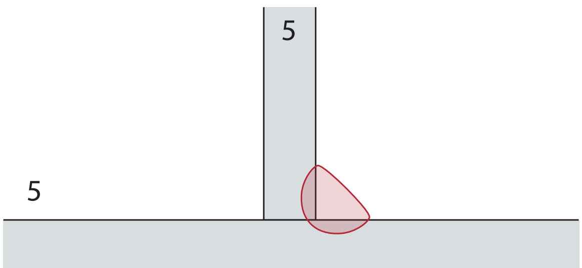
S355, material thickness: 5 mm

Overhead welding, easy handling



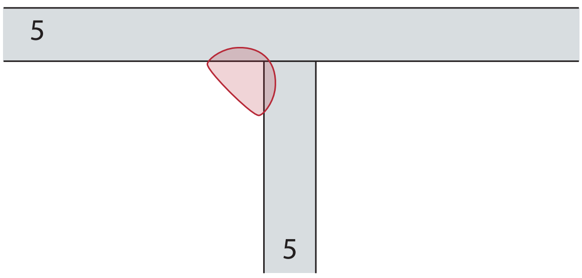
S355, material thickness: 5 mm

Vertical-up weld, straight torch guidance without using the "Christmas tree" technique



1.4301 material thickness: 5 mm

Overhead welding, easy handling



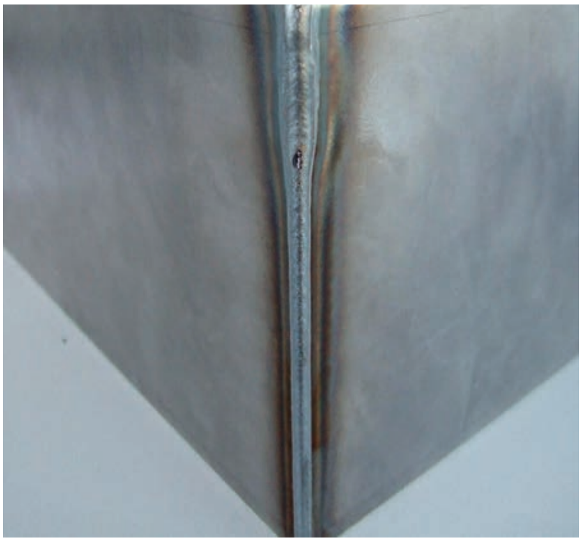
1.4301 material thickness: 5 mm

12.9 Welding and brazing of unalloyed, low-alloy and high-alloy steel thin sheet metal and galvanised sheet metal

Welding processes: coldArc® XQ/ coldArc® puls XQ

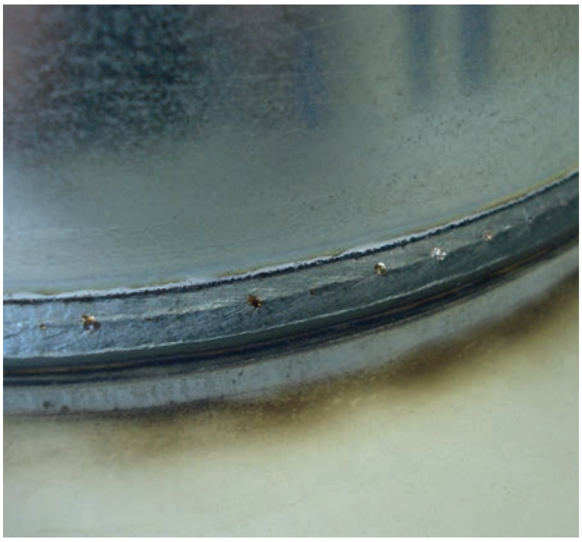
Advantages:

- Lower heat input due to digital control of droplet transfer in short-circuit welding thanks to RCC power module (Rapid Current Control)
- Flat, smooth weld surface and virtually spatter-free process, less discolouration and distortion reduces finishing work, excellent wetting of surfaces when brazing
- No sagging of the molten metal, reliable sidewall fusion even with misaligned edges
- Optimum process performance configuration, steady and stable welding process
- Rapid digital control of the process, easy to guide and control
- Welding even with long hose packages without additional voltage measuring leads thanks to RCC power module
- Minimal spatter formation, minimal impact on corrosion resistance



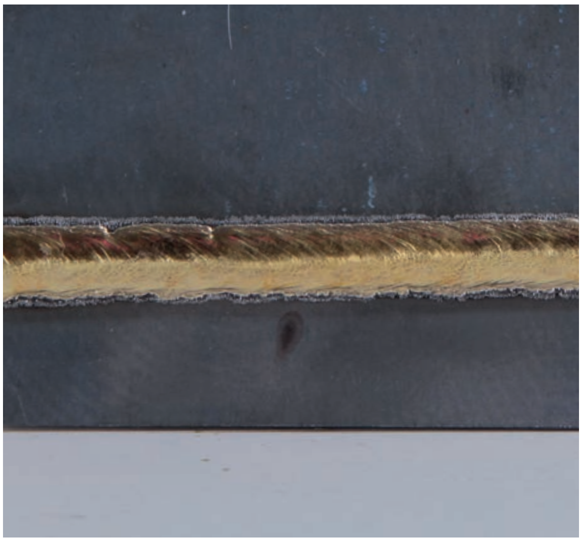
Welding unalloyed sheet metal

Welding high-alloy sheet metal

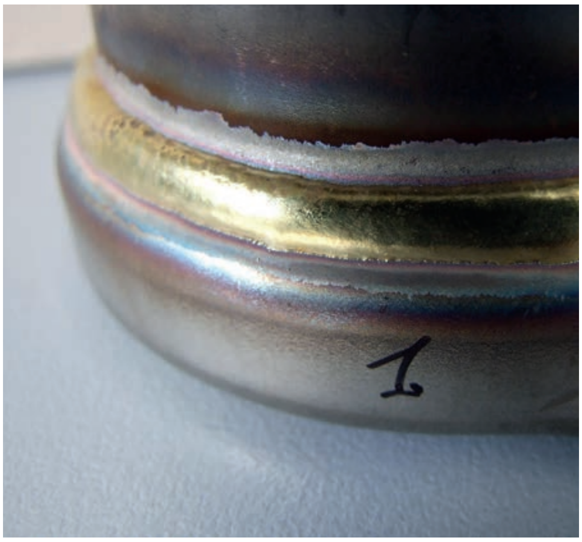


Welding galvanised sheet metal

Brazing galvanised sheet metal



Brazing high-tensile sheet metal, e.g. Usibor®



Brazing high-alloy (CrNi) sheet metal

12.10 Welding filler passes and cover passes of high-alloy steel

Welding process: forceArc puls® XQ

Advantages:

- Concentrated, digitally modified pulsed arc
- Virtually spatter-free welding results thanks to rapid digital control of the welding process
- Lower welding fume emissions compared to pulse arc welding
- Heat-reduced process with low arc power and energy per unit length reduced by up to 20% compared to pulsed arc
- Ability to reduce the seam volume thanks to the smaller included angle in multipass welding
- Symmetrical fillet welds with maximum attainable seam thickness (throat thickness)
- Low interpass temperature/reduced non-productive time
- Flat, smooth weld surface and virtually spatter-free process for reduced finishing work, minimal discolouration
- Rapid digital control of the process, easy to guide and control
- Consistent weld surface from various welding torch positions
- **Up to 30% total cost savings**
  - Reduced costs for wages, welding consumables, shielding gas and power Reduced production time
- **Up to 15% lower heat input**
  - Less finishing work (straightening, sanding, cleaning) thanks to reduced distortion, discolouration and stress
  - Minimisation of non-productive times thanks to shorter waiting times for multipass welding
- **Up to 20% greater throat thickness**
  - Deep, concentrated penetration with reliable root fusion for symmetrical seam formation
- **Virtually spatter-free**
  - Minimised finishing work, even on sheets with scaling or highly soiled surfaces

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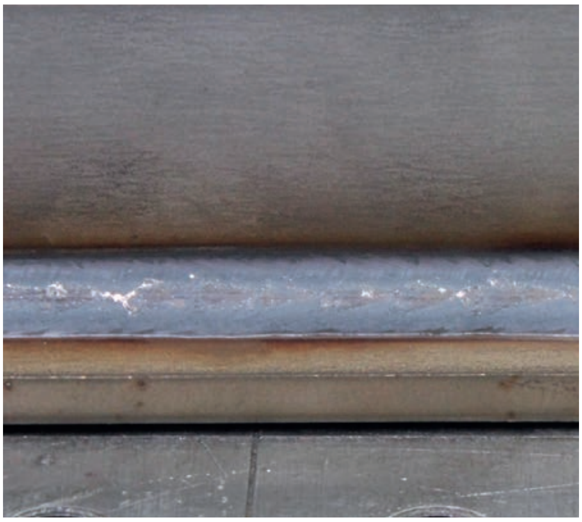
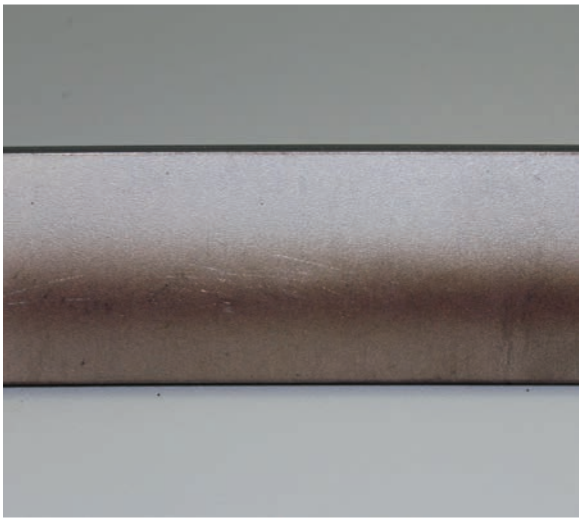
Front view:
Lower heat input using forceArc puls® XQ, less surface oxidation resulting in a better finish



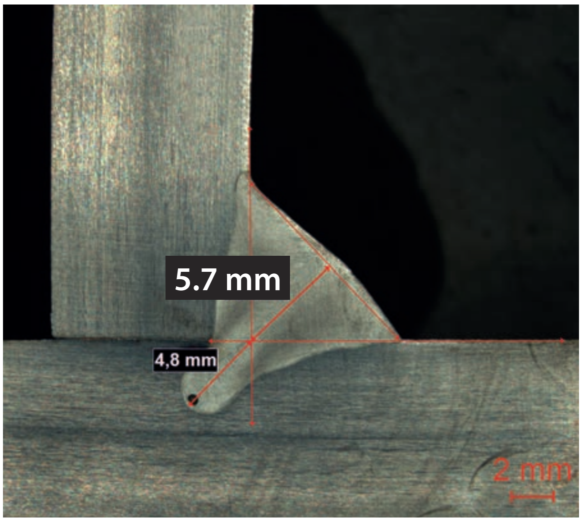
Rear view:
Low heat input using forceArc puls® XQ, less surface oxidation

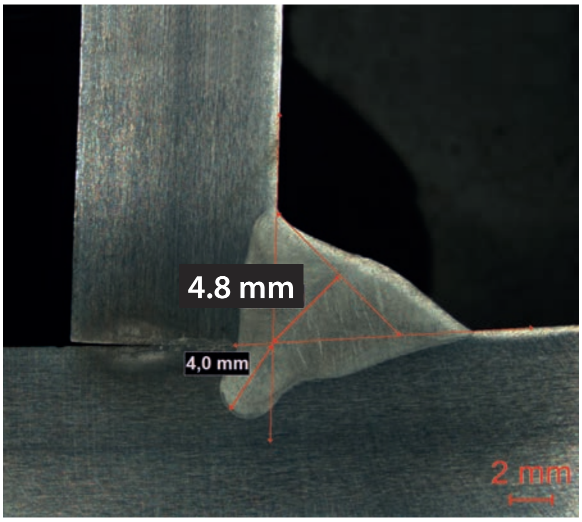


Compared to pulsed arc welding, forceArc puls® XQ inputs up to 15% less heat in the upper power ranges. This results in less discolouration and less distortion in the component.

Advantages:

- Lower heat input
- Minimised energy per unit length
- Reduces distortion, discolouration and stresses
- Less finishing work (straightening, sanding, cleaning)
- Less burn-off of alloying elements, thus producing greater corrosion resistance





Process	Wire feed in m/min	Energy per unit length in kJ/mm	Weld speed in m/min	Throat thickness
forceArc puls® XQ	13	1.21 (-15%)	0.45	5.7 (+15%)
Pulse welding	13	1.44	0.45	4.8

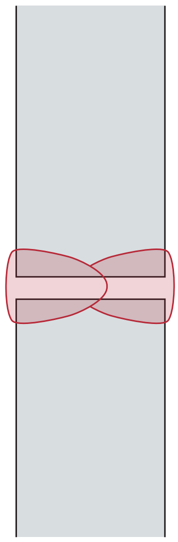
12.11 Welding of aluminium and aluminium alloys

Welding process: pulsed arc XQ

Advantages:

- Rapid and stable process control thanks to the use of the latest microprocessor technology
- Steady, stable droplet transfer, less burn marks on surface
- Individual weld appearance thanks to freely adjustable superPuls function
- Wire feeder reverse for spatter-free ignition
- Reliable process starting from 1 mm
- Rapid digital control of the process, easy to guide and control

Two-sided welding of aluminium in shipbuilding

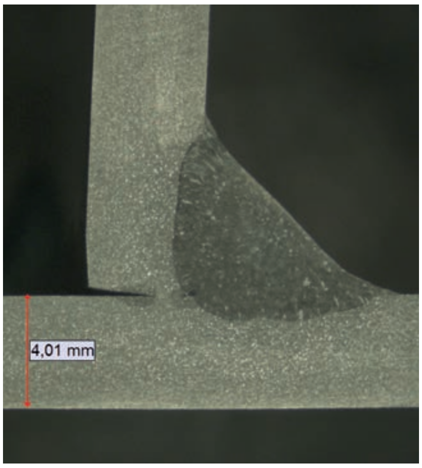


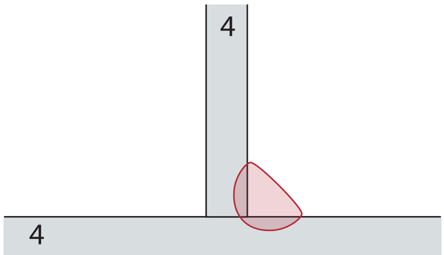
12.12 Positional welding of aluminium and aluminium alloys without use of the “Christmas tree” technique Welding process: Positionweld

Advantages:

- Concentrated, digitally controlled pulsed arc
- Optimum, ex-works configured switching between low and high welding power
- High welding speeds compared to traditional weaving techniques
- Flat weld surface with even ripples and virtually spatter-free process for reduced finishing work
- Rapid digital control of the process, easy to guide and control

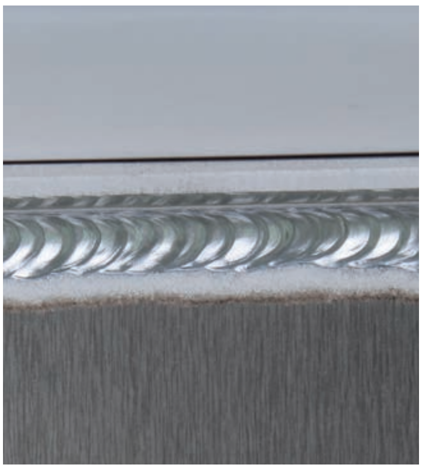
Welding in the vertical up position, easy handling

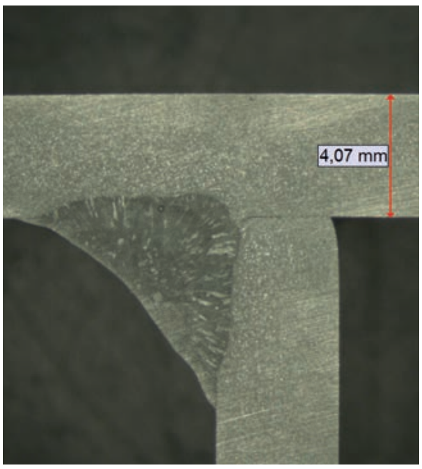


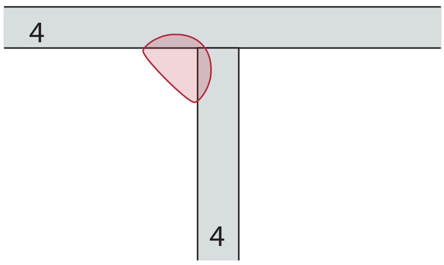


AlMg5, material thickness: 4 mm

Overhead welding, easy handling







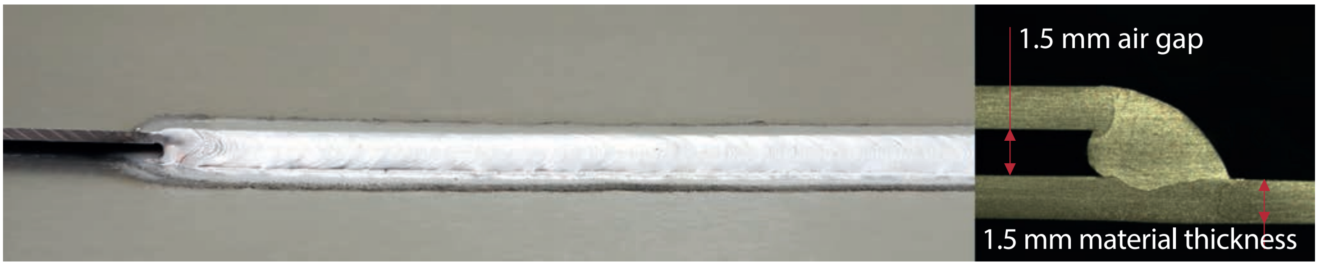
AlMg5, material thickness: 4 mm

12.13 Welding aluminium lap welds
Welding process: acArc puls XQ

acArc puls XQ is the optimal arc for aluminium welding on thin sheets. The easy-to-control arc is brilliantly suited to both manual and automated welding. Thanks to the reduction in welding fume emissions, the welder is less affected, and the welds remain clean.

Advantages:

- Clean weld seams as a result of greatly reduced magnesium oxide thanks to the lower droplet temperature
- Lower welding fume emissions
- Stable arc, even with large air gap
- Reduced heat input into the sheet
- Perfect aluminium welding, even on thin sheets
- Excellent gap bridging, even in automated applications
- Minimised heat input, no fall-through of the sheet



Lap weld: Material thickness: 1.5 mm | 1.2 mm AlMg 4.5 wire | Argon 100% | 69 A | 15.4 V | Welding speed: 70 cm/min. | Air gap: 1.5 mm.

12.14 Welding aluminium fillet welds

Welding process: acArc puls XQ + Positionweld

With acArc puls XQ, sheets of just 1.0 mm material thickness can be welded, even manually, thanks to the low heat input, without falling through.

Advantages:

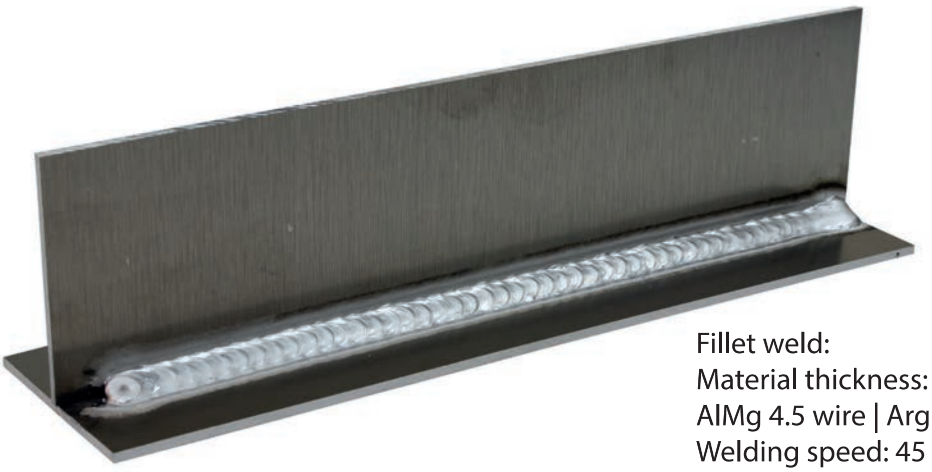
- Minimised heat input
- Faster welding speed
- Simple and safe handling of the arc for both manual and automated welding
- Clean weld seams thanks to greatly reduced magnesium oxide
- Lower welding fume emissions

Fillet weld:
Material thickness: 1.0 mm | 1.2 mm
AlMg 4.5 wire | Argon 100% | 48 A | 14.1 V |
Welding speed: 60 cm/min.

With acArc puls XQ + Positionweld, MIG welds can be welded with a perfect TIG appearance. Even positional welding is very easy using this welding process.

Advantages:

- MIG welding with TIG appearance
- Simplified positional welding
- Excellent for connecting different material thicknesses



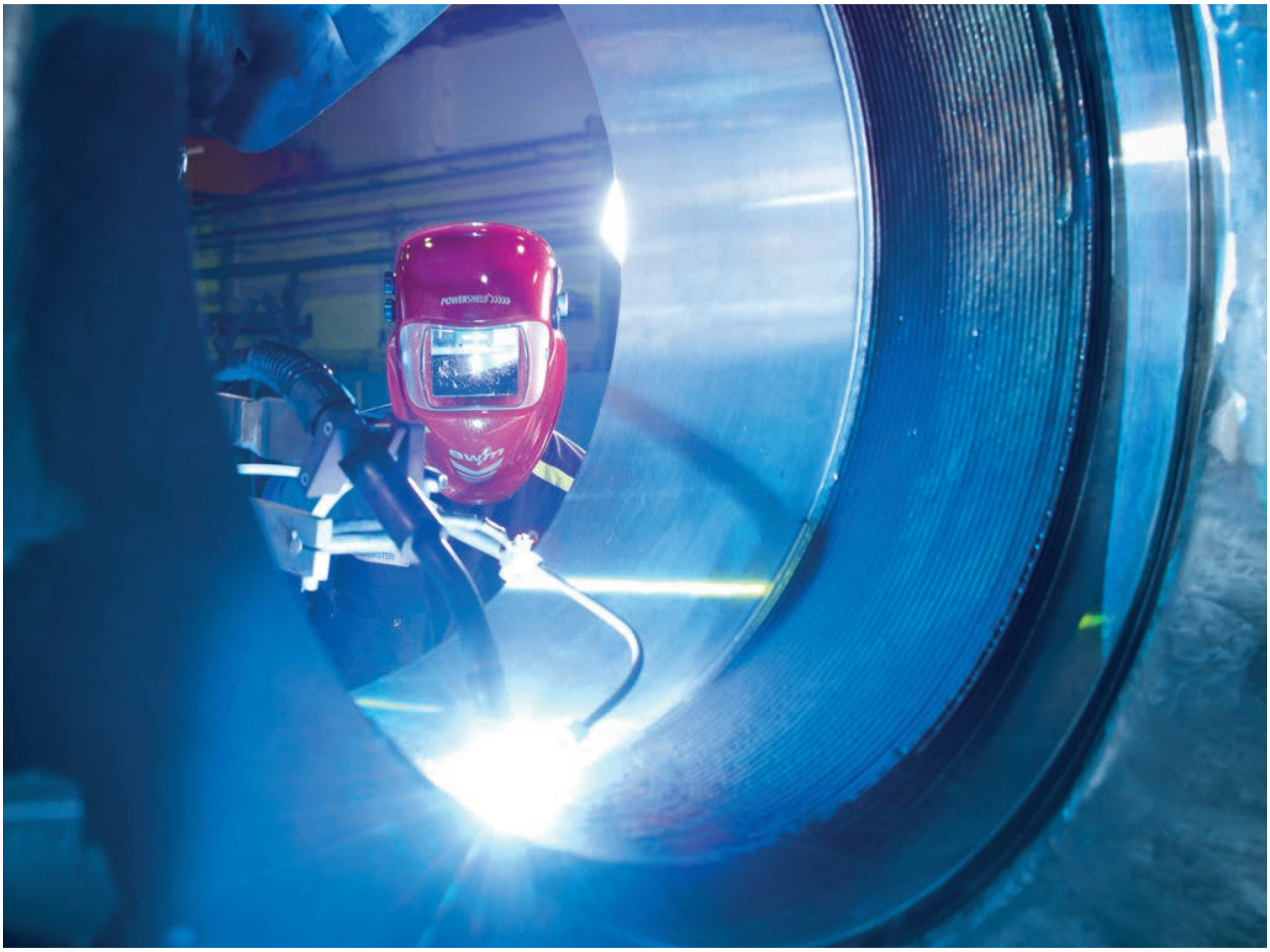
Fillet weld:
Material thickness: 2 mm | 1.2 mm
AlMg 4.5 wire | Argon 100% | 73 A | 15.4 V |
Welding speed: 45 cm/min.

12.15 Surfacing

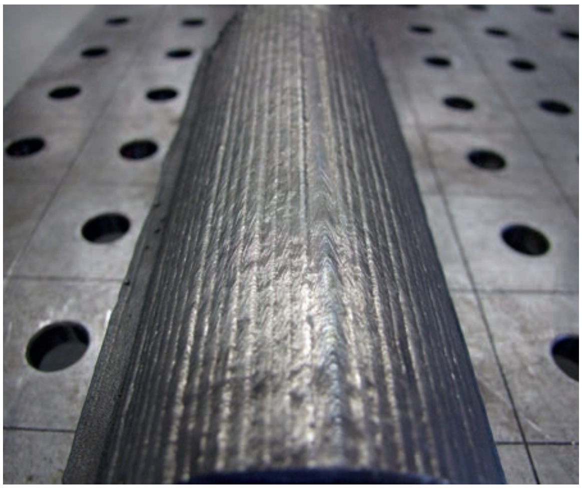
Welding processes: Cladding/ hardfacing

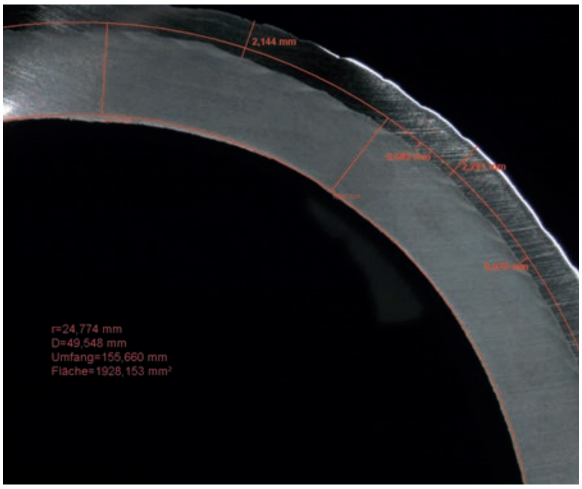
Advantages:

- Optimum process configuration for surfacing, hence low dilution
- Uniform deposit structure, minimal machining work
- High process stability thanks to digitally controlled arc, minimised spatter formation
- Easy to operate and adjust



Surfacing of finned tube walls





Corrosion-resistant surfacing of Alloy 625 Ni-based materials

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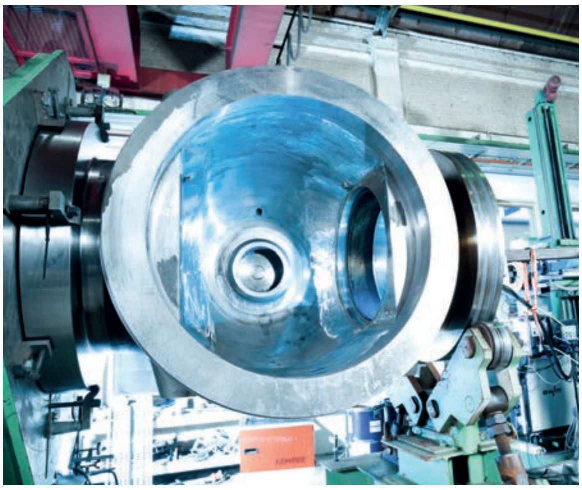
MAG + hot wire surfacing for increased deposition rate

New process variant combines a MAG welding process supplemented with an additional hot wire.

- Up to 13.8 kg deposition rate for significantly increased productivity
- Minimal dilution
- Further improved properties of deposited layers
- Process easy to set up and configure
- Suitable for cladding and hardfacing

Additional information
www.ewm-group.com/sl/cladding



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Imprint

Die MIG/MAG-Fibel, 6th edition

From the "EWM-Wissen – rund ums Schweißen" publication series

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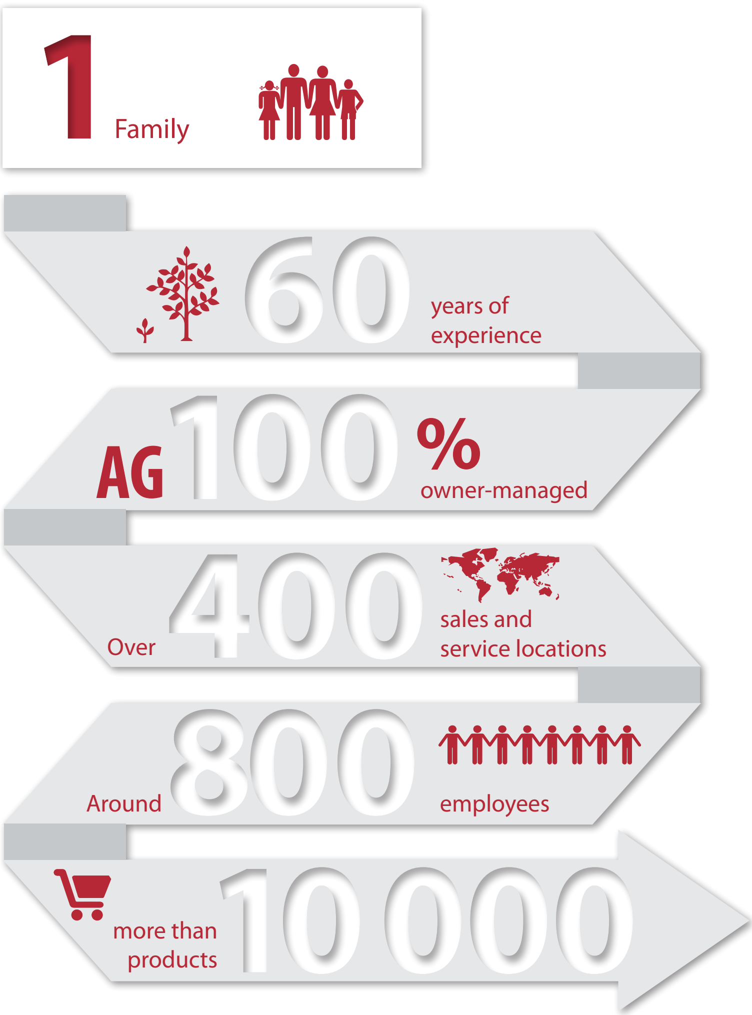

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