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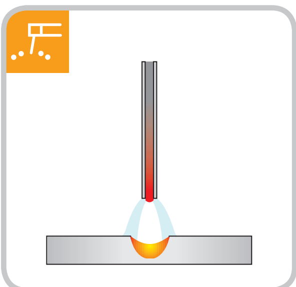
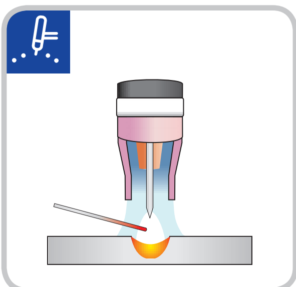
Welding Dictionary

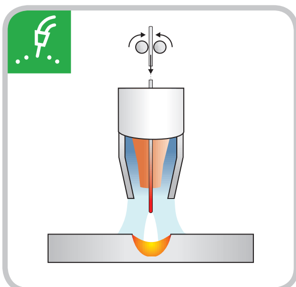
MMA



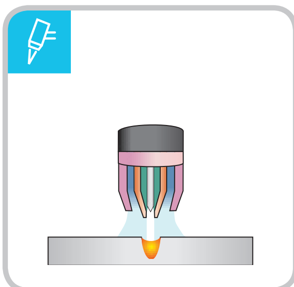
TIG



MIG/MAG



PLASMA



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WE ARE WELDING

MMA PRIMER

Contents

1 Preface

Manual metal arc welding, known as MMA welding for short, is one of the oldest welding processes still in use today. It goes back to research carried out by Slawjanow who in 1891 was the first to use a metal rod that was simultaneously the arc carrier and the welding additive, rather than the standard carbon electrode that had been used for arc welding up until that point. The first stick electrodes were not coated and were therefore difficult to weld with. Later on the electrodes were coated with materials that made welding easier, protected the weld metal and had a metallurgic affect on the process. The first patent for a coated stick electrode was created in 1908. Electrodes can be coated by dipping or by pressing on an extruder press. Today only electrodes with extruded coatings are used.

MMA welding is characterised by a relatively low level of investment and an universal application. The process can be used for a wide range of materials and ensures high-quality weld seams. In recent times, however, MMA welding has been superseded, frequently for economic reasons, by other welding techniques that can be mechanised.

This primer clarifies the special features of this process and provides information on the correct application of the technique.

2 The process

2.1 General remarks

MMA welding (process number 111) is a fusion welding process, and more precisely, a metal arc welding process. ISO 857-1 (1998 edition) describes the welding processes in this group as follows:

Metal arc welding: Arc welding process using an electrode used up during the procedure.

Metal arc welding without gas shielding: Metal arc welding process without the addition of external shielding gas and

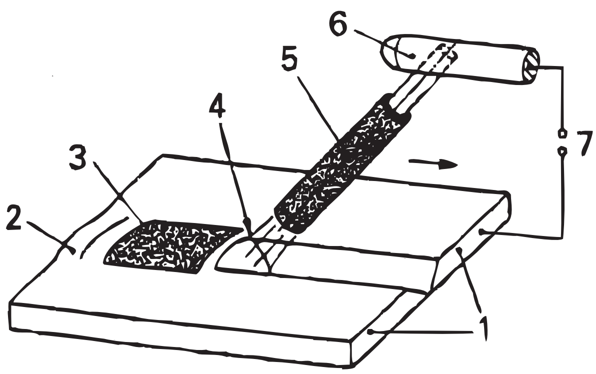
Manual metal arc welding: Metal arc welding performed manually using a coated electrode.

In Germany the last process mentioned is known as manual arc welding or MMA welding for short, and is characterised by the arc arcing between a melting electrode and the molten bath (Figure 1).

There is no external protection; any protection against the atmosphere comes from the electrode. In this case the electrode is both the arc carrier and the welding additive. The coating forms slag and/or shielding gas, which among other things protects the drop being transferred and protects the molten pool against the ingress of the atmospheric gases oxygen nitrogen and hydrogen.

2.2 Current type

For manual arc welding (MMA welding), both d.c. and a.c. can in principle be used, but not all types of stick electrode coatings can be welded on sinusoidal a.c., e.g. not pure basic electrodes. When welding with d.c., the minus pole is generally connected to the electrode and the plus pole to the workpiece with most electrode types. Basic electrodes are an exception to this. They are better welded on the plus pole. The same applies to certain manufacturers of cellulose electrodes. More information on this can be found in section 2.3 Electrode types.



1 Workpiece
2 Weld seam
3 Slag
4 Arc
5 Coated electrode
6 Electrode holder
7 Power source

Figure 1 Scheme of manual metal arc welding irrespective to ISO 857-1

The electrode is the welder's tool. The welder moves the arc burning on the electrode in the weld groove side walls, thus melting the edges of the groove (Figure 2).

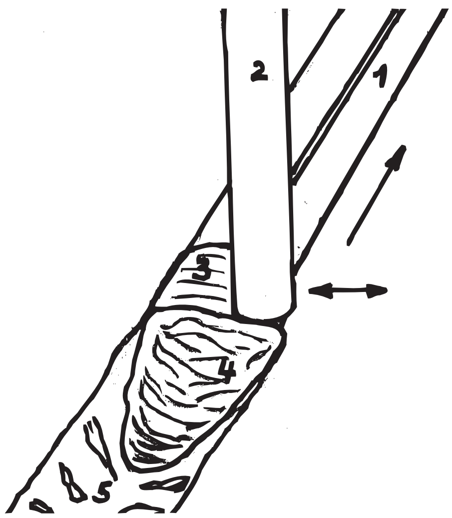
Different current intensities are required depending on the type of groove and the thickness of the parent material. The stick electrodes are available in different diameters and lengths, since their diameter and length determine the current loading possible. Table 1 shows the standardised dimensions as specified in DIN EN 759.

Higher welding currents can be used with larger core wire diameters.

2.3 Electrode types

There are stick electrodes with coatings of very different compositions. The composition of the coating determines the melt characteristics of the electrode, its welding properties and the quality of the weld metal. Irrespective to DIN EN 499 the coating types given in Table 2 exist for stick electrodes for welding unalloyed steels.

A distinction is drawn here between single-material types and mixed types. Letters are used to designate the different types of electrode. The letters stand for the following: C=cellulose, A=acid, R=rutile and B=basic. In Germany the rutile type plays a leading role. Stick electrode may be thin-coated, medium-coated or thick-coated. With rutile electrodes, which are available as standard in all three coating thicknesses, the thick-coated electrodes are therefore known as RR for clearer identification.



1 Weld groove side walls
2 Stick electrode
3 Molten weld metal
4 Molten slag
5 Solidified slag

Figure 2 Position of the electrode in the weld groove side walls

Nominal diameter in mm	Permissible deviation	Nominal length in mm	Permissible deviation
1.6	± 0.06	200 to 350	± 3
2.0			
2.5			
3.2	± 0.10	350 to 450	± 3
4.0			
5.0			
6.0			

Table 1 Diameter and lengths of stick electrodes conforming to DIN EN 759 Electrodes

With alloyed and high-alloy stick electrodes, there is no such variety in the types of coating. With stick electrodes for welding stainless steels, which are standardised in DIN EN 1600, a distinction is only made between rutile electrodes and basic types, for example, as with stick electrodes for welding creep resistant steels (DIN EN 1599), but in this case there are only basic mixed types, as with the rutile electrodes, although this is not specifically marked. This is the case with electrodes that have better welding characteristics in out-of-position welding, for example. Stick electrodes for welding high-tensile steels (DIN EN 757) are only available with basic coatings.

Type	Coating
A	acid
C	cellulose
R	rutile
RR	thick rutile
RC	rutile cellulose
RA	rutile acid
RB	rutile basic
B	basic

Table 2 Coating types to DIN EN 499

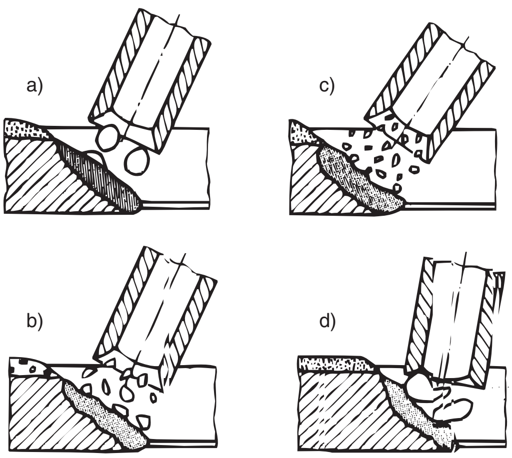
2.4 Properties of the coating types

The composition and the thickness of the coating have a significant effect on the welding characteristics. This relates both to the stability of the arc and to the material transition during welding and the viscosity of slag and molten bath.

The size of the drop being transferred in the arc is of particular significance. Figure 3 shows a scheme diagram of the drop transferin the four basic types of coatings [1].

The cellulose type (Figure 3, c) has a medium- to large-drop material transfer. The coating consists primarily of organic components that burn in the arc, thus forming shielding gas to protect the welding position. As the coating contains only small quantities of arc-stabilising materials with the exception of cellulose and other organic materials, virtually no slag is produced. Cellulose types are especially well suited to vertical-down welding (Figure 4, vertical-down position) because there is no need to worry about slag formation.

The acid type (A), where the coating consists primarily of iron ore and manganese iron ore, provides the arc atmosphere with greater quantities of oxygen. The weld metal also takes this up, thus reducing the surface tension. The consequences are a very fine, spray-type material transfer and a fluid weld metal. Electrodes of this type are not therefore suitable for out-of-position welding. The arc is also very "hot-running"; it permits high welding speeds, but tends towards the formation of undercuts. The disadvantages described have meant that pure acid type stick electrodes are now barely used in Germany. The rutile acid type (RA), a mixture of the acid and the rutile electrode, has instead taken its place. The electrode also has the corresponding welding properties.



a) Cellulose type c) Acid type
b) Rutile type d) Basic type

Figure 3 Material transition with different coating types [1]

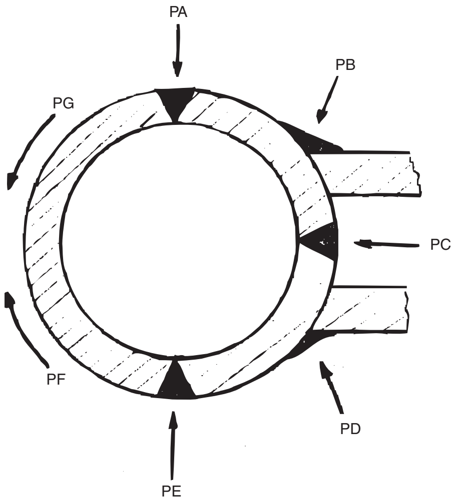


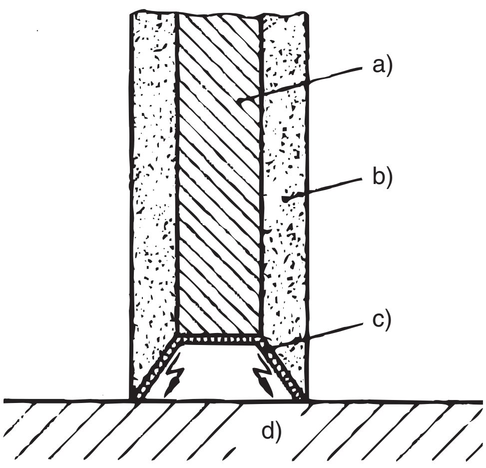
Figure 4 Welding positions to ISO 6947

The coating of the rutile type (R/RR) consists primarily of titanium oxide in the form of the minerals rutile (TiO_2) or ilmenite ($TiO_2 \cdot FeO$) or even artificial titanium oxide. Electrodes of this type are characterised by a fine- to medium-sized drop material transfer, quiet, low-spatter melting off, very fine seam formation, good slag removability and good re-ignition characteristics. The latter is only observed in this form with rutile electrodes with a high proportion of TiO_2 in the coating. It means that with an electrode which has already meltdown, re-ignition is possible without removing the coating crater (Figure 5) [2].

The slag film formed in the crater has virtually the conductivity of a semiconductor, if it has a sufficiently high TiO_2 content, which means that when the edge of the crater is placed on the workpiece, enough current flows for the arc to be able to ignite without the core wire touching the workpiece. A spontaneous re-ignition of this type is always important if the welding process is being frequently interrupted, e.g. with short seams.

In addition to the pure rutile type, there are several mixed types in this group of electrodes. Of particular note is the rutile-cellulose type (RC) in which part of the rutile has been replaced with cellulose. As cellulose combusts during welding, less slag is produced. This type can therefore also be used for vertical-down welding (vertical-down position). However, it also has good welding characteristics in most other positions. Another mixed type is the rutile/basic type (RB). It also has a slightly thinner coating than the RR type. This and its special slag characteristics make it especially useful for welding in the vertical up position.

There only remains the basic type (B). In this case the coating consists primarily of basic oxides of calcium (CaO) and magnesium (MgO), to which fluorspar (CaF_2) has been added as a slag thinner. The fluorspar impairs a.c. weldability in higher proportions. Pure basic electrodes cannot be welded on sinusoid a.c. current, but there are also mixed types with less fluorspar in the coating that can be used with this type of current. The material transfer of basic electrodes uses medium- to large-drops and the molten pool is viscous. The electrode has good welding properties in all positions. However,



a) Core wire
b) Coating
c) Slag film in coating crater
d) Workpiece

Figure 5 Re-ignition of the coating crater

the beads produced are slightly reinforced and more roughly rippled due to the higher viscosity of the weld metal. The weld metal has very good toughness properties. Basic coatings are hygroscopic. Care must therefore be taken that the electrode are stored especially carefully in a dry location. Electrodes that have become damp must be oven-dried. However, when the electrodes are welded dry, the weld metal has a very low hydrogen content.

In addition to stick electrodes with normal efficiency ($\leq$105%), other stick electrodes have, thanks to iron powder added across the coating, an higher efficiency, generally >160%. These electrodes are known as iron powder types or high-efficiency electrodes. Thanks to their high desposition efficiency, they can be used more efficiently for many applications than normal electrodes, but their use is normally restricted to vertical (flat position) and horizontal positions (horizontal vertical position).

3 Which electrode for what purpose

When choosing stick electrodes, material and welding-engineering considerations need to be taken into account.

3.1 Welding-engineering considerations when choosing stick electrodes

Each type of electrode has highly specific welding properties and is therefore also used for highly specific welding tasks.

Thanks to its suitability for vertical-down welding (vertical down position), cellulose electrodes (C) are used for welding circumferentially seams on tubes with larger diameters. The preferred application here is for laying pipelines (Figure 6).

In comparison with welding in the vertical up position (vertical up position), relatively thick electrodes (4 mm) can be used here for the root pass. This makes for increased efficiency.

The particular advantage of the mixed rutile/acid type (RA) is the slag residue in narrow grooves, where compact slag is squeezed and is hard to remove. The slag from the RA type itself is porous and breaks into small pieces under the slag hammer, and then these pieces can be easily removed.

The special properties of rutile electrodes (R, RR), namely good re-ignition, easy slag removal and good seam appearance, determine their main applications. These are tacking work, as well as welding fillet welds and final passes where complete slag removal and good seam appearance are critical.

The rutile-cellulose type (RC) can be welded in all positions including vertical-down. This means it has universal applications, especially in the field of assembly work. The thick-coated variant in particular, which also meets high demands in terms of the seam appearance, is therefore often the all-round electrode in smaller companies.

The rutile/basic electrode (RB) is particularly well suited to welding root passes and welding in the vertical up position thanks to its slightly thinner coating and its special characteristics.

The basic electrode (B) is suitable for welding in all positions. Special types are even suitable for vertical-down welding. However, the seam appearance is not quite as good as with other types. Having said that, the weld metal does have "inner qualities". Of all the types of electrode, basic electrodes have the best toughness properties and the best crack resistance of the weld metal. They are therefore used where difficult conditions in terms of the weldability of the parent materials exist, e.g. with steels with restricted weldability or with very thick walls. Further applications include those where considerable toughness is required for the joint, e.g. in buildings which will be subjected to low temperatures later on. The low hydrogen content also makes this type particularly well suited to welding high-tensile steels.

Figure 6 Welding in pipeline construction with cellulose electrodes

3.2 Material considerations when choosing stick electrodes

The strength and toughness properties of the parent material must normally also be achieved in the weld metal. To simplify the process of choosing electrodes in this regard, the full name for a stick electrode conforming to DIN EN 499 also contains information on the minimum values for the yield point, tensile strength and toughness of the weld metal and on various welding properties. Table 3 clarifies this using an example.

The code E 46 3 B 42 H5 means:

The stick electrode for MMA welding (E) has a yield point of min. 460 N/mm^2, a toughness between 530-680 N/mm^2 and a minimum expansion of 20% (46). An impact energy of 47 joules is reached up to a temperature of -30°C (3). The electrode has a basic coating (B). This is followed by various pieces of non-compulsory information on the efficiency and the current suitable for the electrode. The stick electrode given in the example has an efficiency of 105 to 125% and should only be used for welding on d.c. (4) in all positions except vertical-down (2). The hydrogen content of the weld metal is below 5 ml / 100 g / weld metal (H5). If the weld metal contains alloy elements other than manganese, these are given before the code for the coating type with the code for the chemical elements and sometimes with numbers for the percentage (e.g. 1Ni).

A low hydrogen content is important when welding steel with a tendency towards hydrogen-induced crack formation, such as high-tensile steel. The code for the hydrogen content provides the necessary information here.

Similar identification systems also exist for high-tensile electrodes (DIN EN 757), creep resistant electrodes (DIN EN 1599) and for stainless electrodes (DIN EN 1600). For creep resistant and stainless electrodes, however, both the strength properties and the creep resistance and corrosion properties of the weld metals must match those of the parent metals. The general rule here is therefore that the weld metal should ideally be the same type or higher-alloy than the parent metal.

4 Groove preparation

4.1 Groove shapes

Figure 7 shows the most important groove shapes used in MMA welding. For square grooves, the root must be grooved out from the rear side for larger sheet thicknesses. In order to avoid faults, the same applies to welding with backing runs and to welding on both sides of double-V butt seam and double-V butt seams with root faces for larger sheet thicknesses. With single-V butt seams and single-bevel butt seams, the root phase can also be broken slightly; the root face thickness in single-V butt seams with broad root face is determined by the current intensity that can be applied. For economic reasons, single-U butt seams and double-U butt seams are used primarily for larger wall thicknesses because the weld volume to be applied is lower than with single-V butt, single-V butt with broad root face, double-V butt and double-V butt with root face welds due to the smaller opening angle.

With fillet welds, the gap between the two joining members should be kept as small as possible so that no slag can penetrate the gap. This applies in particular to T-seams, lap seams and fillet welds.

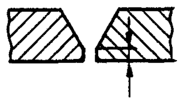
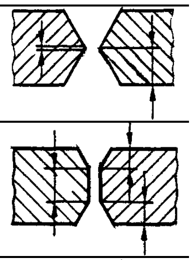
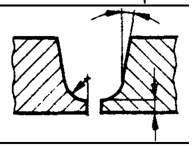
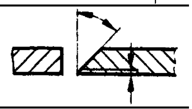
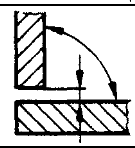
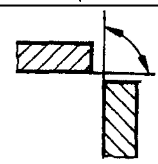
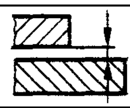
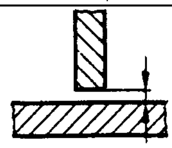
Joint type	Workpiece thickness (mm)	Diagram
Butt weld	One side 3-8 both sides <8	
Single-V butt weld	One side 3-10 with backing runs 3-40	
Single-V butt weld with broad root face	One side 5-40 with backing runs >10	
Double-V butt weld	Both sides > 10	
Single-U butt weld	One side > 12 with backing runs >12	
Single-V butt weld	One side 3-10 with s.u. 3-30	
Fillet weld T-joint	One side >2	
Fillet weld - corner joint	One side >2 Both sides > 3	
Fillet weld - lap joint	One side >2	
Fillet weld – double fillet weld	Both sides > 2	

Figure 7 Groove shapes irrespective to DIN EN 29692-ISO 9692

Codes for the strength and expansion properties of the weld metal

Code	Min. yield strength N/mm²	Tensile strength N/mm²	Min. fracture strain %
35	355	440 to 570	22
38	380	470 to 600	20
42	420	500 to 640	20
46	460	530 to 680	20
50	500	560 to 720	18

Codes for the impact energy of the weld metal

Code	Temperature for min. notch impact energy 47J °C
Z	No requirements
A	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

Codes for the coating types

Type	Coating
A	acid
C	cellulose
R	rutile
RR	thick rutile
RC	rutile cellulose
RA	rutile acid
RB	rutile basic
B	basic

E 46 3 B 42 H5

Code	Efficiency %		Current type
1	≤105		A.c. and d.c.
2			D.c.
3	>105	≤125	A.c. and d.c.
4			D.c.
5	>125	≤160	A.c. and d.c.
6			D.c.
7	>160		A.c. and d.c.
8			D.c.

1. All positions
2. All positions except vertical-down
3. Butt weld in flat pos., fillet weld in flat and horizontal vertical pos.
4. Butt weld in flat pos. fillet weld in flat pos.
5. Position as for 3. plus vertical down pos.

Code	Hydrogen content in ml / 100 g weld metal max.
H5	5
H10	10
H15	15

Codes for the hydrogen content of the weld metal

Table 3 Electrode designations irrespective to DIN EN 499

4.2 Placement of the weld groove side walls

The groove edges are normally bevelled by oxyacetylene cutting for unalloyed and low-alloy steels. High-alloy steels and metals that can be MMA welded, can be fusion cut using a plasma arc. It is not absolutely necessary to remove the oxide skin produced by thermal cutting, but may be required in special cases.

If there are special requirements in terms of observing low tolerances, mechanical undercutting of the edges of parts to be joined may be recommended. This applies to circumferential welds in particular. The modern options for cutting with an electron or a laser beam are more commonly available in automated production and are the exception rather than the rule with MMA welding.

5 Electrode holders and welding cables

Figure 8 shows the current course in the welding current circuit.

The electrode is connected to one pole of the current source via the electrode holder (Figure 9) and the welding cable. The other pole is connected to the workpiece via the workpiece lead and the workpiece clamp.

The electrode holder is available in different sizes depending on the electrode diameter being used and the current intensity being applied.

They were previously standardised into 5 sizes in Germany in DIN 8569, Part 1. In Europe DIN EN 60974, Part 11, covers them.

The cross-section and the length of the leads must be such that the voltage drop

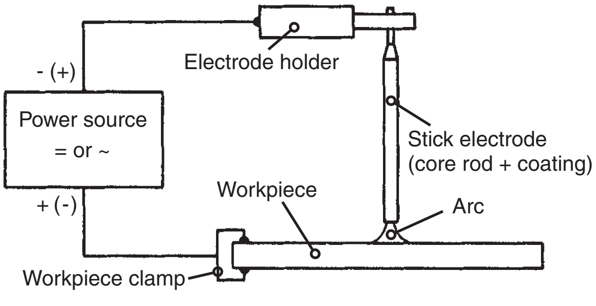


Figure 8 The power circuit [2]

Figure 9 Example of an electrode holder

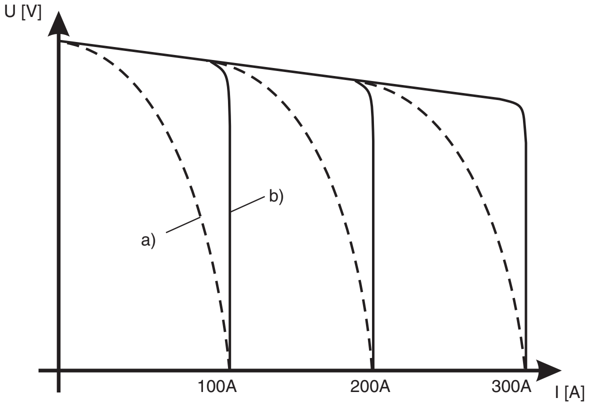
does not exceed certain values due to its resistance. Irrespective to the VDE standard, this is 2 volts up to 200 amperes and 5 volts up to 500 amperes. When calculating the necessary lead cross-section, the lengths of the welding lead and the workpiece lead should be added. Standard lead cross-sections for MMA welding are 25, 35, 50 and 70 mm^2 depending on the current intensity being applied.

6 Power sources

The power source converts the high mains voltage to the main lower welding voltage and supplies the high current intensities required for welding which the mains cannot provide. It is also possible to set and control the current. Both a.c. and d.c. can be used for welding.

Direct Power sources are general purpose because not all stick electrode types are weldable on sinusoid a.c.– see also the Current type section. Power sources

Figure 10 EWM power source PICO 162



a) Continually falling characteristic

b) Vertically falling characteristic (constant current characteristic)

Figure 11 Characteristics for MMA welding

for MMA welding have a falling, static characteristic, and with conventional power sources (such as for the PICO 162, Figure 10) generally continuously falling and with electronic power sources falling vertically in the work area (Figure 11).

This ensures that with the unavoidable changes in length of the arc with MMA welding, the most important parameter for the quality of the welding connection – the current intensity – is changed only slightly or not at all.

6.1 Power source designs

The simplest way to convert mains current into welding current is by means of the welding transformer. It converts the current only in terms of the current intensity and voltage (transformer) and supplies sinusoid a.c. for welding. The transformer principle is shown in Figure 12 [2].

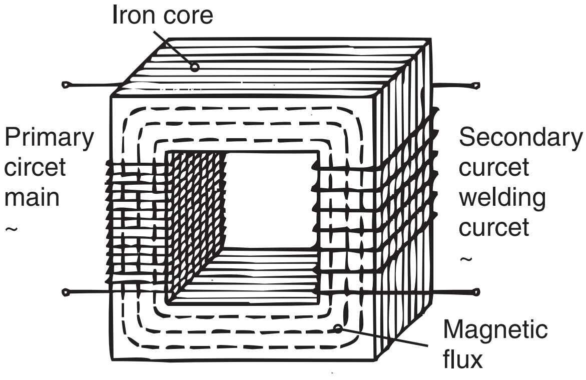


Figure 12 Transformer principle [2]

With power line-fed networks, the transformer is single-phase connected between one phase and the outer conductor or between two phases of the three-phase network. Different current intensities can be set via scattering kernel adjustment, primary side turn tapping or via transducer.

With the welding rectifier the current is rectified after transformation by diodes or thyristors, i.e. d.c. current is available for welding. For basic welding rectifiers, the transformer is single-phase or two-phase connected, but with more demanding machines, connected three-phase to all phases of the three-phase network. The latter supplies a very even current without significant current ripples. The evenness of the current is particularly useful when welding with basic electrodes and when welding with metal alloys, such as nickel-based alloys.

With simple machines the welding rectifier is set in the transformer – see Setting the welding transformer. Modern welding rectifiers are set using thyristors, which are controllable rectifiers, using phase shift control.

Electronic power sources (inverters) are also increasingly being used for MMA welding in practise (Figure 13).

Figure 14 shows the block diagram of a 3rd generation inverter with a clock frequency of up to 100 kHz.

These Power sources have a completely different layout to conventional power sources. The current coming from the mains is first rectified and then "hacked"

Figure 13 EWM power source STICK 350

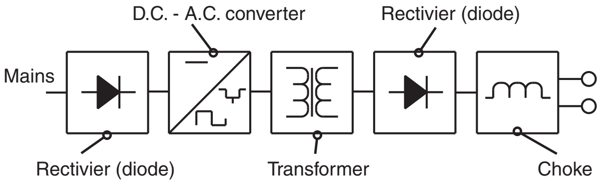


Figure 14 Block diagram of a 3rd generation inverter – clock frequency up to 100kHz

into small particles by switching on and off by means of transistorss using a clock frequency of up to 100 kHz. This chopping process is necessary so that the current can be transformed. The chopped current is then discharged as alternating current into a transformer. This produces a square-wave alternate current on the secondary side with the corresponding frequency. This is then rectified and smoothed using a choke. The high frequency of the current being transformed permits the use of transformers with a low mass. This permits high deposition power welding machines to be manufactured that nevertheless have a very low weight. They are therefore especially useful for use on construction sites. Figure 15 shows the EWM Inverter Triton 220 AC/DC that can be used for MMA welding up to a current intensity of 180 amperes and which weighs only 17.9 kg.

With inverters, the gradient of the static characteristic can be changed within broad limits. They can therefore also be used as multiprocess systems for multiple welding processes. With MMA welding the characteristic is generally vertically falling (constant current characteristic) in the work area.

Figure 15 EWM inverter TRITON 220 AC/DC for TIG and MMA welding

With electronic Power sources, much of what is achieved using components such as resistors, chokes and capacitors, is triggered electronically by the control. The control for these Power sources is therefore just as important as the power unit. The current is adjusted, for example with switched-mode sources, by changing the ratio between the current input/current output times. The clock frequency can also be changed to adjust the current level. The new technology also means that controlled Power sources are possible, which is precisely what welding technology had been waiting for. A control device measures the welding current and welding voltage and compares it to the set values. If the set set welding parameters change, for example due to unwanted resistances in the welding current circuit, the control will regulate it as appropriate. This is carried out very quickly, in the µs range. In a similar way, the short-circuit current can also be limited and the cosφ improved [3]. An improved level of efficiency and lower open circuit losses in the inverter Power sources are produced simply from the lower mass of the transformer.

Modern inverters now also supply sinusoid and square-wave A.C. in addition to D.C. Electrodes such as those with purely basic coatings, which cannot be used for welding on sinusoid, deposition can successfully meltoff with square-wave A.C.

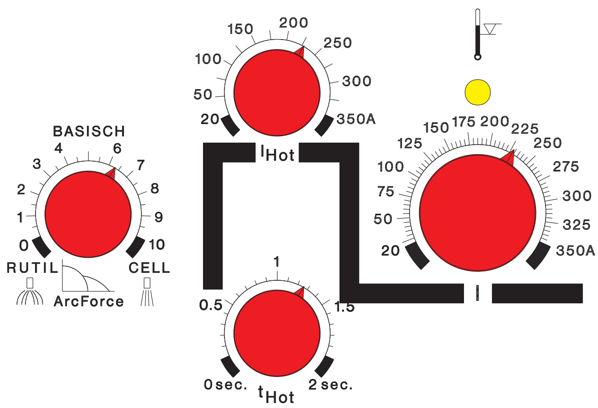


Figure 16 Control (operating panel) for a modern STICK power source

This may be necessary if undesirable magnetic arc blow conditions exist.

6.2 Special functions with inverters for MMA welding

Modern inverter Power sources also offer a range of special functions, which simplify welding and make the process safer [4]. This is how the arc force is set (Figure 16).

For example, if the arc voltage becomes too short due to a large drop forming on the electrode, and drops to below 8 volts, the current intensity is automatically increased (Figure 17).

This means that the arc can burn freely once more and does not go out. This function is particularly important when welding using cellulose-coated electrodes, as well as those with basic coatings.

The width of the arc and thus the arc hardness can be infinity adjusted using an adjustable choke. A hard arc is advantageous for difficult magnetic arc blow conditions exist, for example.

The Hotstart function used ensures safe ignition of the arc and sufficient warm-up of the cold parent material at the start of welding. The ignition process is carried out at an increased current intensity (Figure 18).

The Antistick function prevents the electrode annealing if the ignition process fails and the electrode "sticks" to the workpiece. The warning up of the electrode caused by the resistance heating may damage the coating until it breaks off. With Power sources equipped with the relevant function, the current is immediately regulated down to few amperes if the voltage does not rise after the ignition short-circuit. The electrode can then be removed from the ignition point very easily.

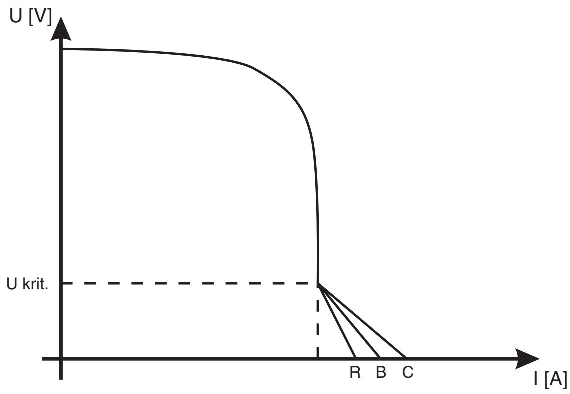


Figure 17 Principle for setting the arc force R= rutile electrode; B= basic electrode; C= cellulose electrode

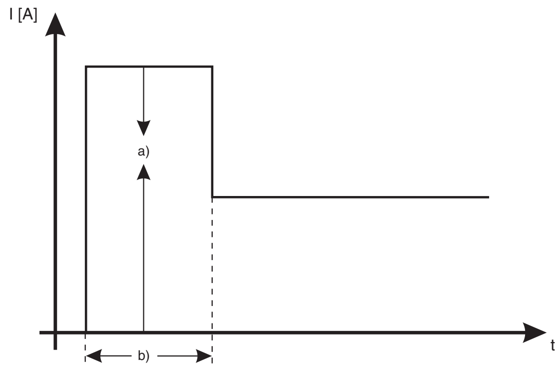
7 Performing welding work

The welder requires good training, not just in terms of skills, but also in terms of the relevant specialist knowledge in order to avoid errors. The training guidelines from the *DVS – Deutscher Verband für Schweißen und verwandte Verfahren e.V.* (German Association for Welding and Related Procedures) are recognised worldwide and have now been adopted by the International Institute of Welding (IIW).

Before starting welding, the workpieces are generally tack-welded. The tack points must be long and thick enough to ensure that the workpieces cannot contract to a non-permissible extent during welding and that the tack points do not break.

7.1 Igniting the arc

The welding process is initiated by contact ignition with MMA welding. To close the power circuit, a short-circuit needs to be created between the electrode and the workpiece first and the electrode raised slightly immediately afterwards; the arc will ignite. The ignition process should never take place outside the groove, but only at points that will be fused again im-



a) Hotstart current

b) Hotstart time

Figure 18 Principle of the “Hotstart” function

mediately once the arc is burning. This is because at ignition points where this does not occur, cracks may occur in suitably sensitive materials due to the sudden heating.

When using basic electrodes with a tendency to initial porosity, the ignition process must actually take place significantly before the start of the weld. The arc is then moved back to the starting point for the seam and during the course of the welding process the first drops deposited, which are generally porous, will be fused once more.

7.2 Moving the electrode

The electrode is positioned vertically or at a slight slant to the panel surface. It is titled slightly in the direction of welding. The visible arc length, i.e. the distance between the edge of the crater and the workpiece surface should be roughly equal to the core wire diameter. Basic electrodes must be welded with a very short arc (distance=0.5 x core wire diameter). To ensure this, they need to be held in a more steeply inclined position than rutile electrodes.

In most positions, stringer beads are welded or a slight weaving movement is used with an increasingly large groove width. Only in the vertical up position are weave beads drawn across the entire width of the groove. Welding is normally carried out with the torch directed at the finished part of the joint; only in the vertical up position is forehand welding used with the electrode.

7.3 Magnetic arc blow

Arc blow is where the arc being diverted from its central axis lengthens and a hissing noise is emitted as a result. This diversion could result in discontinuities, such as the fusion penetration becoming inadequate and, in slag-forming welding processes, slag inclusions being produced in the seam due to the slag flowing ahead of the molten pool.

Forces arising from the surrounding magnetic field cause the diversion. Just like any other current-carrying conductor,

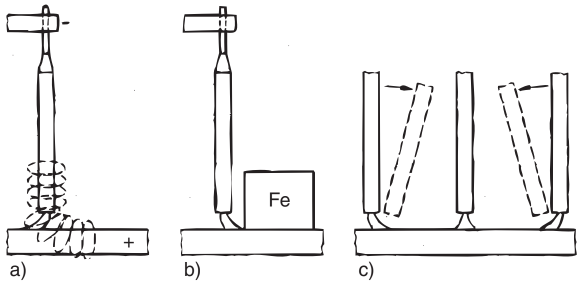


Figure 19 Deviation of the arc caused by surrounding magnetic fields

the electrode and arc are also surrounded by a toroidal magnetic field, in the area of the arc it is diverted, when it comes into contact with the parent material. This compresses the magnetic lines of force on the inside and expands them on the outside (Figure 19, a) [2].

The arc slips into the area of reduced flux line density, is thereby lengthened and emits a hissing noise due to the increased arc voltage created. The opposite pole therefore exerts a repulsive effect on the arc.

The presence of another magnetic force means that the magnetic field can spread more easily in a ferromagnetic material than in air. The arc is therefore attracted by large ferric masses (Figure 19, b). This is reflected, for example, in the arc moving inwards at the ends of the sheet when welding a magnetic material.

The movement of the arc can be counteracted by tilting the electrode as appropriate (Figure 19, c). As arc blow is particularly noticeable with d.c. welding, it can be avoided, or at least reduced, by welding with a.c.

The arc blow effect may be particularly strong due to the surrounding ferric masses when welding root passes. In this case it is helpful to support the magnetic flux by closely positioned and sufficiently long tack welds.

7.4 Set welding parameters

In MMA welding only the current intensity is set; the arc length being used by the welder gives the arc voltage. When setting the current intensity, the current carrying capacity of the electrode diameter being used needs to be taken into account. Table 4 provides guideline values for the current carrying capacity for the various electrode diameters.

The rule which can be used here is that lower limit values are used for welding root passes and for the vertical up position, and the upper values apply to all other positions and for intermediate and final passes. As the current intensities increase, the melt deposition power increases and therefore also the welding speed. The fusion penetration also increases with increasing current levels. The current intensities given only apply to unalloyed and low-alloy steels. With high-alloy steels and nickel-based materials, lower values should be set due to the greater electrical resistance of the core wire.

Settings for various welding tasks are given in Table 5, Table 6 and Table 7, [2], [5].

8 Work safety

In MMA welding, risks to the welder arise from the smoke and gases of the stick electrode coatings and from metal vapour, as well as from visible and ultraviolet rays and infrared radiation emitted by the arc; electrical risks are also present.

Irrespective to current accident prevention regulations, an extraction system is required directly at the point of emission for MMA welding at fixed workstations. Only for short-term and mobile welding is air ventilation or a welding-engineering ventilation device permissible in certain circumstances.

Diameter (d in mm)	Length (l in mm)	Current intensity (I in A)	Rule of thumb for current intensity in A
2.0	250/300	40... 80	20...40 x d
2.5	350	50...100	
3.2	350/400	90...150	30...50 x d
4.0	350/400	120...200	
5.0	450	180...270	
6.0	450	220...360	35...60 x d

Table 4 Current intensities irrespective to the electrode diameter

Sheet thickness (mm)	Welding position	Seam type	Electrode type	Electrode diameter (mm)	Current intensity (ampere)	Note
4	Flat	V	RA	2.5	75	-
6				3.2	140	Root
				4.0	180	Final pass
10			B	3.2	120	Root
				4.0	170	Final pass
	V-up		RB	3.2	95	Root
				4.0	160	Final pass
15	Flat		B	3.2	130	Root
				4.0	170	Fill and final pass
	V-up		B	3.2	90	Root
				4.0	140	Final pass
20	Flat		B	4.0	160	Root
				5.0	220	Fill and final pass
	V-up		B	3.2	90	Root
				4.0	140	Fill and final pass

Table 5 Settings for butt welds on unalloyed and low-alloy sheet materials, values from [2] and [5]

The beam from the arc dazzles eyes and may cause "arc eye", i.e. an eye inflammation. However, the beam can also cause skin burns and symptoms similar to sunburn. Welders must therefore protect themselves using suitable work clothing and a welding safety shield with the relevant safety filters conforming to EN 166 and EN 169. The safety filters to be used should be of protection level 9 – for thin electrodes and low current intensities up to 14 – for thick electrodes and high current intensities. A plain cover glass in front of the safety filters or a pair of clear glasses protect against eye injuries from slag breaking.

Wall thickness (mm)	Welding position	Seam type	Electrode type	Electrode diameter (mm)	Current intensity (ampere)	Note
8	Vertical down	V	C	4.0	125	Root
					170	Hotpass
					150	Fill pass
					130	Final pass
10				4.0	130	Root
					180	Hotpass
				5.0	190	Fill pass
					175	Final pass
12				4.0	130	Root
					180	Hotpass
				5.0	200	Fill pass
					175	Final pass

Table 6 Settings for butt welds on pipes made from unalloyed and low-alloy steel, values from [2]

Electrical dangers occur in arc welding mainly from the open-circuit voltage because this is the maximum voltage present between the two poles when the power source is on when no welding is being carried out. The arc voltage produced during the actual welding process is much lower, on the other hand, and depending on the electrode diameter and arc length may be around 20-30 volts. The level of open-circuit voltage is therefore limited by the accident prevention regulations. It must not exceed a peak value of 113 volts with d.c. and a peak value of 113 volts with a.c. and an r.m.s. value of 80 volts.

The electrical risk to the welder is especially great when welding in small and damp areas and when welding on and in large ferric masses. In this situation, d.c. power sources with a peak value of 113 volts are permissible. With a.c. the level of open-circuit voltage is restricted even further. It must not exceed a peak value of 68 volts and an r.m.s. value of 48 volts. Power sources fulfilling these requirements are identified as such. Newly manufactured machines bear the "S" sign (safety), and with older machines the mark "K" for d.c. machines and "42 V" for a.c. machines can still be found.

However, welders must also protect themselves from contact with current carrying parts by wearing insulated clothing, shoes with undamaged rubber soles and leather gloves. When working on metal constructions, use of an insulating mat is also recommended.

9 Special notes for MMA welding on different materials

MMA welding is today used mainly for welding unalloyed and low-alloy steels, in other words, constructional steels, creep resistant, high tensile and low temperature steels, as well as stainless chrome/nickel steels and nickel-based alloys. Another application for stick electrodes is GMA surfacing.

The welding of aluminium and aluminium alloys and of copper and copper alloys with coated stick electrodes has been all but overtaken by shielded arc welding and is now only used as an emergency support measure, if for some reason it is not possible to use shielded arc welding, such as on construction sites.

Given below are some special features and possible uses with different materials.

Eff. throat thickness (mm)	Welding position	Seam type	Electrode type	Electrode diameter (mm)	Current intensity (ampere)	Note
2	V-down	T	RC	2.5	70	-
3	Hor. vert.		RR	3.2	130	-
4				4.0	180	-
			RR160		190	-
5			RR		180	Root
				5.0	240	Final
6			RR160		290	-
			RR	4.0	180	Root
				5.0	240	Final
					255	-
8	V-up		B	3.2	110	Root
				4.0	140	Final

Table 7 Settings for fillet welds on unalloyed and low-alloy steels, values from [2]

9.1 Unalloyed and low-alloy steels

Due to the low level of investment required, MMA welding is still used with unalloyed and low-alloy steels in smaller companies with less intense welding requirements where purchasing larger, automated welding systems would not be economically viable. Stick electrodes are also still used on construction sites, e.g. out-of-doors welding, where shielded arc welding would necessitate complex precautions to shield against the wind, Figure 20.

In all other cases, the process has yet to prove its efficiency in contrast to other, automated arc-welding techniques. High deposition power electrodes with an efficiency of 160-180% are therefore used wherever possible. High efficiency rutile electrodes are especially well suited to welding fillet welds with effective throat thickness of 3-5 mm, thanks to high welding speed and good seam appearance.

In the construction of pressurised containers and boilers, basic stick electrodes continue to enjoy a certain degree of popularity because of the excellent quality values of the welding join, with the improved quality of the welds sometimes proving more important than economic considerations.

Figure 20 Use of inverter power source PICO 162 on a construction site

High-tensile steels, including construction steel S355 if present in larger wall thicknesses (>20 mm), have a tendency to crack during welding if three contributory factors are combined, namely, a high hydrogen content, high stresses and rapid cooling after welding. Such hydrogen-induced cracks can be most safely avoided if the hydrogen content of the weld metal is kept low (<5 ml / 100 g). As, unlike with shielded arc welding, in MMA welding hydrogen is supplied primarily by the coating, only dry, basic electrodes can be used for these purposes. Electrodes that have become damp or may have absorbed some moisture need to be oven-dried before welding. As a guideline for the drying process, a temperature of 250-350°C and a drying time of 1-2 hours should be sufficient, but this may vary for different manufacturers. The best option is to follow the instructions from the manufacturer.

9.2 High-alloy steels and nickel-based alloys

MMA welding still finds relatively widespread application in the construction of chemistry equipment for welding stainless CrNi steels. Unlike shielded arc welding, the MMA welding weld seam is still protected against the atmosphere during cooling by the slag. The seams are therefore subject to less oxidisation. The oxide skins produced must be removed by brushing, grinding, blasting or etching before using the component because they have a detrimental effect on corrosion-resistance. Due to the reduced oxidation of the surface, less work is required to clean up the seams. This can compensate for any economic advantages provided by MAG welding over MMA welding, for example. When welding corrosion-resistant steels, MMA is sometimes given preference over MAG welding for fear of lack of fusion.

As austenitic steels do not become brittle even under the influence of hydrogen, and do not have a tendency to crack, electrodes with rutile coatings are used mainly for these steels, as they provide a good seam appearance. This applies to fillet welds and to final passes in particular. High deposition power electrodes with an efficiency of 160% are also available for this purpose.

Electrodes for steels with high corrosion-resistance and nickel-based alloys are generally supplied with basic coatings, however. This coating type can also be required for compound steels that, because of their two-phase structure, are rather more susceptible to becoming brittle due to hydrogen.

When welding high-alloy materials, overheating must be avoided because this reduces the strength and corrosion-resistance of the welded joint, and may result in heat cracks. Therefore, with thinner workpieces, including occasional cooling breaks or accelerating the cooling process by underlaying pieces of copper is recommended.

9.3 GMA-surfacing

Stick electrodes enable hard alloys that cannot be manufactured in the form of solid wire for reasons of ductility (such as cast iron alloys with a high chrome content) to be applied by alloying via the coating. One alternative here is cored wires, which can be alloyed via the core, but MMA welding is still used in this sector with relative frequency.

10 Applications for MMA welding

MMA welding can in principle be used for wall thickness starting at 1.5 mm, but many manufacturers produce stick electrodes starting at 2.0 mm Ø, because very thin sheets are now generally TIG-welded. This increases the minimum wall thickness for MMA welding to 2 mm.

The proportion of MMA welding has continued to fall continuously over the past few years to be superseded by MIG/MAG welding. Irrespective to more recent statistics, the proportion today in relation to all arc-welding processes is still around 7.5% [6].

Figure 21 Use of MMA welding in container construction

The main applications remain shipbuilding, where fillet welds are predominantly used, and steel construction work, where stick electrodes are used mainly on construction sites. Previous sections have covered some of the advantages of MMA welding in boiler, equipment and pipeline construction. A further application is in repair workshops, both for joint welding and GMA-surfacing.

10.1 Example applications

In place of many different applications, typical possible uses of MMA welding are given below using two examples.

Figure 21 shows an application from container construction.

Add-on pieces have yet to be welded onto a container manufactured by automated welding. MMA welding is ideal for this application. The use of a lightweight inverter as a power source is particularly useful for this purpose. Thick and less flexible welding leads are no longer needed, because the inverter can be moved onto or close to the workpiece.

The second example shows one application of MMA welding in beam construction.

Many metalworking firms or small steel construction companies manufacture rail-

Figure 22 Use of MMA welding in beam construction

ings, balconies or beams prefabricated in the workshop and then installed on construction sites. Multiple short weld seams are used for this purpose, to which MMA welding is ideally suited.

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The MMA Primer, 3rd edition 2009

From the EWM Knowledge range of publications – All about welding

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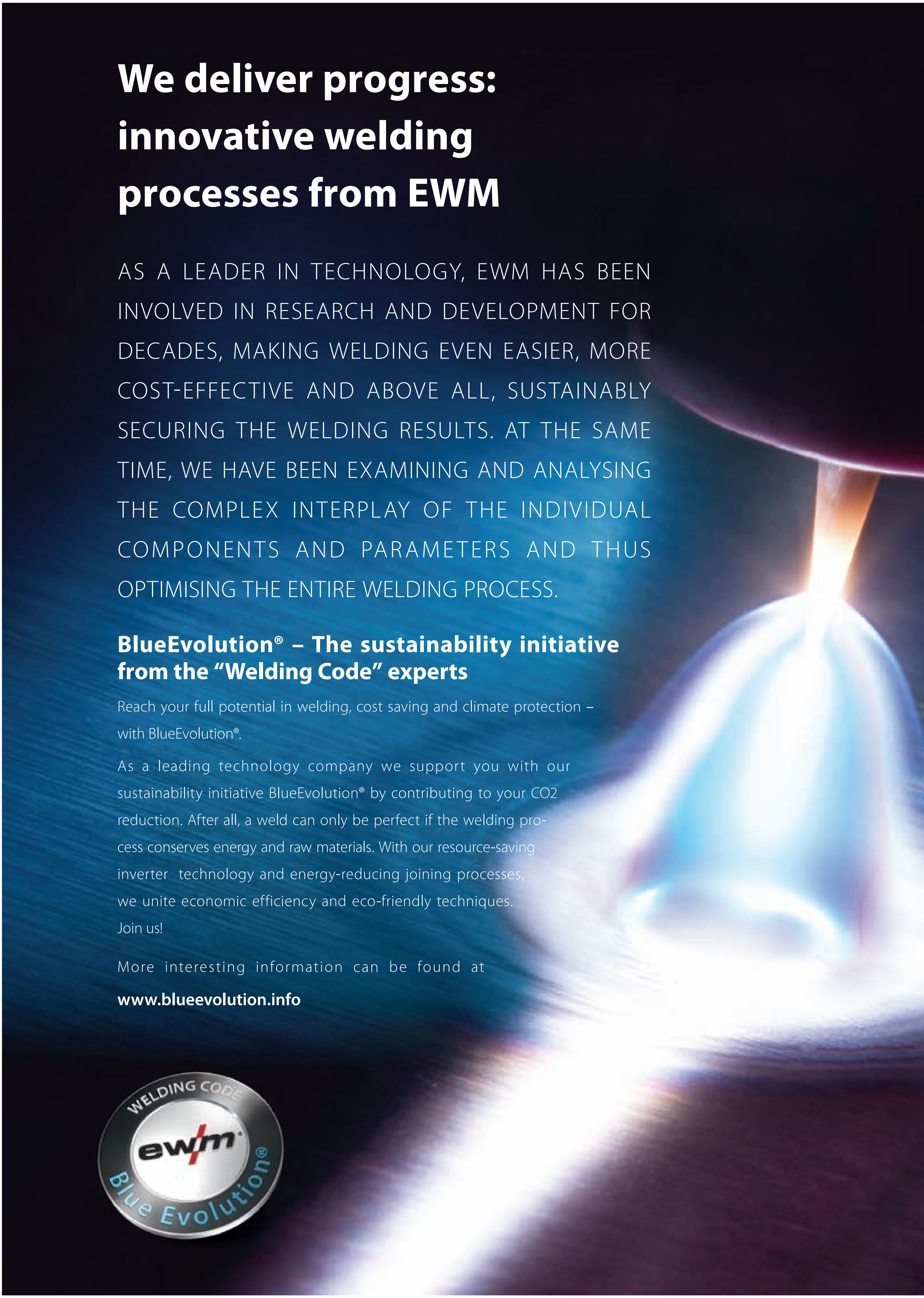
TIG PRIMER



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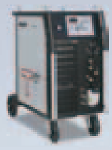

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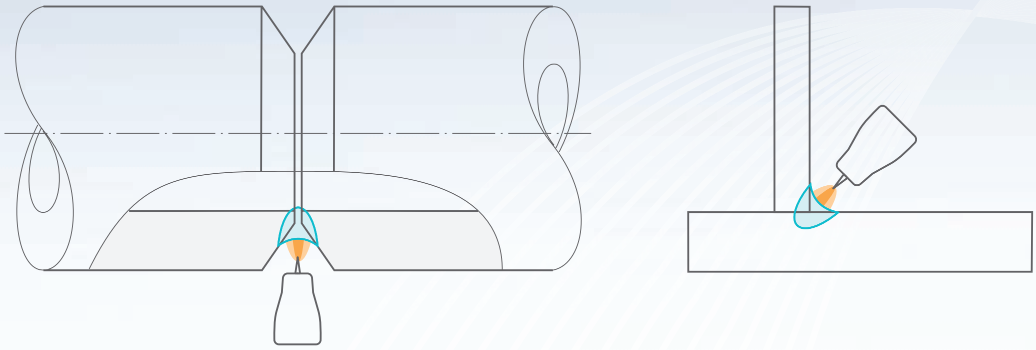

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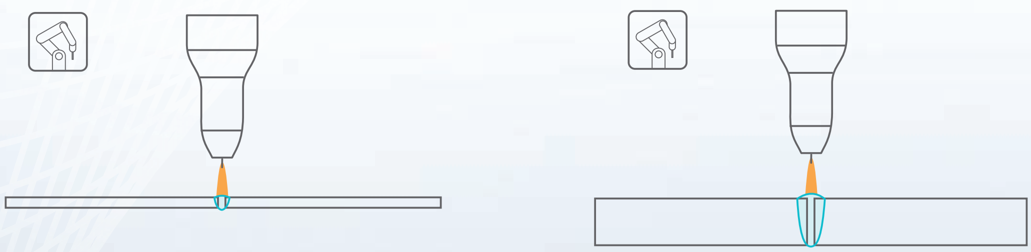

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- For fully mechanised and automated manufacturing processes
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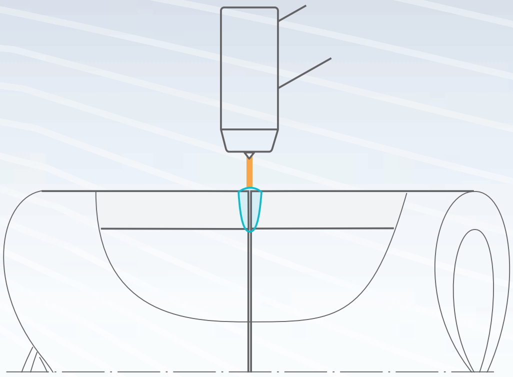
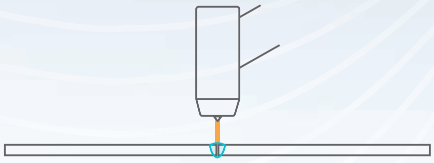
Plasma

Focusedar c
with high energy density.

Tetrix Plasma

microplasma





Plasma

- Focused, directionally stable arc
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- Plasma keyhole welding with excellent root formation
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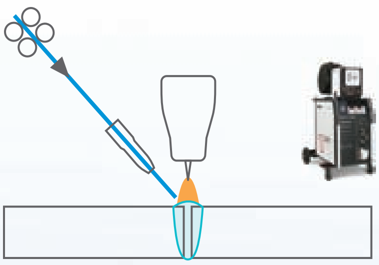
Coldw ire Hotw ire

Effective and productive TIG processes
thanks to the mechanised addition of the welding consumable.

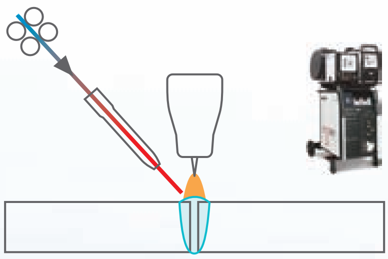
tigSpeed

Particular safety in positional welding
as a result of the dynamic forward/backward wire motion



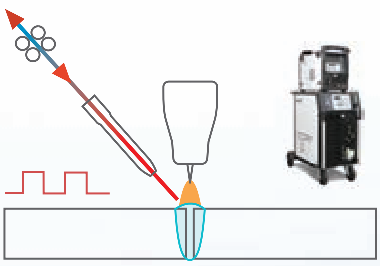
Cold wire

- Effective handling of the TIG process
- Also advantageous when manually welding long welds and large cross-sections
- Greater welding speed and deposition rate in comparison to conventional TIG welding
- Also suitable for non-ferrous metals, e.g. aluminium and aluminium alloys



Hot wire

- High deposition rates comparable to MIG/MAG welding
- Highw eldings peed
- Minimal risk of a lack of fusion
- Highly suitable for narrow-gap welding and GMA-surfacing
- High-quality, fine-flaked seam
- Especially effective in mechanised and automated applications



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- Dynamic wire feed – the wire feeding is superimposed by a forward/backward wire motion.
- The logical extension of the TIG cold and TIG hot wire welding
- High welding speed and simplest handling – particularly in positional welding
- Perfect results without any lack of fusion – particularly suitable in pipe root welding
- High-quality, fine-flaked seam

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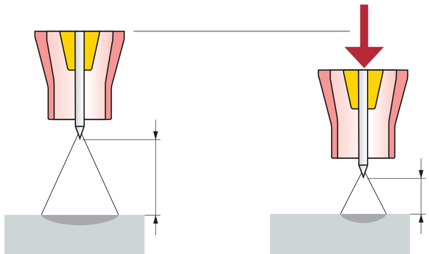
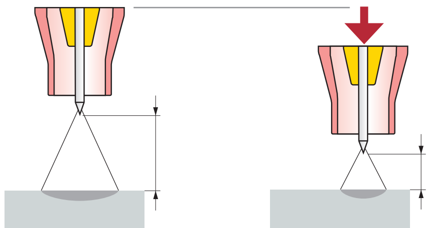


Large distance, approx. 12 V
Welding current: 60 A

Smaller distance, approx. 10.5 V
Welding current: 60 A

WITH activArc®

- Output fluctuations are compensated for when the arc length is changed.



Large distance, approx. 12 V
Welding current: 60 A

Smaller distance, approx. 10.5 V
Welding current: 68.5 A

CONTROLLED HEAT INPUT

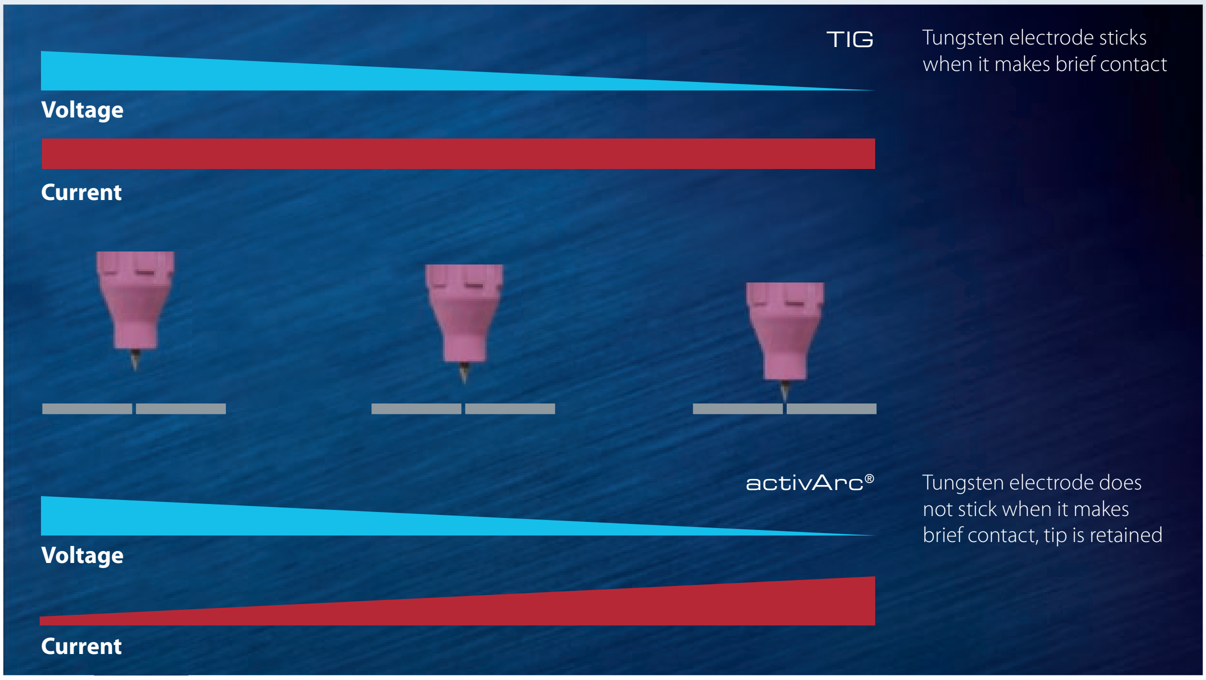
- The welding current is increased as the arc is shortened.

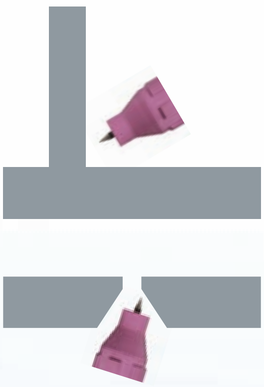
VoltageV ↓ CurrentI ↑

- The welding current is decreased as the arc is lengthened.

VoltageV ↑ CurrentI ↓

Simpler and safer TIG welding





Requirement:

Sufficient energy density and high arc force for reliable sidewall fusion

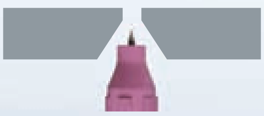
Problem:

Constant welding current and dropping output due to dropping welding voltage

Solution using activArc:

Dropping voltage with a shortening arc is compensated for by increasing the welding current.

- Sufficient energy density
- Increased arc force thanks to increasing welding current
- Reliables idewallf usion



Requirement:

Low energy density and low arc force for better control of the molten pool

Problem:

Constant welding current and increasing output due to increasing voltage

Solution using activArc:

Dropping welding current as the arc becomes longer

- Low energy density
- Low arc force
- Influence on molten pool viscosity

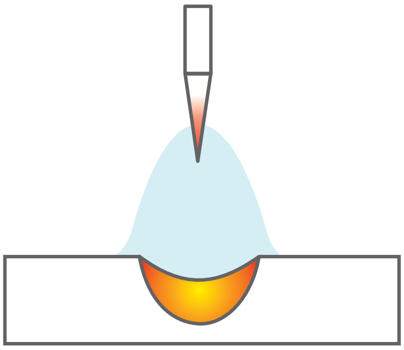
PATENTED *

forceTig®

TIG welding process with especially concentrated arc for greater penetration and faster welding speeds

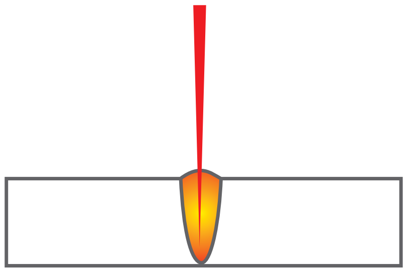
forceTig

ADVANTAGES OF TIG



- Low procurement costs
- Lowop eratingc osts
- Easy handling

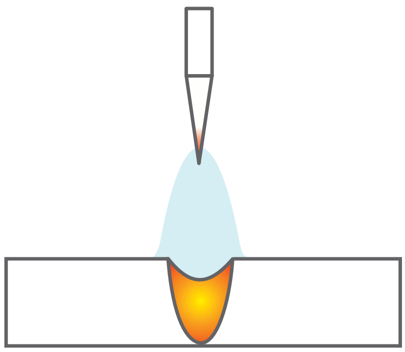
ADVANTAGES OF LASER



- High process stability
- High joining speed
- High energy density
- Deepp enetration

forceTig® - A COMBINATION OF ADVANTAGES

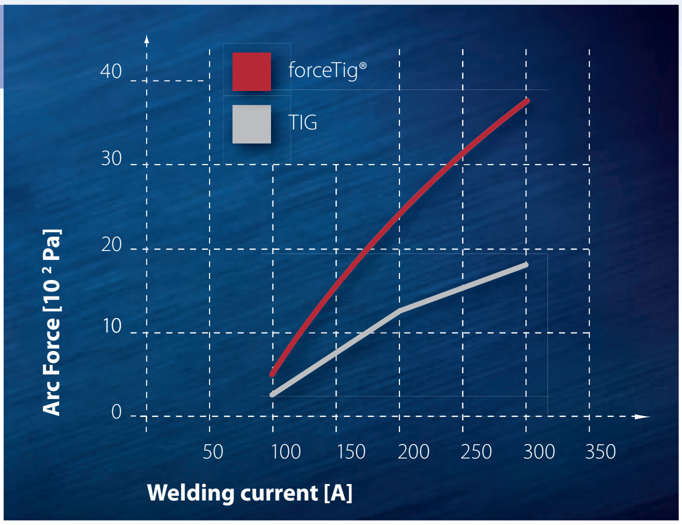
- Optimum for mechanised and automated applications, with or without welding consumables
- High torch power: 800 A at 100% DC
- Very high current-carrying capacity, high current density
- Stable torch design for increased crash safety
- Closed, highly effective cooling circuit
- Electrode easy to change without gauges thanks to defined, calibrated geometry
- 100%r eproducibleT CP
- Low procurement costs and energy requirement



* EP 2 008 750 B1

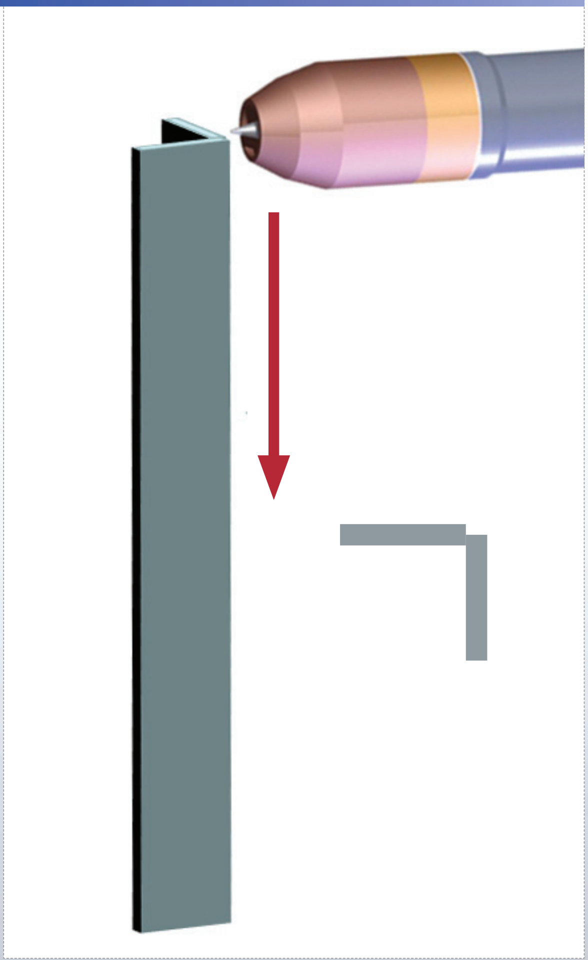
Universal in use, from thin to thick

ARC FORCE COMPARISON
TIG/forceTig®



EDGE WELD IN VERTICAL-DOWN POSITION forceTig® **CORNER JOINT**

- Material: 1.4301
- Panel thickness: 2 mm
- Welding current: 250 A
- Welding speed > 2 m/min

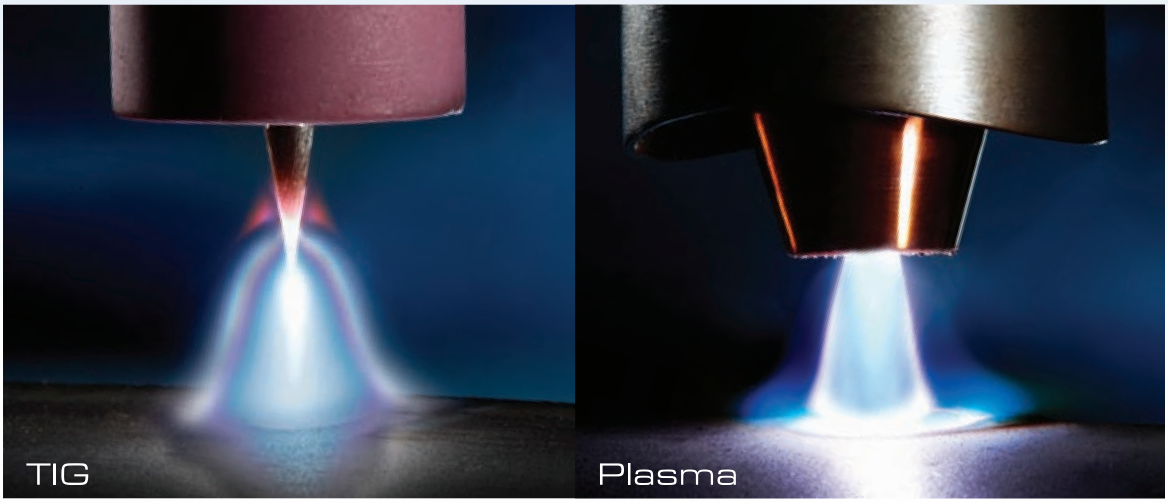


Plasma

Focused arc with high energy density.

Tetrix Plasma

microplasma



PLASMA ARC: FEATURES

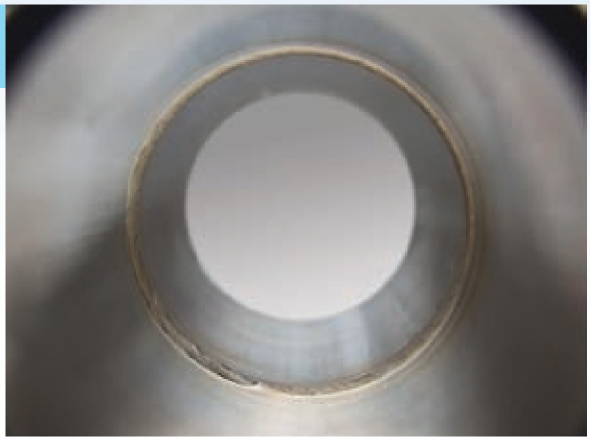
- Constricted, nearly cylindrical arc
- High energy density
- Low divergence (temp. = 10,000 to 20,000°K)
- Stable, even with extremely low currents as from 0.1 A (microplasma welding)
- Veryd irectionallys table
- Insensitive to changes in distance between the torch and workpiece
- High ignition reliability thanks to pilot arc

PLASMA ARC: ADVANTAGES FOR PROFESSIONALS

- Faster welding speed compared to TIG welding, especially with metal sheets thicker than 2.5 mm (plasma keyhole welding)
- Reliable single pass penetration up to 8 mm (high-alloy steels) and 10 mm (unalloyed steels)
- Narrow heat-affected zones, less discolouration
- Minimal distortion
- Favourable ratio of seam width to seam depth
- Controllablep enetrationd epth
- Minimal excess weld material and root-side drop-through, so normally no mechanical post weld work of the weld seam is necessary
- Advantageous in comparison to TIG welding in preproduction
- Insensitive to misaligned edges of the workpieces
- Insensitive to component tolerances which change the arc length
- No risk of tungsten inclusions in the weld metal
- Small molten pool

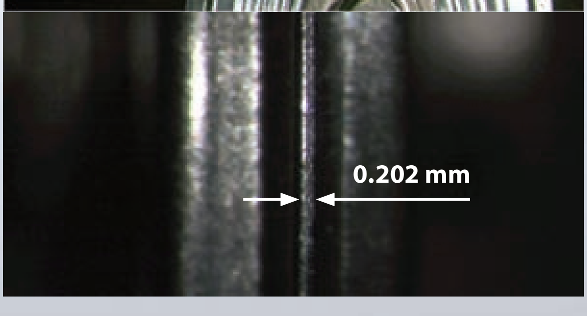
Fast, safe and for the most stringent of quality requirements

PLASMA/PLASMA KEYHOLE WELDING

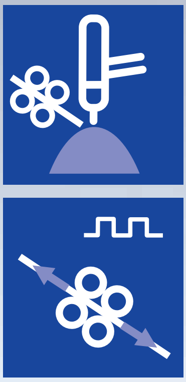


- Container, equipment and pipeline construction
- Vehicle, automobile, track and ship construction
- Food and chemicals industry
- Machine and plant construction
- Production and repair work in the aviation and aerospace industry
- Mouldm aking
- Production of dished boiler heads
- Cryogenics

MICROPLASMA WELDING



- Production and repair work in the aviation and aerospace industry
- Food and chemicals industry
- Vehicle, automobile and ship construction
- Mouldm aking
- Cryogenics
- Measurement and control technology
- Medicalt echnology
- Printing technology
- Electronics



Cold wire
Hotw ire

Effective and productive TIG processes thanks to the mechanised addition of the welding consumable.

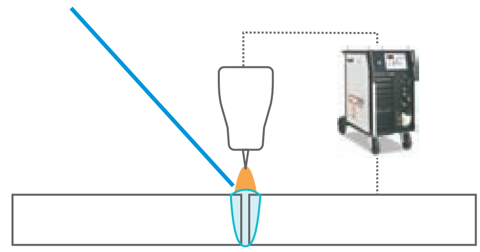
tigSpeed

TIG hot wire welding process with dynamic forward/backward wire motion.

Tetrix AW Cold wire	Tetrix AW Hot wire	tigSpeed **Hot wire**

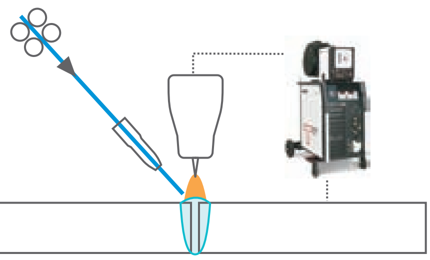
TIG WELDING

- With regard to the materials to be used, wall thicknesses and welding positions, TIG welding is a universal welding process. It enables top-quality joints to be created.



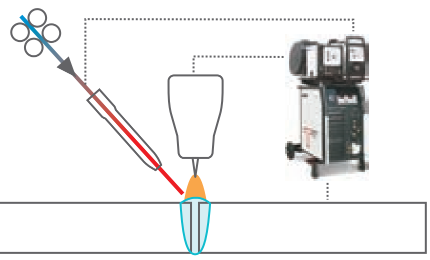
TIG COLD WIRE WELDING

- TIG cold wire welding was developed primarily with the aim of making TIG welding easier and more convenient to use and secondarily to increase the welding speed. In this process, the welding consumable is conveyed to the weld pool by a wire feed unit. Deposition rates, however, remain limited.



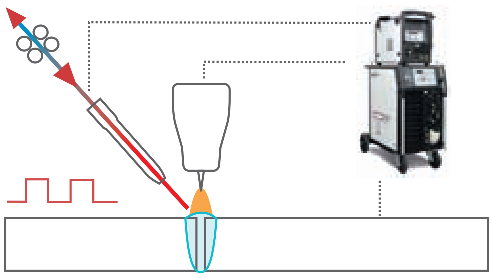
TIG HOT WIRE WELDING

- TIG hot wire welding is a further development of TIG cold wire welding. The welding consumable is heated by a separate power source using resistance heating of the wire stick-out between the contact tip of the hot wire torch and the molten pool. There are many advantages over cold wire welding thanks to the improved heat balance provided by this process.

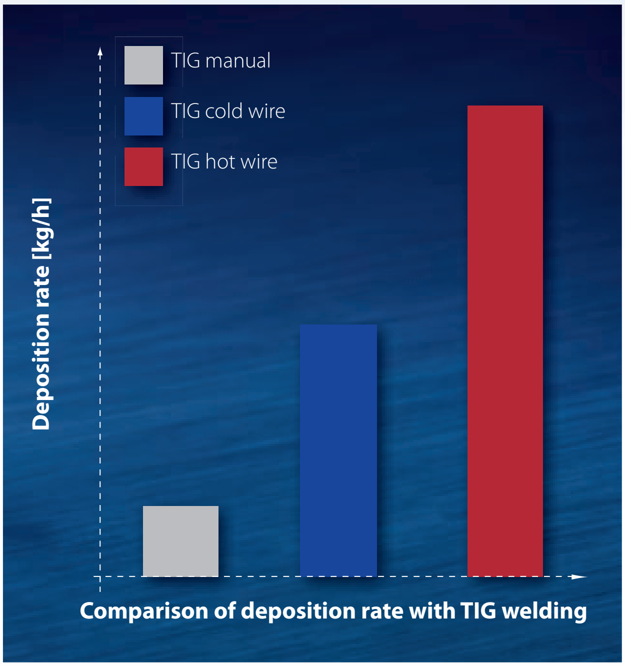


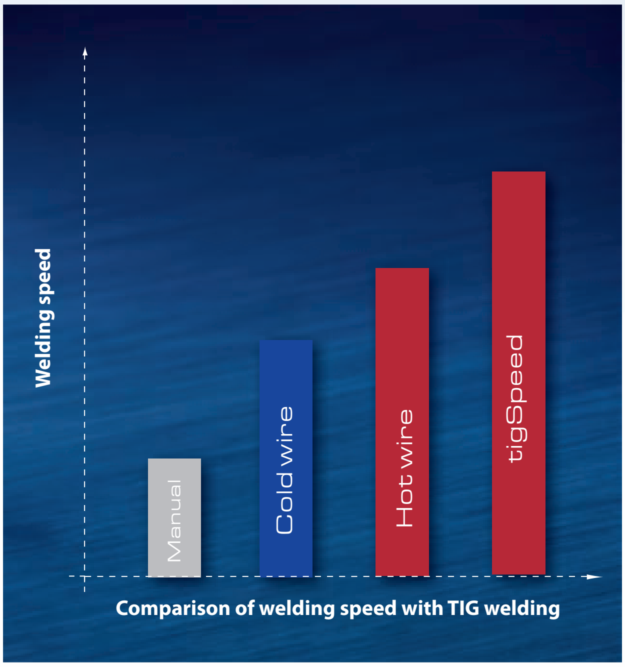
tigSpeed HOT WIRE WELDING

- TIG speed welding is the logical extension of TIG cold and TIG hot wire welding. The continuous wire feeding is superimposed by a forward/backward wire motion. This leads to a particularly stable welding process with a high deposition rate, which is particularly suitable for positional welding.



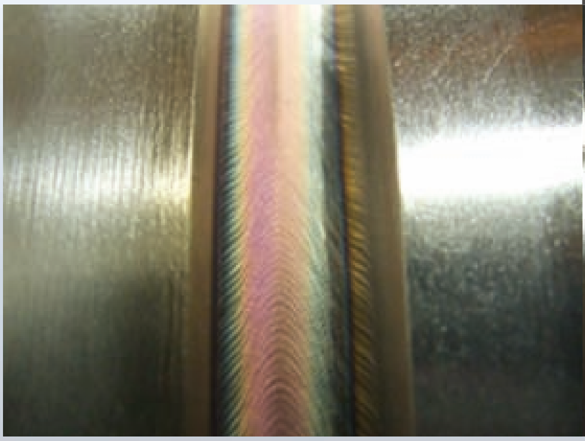
TIG hot wire
Up to 100% faster welding speed





ADVANTAGES OF TIG HOT WIRE WELDING

- Up to 100% faster welding speed
- Up to 60% increase in deposition rate
- Dilution reduced by up to 60%
- Greater deposition rate (30–50%) with the same welding performance
- Simplifiedp ositionalw elding



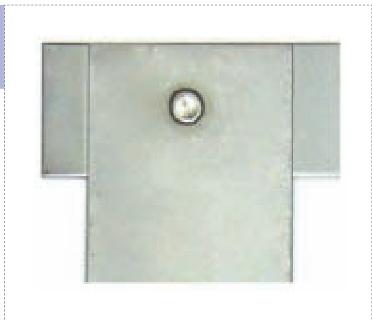
spotArc®

Use TIG spotArc® spot welding and metal sheets are joined perfectly

USE TIG spotArc® SPOT WELDING AND METAL SHEETS ARE JOINED PERFECTLY

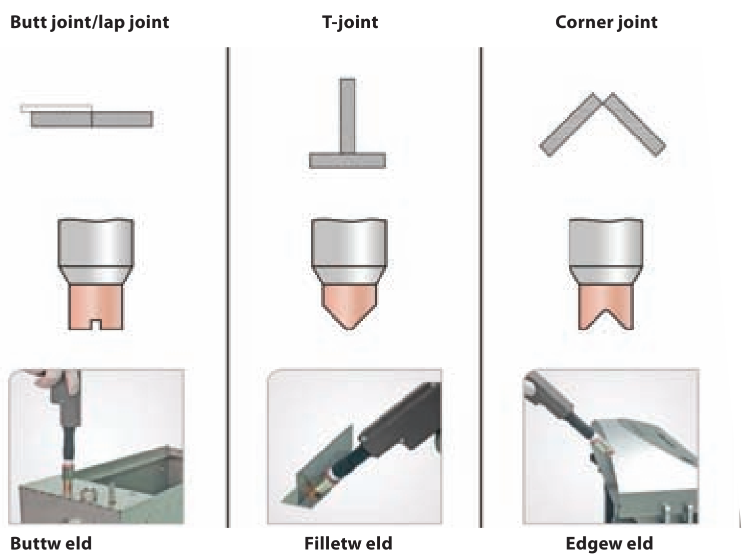
- Universal in use thanks to the option of joining two metal sheets of the same thickness and of different thicknesses
- Optimal for tacking workpieces for manual and automated applications
- Simple to use – welding is only carried out on one side
- Excellent seam quality with low distortion thanks to the minimal amount of heat input
- Ergonomic torch design for the best possible handling and optimum power utilisation
- Economic solution consisting of standard components: EWM TIG DC welding machine, TIG spot welding torch and optional spot remote control
- Alternative to resistance welding with greatly simplified handling

PERFECT SURFACE FORMATION



- Flatter spot formation in comparison to MAG spot welding
- Exceptional spot connection characteristics thanks to minimal heat input
- Very low thermal tension and little distortion thanks to short welding times
- Optimal for visible joints thanks to the clean seam appearance

THE RIGHT NOZZLE SHAPE FOR EVERY APPLICATION



PATENTED *

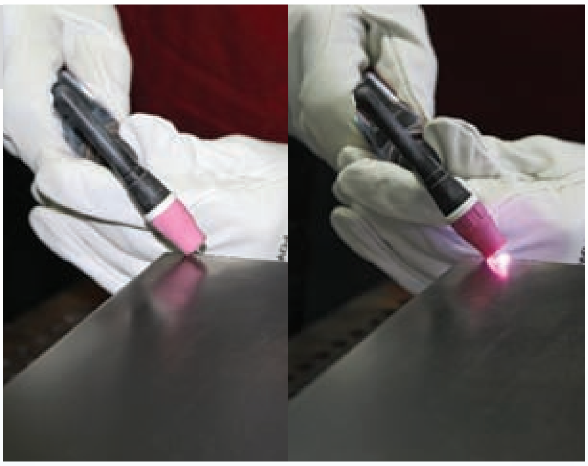
Spotmatic

Spot for spot for a perfect TIG weld with minimised spot and tacking times

Spotmatic – UP TO 50% LOWER MANUFACTURING COSTS

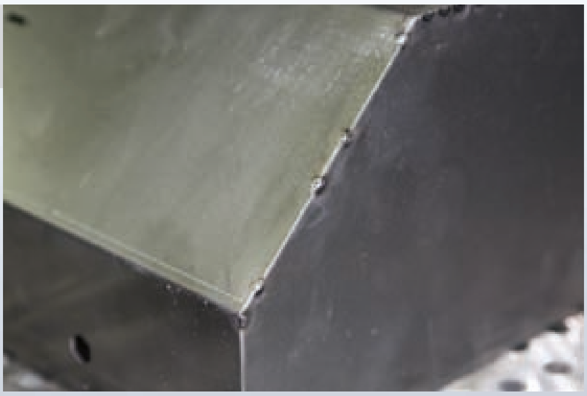
- Up to 50% less tacking time thanks to the elimination of the usual trigger pulling
- Practical and innovative solution
- Easily reproducible welding results
- No special torches are required! Any "standard" TIG welding torch is perfectly adequate!
- Several hundred tack points can be made without having to grind the tungsten electrode

RELIABLE – FAST AND EASY TO USE



- Easier handling – also easy to teach to non-professionals
- The arc is ignited by touching the tip of the electrode to the workpiece instead of using the torch trigger
- The electrode does not stick to the metal

QUALITY AND REPRODUCIBILITY



- Even tack point appearance
- Spot results comparable to mechanised or automated applications
- No rocking motion when starting or stopping the spot process
- Prevents imprecise welding results

* EP 2 172 298 B1

A host of functions which save time and money

Pulsing

AC pulsing

Safer TIG welding saves money.

With "TIG pulsing", switching occurs back and forth between two different welding current levels, the pulse current and the pause current. The times, and therefore the frequency and duty cycle, can be adjusted individually at the machine or using the remote control. TIG pulsing is possible with direct current (DC) and alternating current (AC) welding.

Difficult welding applications can be implemented easily

- Improved molten pool control in positional welding, especially in the vertical-up position
- Easy bridging of larger gaps and gaps of different sizes

Excellent weld seam quality

- Lower heat input
- Targeted control of the heat input
- Minimised material distortion
- Reduction of the energy per unit length, optimum for CrNi welding and heat-sensitive materials
- Weld seam appearance with extraordinarily even bead ripples – optimal for visible welds

kHz pulsing

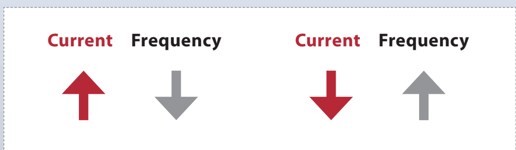
From 0.05 to 15 kHz

- Constriction of the arc with increasing frequency
- Concentration of the arc energy to a smaller surface
- Arc stability, even at very high welding speeds
- Smaller heat-affected zone
- Improved seam surface

Automated pulsing

To increase the arc stability and the penetration properties, especially with low currents, the current is pulsed automatically.
The ideal area of use is the tacking and spot welding of workpieces

- Pulse frequency depends on welding current
- Ideal for tacking and passing thanks to the vibrations in the weld pool



AC functions – optimal for aluminium welding

AC special

The "AC special" operating mode is a TIG pulse variant in which switching occurs between alternating current in the pulse phase and direct current in the fundamental current phase. The welding current and the respective times can also be set individually for each phase here.

- Highly suitable for welding in the vertical-up position, even without weaving
- Controlled root formation when welding thin metal sheets in the butt joint
- Faster welding speed with fully mechanised and automated applications with and without welding consumables
- Excellent seam appearance, deep penetration thanks to the higher current carrying capacity of the tungsten electrode

AC wave forms

- Sinusoidal – quiet arc noise, low-vibration molten pool, ideal for welding with welding consumables, low electrode load
- Trapezoidal – the all-rounder
- Rectangular – good cleaning effect, high electrode load, safe zero crossing

AC frequency

50–200 Hz

- High frequency – narrow, constricted arc with deeper penetration
- Low frequency – wide arc

AC balance

-30% to +30%

- Positive current proportion, good cleaning, high electrode load
- Negative current proportion – deep penetration, low electrode load

Machines and processes from EWM – the optimum solution for every need.

Our welding systems enable our customers to carry out their individual welding tasks faster, for less money and with top quality.

Overview of innovative TIG/plasma processes

Control	Smart	Classic	Comfort	Synergic
Tetrix 	•	•	•	•
Tetrix plasma 		•	•	•
Tetrix cold/hot wire 				•
tigSpeed	•	•	•	•
activArc	•	•	•	•
spotArc		•	•	•

forceTig

- forceTig high-performance inverter welding machine up to 1000A for automated applications – with integrated hot wire power source and digital gas control
- Hot wire power 5 - 180A 100% DC and digital gas control, can be set using PC 300 software
- Prepared for cold wire/hot wire applications in conjunction with T drive 4 Rob 3 Hotwire
- Serial analogue interface for automated welding (start/stop, nominal value control voltage 0-10V, current flow signal)

Overview of innovative TIG/plasma functions

Control	Smart	Classic	Comfort	Synergic
Spotmatic	●	●	●	●
Spot welding	●	●	●	●
Pulsing		●	●	●
Automated pulsing	●		●	●
kHz pulsing			●	●
Additional functions of AC/DC welding machines				
AC pulsing		●	●	●
AC special			●	●
AC balance	●	●	●	●
AC frequency	●	●	●	●
AC wave forms		●	●	●

Contents

1 Preface

The TIG welding process (Figure 1) – the full name of this process irrespective to DIN 1910 – Part 4 is Tungsten Inert Gas welding – originated in the USA where in 1936 it was known as argon arc welding. It was not introduced to Germany until after the Second World War. The process differs from other fusion welding techniques in that it offers various interesting advantages. For example, it is a general purpose technique. If a metallic material is suitable for fusion welding, it can be joined using this process. It is also a very "clean" process which generates virtually no spatter and a minimal amount of harmful substances and when used correctly, guarantees a high quality welded joint.

Another significant advantage of TIG welding is that unlike other processes which use melting electrodes, there is no correlation between the addition of welding filler material and the current intensity. This means that the welder can match the current optimally to the welding task and only add the quantity of welding filler material actually required. This makes the process especially well suited to welding root passes and for out-of-position welding. These advantages have meant that the TIG process is used successfully in many sectors of trade and industry today. However, for manual welding it does demand special skills on the part of the welder, and a good level of training. This brochure explains the particular features of this process and may even generate interest in companies who are not yet using the technique despite having welding tasks which would be suitable for the process.

Figure 1 TRITON 260 DC, TIG welding of cooling spirals

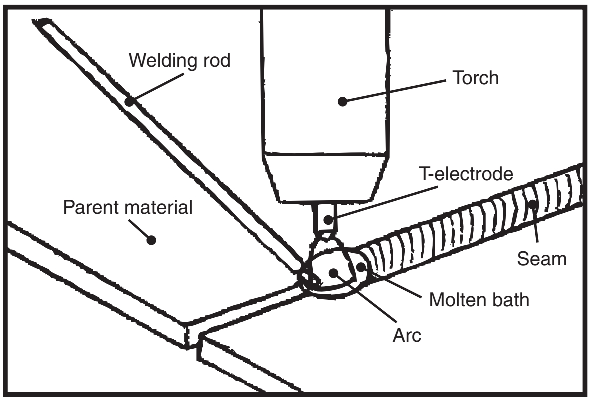


Figure 2 Principle of TIG welding

2 The process

2.1 General

TIG welding is a gas-shielded welding process with non-consumable electrode (Process No. 14). ISO 857-1 describes the process as follows:

"Gas-shielded arc welding process using a non-consumable electrode made from pure or doped tungsten in which the arc and the welding molten pool is protected by a gas coating made from inert gas"

With tungsten inert gas welding (process no. 141) the arc burns freely, with plasma arc welding (process no. 15), which is another gas-shielded welding process using a non-consumable electrode, it is constricted. Figure 2 shows a diagram of the process.

Electrode diameter [mm]	D.C. [A]				A.C. [A]	
	Minus pole on the electrode		Plus pole on the electrode			
	Pure tungsten	Tungsten with oxide	Pure tungsten	Tungsten with oxide	Pure tungsten	Tungsten with oxide
1.6	40-130	60-150	10-20	10-20	45-90	60-125
2.0	75-180	100-200	15-25	15-25	65-125	85-160
2.5	130-230	170-250	17-30	17-30	80-140	120-210
3.2	160-310	225-330	20-35	20-35	150-190	150-250
4.0	275-450	350-480	35-50	35-50	180-260	240-350
5.0	400-625	500-675	50-70	50-70	240-350	330-460

Table 1: Recommended current intensity ranges for tungsten electrodes, values acc. to DIN EN 26848

The process is named after the type of electrode (tungsten) and the shielding gas used (inert). The electrode does not melt due to the high melting point of tungsten (3380°C) when the process is used correctly. It acts solely as the arc carrier. The welding filler is added by hand in the form of a bar or with fully automated welding as a wire via a separate feed system. The shielding gas is emitted from the shielding gas nozzle and surrounds the electrode concentrically, protecting the electrode and the weld metal underneath it from the atmosphere.

2.2 Current type

Direct current is normally used for TIG welding. When welding steel and many other metals and alloys, the colder minus pole is positioned against the electrode and the hotter plus pole on the workpiece. The current-carrying capacity and the service life of the electrode are considerably greater with this polarity than with plus pole welding. Alternating current is used with aluminium and aluminium alloys, and with some bronzes, in other words materials which form high-melting or highly viscous oxides. This will be covered in more detail later on. When welding with alternating current, the current-carrying capacity also is still lower than direct current welding on the minus pole – for more on this, please see Table 1.

There are also differences in the fusion penetration characteristics. The optimum situation is direct current welding on the minus pole. When welding with alternating current, the fusion penetration is flatter and wider simply because of the less pointed shape of the electrode and lowest on the plus pole due to the low current-carrying capacity (Figure 3).

2.3 Electrodes

Tungsten electrodes cannot be manufactured by moulding because of the high melting point of the metal. They are therefore manufactured using powder metallurgy techniques via sintering followed by compression and compaction. The standard diameters defined in DIN EN 26848 (ISO 6848) are between 0.5 and 10 mm. The diameters most commonly used are 1.6; 2.0; 2.5; 3.2 and 4.0 mm. Standard lengths are 50, 75, 150 and 175 mm. The length is based around the design of the torch, among other factors.

As well as electrodes made from pure tungsten, there are also electrodes which have quantities of around 0.5 to 4% oxide such as thorium oxide, zircon oxide, lanthanum oxide or cerium oxide mixed in before sintering. The use of pure tungsten electrodes creates a very quiet arc, however electrodes containing oxide have the advantage that they heat up less during use because the coming out of the electrodes with the oxide in the electrodes occurs more readily than with the tungsten. The ease of ignition, current-carrying capacity and service life are therefore better with types containing oxides. Table 1 with values from DIN EN 26848 contains the recom-

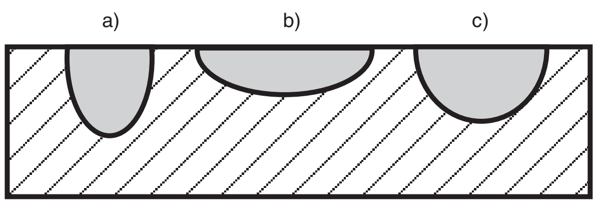


Figure 3: Fusion penetration with different current types
a) D.c. (minus pole)
b) D.c. (plus pole)
c) A.c.

Code	Composition				Identifying color
	Added Oxides		Contamination	Tungsten	
	% (M/M)	Type	% (m/m)	% (m/m)	
WP	-	-	≤ 0,20	99,8	green
WT 4	0,35 to 0,55	ThO_2		residue	blue
WT 10	0,80 to 1,20				yellow
WT 20	1,70 to 2,20				red
WT 30	2,80 to 3,20				violet
WT 40	3,80 to 4,20				orange
WZ 3	0,15 to 0,50	ZrO_2			brown
WZ 8	0,70 to 0,90				white
WL 10	0,90 to 1,20	LaO_2			black
WC 20	1,80 to 2,20	CeO_2			grey

Table 2 Tungsten electrodes defined by DIN EN 26848

mended current intensity ranges of pure tungsten electrodes and those with added oxides on both poles with direct current and alternating current, for comparison purposes. This explains the higher current carrying capacity thanks to the added oxides.

Previously, tungsten electrodes with around 2% thorium oxide were generally used. The use of these is declining, however. Thorium is an alpha emitter which is why electrodes containing thorium oxide also emit a low level of radioactivity. This in itself is not dangerous to the welder, although it does increase the general radiation load. What is more dangerous, however, is breathing in the dust from grinding the electrode. This is why today tungsten electrodes containing "arc-friendly" materials such as lanthanum oxide or cerium oxide are often used.

Electrodes can be identified by the code and the identifying colour specified in the standards (Table 2).

2.4 Shielding gases

As the name of the process indicates, inert gases are normally used for TIG welding. Shielding gases are defined in the standard DIN EN 439. Irrespective to this standard they bear the designations I1, I2 and I3. The shielding gas most commonly used for TIG welding is argon (I1). The degree of purity should be at least 99.95%. With metals with very good heat conductance properties, such as aluminium or copper, helium (I2) is also used. When using helium as the shielding gas, the arc is hotter. The heat distribution between the core and the edge of the arc is more even in particular. The use of pure helium in TIG welding is rare and limited to special situations, although argon/helium mixtures (I3) with 25, 50 or 75% helium have been increasingly used in recent years. This means, for example, that with thicker aluminium structures the pre-heating temperature required to achieve sufficient fusion penetration can be reduced. It is also often possible to increase the welding speed.

When using TIG welding on stainless chrome/nickel steels, argon / hydrogen mixtures (R1) are also used for this purpose, but the hydrogen content should not be much greater than 5% to prevent the formation of pores.

The flow quantity of shielding gas is based on the gas nozzle diameter and the surrounding air flow. As a rough guide, a volume of 5-10 l / min can be assumed for argon. In draughty rooms (Figure 4).greater flow rates may be necessary. With argon / helium mixtures, greater flow volumes should be used due to the lower density of helium.

Figure 4 TIG welding on a beam

3 Groove preparation

3.1 Groove shapes

The most important groove shapes used in TIG welding are shown in Figure 5**.**

Thin sheets can be joined on one side or on two sides as with a butt joint. If the sheet thickness is too great to permit complete penetration even from both sides, the edges of parts to be joined need to be bevelled. The opening angle of the V joint produced is generally 60°, but with aluminium also 70°. To prevent complete melting the tips of the sheets in the root area are often slightly broken. With a distinct root face, this is called a V joint with broad root face rather than a simple V joint. With steel, workpiece thicknesses of up to around 6 mm can be welded in one pass. Beyond this a multi-pass weld may be required as well.

Lap seams are also used with thin sheets. Particularly well-suited to TIG welding is the raised edge joint. The high raised edges of the sheet can be melted and thus joined under the arc without the addition of welding filler. With corner seams one or both panels can be angled.

3.2 Placement of the weld groove side walls side walls

With unalloyed and low-alloy steels, the edges of parts to be joined are normally prepared by oxygen cutting. With high-alloy steels, aluminium and metal alloys, fusion cutting can be used irrespective to the plasma, laser or electron beam principle. Thin sheets are often cut using mechanical methods (shearing), whereas with thicker materials the grooves are also prepared using mechanical processing (turning, gouging).

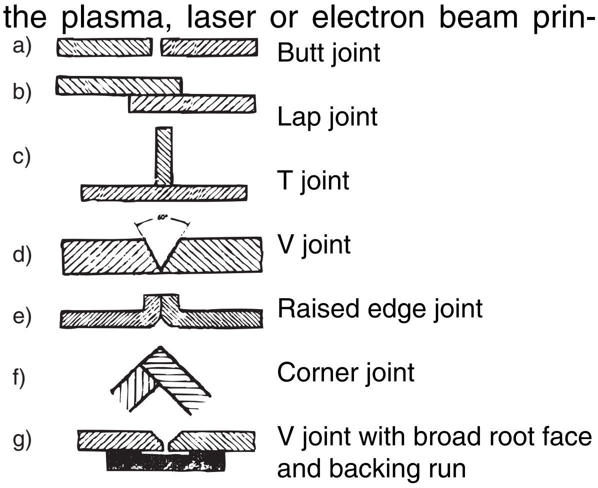


Figure 5 The primary groove shapes with TIG welding

3.3 Backing

Whereas in manual welding the welder monitors the progress of the weld and achieve an even root run even if the root opening is uneven by setting the correct current intensity, adjusting the position of the arc in the groove and the welding speed, in fully automated welding everything must be correct from the root opening set to the correct set welding parameters and the continuous quantity of filler wire added.

Backing runs are therefore often used with machine welding to simplify the root welding, see Figure 5. These backing runs with most metals and alloys consist of copper, and for aluminium which has a low melting point, stainless steel as well. Ceramic backing plates are also used in welding for this purpose. The backing plate should prevent the spontaneous sagging of the weld metal, e.g. at points where the gap is slightly wider, so that the molten metal is caught and a root bead can be produced. The backing also forms the underside of the root bead. For this purpose a groove is therefore generally created for backing.

3.4 Forming

This is the extra addition of shielding gas to the back of the root where the material being welded is also in a molten state, but is not reached by the shielding gas supplied to the top side. With TIG welding in particular with its relatively low welding speed, the back of the root often has a “burnt” appearance due to oxidation. The forming gas is used to prevent this. The cold shielding gas also helps to form the back of the root, hence the name “forming gas”.

Figure 6 TIG welding work in the chemical industry

Thanks to the forming process, the formation of oxide skins and annealing colours on the back of the root is also prevented, or at least reduced. This is important when welding corrosion-resistant steels, for example, because these oxide skins impair the corrosion-resistance of the weld (Figure 6).

When welding pipes, the ends can simply be blocked and the forming gas fed into the interior. When welding metal panels, it can be allowed to flow out of openings in the backing bars. Argon or an argon / hydrogen mixture can be used as the forming gas. In DIN EN 439 reasonably priced forming gases are also defined in group F. These consist of a hydrogen/nitrogen mixture, for example. Pure nitrogen can also be used for forming under certain circumstances.

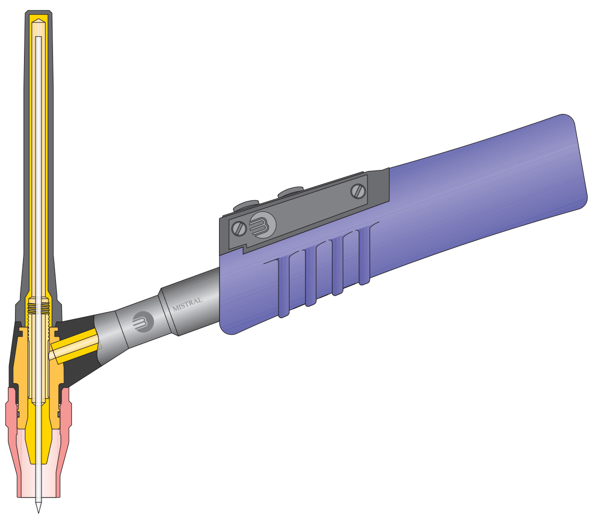


Figure 7 Gas cooled TIG welding torch

4 The welding torch

The welding torch is the TIG welder's tool. Its function has a significant impact on the weld seam produced. Figure 7 shows a gas cooled TIG welding torch.

The torch is connected to the welding machine via the tube package. The welding current lead runs through the tube package, along with the shielding gas supply and the control lead which allows various functions to be switched on and off using the switch on the torch.

4.1 Cooling

With torches designed for current intensities up to around 150 amperes only, the cooling from the shielding gas flowing through and the surrounding air is sufficient. Higher power torches are water cooled. In this case, the leads for the water supply and water return also run through the hose package, whereby the welding current lead is cooled by the returned water. It need not therefore be very large and the hose package remains flexible. For this purpose there is a combined current/water cable in the hose package. A pressure monitor, generally installed in the welding machine, ensures that if the cooling water supply is too low or missing, the welding current is switched off.

As water is a relatively expensive operating material, return water equipment is normally used for cooling with a closed coolant circuit.

4.2 Torch design

The tungsten electrode is positioned in a collet and is secured by tightening the torch cap. The length of the torch cap is selected irrespective to the application. For example, when welding in tight spaces it may be significantly shorter than shown in Figure 8.

The torch switch has an important function. It may be designed in the form of one or two key buttons or as a rocker switch which is operated by moving it backwards and forwards. The welding current can be switched on and off by pressing the key button, but the current can also be adjusted during welding. The speed of the change in current can also be set using this button.

The diameter of the tungsten electrode is based on the current intensity being used, the current type (direct/alternating current) and the polarity. You may find the current intensity ranges given in Table 1 useful when selecting the diameter.

At the bottom end of the welding torch is the gas nozzle. This may consist of metal or ceramic material. The diameter of the gas nozzle must be matched to the welding task. If a larger molten bath is being protected, the gas nozzle also needs to be larger. One ration used is therefore to the current intensity or to the electrode diameter. The tungsten electrode extends beyond the gas nozzle depending on the diameter, e.g. 2mm with thin electrodes or up to 3mm with thicker electrodes.

4.3 Shape of the electrode tip

In direct current welding (minus pole) the tungsten electrode normally has a cone shape. This is generally achieved by grinding. The grinding should be carried out so that grinding grooves remain in the longitudinal direction on the ground tip only. This means that the arc starts more quietly than if there were crosswise grooves. The starting angle is given by the ratio between the electrode diameter and the length of the tip. This ratio should be around 1: 2.5.

With the current intensity set correctly, only a small part of the electrode tip melts and forms a small ball there. The arc burns particularly quietly on this. It is therefore advisable to create this ball before starting welding via short-term overload. With modern equipment, this type of function can be initiated from the control.

In alternating current welding the thermal loading of the tungsten electrode is significantly greater than with direct current welding (minus pole). The electrode is therefore either not tipped at all with this current type, or is shaped into a truncated cone with a ratio between both diameters of 2:1.

In direct current welding (plus pole), which is relatively rare, the electrode is not ground at all.

It should be noted that the shape of the electrode tip also has a significant impact on the fusion penetration characteristics. With a pointed electrode, narrower, deeper fusion penetration is produced, and with a more truncated electrode, the fusion penetration is wider and flatter in otherwise the same conditions (Figure 9).

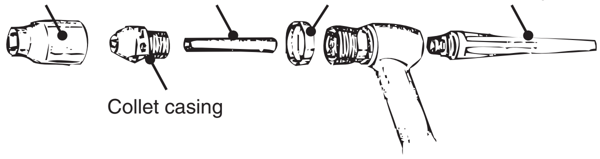


Figure 8 Exploded diagram of the TIG welding torch

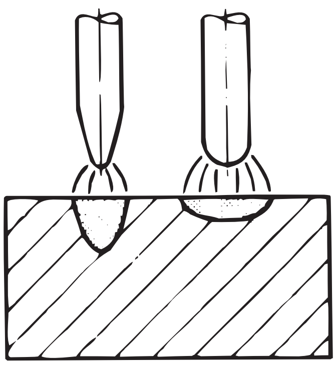


Figure 9 Fusion penetration with different electrode tip shapes

5 Welding machines

TIG welding machines consist of the current source and the control.

5.1 Control

The control has the task of switching the welding current on and off, adjusting it and keeping it constant. It also provides additional functions which actually allow welding to be carried out or which simplify the process (Figure 10).

With modern machines the current can be reduced in a time-controlled way for crater filling (down-slope) when switching off at the end of a weld seam. The current can also be raised gradually at the start of welding (up-slope). These functions can be initiated from the torch switch in non-latched and latched operation. This produces a welding program as shown in Figure 11.

With high-tech machines the set rise and lower times remain constant, regardless of the current intensity level set. The pre- and post-flow times for the shielding gas can also be set.

Also integrated into the control is the ignition unit. Naturally the TIG arc can also be ignited by touching between the electrode and the workpiece, but in this case there is a risk of the electrode tip becoming damaged and the arc burning erratically. It is also possible that tungsten is transferred into the weld metal where it would not melt due to the high melting point but would remain as a foreign body. For this reason, with simple machines

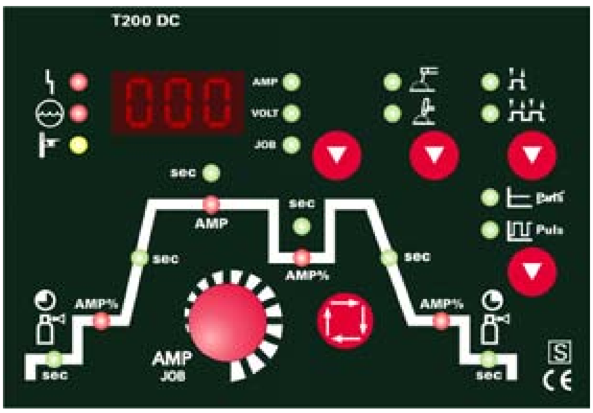


Figure 10 Control for the EWM TIG Inverter current source TRITON 220 DC powerSinus

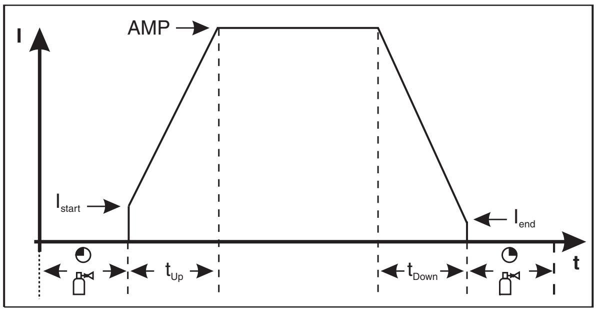


Figure 11 Function sequence at the start and end of welding

which do not have specific devices for non-contact ignition, the arc should always be ignited outside the groove on a run-on plate or on an adjacent copper panel.

There are various ways of igniting the arc without damaging the electrode. With high voltage pulse ignition, sometimes also called high frequency ignition, a pulsed alternating current of several thousand volts (e.g. 6-8 kV) is created between the electrode and the workpiece. The very short voltage pulses (e.g. 0.5-1µs) are transferred from the electrode to the workpiece in the form of a spark gap after the torch switch is pressed; with direct current welding generally at a frequency of 100 Hz, and with alternating current at the standard 50 Hz frequency or with modern machines at the frequency set for the welding current. The spark gap can be heard and seen. It pre-ionises the gas molecules in the space between the electrode and the workpiece so that the arc ignites without contact when the electrode tip is moved to a few millimetres away from the arc strike. One rule of thumb is that ignition is possible across a gap of 1 mm / 1000 volt ignition voltage. To prevent accidental contact between the electrode and the workpiece, it is best to angle the position of the torch on the edge of the gas nozzle, as shown in Figure 12, and to move the electrode tip closer by straightening up the torch, until the arc ignites.

Only then is the gas nozzle raised off the workpiece and the normal torch position adopted. When welding using sinusoidal alternating current the igniting aid must

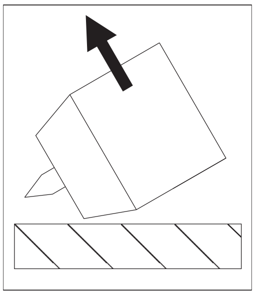


Figure 12 Ignition with high voltage pulses

actually burn through to reignite the arc safely after the current and voltage pass through zero.

Another option is what is known as "lift-arc" ignition. This is a contact ignition type in which the electrode is not damaged because during the contact only a very small current is flowing. Only once a weak arc is burning when the electrode is lifted off is the set welding current connected by the control.

Further functions of the control include switching from normal operation to pulse operation and, where applicable, also switching to other welding processes, whereby in some circumstances the characteristics may need to be changed.

5.2 Power sources

The current source has the task of converting the high voltage/low current alternating current coming from the mains into high current/low voltage welding current and where applicable, to rectify the welding current as well. For TIG welding both alternating current and direct current are used.

The welding transformer is the most simple and most cost-effective welding current source. It consists of the primary coil with numerous thin windings and the secondary coil with a few thick windings. The mains current is transformed upwards in relation to the number of windings on this coil, and the mains voltage is transformed downwards irrespectively. The welding transformer normally has a falling static characteristic. Different current intensities can be set via scattering kernel adjustment, transducer or primary side turn tapping.

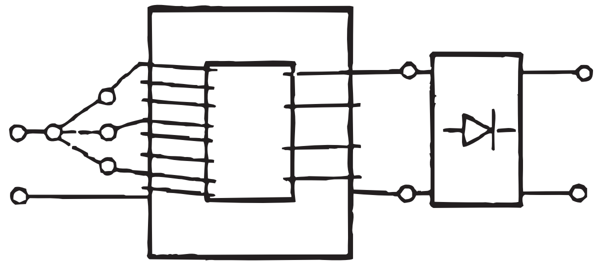


Figure 13 Basic diagram of the welding rectifier

The welding rectifier consists of a transformer with a downstream rectifier stack (Figure 13).

Today silicon diodes or thyristors are used as rectifiers. In these devices the alternating current previously transformed in the transformer to the required current intensity and voltage is converted into direct current. Single welding rectifiers are single-phase connected (double-pulse bridge). They produce a welding current with considerable ripples. Improved smoothing of the current is achieved when all 3 phases of the alternating current are transformed and rectified (six-pulse bridge connection). Single rectifiers are also available as combined devices which can be switched to supply either direct or alternating current. Welding rectifiers for TIG welding have a falling static characteristic. They can be set using scattering kernel adjustment, transducer and primary side turn tapping in the a.c. circuit or via phase shift control of the thyristors.

Modern TIG systems (Figure 14) are equipped with inverters as the power

Figure 14 TRITON 220 DC, TIG Inverter welding machine

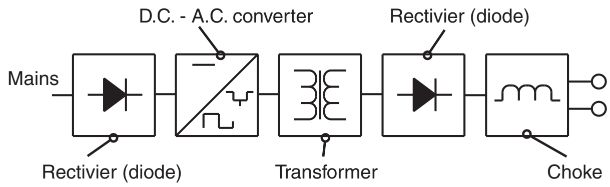


Figure 15 Block diagram for a 3rd generation inverter, cycle frequency up to 100 kHz

source.

The inverter is an electronic power source which functions using a completely different operating principle to conventional power sources (Figure 15).

The current coming from the mains is first rectified and then, so that it can be transformed, chopped into short sections by switching on and off. This process is known as clocking. This is possible thanks to electronic switches with fast reactions, the transistors. The first transistorsised inverters used a clock frequency of around 25 kHz. Today with highly developed transistorss, clock frequencies of 100 kHz and more are possible.

After "chopping" (clocking) the current, the current is transformed to the necessary high current intensity and low voltage. A square-wave alternating current is then created on the transformer, and is rectified once more. The high clock frequency has the advantage that the mass of the transformer can be kept very small. This is because it is dependent on the frequency of the current being transformed. This enables lightweight power sources to be produced. A modern system for TIG welding with an output of 260 A / 20.4 V therefore only weighs 24.5 kg (Figure 16).

That covers the power unit for electronic power sources.

With electronic power sources, many operations are triggered electronically by the control; in conventional power sources this is achieved using components such as resistors, chokes and capacitors. The control for these power sources is therefore just as important as the power unit. The current is adjusted in clocked sources, for example, by changing the ratio between the current input/output times. Changing the clock frequency can also be used to adjust the current level. To generate pulse-shaped current, the ratio of the input/output times is changed cyclically by the control. The slope-up/slope-down is produced in a similar way.

Figure 16 TRITON 260 DC, TIG Inverter welding machine

However, new technology means that controlled power sources are also possible, which is something which had been missing in welding technology for a long time. A control device measures the welding current and welding voltage and compares it to the set values. If the set welding parameters change, e.g. due to undesirable resistances in the welding current circuit, the control will adjust them irrespectively. This occurs very rapidly in the μs range. Similarly, the short-circuit current can also be limited and the cos φ improved. Greater efficiency and lower open circuit losses of the inverter power sources are already produced by the lower mass of the transformer.

Welding power sources may have a horizontal (constant voltage) curve, a slightly falling curve or a curve falling vertically in the operating range (constant current) curve (Figure 17).

With many modern power sources, the characteristics can be changed in a simple way, which means that they can be used for multiple processes (multiprocess systems). Inverter power sources for TIG welding have a constant current curve (Figure 17, c), i.e. in the operating range the static characteristic drops vertically. This means that with changes in the arc length, which cannot always be prevented in manual welding, only the voltage changes and not the current intensity. This ensures sufficient fusion penetration and a constant deposition efficiency. The same characteristic can also be used for manual arc welding. However, if the current source is to be used for MIG/MAG welding, a constant voltage characteristic is set when switching to this process (Figure 17, a).

Many inverter power sources are also programmable, which is required for automated welding, e.g. TIG orbital welding or for use with robots.

6 Performing welding work

In addition to specialist theoretical knowledge, the TIG welder also requires good practical skills. These skills are taught in welding courses, such as those run by the Deutscher Verband für Schweißen und verwandte Verfahren e.V. (German Association for Welding and Allied Processes) in its training centres and educational establishments.

6.1 Choice of welding filler

The welding filler with TIG welding is generally in the form of a rod, but when used with fully automated welding techniques it is supplied in the form of wire via a separate feed unit.

The welding fillers selected are normally the same type as the parent material. However, sometimes it may be that for metallurgic reasons, the filler may be different to the parent material with some alloy elements. This is the case with carbon content, for example, that is kept very low, wherever possible, to increase the resistance to cracking. Such fillers are known as equivalent welding fillers in these situations. There are also situations where fillers of a completely different type are required. This is the case when joining carbon steels which are difficult to weld, for example, in which case austenitic welding fillers or even nickel-based alloys are used.

The diameter of the welding filler must be matched to the welding task. It is based on the material thickness and also the diameter of the tungsten electrode. Table 3 contains the electrode, gas nozzle and welding rod diameter assigned to the panel thickness.

The welding rods are normally 1000 mm long. They are supplied in bundles and should be identified individually using the DIN or the trade designation to avoid confusion.

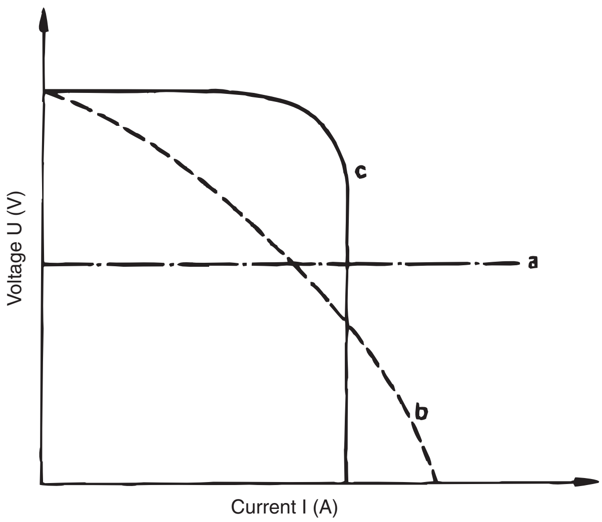


Figure 17 Static characteristics of welding power sources

6.2 Setting the shielding gas quantity

The shielding gas quantity is set as a volume flow in l/min. This is based on the size of the molten bath and thus on the

Panel thickness [mm]	Tungsten electrode diameter [mm]	Gas nozzle size no.	Filler rod diameter [mm]
1	1.0	4	1.6
2	1.6	4 to 6	2.0
3	1.6	6	2.5
4	2.5	6 to 8	3.0
5	2.5 to 3.0	6 to 8	3.2
6	3.2	8	4.0
8	4.0	8 to 10	4.0

Table 3 Tungsten electrode diameter, gas nozzle size and filler rod diameters with different panel thicknesses

electrode diameter, the gas nozzle diameter, the distance of the nozzle from the parent material surface, the surrounding air flow and the type of shielding gas – see also the section shielding gases. One rule of thumb is that when using argon as the shielding gas and the most commonly used tungsten electrode diameters of 1 to 4 mm, 5 to 10 litres of shielding gas are to be added per minute.

The gas flow can be measured indirectly using manometers which measure the pressure proportional to the flow quantity in front of an installed pitot-static tube. The manometer scale is then calibrated directly in l/min. Measuring devices which use glass tubes and suspended loads to measure directly in the shielding gas flowing into the torch are more precise (Figure 18).

6.3 Cleaning the workpiece surface

For a good welding result, it is important that the edges of parts to be joined and the surface of the workpiece in the welding area are cleaned thoroughly before starting welding. The surfaces should be bare and free of grease, dirt, rust and paint. Layers of scale should also be removed if possible. In many cases brushing is sufficient. Where this is not enough, the surface should be treated by grinding or by mechanical processing. With corrosion-resistant materials only stainless steel brushes should be used, as otherwise foreign rust could be produced from iron particles introduced onto the surface. With aluminium it particularly important that there is no thick oxide skin on the surface in order to prevent pore formation. This topic will be covered in more detail later on. Appropriate solvents should be used for cleaning and degreasing purposes. Caution: When using solvents containing chlorine, poisonous vapour could be produced.

6.4 Igniting the arc

The arc should never be ignited outside the groove on the parent material, but always so that the ignition point is melted immediately again afterwards during welding. At the start of welding, the highly heated parent material on the ignition point cools very quickly due to heat extraction from the cold masses at the back. The consequence of this rapid cooling may be embrittleed areas, possibly also with cracks, and pores. This fast cooling can be avoided by igniting the arc directly at the start of the weld seam and by immediately melting any discontinuities which occur.

Contact ignition should be the absolute exception if an older welding machine being used does not have an igniting aid (high voltage pulse ignition) – see also section 5.1 Control. In this case the arc is ignited on a copper plate placed in the groove close to the start of the weld seam. From there the arc is then moved to the planned start of the seam and the welding started. With contact ignition directly on the parent material, tungsten may enter the weld metal which is not melted due to the high melting point and can be seen later on as a pale point in the radiation film due to the larger absorption of x-ray beams of tungsten.

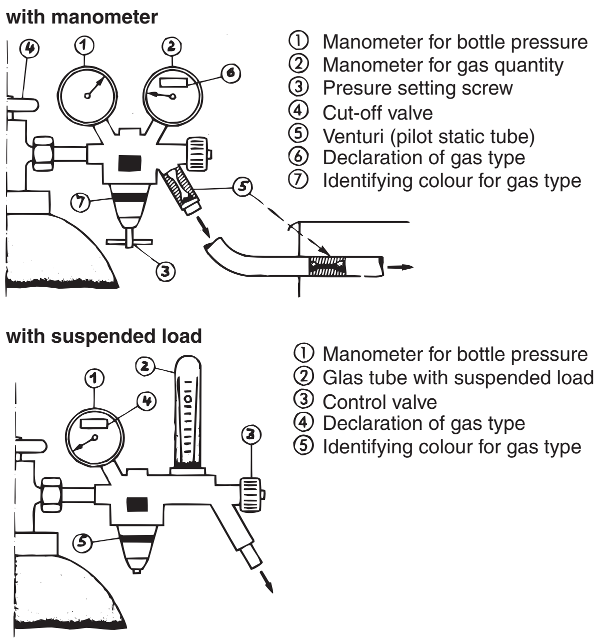


Figure 18 Measuring the shielding gas flow

6.5 Moving the torch

With TIG welding the leftward welding principle is used (Figure 19). This definition is only applicable, however, if the welder holds the torch with his right hand and moves the filler rod with the left hand as right-handed persons would normally do, and when viewing the positions from the welder's point of view. The direction of welding is more accurately defined by saying that the welding rod is moved in the direction of welding in front of the torch**.**

This applies to all positions except for vertical down welding. With GMA-surfacing, rightward welding is also sometimes used due to the greater melting deposition power.

The torch is placed in a forehand position at a angle of around 20° from the vertical in the direction of welding, and the filler rod is added from the front at a fairly flat angle of around 15° to the workpiece surface.

The arc first melts to form a molten bath. The filler rod then melts under the arc, whereby the welder makes dotting movements by moving the rod back and forth. In this process the rod must not be moved too far underneath the arc during joint welding because otherwise the fusion penetration into the parent material is reduced. With GMA-surfacing, where low mixing is of less importance, this can be turned to the welder's advantage.

With joint welding, the end of the rod should melt on the front of the molten bath. In this process the welder should ensure that the melting end does not move out of the shielding gas bell in the dotting movements. Oxidation of the end of the rod would be the result and oxide could enter the molten bath.

Welding is normally carried out with no movement or with a slight weaving movement. This creates the least disturbance of the shielding gas bell. In the vertical up position (PF) on the other hand, a slight weaving motion should be used on the torch and the filler rod. The same applies to filler runs in a width which cannot be filled using a stringer bead, but which are too narrow for two stringer beads.

6.6 Magnetic arc blow

Arc blow is where the arc is lengthened due to being diverted from its central axis and emits a hissing noise. This diversion could result in discontinuities. This means that the fusion penetration may become inadequate and with slag-forming welding processes, slag inclusions could be produced in the seam due to the slag flowing ahead of the molten pool.

The diversion is caused by forces arising from the surrounding magnetic field. As with any current-carrying conductor, the electrode and the arc are also surrounded by a toroidal magnetic field; this is diverted in the area of the arc when it comes into contact with the parent material. This compresses the magnetic lines of force on the inside and expands them on the outside (Figure 20 a).

The arc slips into the area of reduced flux line density. This lengthens the arc and it emits a hissing noise due to the increased arc voltage this creates. The opposite pole therefore exerts a repulsive effect on the arc.

Another magnetic force means that the magnetic field can spread more easily in a ferromagnetic material than in air. The arc is therefore attracted by large ferric masses. This is reflected, for example, in that when welding a magnetic material the arc will move inwards at the end of the panel.

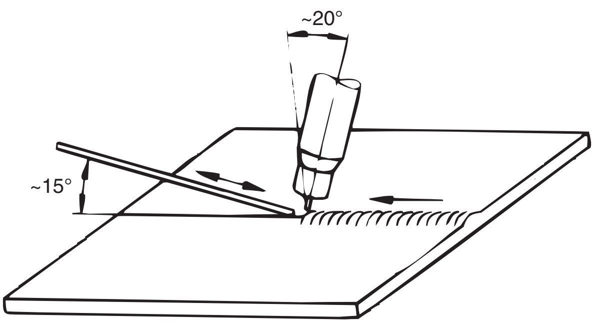


Figure 19 Positioning the torch and the filler rod [1]

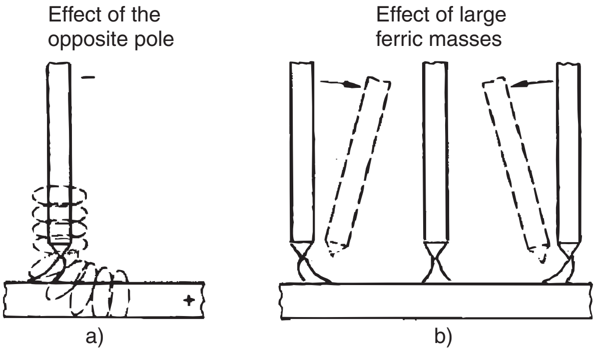


Figure 20 Magnetic arc blow

The movement of the arc can be counteracted by tilting the electrode as appropriate (Figure 20 b). As arc blow is particularly noticeable with d.c. welding, it can be avoided, or at least reduced, by welding with alternating current.

The arc blow effect may be particularly strong due to the surrounding ferric masses when welding root passes. In this case it helps if the magnetic flux is supported by closely positioned tack welds which should not be too short.

6.7 Welding positions

Irrespective to ISO 6947, the welding positions are identified with PA – PG. These are ordered alphabetically when viewed on a pipe from above (flat position – PA) starting in the clockwise direction (Figure 21).

The flat position (PA) used to be referred to as horizontal. Then there are the butt weld positions, horizontal on a vertical wall (PC) and overhead (PE), and the fillet weld positions (PB; horizontal) and horizontal/overhead (PD). When welding panels, the vertical up position (PF) means welding straight upwards, and the vertical down position (PG) is welding straight down. When welding pipes several positions are used at the same time. The vertical up position applies when the pipe is welded starting from the overhead position without turning upwards on both sides; the equivalent applies to the vertical down position for welding from top to bottom (vertical-down). TIG welding can be carried out in all positions. The welding data must be matched to the position, as with all other welding processes.

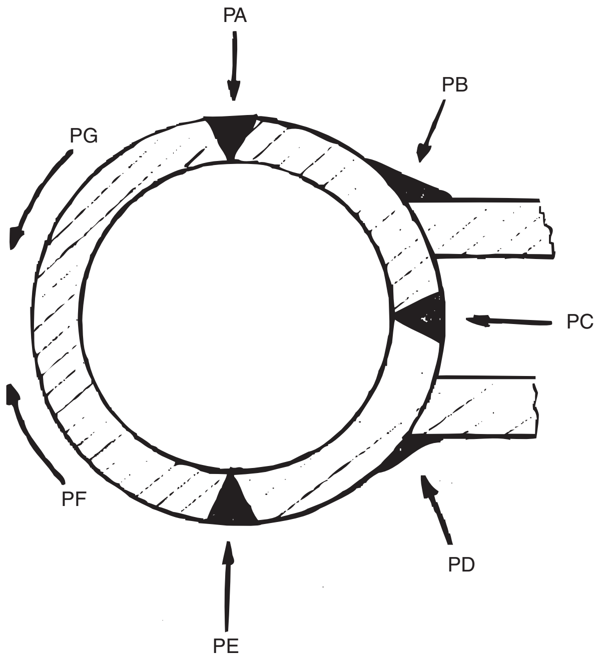


Figure 21 Welding positions as defined in ISO 6947

6.8 Set welding parameters

The lower limit of possible use of the TIG process for steel is around 0.3 mm, and with aluminium and copper, 0.5 mm. Maximum efficiency limits are set upwards for the application. The melt deposition power for the process is not particularly great. For this reason, only the root runs are commonly TIG welded and the other runs are welded using other processes (MMA, MAG) which have a higher level of deposition power.

When choosing the set welding parameters, bear in mind that only the current intensity is set on the welding machine, and the arc voltage is given by the arc length used by the welder. In this case the voltage increases the longer the arc becomes. A guideline value for an adequate current intensity for complete fusion when welding steel with alternating current (-pole) is a current intensity of 45 amperes per mm of wall thickness. When a.c. welding aluminium, 40 amperes/mm are required.

The appropriate welding data for butt welds on different materials can be found in Table 4 to Table 8.

6.9 Welding with current pulses

When welding with pulse-wave current, the current intensity and voltage change to the rhythm of the pulse frequency continuously between a low base value and the higher pulse value (Figure 22).

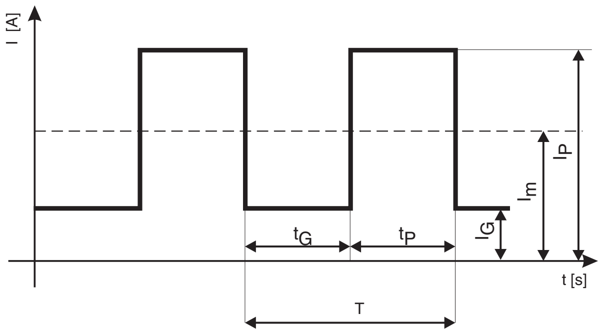


Figure 22 Time sequence of the welding current during pulse welding

I_G: Basic current
I_M: Moderate current
I_P: Pulse current
t_G: Basic current time
t_P: Pulse current time
T: 1 period = 1/f
f: Frequency

Panel thickness [mm]	Groove shape	No. of runs	Tungsten electrode diameter [mm]	Welding current [A]	Welding speed [cm/min]
1.0	I	1	1.0	45	32
2.0	I	1	1.6	100	30
3.0	I	1	1.6	125	30
4.0	I	2	2.4	170	25
5.0	I	2	3.2	225	22
6.0	V	2	4.0	300	20

Table 4 Guideline values for TIG welding high-alloy steel Current type: D.c. (- pole) – Flat position – Shielding gas: Argon [1]

Panel thickness [mm]	Groove shape	No. of runs	Tungsten electrode diameter [mm]	Welding current [A]	Welding speed [cm/min]
4.0	I	2	2.0	90	24
6.0	I	2	2.4	110	20
8.0	I	2	2.4	120	18
10.0	DV	2	2.4	120	16
12.0	DV	2	3.2	140	15

Table 5 Guideline values for TIG welding aluminium Current type: A.c. – Vertical up position – Shielding gas: Argon [3]

Material	Panel thickness [mm]	Groove shape	No. of runs	Tungsten electrode diameter [mm]	Welding current [A]	Welding speed [cm/min]
Pure nickel	1.0	I	1	1.0	65	13
	1.5	I	1	1.6	90	12
	3.0	I	1	2.4	140	10
	5.0	V	3	2.4	145	12
	10.0	V	8	2.4	150	12
Copper	1.5	I	1	1.6	130	28
	3.0	I	1	3.2	200	25
	5.0	I	2	4.0	270	15

Table 6 Guideline values for TIG welding nickel and copper Current type: D.c. (- pole) – Flat position – Shielding gas: Argon [3], [1]

Panel thickness [mm]	Groove shape	No. of runs	Tungsten electrode diameter [mm]	Welding current [A]	Welding speed [cm/min]
1.0	I	1	1.0	60	32
2.0	I	1	1.6	110	30
3.0	I	1	1.6	140	30
4.0	I	2	2.4	190	25
5.0	I	2	3.2	250	22
6.0	V	2	4.0	350	20

Table 7 Guideline values for TIG welding unalloyed and non-alloy steel Current type: D.c. (- pole) – Flat position – Shielding gas: Argon [1]

Panel thickness [mm]	Groove shape	No. of runs	Tungsten electrode diameter [mm]	Welding current [A]	Welding speed [cm/min]
1.0	I	1	1.6	75	26
2.0	I	1	2.0	90	21
3.0	I	1	2.4	125	17
4.0	I	1	3.2	160	15
5.0	V	2	3.2	165	14 to 17
6.0	V	2	4.0	185	10 to 15

Table 8 Guideline values for TIG welding aluminium, current type: A.c. – flat position – shielding gas: Argon [3]

Modern inverter power sources generally allow pulse frequencies of between 0.5 and 300 Hz to be set. Special power sources also pulse in the kHz range.

Whereas in the higher frequency ranges, effects such as grain refining in the weld metal and arc constriction can be produced, the lower frequency range is used primarily in the flat position for better control of the molten bath in out-of-position welding. This occurs as follows (Figure 23):

The fusion penetration in the parent metal is produced thanks to the high pulse current and a dot-shaped molten bath is formed. This starts to become brittle from the edge inwards due to the effect of the low base current which follows, until the next current pulse melts it again and enlarges it. In the meantime the arc has already been moved at the welding speed, which means that in TIG pulse welding the weld seam is created from numerous overlapping welding spots. The size of the molten bath is on average smaller than when welding with an even current,

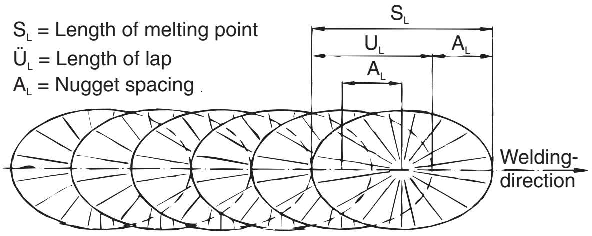


Figure 23 Structure of the weld seam from individual spots [2}

which means that it is more easily controlled in out-of-position welding. Adequate fusion penetration is still ensured, however. The effect just described only occurs if there is a sufficient temperature difference in the molten bath between the base phase and the pulse phase. This is only the case with pulse frequencies less than around 5 Hz.

One disadvantage is that the welding speed needs to be greatly reduced with pulse welding. The welder can also detect the pulses in the low frequency range as a disruptive flickering of the arc. This is why this type of TIG welding is used less often with manual welding where the welder has other options to control the bath than with automated TIG welding.

6.10 Automation options

The manual TIG process (Figure 24) can be mechanised using simple equipment. This is of particular interest if longer lengthways seams are being welded on panels or if frequent circumferential welds are being performed on pipe-shaped bodies.

When welding longitudinal seams, the torch can be fixed onto a simple travel carriage which is used to move over the weld groove side walls. If discontinuities occur in the groove geometry, it is advisable to use backing.

When welding circumferential welds, the torch is suspended stationary and the workpiece moves in a manipulator rotating device underneath the torch.

With complex parts welding robots are also used for TIG welding.

In all cases where filler is required, this is automatically feeded to the arc in wire form.

6.11 Work safety

TIG welding is a very clean process. Virtually no harmful gas or smoke is produced, which means that no suction directly at the place of origin is required by the current work safety regulations. Fresh air is sufficient, or mechanised ventilation of the room. However, the welder must protect himself against radiation from the arc and against electrical dangers.

To protect against the infrared and ultraviolet radiation, the TIG welder normally wears a helmet (Figure 24), which leaves both hands free for moving the torch and for adding filler metal. The filter glass is integrated into this safety helmet. This filter has recently been defined in DIN EN 169. There are various grades of protection which need to be permanently affixed to the glass. With TIG welding, filters of protection grades 9 to 14 are used, depending on the used current intensity, where grade 9 is prescribed for lower currents and 14 for the higher current intensities.

The greatest electrical risk is represented by the open circuit voltage. This is the maximum voltage which is present on the activated power source between the connection sockets when the arc is not burning. After the arc is ignited, the voltage is much lower; in TIG welding only around 12 to 20 volts. Irrespective to the relevant German accident prevention regulations, power sources for direct current in normal operation should have an open circuit voltage peak value of max. 113 volts. With alternating current system this value is also 113 volts, but the r.m.s. value is limited to max. 80 volts. Where there is an increased risk of electric shock, e.g. when welding in small spaces or on large iron masses, reduced values apply for alternating current, e.g. a peak value of 68 volts and an r.m.s. value of 48 volts. Modern welding power sources meeting these requirements bear the “S” safety sign in conformance with DIN EN 60974-1. Older power sources may still be marked with “K” (d.c.) or “42 V” (a.c.). The safest way for welders to protect themselves against electric shocks is to wear undamaged welding gloves made from leather and well-insulated work clothes including safety shoes.

Figure 24 TIG 230 DC, TIG welding in the food industry

7 Special features of different materials

As already mentioned, the TIG process is suitable for welding a large range of materials. Some materials are welded using direct current, and others using alternating current. Table 9 lists which materials are better welded with direct current, and which with alternating current.

The sections below cover various special features of the different materials.

Material	D. c.		
	Electrode “–“ pole	Electrode “+” pole	A.c.
Carbon steel	XX	-	-
Stainless steel	XX	-	-
Aluminium and Al alloys	-	X [1)]	XX
Magnesium and Mg alloys	-	X [1)]	XX
Copper	XX	-	-
Aluminium bronze	X	-	XX
Silicon bronze	XX	-	-
Brass	X	-	XX
Nickel and Ni alloys	XX	-	X
Titanium	XX	-	-

Table 9 Suitable current type for different materials, shielding gas: Pure argon
[1)] for materials only thin

XX = best results,
X = can be used,
- = not recommended

7.1 Unalloyed and non-alloy steels

These steels can be joined using any molten welding technique. When choosing the welding process, it is generally the economic factors which outweigh the quality considerations. The TIG process is therefore underrepresented due to its low deposition power with these steels. One exception is welding root runs. With wall thicknesses larger than around 6mm, often only the root is TIG welded and the other runs are welded using a more powerful process. Another exception is welding pipes with smaller diameters. For this purpose there is no other process which is as well-suited for the task as TIG welding.

One point to note is that pores may be produced, e.g. with unalloyed pipe steels (e.g. P235) which contain less silicon or with welding in of these pipes in boiler bases. Similarly, with deep drawing quality steels which can only be deoxidised with aluminium, pores may occur if a reduced amount of filler material is used for welding. Due to Oxygen intake from the atmosphere, which cannot be completely avoided, even with shielding gas welding, the weld metal is oxidised and pores may occur in the weld metal because of carbon monoxide formation. The remedy for this is to use as much Si/Mn alloyed filler metal as possible, which means that the oxygen is rendered harmless.

7.2 Austenitic CrNi steels

These materials are particularly well-suited to TIG welding because the good viscosity of the weld metal produces finely feathered, smooth upper beads and flat root undersides.

The relatively slow welding speed of the TIG process and the low heat conductance of CrNi steels mean that overheating can easily occur with small wall thicknesses. This could mean that heat cracks occur and the corrosion-resistance may also be reduced. Overheating can be prevented if required by including cooling pauses or by cooling the workpieces. This also reduces the distortion which is greater with CrNi steels due to the higher expansion coefficients than with unalloyed steel.

With components later subject to corrosion, any oxide skins and annealing colours surface of the seam and on the edges on both sides need to removed after welding by brushing, blasting, grinding or etching before the component is used. Increased corrosion would otherwise form underneath these skins. This also applies for the root side when welding pipes. As mechanical processing is difficult in this case, it is advisable to prevent oxidation via forming – see also chapter 3.4 Forming.

7.3 Aluminium and aluminium alloys

Alternating current is normally used when welding aluminium materials, with the exception of the cases described below. This is necessary to deal with the high-melting oxide layer on the bath. Aluminium oxide (Al_2O_3) has a melting point of around 2050°C. The base material, e.g. pure aluminium melts at 650°C, however. Aluminium bears such a great chemical similarity to oxygen that even if the surface of the base material is cleaned of oxide by brushing or scraping, these skins will still form on the surface of the bath. Due to their high melting point, they melt

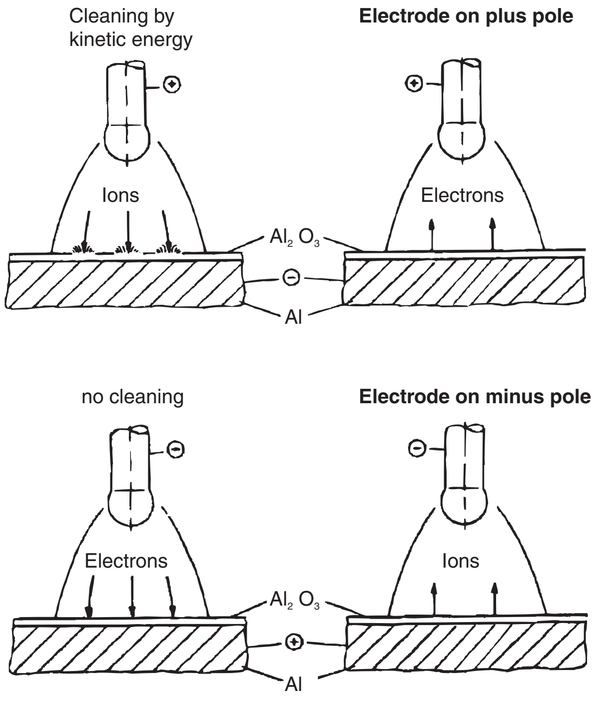


Figure 25 Explanation of the cleaning effect

partially only directly underneath the arc. The majority of the seam surface would therefore be covered with a solid layer of aluminium oxide when welding with direct current (- pole). This makes it impossible to observe the bath and makes it more difficult to include filler. This oxide layer can be removed by using flux agents, as in brazing, but this would mean additional work.

With alternating current welding, there is the option of cracking open and getting rid of this oxide layer using high-energy densities in the arc. This only applies to the ions as the electrons do not have sufficient kinetic energy for the purpose due to their low mass. Figure 25 shows the high-energy density flow in the arc.

If the minus pole is on the electrode, the electrons move from the electrode to the worpiece and the remaining ions from the workpiece to the electrode. With this polarity, no cleaning effect is possible. With reversed polarity, on the other hand, the heavy ions hit the surface of the workpiece. The kinetic energy in these ions can crack open and eliminate the oxide skin.

Welding on the hotter plus pole would mean that the current-carrying capacity of the electrode would be very low. This variant of TIG welding can therefore only be used for welding very thin aluminium structures (up to around 2.5 mm wall thickness). As a compromise, alternating current can be used. If the positive half-wave is on the electrode, the cleaning effect is started. In the subsequent negative half-wave, the electrode can then cool down once more. This is therefore also known as the cleaning and cooling half-wave. The current-carrying capacity is lower when welding with alternating current than with direct current minus pole welding. However, it is significantly higher than when welding on the plus pole – see

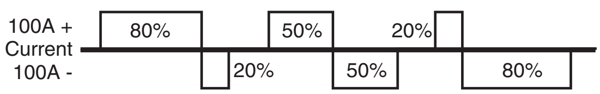


Figure 26 Different balance settings with square-wave alternating current

also Table 1. It has been shown that for an adequate cleaning effect, not all the positive half-wave is required, but that just 20 or 30% of it is sufficient. This has been exploited in modern TIG power sources. These generate an artificial square-wave alternating current in which fast-reacting switches (transistorss) are used to connect the plus and minus poles of a direct current source alternately to the electrode. This means that the balance of both half-waves can be changed in relation to one another, e.g. from 20% plus / 80% minus to 80% plus / 20% minus (Figure 26).

The lower proportion on the plus pole results in a higher current-carrying capacity of the electrode or with the same current setting in an extended service life. With these “square-wave sources” the frequency of the artificial alternating current can normally also be changed, e.g. between 50 and 300 Hz. The increase in frequency also conserves the electrode.

The artificial square-wave alternating current has another advantage, however. As the current course form is very steep when the polarity is changed, the idle times of the arc are considerably shorter with the zero pass than with a sinusoidal waveform. The reignition is therefore safer, even without an igniting aid, and the arc is more stable overall. However, the reignition operations are more noticeable due to the louder humming noise. Modern TIG power sources permit welding with direct current, as well as with sinusoidal and square-wave alternating current (Figure 28).

In recent times a variant of TIG minus pole welding has been used which uses shielding gas with a high helium content (e.g. 90% He / 10% Ar). When welding on the minus pole, the oxide skin cannot be cracked open, as explained above. But the high temperature of the energy-rich helium arc means that it can be liquefied. This makes it much less problematic. TIG direct current welding on the minus pole using helium is used primarily for repair welding on cast components made from aluminium/silicon alloys due to the improved fusion penetration characteristics.

A particular feature of welding the material aluminium is its tendency to form pores when retaining hydrogen. The conditions are considerably more important than when welding steel. Whereas iron still has a dissolving power for hydrogen of 8 cm^3/100 g of weld metal in the transition from liquid to the solid state, aluminium in the solid state has virtually no dissolving power for hydrogen. This means that all hydrogen taken up during welding must exit the weld metal before it embrittles. Otherwise pores will be produced in the weld metal.

Sources of hydrogen when TIG welding aluminium are primarily oxide skins on the parent material. These attract moisture and therefore need to be removed before welding by brushing or scraping. On the other hand, the arc is quieter if there is a thin oxide skin on the surface because this better emits electrons than the pure metal. This means that a compromise needs to be found between a stable arc and sufficient resistance to porosity. The best option has proved to be cleaning oxides from the workpiece surfaces thoroughly before welding, but then waiting another one or two hours so that a thin oxide coating can form. The oxide skins formed on the surface of the filler rods also contribute to pore formation. Aluminium fillers should therefore be stored carefully and for short periods only.

Figure 27 Using the PICOTIG 160 HF

7.4 Copper and copper alloys

The welding of copper is more complicated primarily because of its high level of heat conductance. With larger panel thicknesses, the material therefore needs to be pre-heated at least at the start of the weld seam. A pre-heating effect is produced later on by the forward welding heat, which means that large-scale pre-heating is only required for wall thicknesses > 5 mm. The TIG process provides the option of using the arc itself for pre-heating, by using an extended arc in circling movements to heat the start of the weld seam.

Pure copper and many Cu alloys are welded using direct current, with the electrode on the minus pole. Only a few bronzes such as brass and aluminium bronze are better welded with alternating current.

7.5 Other materials

In addition to the materials already discussed, nickel and nickel alloys are also TIG-welded to a significant extent. The

Figure 28 TRITON 220 AC/DC, TIG inverter welding machine

Figure 29 TRITON 160 DC, TIG welding in equipment construction

most important are nickel/chrome alloys (e.g. Inconel) and nickel/copper alloys (e.g. Monel). Titanium and titanium alloys are also TIG-welded. Direct current with a negative poled electrode is also best suited to these materials. When welding titanium, however, not only the welding seam area itself should be protected by shielding gas but to prevent annealing colour shielding gas should also be added at a great distance from the welding point and where applicable also on the back using a gas trailer. Otherwise the material will become brittle due to the take-up of atmospheric gases.

8 Applications for TIG welding

Example applications for TIG welding are given in Figure 27 to Figure 32. The TIG process is used primarily to join thin-walled workpieces; for thicker materials generally only the root pass is welded using this process and the filler and final passes carried out using other more powerful techniques. Irrespective to one statistic, the percentage of this process is just below 2% based on the total of all welding seams produced in Germany**.** However, this figure comes out particularly unfavourably for TIG welding because it is based on the consumption of filler material. As already mentioned, TIG welding normally uses little filler material. The actual proportion of this process could therefore well be greater, although not approaching the use of manual arc welding at around 7.5**%**. Nevertheless, TIG welding is a very important process. Its advantages have been described in a different section of this publication.

8.1 Uses in manufacturing

TIG welding is used primarily in the manufacture of boilers, containers, equipment and pipes, but also in the aerospace and space industry and for the production of stainless steel longitudinal seam welded pipes.

A further application of TIG welding lies in GMA surfacing, particularly in tool manufacture where this process can be used to improve even very fine contours, e.g. on dies and blanking dies.

8.2 Example applications

Figure 29 shows the use of manual TIG welding in equipment construction.

A flange is welded into a housing made from stainless CrNi steel (material number 1.4301). The TRITON 160 DC welding system being used supplies direct current up to 160 amperes at a duty cycle of 50%.

Similarly, the application shown in Figure 30 is the welding of CrNi steel in the chemical industry.

Figure 30 TRITON 260 DC, TIG welding on pipes

Figure 31 TIG welding in the repair of drive unit components

Circumferential welds on pipelines from this material are TIG welded using direct current. Being used here is the more powerful TRITON 260 DC welding system with a nominal current intensity of 260 amperes. The TIG process has been chosen here primarily because perfect complete root fusion from outside was required. With welding tasks such as this, the inside of the pipe needs to be shaped.

Figure 32 TIG welding used to weld pipes into pipe bends

As mentioned above, a sector where TIG welding is often the preferred choice is the aerospace and space industry. Figure 31 shows the application of the process of repairing a jet chamber for an aircraft engine.

The basic material here is a high-temperature and corrosion-resistant nickel-based alloy.

In Figure 32 pipes made from heat-resistant steel are being welded into the pipe bend of a heat exchanger. This involves the manual use of the process.

However, such welding tasks are also often mechanised. In this case the torch is centred in the interior of the pipe using a tensioning spindle. It normally runs from a position starting from the flat position in a circle around the pipe (orbital welding). Filler material can also be added during this process. As this runs through all positions from horizontal via vertical down and overhead to vertical up, the welding power sources used here are programmable so that the welding data for the relevant welding position can be modified for the position in question. These TIG orbital welds also occur as butt welds on pipes. In this case the torch runs around the pipe on a collect chuck.

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10 Imprint

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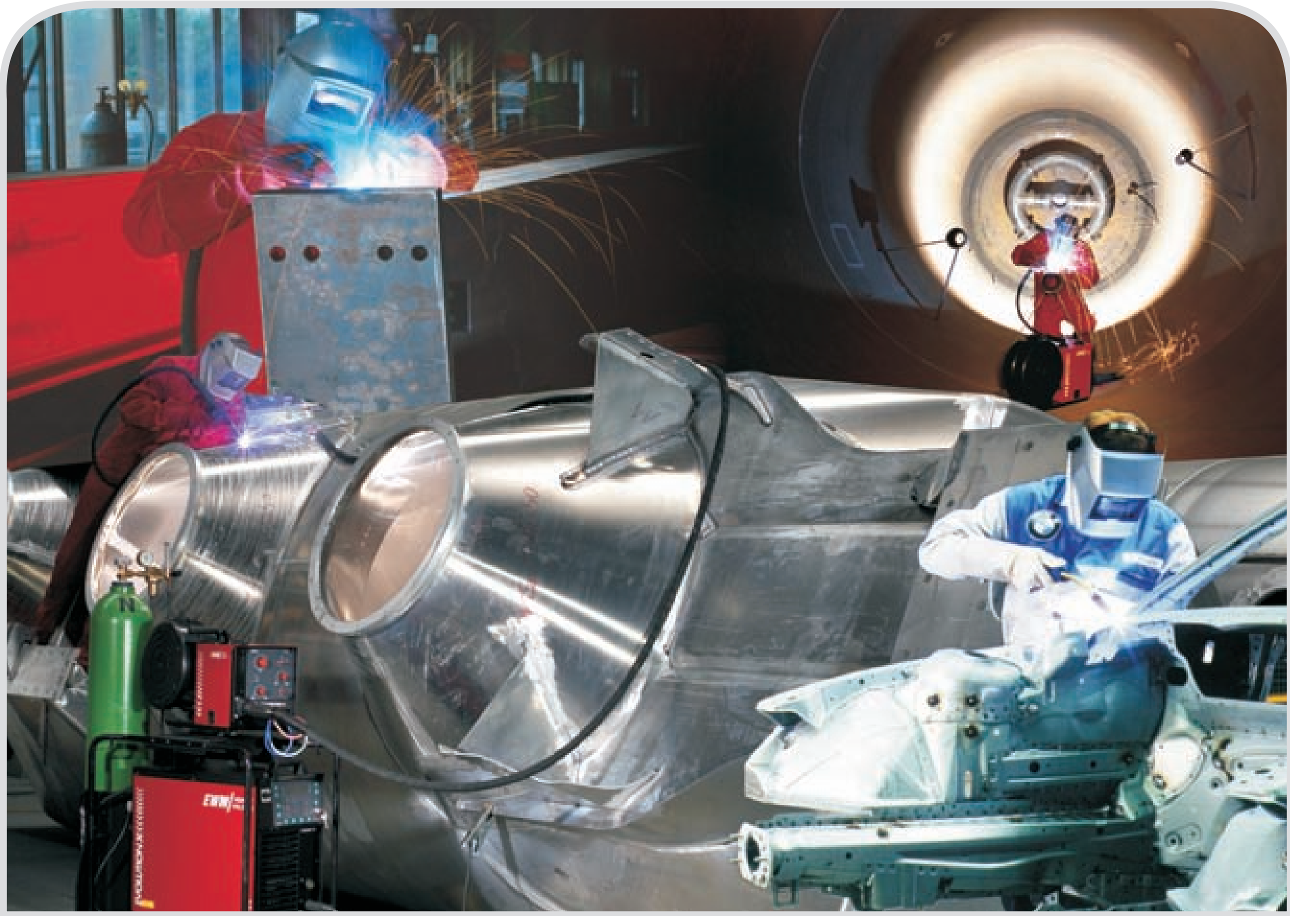
MIG/MAG PRIMER



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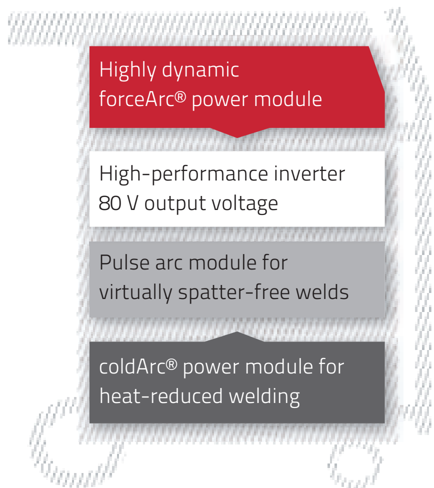

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MIG/MAG			
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coldArc/coldArc puls	✓	/	✓
rootArc/rootArc puls	✓	/	✓
Pulsed arc		✓	
Standard arc		✓	
pipeSolution		✓	
superPuls		✓	
MMA		✓	
TIG (lift arc)		✓	
Gouging		✓	

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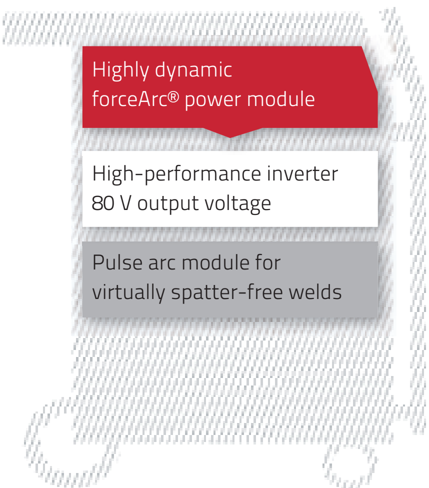

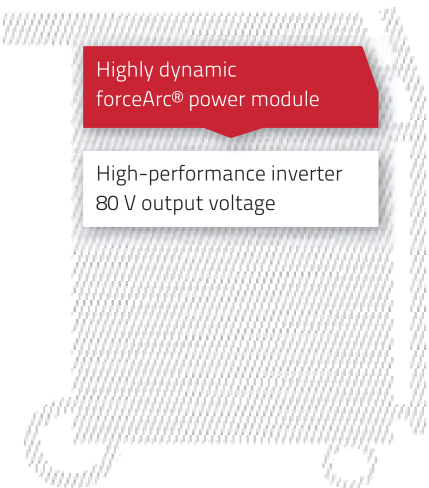

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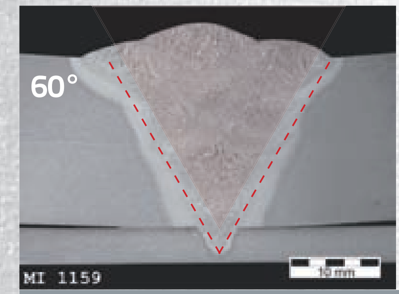
standard spray arc



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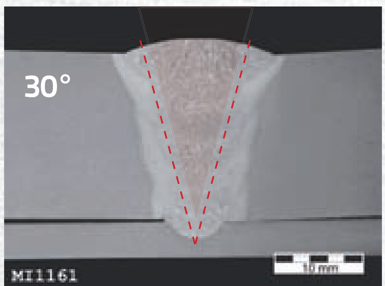

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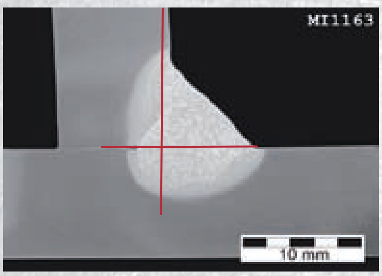

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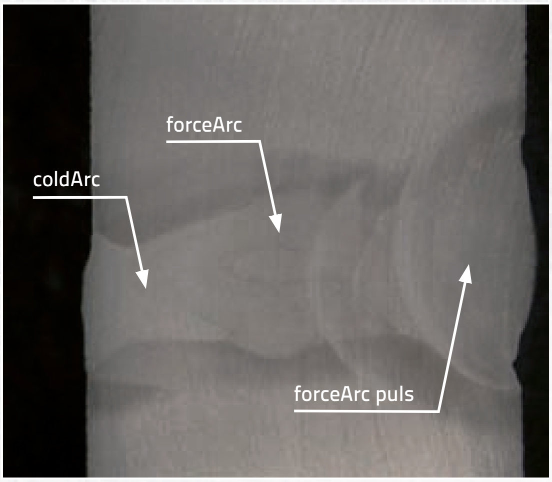

Sheet metal: S 235; 20 mm
Gas: M21-ArC-18
Wire: 1.2 mm G4Si1
Passes: 4
Position: PC
Included angle: 10°
Welded on one side, without weld pool backing

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Sheet metal: S 355; 30 mm
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Passes: 11
Position: PB/PA
Included angle: 25°
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- Brazing of CrNi sheets with CuAl8/AlBz8
- Brazing and welding of coated metal sheets, e.g. with CuSi, AlSi and Zn
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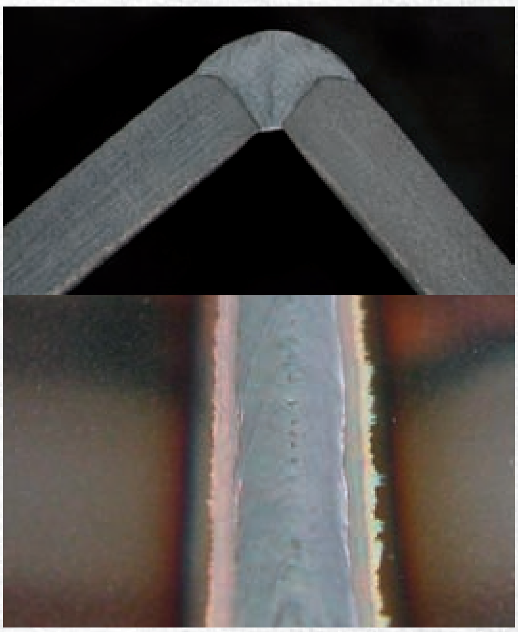
- Visible CrNi seams within the thin metal sheet range

Minimised heat input -99% less spatter

- Outstanding for butt welds, lap welds and edge welds
- Perfect for visible seams – no post weld work necessary
- Ideally suited for high-alloy steels and coated metal sheets
- Less discolouration and scaling
- Reduced heat-affected zone
- Excellent control for positional welding

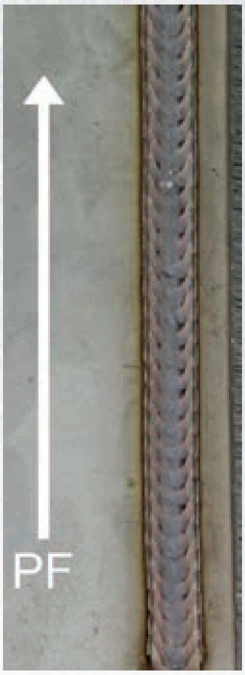


CrNi edge weld of 1 mm sheet metal, with coldArc

The ewm EN 1090 WPQR Package saves time and money

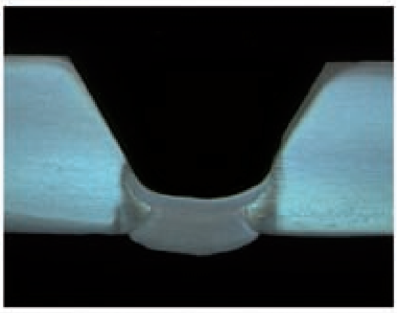
// coldArc // coldArc puls

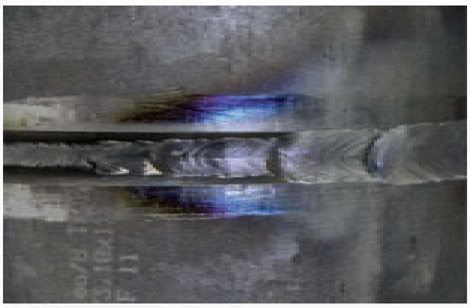
- Heat, where it is required with coldArc puls
- Root welding with coldArc: full control of the globular transfer, minimised risk of bonding faults
- Pass build-up and final passes with coldArc puls
- Performance enhancement for thicker metal sheets with coldArc puls
- Perfect welding in transitional areas with coldArc puls
- Switching between coldArc and coldArc puls by pressing the torch trigger for secure overlaying of tack points.
- Simple modelling of the molten metal through automatic changing between coldArc and coldArc puls by switching on superPuls.
- Excellent and easy welding from a standing position through changing between coldArc and coldArc puls by switching on superPuls, without using the "Christmas tree technique".



Unique gap bridging for root passes

- Perfect gap bridging, even with alternating gap widths, thanks to coldArc
- No sagging of the molten metal
- Secure sidewall fusion, even with misaligned edges
- Complete elimination of "wire stab"
- Root passes for all panel thicknesses in all positions
- Pass build-up and final passes with coldArc puls





Advantages of the MULTIMATRIX technology

coldArc
coldArc puls

- Root welding with TIG quality and MAG speed – up to 400% quicker than manual TIG and MMA welding.
- Thin metal welding of plain steel and stainless steel, with much less distortion.
- Reduced-energy short arc with unique gap bridging.
- Digitally controlled, nearly power-free material transfer.
- Perfect for sheet metal from 0.5 mm onward.
- -99% less spatter
- Outstanding for butt welds, lap welds and edge welds.
- Ideal for CO_2 and mixed gas.
- Heat-reduced brazing with innovative, zinc-based solders with low melting point.
- Up to 75% less welding fume emissions when compared with coldArc/coldArc puls vs. standard short arc

MULTIMATRIX
/// Perfection is the principle

Taurus Synergic S

Phoenix puls

alpha Q puls

root Arc
root Arc puls

The arc with optimum control of the weld pool

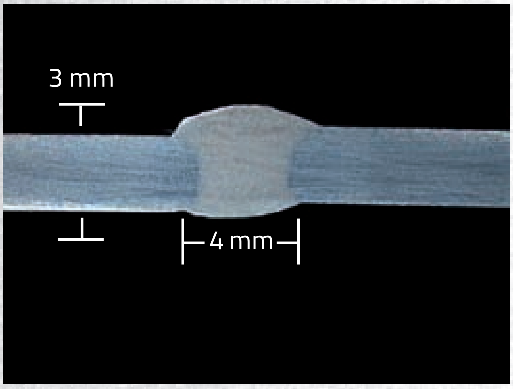
rootArc: Short arc with perfect weld modelling capabilities for effortless gap bridging and positional welding

rootArc puls: The perfect enhancement for focused heat input for the higher performance range

- Optimum reduction of spatter compared to standard short arc
- Perfect for sheet metal from 1 mm onward
- Optimal for positional and overhead welding
- Reduced-energy short arc
- rootArc puls for welding in transitional areas and for initial and final passes
- Excellent, heat-reduced welding in vertical-up positions (PF) through rootArc superPuls
- Superb root formation and secure sidewall fusion
- Vertical-up welds without weaving
- Un-alloyed and low-alloy steels
- Manual and automated applications

Effortless gap bridging in the vertical-down weld

- Stable, firm vertical-down weld
- Very good gap bridging
- Heat-reduced, low-spatter arc
- Superb root formation and secure sidewall fusion



Front

Back

Sheet metal:	3 mm
Gap:	4 mm
Gas:	M21-ArC-18
Wire:	1.0 mm SG3

The ewm EN 1090 WPQR Package saves time and money

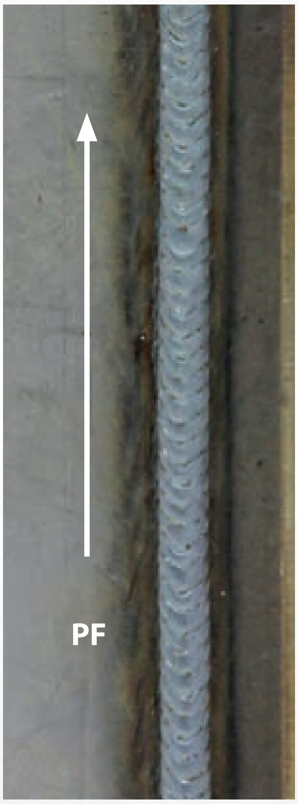
//rootArc // rootArc puls

- Heat input, if necessary, with rootArc puls
- Root welding with rootArc: Effortless controlling of the weld pool
- Pass build-up and final passes with rootArc puls
- Performance enhancement for thick metal sheets with rootArc puls
- Switching between rootArc and rootArc puls by pressing the torch trigger for secure overlaying of tack points
- Effortless mastery of the weld pool by changing between rootArc and rootArc puls through switching on superPuls
- Quick and easy welding of vertical-up welds by changing between rootArc and rootArc puls through switching on superPuls

Vertical-up welds in the PF position

- Excellent welding in vertical-up weld positions (PF) with rootArc-superPuls
- Secure formation of the root base
- No more weaving required
- Smooth "herring bone" effect results in aesthetically pleasing weld seams

The "Christmas tree technique", normally reserved for true experts, can be avoided, which is advantageous for less experienced staff.



Advantages of the MULTIMATRIX technology

root Arc
root Arc puls

- Reliable short arc welding in all positions
- Ideally suited for vertical-up welds (PF) without using the laborious "Christmas tree technique"
- Quick and reliable root welding in TIG quality
- Effortless welding of vertical-up/down welds and overhead welds
- Ideal for CO2 and mixed gas
- Reduced-energy short arc for effortless mastery of gaps
- Low-spatter, digitally-controlled material transfer
- Perfect for sheet metal from 1 mm onward
- Excellent for butt welds and lap welds

MULTIMATRIX
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Taurus Synergic S


Phoenix puls


alpha Q puls

Pulsed arc
Standard arc

The arc with optimum control of the weld pool

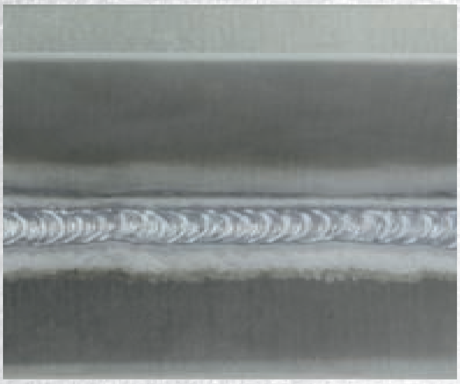
Pulsed arc: Controlled, short circuit-proof pulsed arc for all positions

Standard arc: Controlled short arc far into the transitional area

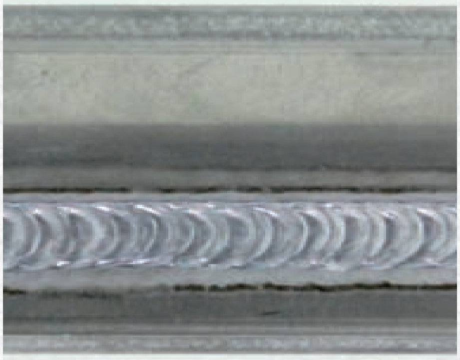
- Welding of aluminium and aluminium alloys
- Welding of high-alloy steels and Ni alloys
- Even globular transfer also for materials with high Ni content
- Stable arc in the wide transitional area between short and spray arc
- Copper welding
- Positional welding
- Controlled heat input via 1-globular-per-pulse-transfer

Aluminium welding with pulsed arc

- Perfect pulse welding of aluminium and aluminium alloys, for sheet metal thicknesses from 1 mm onward
- Stable arc in all positions, even when welding the thinnest aluminium sheets
- Almost spatter-free welding
- Spatter-free ignition by reversing the wire feeding
- Simple modelling of the molten metal through superPuls



Fillet weld, 1 mm sheet metal, AlMg, argon
1.2 mm wire electrode



Fillet weld, 8 mm sheet metal, AlMg, argon
1.2 mm wire electrode
Perfect ripples, thanks to superPuls

The ewm EN 1090 WPQR Package saves time and money

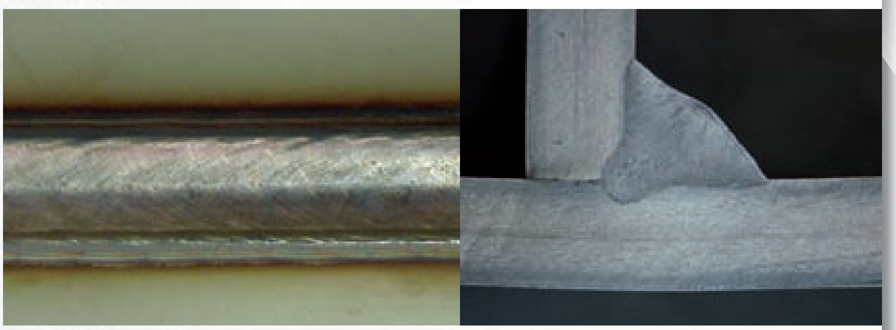
Advantages of the MULTIMATRIX technology

// Pulsed arc // Standard arc

- Extended standard short arc range of up to 11 m/min wire, with 1 mm wire diameter G4Si1 under mixed gas
- Less spatter and better arc stability through controlled short arc – to far beyond the transitional area
- High short-circuit frequency, steady weld pool, fine-globularlet material transfer
- Higher welding speeds
- Simple modelling of the molten metal through automatic changing between pulse and standard arc by switching on superPuls
- Excellent welding in the vertical up position through automatic changing between pulse and standard arc by switching on superPuls

CrNi welding with pulsed arc

- Perfect pulse welding of high-alloy steels and Ni alloys, also for thin sheet metal from 1 mm onward
- Reliable arc welding in all positions
- Very low-spatter process (fewer corrosion attack points)
- Reduced pore susceptibility
- Flat, smooth and notch-free weld seams



Sheet metal:	3 mm
Materials:	CrNi 1.4301
Gas:	97.5% Ar/2.5% CO_2
Wire:	1.2 mm 1.4316
Position:	PB

Pulsed arc
Standard arc

- Perfect welding of aluminium and aluminium alloys, high-alloy steels and Ni alloys, from 1 mm metal sheet thickness onward
- Even globular transfer also for materials with high Ni content
- Copper welding
- Extreme low-spatter pulsed arc, also in positional welding
- Quick and reliable changes to stick-out lengths
- Spatter-free ignition through reversible wire feeding
- Extended standard short arc range, to far into the transitional area
- Fine globular material transfer in the extended short arc range when welding low-alloy steels

MULTIMATRIX
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Advantages of the MULTIMATRIX technology

pipeSolution
pipeTruck – MAG orbital system

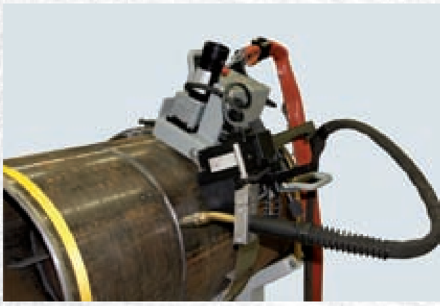
- pipeSolution/pipeTruck – up to 400% quicker than manual TIG and MMA welding
- Low and high-alloy solid wires (e.g. for the parent metal alloy 625)
- Rutile and basic flux-cored wires (e.g. for the parent metal high heat-resistant steel P91)
- Performance is significantly enhanced for root welding: Automated pipeSolution® achieves 150 to 500 mm per minute
- root welding in one operation without backing run
- MAG welding with pipeSolution® process on pipes with 3,400 mm diameter – wall thicknesses up to 30 mm
- Flawless welding result – high quality: certified by TÜV Hesse in welding procedure test according to AD 2000 regulations
- Root welding in one operation: Especially efficient, without a backing run, without weld pool backing
- The entire pipeTruck MAG orbital system from a single source:

  Welding tractor with control unit
  alpha Q power source
  Welding consumables
  Welding torch
  Wear parts
  Welding accessories
  Training and consultancy

pipeSolution
pipeTruck – MAG orbital system
Welding at MAG speed with TIG reliability.

Powerful short arc for rapid, safe welding, with and without gaps, in all positions.

- Root welding for metal sheets and pipes in all positions
- Hot pass/intermediate pass with pulsed arc
- Intermediate/final pass with flux cored wire
- Safe overhead welding thanks to optimum viscosity of the weld pool
- Reduction or elimination of preparation work, e.g. weld pool backing
- Virtually power-free material transfer
- Impressive process stability, even with long hose packages without additional sensor leads
- Unalloyed, low-alloy and high-alloy steels and high-tensile fine-grained steels



pipeTruck MAG orbital system

- Considerable reduction in set-up time – the 19-kg tractor is placed effortlessly on the track system and can be clamped in quickly
- High precision of the orbiting speed, linear pendular motion with adjustable frequency and holding times
- Seam can be accessed at any time thanks to the arrangement of the welding system on the tractor side
- Pipe welding in any position
- Pipe diameters of DN300 and up
- Pipes can be welded automatically and in high quality in all wall thicknesses

The ewm EN 1090 WPQR Package saves time and money

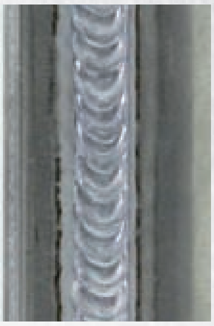
Advantages of the MULTIMATRIX technology

superPuls

The superPuls combination of ewm welding processes offers a multitude of possibilities.

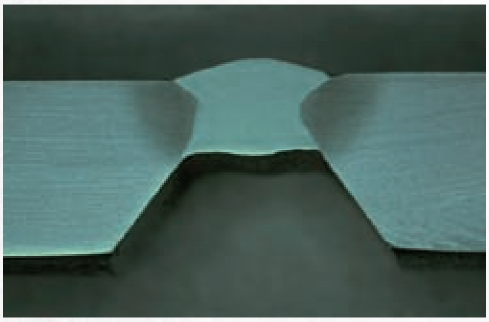
- Reliable fusion of the root base
- Effective filling with pulse
- No more weaving required
- Smooth bead ripples result in aesthetically pleasing weld seams
- Controlled reduced heat input
- Reduced spatter formation
- Easy modelling of the molten metal
- Quick and reliable welding of vertical-up welds without using the "Christmas tree technique"

The "Christmas tree technique", an application normally reserved for true experts, can be avoided, which is advantageous for less experienced staff.



Aluminium superPuls
PF position

CrNi superPuls
PF position



Steel superPuls
PF position

superPuls

- Quick and easy welding of vertical-up welds without using the "Christmas tree technique"
- Effortless mastery of the weld pool
- Performance increase by pressing on the torch trigger for secure overlaying of tack points
- Extreme low-spatter pulsed arc, also in positional welding

MULTIMATRIX
/// Perfection is the principle

forceArc
forceArc puls

Heat-reduced, directionally stable and powerful arc with deep penetration for the upper power range.

Non-alloyed, low-alloy and high-alloy steels and high-tensile fine-grained steels

Pulsed arc
Standard arc

Pulsed arc: Controlled, short circuit-proof pulsed arc for all positions

Standard arc: Controlled short arc far into the transitional area

	forceArc	forceArc puls	Standard arc	Pulsed arc
Cost savings thanks to reduced weld volume	★★★★★	★★★★	★★	★★★
Reduced energy costs	★★★★★	★★★★	★★	★★★★
Penetration depth	★★★★★	★★★★	★★	★★★★
Reduced heat input	★★★★★	★★★★	★★	★★★
Arc force	★★★★★	★★★★	★★	★★★★
Directionally stable arc	★★★★★	★★★★	★★	★★★★
Minimised spatter formation	★★★★★	★★★★★	★★★	★★★★★
Reduced undercuts	★★★★★	★★★★	★★★	★★★★
Highly dynamic current control	★★★★★	★★★★★	★★★	★★★★★
Reduced emissions/ less welding fumes	★★★★★	★★★★	★★	★★★★

Applications				
Unalloyed and low-alloy steels	Yes	Yes	Yes	Yes
High-alloy steels	Yes	Yes	No	Yes
High-tensile fine-grained steels	Yes	Yes	No	Yes
Aluminium	Yes	Yes	No	Yes
Copper	No	Yes	No	Yes

★ Good ➡ ★★★★★ Excellent

coldArc
coldArc puls

coldArc: Heat-reduced, low-spatter short arc for high dimensional stability welding and brazing, plus root welding with excellent gap bridging capabilities.

coldArc puls: The optimum enhancement for the higher performance range, with focused heat input – there where the heat is required.

rootArc
rootArc puls

rootArc: Short arc with perfect weld modelling capabilities for effortless gap bridging and positional welding

rootArc puls: The perfect enhancement for focused heat input for the higher performance range

pipeSolution

Powerful arc for rapid, secure welding with and without gap in all positions.

	coldArc	coldArc puls	rootArc	rootArc puls	pipeSolution
Reduced heat input/ less distortion	★★★★★	★★★	★★★★	★★★	★★★
Reduced energy costs	★★★★★	★★★★	★★★★	★★★★	★★★★
Minimised spatter formation/ less finishing work	★★★★★	★★★★★	★★★	★★★★★	★★★★
Gap bridging	★★★★★	★★★	★★★★★	★★★	★★★★★
Reduced harmful emissions/ less welding fumes	★★★★★	★★★★★	★★★	★★★★★	★★★★
Arc force	★★★	★★★★	★★★★	★★★★	★★★★
Good root formation	★★★★★	★★	★★★★★	★★	★★★★★
Root welding in any position	★★★★★	★	★★★★★	★	★★★★★
Thin panel welding	★★★★★	★★★★	★★★★	★★★★	★★★

Applications					
Unalloyed and low-alloy steels	Yes	Yes	Yes	Yes	Yes
High-alloy steels	Yes	Yes	Yes	Yes	Yes
High-tensile fine-grained steels	Yes	Yes	Yes	Yes	Yes
Brazing (CuSi, CuAl)	Yes	Yes	No	Yes	No
Brazing (zinc wire ZnAl)	Yes	No	No	No	No
Dissimilar joint, aluminium with galvanised steel panel (braze welding)	Yes	Yes	No	Yes	No

★ Good ➡ ★★★★★ Excellent

Contents

1 Preface

MIG/MAG welding (Figure 1) is one of the more recent developments in arc welding processes. It originated in the USA where

Figure 1 MAG welding in a workshop

it was first used in 1948.

A short time afterwards it came to Europe. It was first only used with inert gases or with argon containing only low quantities of active components (e.g. oxygen) and was therefore called S.I.G.M.A. welding. This stands for “shielded inert gas metal arc”. In 1953 the Russians began to use an active gas for welding instead of the expensive inert gases such as argon or helium, namely carbon dioxide (CO_2). This was only possible because in the meantime wire electrodes had been developed that compensated for the higher alloy burn-off with active gas welding.

MIG/MAG welding enjoys great popularity today in virtually all branches of industry from workshops to large-scale industrial applications because it is by nature partially mechanised and, with relative ease, can be fully mechanised or used automatically.

This publication covers the special features of the process and provides information on its correct usage.

2 The process

2.1 General

The new generic term for all arc welding processes where a wire electrode is melted using shielding gas, as defined in ISO 857-1, is gas-shielded metal arc welding (process no. 13). In Germany the generic term previously used was metal shielding gas welding. The ISO standard defines the process as follows: metal-arc welding using a wire electrode in which the arc and the weld pool are shielded from the atmosphere by a shroud of gas supplied from an external source. Depending on the type of shielding gas being used, there are further sub-classifications into metal inert gas welding (MIG), process no. 131, when an inert gas is used and metal active gas welding (MAG), process no. 135, when an active gas is used.

Other variants also given in ISO 857-1 are: Flux-cored wire welding with active gas shield (process no. 136), Flux-cored wire welding with inert gas shield (process no. 137), plasma MIG welding (process no. 151) and electrogas welding (process no. 73).

This primer relates to MIG/MAG welding only. This is characterised in that a wire electrode supplied from the spool by a wire feed motor is supplied with current by the contact nozzle shortly before it

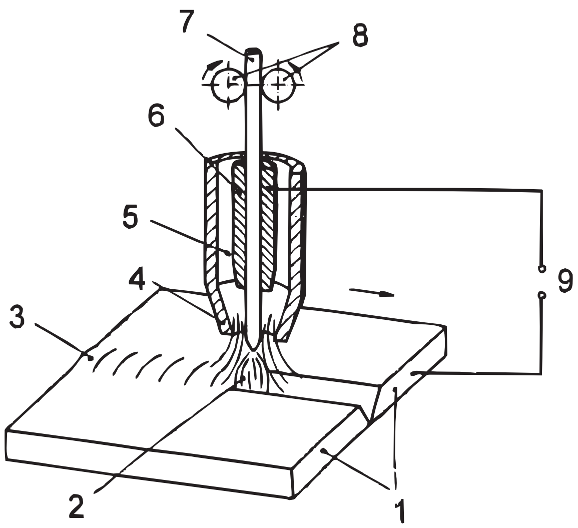


Figure 2 Principle of gas-shielded metal arc welding as defined by ISO 857-1

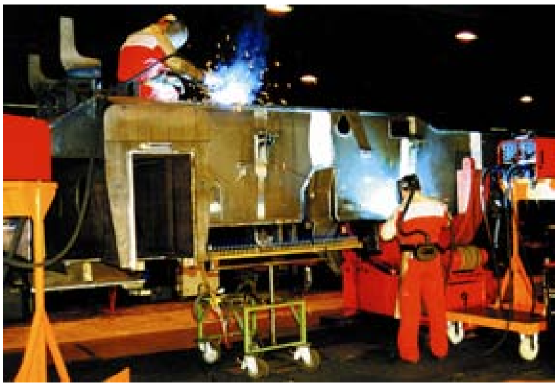


Figure 3 Welding fine-grained constructional steels in crane construction work

leaves the torch so that the arc can burn between the end of the wire electrode and the workpiece. The shielding gas flows out of the shielding gas nozzle, which covers the wire electrode concentrically (Figure 2).

This shields the weld metal from being penetrated by the atmospheric gases oxygen, hydrogen and nitrogen. The shielding gas has other purposes in addition to its protective function. As it determines the composition of the arc atmosphere, it also affects its electrical conductance and thus the welding characteristics. It also affects with pick-up and burn-off processes and the chemical composition of the weld metal produced - in other words, it also has a metallurgic effect.

2.2 Current type

Apart from more recent exceptions, MIG/MAG welding is normally performed using direct current, with the plus pole of the power source on the electrode and the minus pole on the workpiece. With some cored wire the reverse polarity is also sometimes used.

In more recent times alternating current is also used for very special applications, e.g. for MIG welding on very thin panels.

3 Fillers and auxiliary materials

3.1 Types of wire electrodes

Wire electrodes for MIG/MAG welding of unalloyed steels and fine-grained constructional steels are defined in DIN EN 440. The standard differentiates between the chemical compositions of 11 types of welding wires. It also contains welding wire types commonly used in other European countries. In Germany only types G2Si1, G3Si1 and G4Si1 (given in Table 1 for unalloyed steels) are used in any quantity. These contain increasing amounts of silicon and manganese in the order given, with an average of 0.65 to 0.9 % of silicon and 1.10 to 1.75 % of manganese. For fine-grained steels, the types G4Mo, G3Ni1 and G3Ni2 are also used (Figure 3).

Cored wire electrodes for welding these types of steel are given in DIN EN 758. Depending on the composition of the filling, a distinction is made here between rutile types, basic types and metal powder types. In addition to cored wires for MIG/MAG welding, DIN EN 758 also defines self-shielding cored wires, which can be used for welding without the addition of any shielding gas. They are commonly used for GMA-surfacing (Figure 4).

Wire electrodes for welding creep resistant steels are defined in DIN EN 12070, and cored wire electrodes for these steels in DIN EN 12071. The wire electrodes range from molybdenum alloy only variant to wires with 1, 2.5, 5 and 9 % chrome to wire electrodes with 12 % chrome. Other alloy elements are molybdenum, vanadinite and tungsten. There are cored wire electrodes with up to 5 % chrome.

Figure 4 Hard-facing of spiral conveyors

<table>
<tr><th rowspan="2">Code</th><th colspan="10">Chemical composition in % (m/min) [1][2][3]</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>P</th><th>S</th><th>Ni</th><th>Mo</th><th>Al</th><th>Ti and Zr</th></tr>
<tr><td>G0</td><td colspan="9">Any other agreed composition</td></tr>
<tr><td>G2Si1</td><td rowspan="4">0.06 to 0.14</td><td>0.5 to 0.8</td><td>0.9 to 1.3</td><td rowspan="5" colspan="2">0.025</td><td rowspan="5" colspan="2">0.15</td><td rowspan="4">0.02</td><td rowspan="4">0.15</td></tr>
<tr><td>G3Si1</td><td>0.7 to 1.0</td><td>1.3 to 1.6</td></tr>
<tr><td>G4Si1</td><td>0.8 to 1.2</td><td>1.6 to 1.9</td></tr>
<tr><td>G3Si2</td><td>1.0 to 1.3</td><td>1.3 to 1.6</td></tr>
<tr><td>G2Ti</td><td>0.04 to 0.14</td><td>0.4 to 0.8</td><td>0.9 to 1.4</td><td>0.05 to 0.2</td><td>0.05 to 0.25</td></tr>
<tr><td>G3Ni1</td><td rowspan="2">0.06 to 0.14</td><td>0.5 to 0.9</td><td>1.0 to 1.6</td><td rowspan="2" colspan="2">0.02</td><td>0.8 to 1.5</td><td rowspan="2">0.15</td><td rowspan="4">0.02</td><td rowspan="5">0.15</td></tr>
<tr><td>G2Ni2</td><td>0.4 to 0.8</td><td>0.8 to 1.4</td><td>2.1 to 2.7</td></tr>
<tr><td>G2Mo</td><td>0.08 to 0.12</td><td>0.3 to 0.7</td><td>0.9 to 1.3</td><td rowspan="3" colspan="2">0.025</td><td rowspan="3">0.15</td><td rowspan="2">0.4 to 0.6</td></tr>
<tr><td>G4Mo</td><td>0.06 to 0.14</td><td>0.5 to 0.8</td><td>1.7 to 2.1</td></tr>
<tr><td>G2Al</td><td>0.08 to 0.14</td><td>0.3 to 0.5</td><td>0.9 to 1.3</td><td>0.15</td><td>0.35 to 0.75</td></tr>
</table>

[1]) **Unless otherwise specified: Cr ≤ 0.15, Cu ≤ 0.35 and V ≤ 0.03. The proportion of copper in steel plus coating should not exceed 0.35%.**

[2]) **Single values in the table are maximum values.**

[3]) **The results should be rounded to the same place as the values specified by ISO 31-0, Appendix B, Guideline A.**

Table 1 Codes for the chemical composition of wire electrodes

Wire electrodes for welding stainless and heat-resistant steels are defined in DIN EN 12072; cored wire electrodes for these steels are defined in DIN EN 12073. The standards differentiate between fillers for martensitic/ferric chrome steels, austenitic steels, ferric/austenitic steels and full austenitic highly corrosion-resistant steels, as well as special types and heat-resistant types.

For wire electrodes for welding aluminium and aluminium alloys there is currently a draft version of a new European standard (EN ISO 18273).

3.2 Welding-engineering delivery conditions for wire electrodes and cored wire electrodes

Wires, rods and wire electrodes for shielding gas welding are manufactured by cold drawing. Cored wire electrodes for certain manufacturing processes are manufactured by cold rolling.

Standard diameters and permissible limit dimensions for wire electrodes and cored wire electrodes can be found in DIN EN 759. The diameters range from 0.6 to 4.0 mm. With solid wires for MIG/MAG welding, however, the most commonly used diameters are 0.8, 1.0, 1.2 and 1.6 mm. Cored wires generally start from a diameter of 1.0 mm. However, they are also used in thicker dimensions such as 2.4 or 3.2 mm.

Unalloyed and non-alloy wire electrodes are normally used with a copper-coated surface. The copper plating reduces the slippage resistance during feeding and improves the contact. It does not provide any significant corrosion protection because it is porous. Cored wire electrodes can only be copper plated if they have an enclosed coating without any gaps.

High-alloy wires cannot be galvanically or electrolytically copper-plated. They are supplied with a bright surface. Welding wires made from aluminium are also used with a bright surface. As drawing agents can penetrate the soft surface of the aluminium, which would cause pores to form during the subsequent welding process, quality wires are stripped before the final drawing process.

Wire fillers for shielding gas welding are supplied on reels, core spools or basket coils. Larger packs such as barrel reels are also available.

3.3 Shielding gases

Shielding gases for MIG/MAG welding can be found in DIN EN 439. This standard defines all shielding gases for arc welding and arc cutting. The shielding gases are divided into 7 groups and further sub-groups (Table 2).

Group R includes argon/hydrogen mixtures, which have a reducing effect. The gases in group R1 are used for TIG welding and for plasma welding, along with argon and helium, whereas the gases in subgroup 2 with a higher hydrogen content (H) are used for plasma cutting and for root protection (forming gases).

Group I includes the inert gases, including argon (Ar) and helium (He), as well as argon/helium mixtures. They are used for TIG, MIG, and plasma welding, and for root protection.

The large M group, which is divided into subgroups M1, M2 and M3, contains the mixed gases used for MAG welding. Each subgroup also contains 3 or 4 further subgroups. The gases are arranged from M1.1 to M3.3 depending on their oxidation properties, i.e. M1.1 is only slightly oxidising and M3.3 has the highest level of oxidisation. The main component of these gases is argon, and the active components added are oxygen (O) or carbon dioxide (CO_2) or oxygen and carbon dioxide (three-component gases).

In the range of gases used for MAG weld-

Code [1])		Components in volumetric percent							
		Oxidising		Inert		Reducing	Slow reacting	Normal application	Notes
Group	No.	CO_2	O_2	Ar	He	H_2	N_2		
R	1			Residual [2])		> 0 to 15		TIG, plasma welding, plasma cutting, root protection	
	2					> 15 to 35			
I	1			100				MIG, TIG, plasma welding, root protection	inert
	2				100				
	3			Residual	> 0 to 95				
M1	1	> 0 to 5		Residual [2])		> 0 to 5		MAG	low oxidisation
	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							high oxidisation
	2	Residual	> 0 to 30						
F	1						100	Plasma cutting, root protection	slow to react
	2					> 0 to 50	Residual		reducing

[1]) **If components not given in the table are added, the gas mixture is designated as a special gas and marked with the letter S. More information on the designation S is given in section 4.**

[2]) **Argon can be replaced with helium up to 95%. The helium percentage is indicated by an additional code irrespective to Table 5, see section 4.**

Table 2 Classification of shielding gases for arc welding and arc cutting (EN 439: 1994)

ing, group C contains pure carbon dioxide and a carbon dioxide / oxygen mixture. The latter is not used in Germany, however. The gases in group C have the highest level of oxidisation because the CO_2 decomposes in the high arc temperature, producing large quantities of oxygen in addition to the carbon monoxide.

Lastly, group F includes nitrogen (N) and a nitrogen/hydrogen mixture. Both gases can be used for plasma cutting and for forming.

In addition to the oxidation properties, the electrical and physical properties in the arc area and thus the welding properties also change with the composition of the gas. Adding helium to argon, for example, improves the heat conductance and the heat retention of the arc atmosphere. Both result in an energy-rich arc and thus in better fusion penetration characteristics. The addition of active components to the mixed gases creates finer drop formation when melting the wire electrode. The heat transport in the arc is also improved, which in turn means improved fusion penetration characteristics.

The quantity of shielding gas required can be calculated using a rule of thumb; it should be 10 - 12 x wire diameter in litres/minute. The greater tendency towards oxidation of the material when MIG welding aluminium means that slightly higher flow quantities need to be set. With Ar/He mixed gases, significantly higher quantities should be set due to the low density of helium. The pressure of the gas coming out of the cylinder or the ring pipe is first reduced. The quantity set can be read off a manometer that has been calibrated together with a nozzle, or on a flowmeter with suspended load.

More information on the effect of the shielding gases on the welding process is given later on in the description of the various arc types.

3.4 Weld metal properties

With welding fillers for unalloyed steels and for fine-grained constructional steels, the main factor when choosing a wire/shielding gas combination is recreating the strength and toughness properties of the parent material in the weld material. The standard DIN EN 440 provides some help here. Just as for stick electrodes, a designation system provides specifications for the minimum values for the yield point and fracture elongation, and the strength and impact energy of the weld metal. The designation system is shown in Table 3.

In the chosen example, a wire electrode G3Si1 is welded using mixed gas (M). The weld metal for this wire/shielding gas combination has a minimum yield strength of 460 N / mm^2, a strength of 530 to 680 N / mm^2 and a minimum expansion of 20 % (46). Impact energy of 47 joules will achieve a temperature of up to -30 °C (3). A similar system also exists for characterising the weld metal of cored wire electrodes in DIN EN 758.

Codes for the strength and expansion properties of the weld metal

Code	Min. yield strength[1]) N/mm^2	Strength N/mm^2	Min. fracture strain 2) %
35	355	440 to 570	22
38	380	470 to 600	20
42	420	500 to 640	20
46	460	530 to 680	20
50	500	560 to 720	18

Codes for the impact energy of the weld metal

Code	Temperature for min. 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

Table 3 Example codes for a wire/shielding gas combination defined by DIN EN 440

With creep resistant steels, corrosion-resistant and heat-resistant steels and with aluminium materials, the general rule is that to achieve the necessary material properties, the weld metal needs to be of as similar type as possible or with slightly more alloy. For wire electrodes and cored wire electrodes for welding creep resistant, corrosion-resistant and heat-resistant steels, details are given on the minimum values for yield strength, strength, expansion and impact energy of the weld metal in the relevant standards as tables. These values do not form part of the designation system, however.

A wire electrode for MAG welding creep-resistant steel 13 CrMo 4.5 has the designation as defined in DIN EN 12070:

EN 12070 - G CrMo1Si

A wire electrode for MAG welding corrosion-resistant CrNi steel with material number 1.4302 has the following designation as defined in DIN EN 12072:

EN 12072 - G 19 9 L

The designation for a wire electrode for MIG welding material AlMg 5 is:

EN 18273 - G RAlMg5Mn

4 Groove preparation

4.1 Groove shapes

The most important groove shapes used in MAG welding on steel are shown in Figure 5.

Due to the good fusion penetration characteristics the process offers, seams with root faces (square, single-V, double-V welds) can be welded with complete fusion and without gouging on greater panel thicknesses than with manual arc welding. Gouging from the underside is recommended, however, with larger material thicknesses, to avoid faults. The root face height depends on the current intensity being used.

Larger weld preparation angles (70 - 90 °) are recommended with aluminium materials for larger thicknesses due to the greater heat carry-off.

4.2 Placement of the weld groove side walls

With unalloyed and low-alloy steels, the edges of parts to be joined are normally prepared by oxygen cutting. High-alloy steels and metals that can be MIG/MAG welded (e.g. aluminium) can be fusion cut using a plasma arc. It is not necessary to remove the oxide skins formed during the thermal separation, but may be required in some circumstances. The special features of aluminium as a material in this respect are covered in another section.

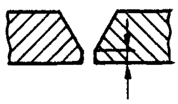
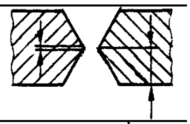
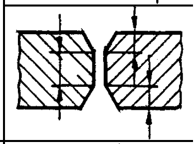
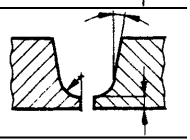
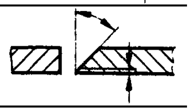
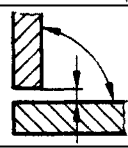
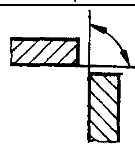
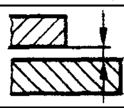
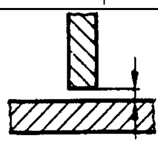
Joint type	Workpiece thickness (mm)	Diagram
Square weld	One-sided 3-8 both sides <8	
Single-V weld	One-sided 3-10 with backing run 3-40	
Single-V butt weld with broad root face	One-sided 5-40 with backing run >10	
Double-V butt weld	Both sides > 10	 
Single-U butt weld	One-sided > 12 with backing run >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 both sides > 3	
Fillet weld lap joint	One-sided >2	
Fillet weld, double fillet weld	Both sides > 2	

Figure 5 Groove shapes as defined in DIN EN 29692 – ISO 9692

If there are any particular requirements for observing lower tolerances, mechanical undercutting of the edges of parts to be joined could be advisable. This applies in particular to circumferential welds. The modern options for cutting with an electron beam or a laser beam are provided in automated production.

4.3 Backing

Whereas in manual welding the welder watches the progress of the weld and can achieve an even root weld even if the root opening is uneven by setting the correct current intensity, adjusting the position of the arc in the groove and the welding speed in fully automated welding everything must be correct from the chosen welding groove the root opening set to the correct set welding parameters and the continuous quantity of filler wire added. Backing runs are therefore often used with machine welding to simplify the root welding (Figure 6).

If there is no significant variation in the root gap, root faces can also be used as natural backings, e.g. with square edge and single-V seams (internal backings). Depending on the root face height, the set welding parameters for welding the first pass need to be selected so that the root face is not fully melted. The remainder of the root face can then be created when welding the backing run, with or without gouging.

Artificial (external) backings consist of metals, for example, with most metals and alloys, of copper, and with aluminium, which has a low melting point, of stainless steel. Ceramic backing plates are also used in welding for this purpose. The backing plate should prevent the spontaneous sagging of the weld metal, e.g. at points where the gap is slightly wider, so that the molten metal is caught and a root bead can be produced. The backing also forms the underside of the root weld. For this purpose a groove is therefore generally created for it.

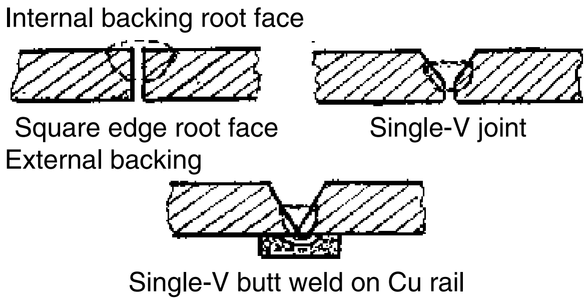


Figure 6 Backings with machine welding

4.4 Forming

This is the extra addition of shielding gas to the back of the root where the material being welded is also in a molten state, but is not reached by the shielding gas supplied to the top side. Unlike TIG welding where because of the relatively low welding speed the back of the root often has a “burnt” appearance due to oxidation that should be prevented by the forming gas, MIG/MAG welding does not require this forming gas for this reason.

Thanks to the forming process, the formation of oxide skins and annealing colours on the back of the root is also prevented, or at least reduced. This is important when welding corrosion-resistant steels, for example, because these oxide skins impair the corrosion-resistance of the weld. These skins need to be removed by brushing, blasting or etching. The best option is to prevent these skins occurring in the first place by using the forming process.

When welding pipes, the ends can simply be blocked and the forming gas fed into the interior. When welding metal panels, the forming gas can be allowed to flow out of openings in the backing bars. Argon or an argon/hydrogen mixture can be used as the forming gas. In many cases, however, the more cost-effective forming gases in group F in DIN EN 439 can be used. These gases may consist of a hydrogen/nitrogen mixture, for example. In some circumstances, pure nitrogen can also be used for forming.

5 Welding machines

Machines for MIG/MAG welding consist of the power source, the control and the wire feed unit with tube package and torch. For various applications, these can be used as compact machines or as universal machines.

With compact machines (Figure 7) the power source, control and wire feed unit are housed in a casing.

The operation radius corresponds to the length of the torch tube package. Depending on the wire electrode diameter being used, this is 3-5m. Irrespectively, compact machines are used mainly at fixed workstations, e.g. in welding booths or on production lines. With universal machines (Figure 8), also known as decompact machines, the wire feed is housed separately in a case and connected to the power source and the control using a link cable.

These machines can be moved to the workpiece, which means that the operation radius is 10 to 20 m larger in comparison to the compact machine. Universal machines are therefore generally used at mobile workstations and on construction sites.

5.1 Power sources

The power source has the task of supplying the welding process with the electrical energy required. This includes reducing

Figure 7 Gas cooled compact machine SATURN 301

Figure 8 Water cooled universal machine WEGA 401

the high voltage from the mains and supplying the high current intensity required, even if a short-circuit occurs. As with MIG/MAG welding, apart from a few recent developments, only direct current is used, rectifiers and inverters are used as power sources. Power sources for

Figure 9 Inverter multiprocess machine PHOENIX

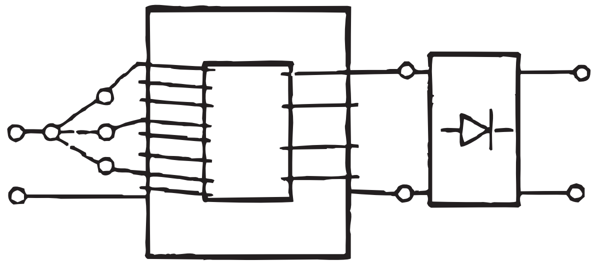


Figure 10 Principle of a step switch machine

MIG/MAG welding have a horizontal or slightly falling characteristic (constant voltage characteristic). This is required to permit the process to be regulated internally. More information on this will be required later on. For machines to be used as multiprocess systems, the characteristic can also be adjusted from vertical falling to horizontal.

The welding rectifier consists of the transformer and downstream rectifier stacks. Whereas the transformer converts the high voltage and low current intensity from the mains supply into welding current with low voltage and high current intensity, the rectifier stacks rectify the alternating current coming from the transformer. To meet the special requirements of different welding tasks, the power sources need to be adjustable. With simple machines for MIG/MAG welding, this occurs via a primary-side turn tapping using step switches. Figure 10 shows the functioning principle of a step switch machine.

Adding more or fewer turns on the primary coil changes the transmission ratio of the transformer and thus the voltage on the secondary side. With more complex power sources, the current is set in the rectifier part using controllable rectifiers (thyristors). A scheme of a system of this type is given in Figure 11.

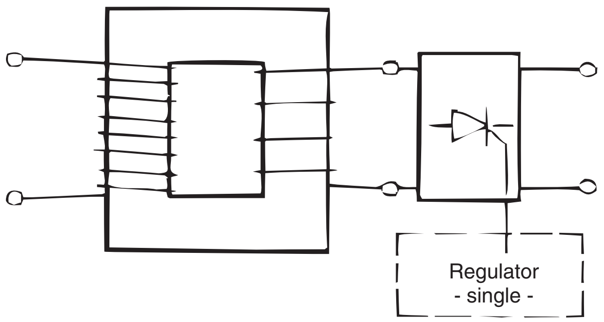


Figure 11 Functional principle of a thyristor-controlled power source

By adjusting the thyristors as appropriate, more or fewer parts of the a.c. half-waves are allowed through, changing the welding voltage.

More demanding MIG/MAG machines are equipped with inverters as power sources. The inverter is an electronic power source. After a period of using analogue, secondary clocked and primary clocked electronic power sources, development has now focussed on primary clocked devices, which work in a completely different way to conventional power sources (Figure 12).

The current coming from the mains is first rectified and then, in order to transform it, chopped into short sections by switching on and off. This process is known as clocking. This is possible, thanks to fast-reacting electronic switches called transistorss. The first transistorsised inverters used a clock frequency of around 25 kHz. Today with highly developed transistorss, clock frequencies of 100 kHz and more are possible.

After “chopping” (clocking), the current is transformed into the necessary high current intensity and low voltage. A square-wave alternating current is then created on the transformer, and is rectified once more. The high clock frequency has the advantage that the mass of the transformer can be kept very small because it is dependent on the frequency of the current being transformed. Lightweight power sources can thus be produced.

With electronic power sources, much of what is achived components such As resistors, chokes and capacitors, is trig-

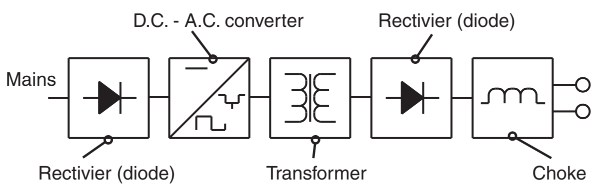


Figure 12 Block diagram for a 3rd generation inverter

gered electronically by the control. The control for these power sources is therefore just as important as the power unit. The current is adjusted in clocked sources, for example, by changing the ratio between the current input/output times. Changing the clock frequency can also be used to adjust the current level. To generate pulse-shaped current, the ratio of the input/output times is changed cyclically by the control. The slope-up/slope-down is produced in a similar way.

However, new technology means that controlled power sources are also possible, something that had been missing in welding technology for a long time. A control device measures the welding current and welding voltage and compares it to the set values. If the set welding parameters change, e.g. due to undesirable resistances in the welding current circuit, the control will adjust them irrespectively. This occurs very rapidly in the μs range. Similarly, the short-circuit current can also be limited and the cosφ improved. Greater efficiency and lower open circuit losses of the inverter power sources are already produced by the lower mass of the transformer.

5.2 Wire feed units

The wire feed unit moves the wire electrode via feed rollers at the speed at which it is melted by the process. The wire is drawn off the spool and moved into the tube package that has the welding torch at its end. For this purpose there is a guide nozzle in front of the feed rollers, which moves the wire in a defined direction and behind the rollers, at the start of the tube package, is the wire inlet nozzle. Systems for fully automated welding often also have an intermediate relay unit, preventing the wire from being bent during unwinding.

The feed rollers are driven by a d.c. motor that can be infinitely adjusted in the speed of rotation. With modern units that permit regulated welding, the wire feed speed is measured using a speedometer and controlled irrespective to the load.

Figure 13 Interior view of a wire feed unit with a 4-roller drive unit

With MIG/MAG welding wire feed speeds of between 2 and 20 m/min are standard, and more with high deposition power units. The motors are therefore connected to the drive roller via a gear unit.

The wire feed unit should not damage the surface of the wire electrode. The wire feed rollers therefore need to have a diameter sufficient to ensure that the specific pressure on the wire surface does not become too great. In contrast to a 2-roller drive unit, 4-roller drive units can feed the wire with reduced surface pressure and without slipping. The surface pressure between the rollers can be reduced further if multiple rollers are being

Figure 14 4-roller drive unit

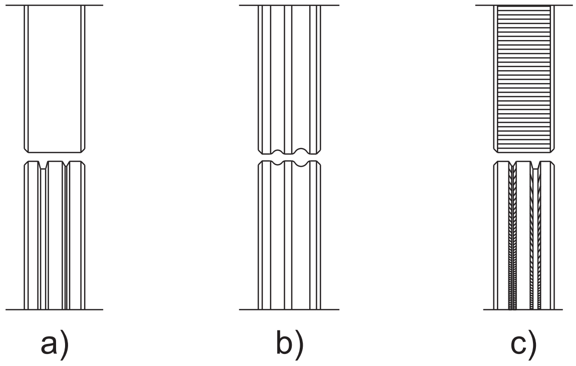


Figure 15 Various drive rollers
a) Steel
b) Aluminium
c) Cored wire

driven. With 4-roller drives, all the rollers are often geared together and driven by a common motor.

Figure 14 offers a view into a wire feed unit with 4-roller drive. Figure 15 shows the details in the drive unit.

Generally only one roller of the feed roller pair has a trapeziform groove, whilst the counter-roller is smooth (Figure 13).

This produces a 3-point support for the wire surface between the rollers, which protects the surface of the wire. With cored wire electrodes and soft wire electrodes, both rollers sometimes also have a semi-circular groove. It is important that the wire surface is not damaged because wire shavings are conveyed into the tube package and can block the package in a short space of time. Increased metal damage is also caused if the feed rollers are worn. Their condition should therefore be checked at regular intervals.

5.3 Tube package and torch

The tube package contains all the necessary supply lines, in other words the power cable, the shielding gas pipe, the wire feed tube, the control lead and, with machines equipped for higher current intensities, the cooling water supply and return lines.

With water cooled machines the power lead is in the water return line. The size of the line can therefore be kept smaller than without cooling and the tube package is more flexible. With unalloyed and non-alloy steel the wire feed tube for

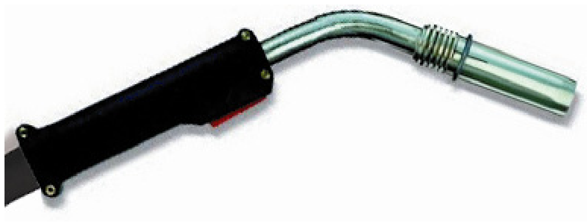


Figure 16 Swan-neck torch

welding consists of a steel spiral. When using wire electrodes made from chrome/nickel steel and from aluminium and other metals, a tube made from wear-resistant plastic (e.g. Teflon) is used. Plastic guides have a more favourable friction coefficient than steel. The control lead allows control signals to be sent from the torch to the control. A torch switch on the torch handle is used to activate the necessary functions during weld-

Figure 17 HIGHSPEED rapid welding torch

ing.

At the end of the tube package is the welding torch. The following illustrations show some common torch types.

The most commonly used type is the swan-neck torch (Figure 16). They are lightweight and affording the arc very good access to the welding point. The rapid welding torch has a special shape and manoeuvrability (Figure 17).

Another torch type is the pistol torch. It is shown in Figure 18 as a push-pull torch.

Figure 18 Push / Pull torch

Figure 19 Torch with display and remote control

Figure 20 Spool gun torch

With a push-pull drive, the wire electrode is drawn by a feed motor located in the torch handle, whilst at the same a motor located in the machine moves the wire into the tube package. This means that even soft and thin wires can be fed in without problems. A push/pull drive is also often used with robot systems and with mechanised welding systems where the wire electrode needs to be transported across large distances due to the design. Figure 19 shows yet another torch type, for a digitised welding system in which welding data is read off the display and can be adjusted on the torch.

With a spool gun torch (Figure 20), a mini wire spool is fitted directly on the torch and the feed motor is fitted in the handle.

The feed lines are therefore very short, and very thin and soft wires can be transported without problems. Figure 21 gives a cross-section diagram of a swan neck torch.

This clearly shows that the steel spiral used to feed the wire is moved right up to the contact nozzle screwed into the nozzle holder. Thus, if feed errors occur, the wire that has been fed in is prevented from buckling here in the front part of the torch.

5.4 Control

Various functions can be set on the welding system control, some of which can then be initiated on the torch switch via the control lead. This also includes switching from non-latched to latched operation. Other functions include setting a creep speed for the wire electrode during ignition and setting a burn-back time for the arc when finishing welding. The adjustable speed of the wire electrode during ignition makes the ignition process safer because the arc, which at the start is burning weakly on the cold material, does not go straight out again due to the wire being fed in. The set burn-back time prevents the electrode sticking in the end-crater. This is achieved in that the wire feed is shut down slightly before the welding current. However, if the burn-back time is too long, the wire may stick to the contact nozzle. Another programme can be used to prevent an excessively large drop remaining on the end of the wire once welding has ended, which would interfere with reignition. For this reason, the drop formed on the wire is detached by a current pulse immediately before the welding process is completed. The latter function is especially

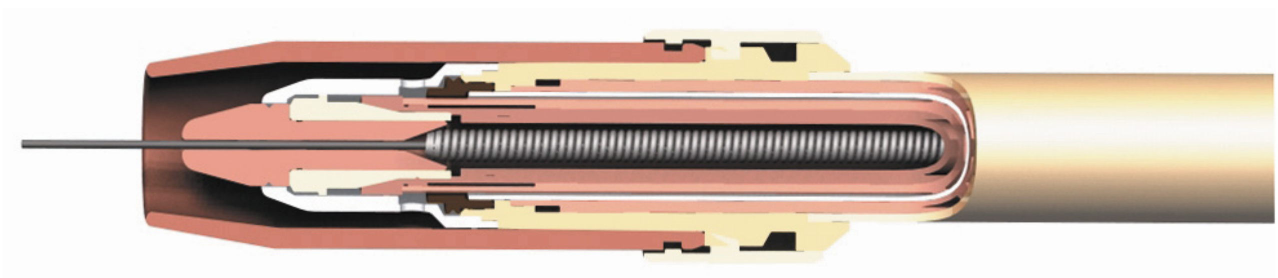


Figure 21 Cross-section diagram of a MIG / MAG torch head

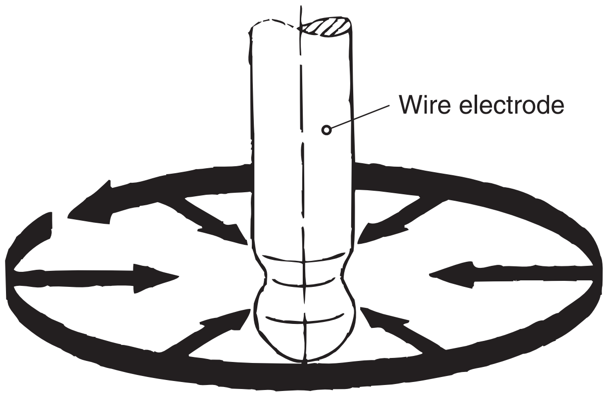


Figure 22 Scheme diagram of the pinch effect [1]

important with fully automated systems, whilst with partially automated processes, the welder can pinch off the end of the wire before reignition. Modern MIG/MAG systems also permit a ramped increase of the current at the beginning and a corresponding reduction at the end of the weld seam.

6 Material transfer with MIG/MAG welding

6.1 Arc ranges

Depending on the set set welding parameters and the shielding gas being used, different material transfer types are created in MIG/MAG welding, also known as arc operating conditions. Various physical phenomena are at play here, including surface tension and viscosity of the metal, gravity and plasma flow, along with electrical forces, such as the Lorenz force. The latter electro-magnetic force has a dominant influence in drop transfers occurring in the open. The Lorenz

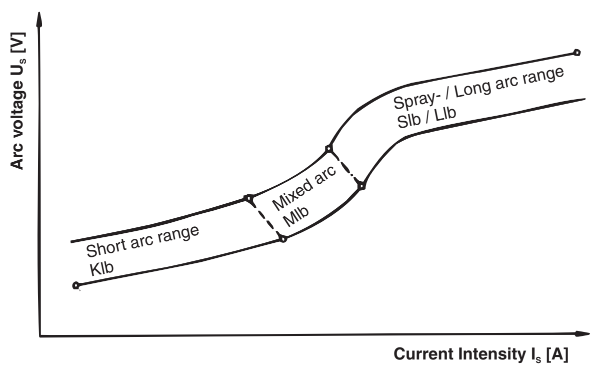


Figure 23 Position of the working ranges

Name	Material transfer
Spray arc	Minimal to fine drops > virtually short circuit-proof
Long arc	Rough drops > not short circuit-proof
Short arc	Fine drops > in short-circuit
Pulse arc	Drop size and drop frequency adjustable > virtually short circuit-proof

Table 4 Arc types as defined in DIN 1910-4

force, also known as the pinch effect, is a radial force directed inwards resulting from the surrounding magnetic field (Figure 22) that cuts into the molten end of the electrode and pinches off individual drops from it.

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

Material transfers carried out with the same type of current occur partly in the lower output range, i.e. at lower current intensities and voltages and partly in the upper output range.

Figure 23 shows a scheme of their position in a current/voltage diagram.

The pulse arc occurs across all output ranges. The individual arc types are described below.

6.2 Short arc

The short arc occurs in the lower power range, i.e. at lower current intensities and arc voltages. Its name does not just describe the fact that it is a very short arc, but it was previously called a short-circuit arc because of the type of drop transfer. Figure 25 shows the stages of the drop transfer process.

Under the effect of the arc heat, a small drop (a) forms on the end of the elec-

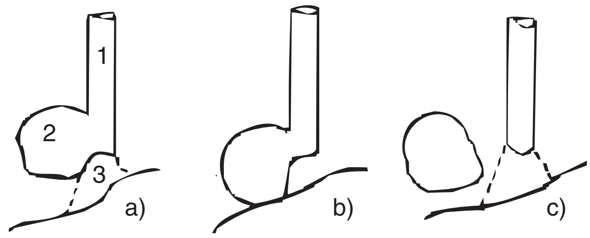


Figure 24 Drop transfer with a long arc
1: Wire electrode
2: Drop
3: Arc

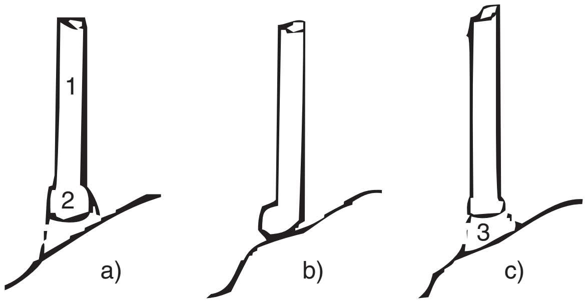


Figure 25 Drop transfer with a short arc
1: Wire electrode
2: Drop
3: Arc

trode, which due to the short arc comes rapidly into contact with the molten bath. A short-circuit is produced and the arc goes out (b). The drop is sucked away from the end of the wire by the surface tension of the molten bath; the pinch effect has no significant impact on the drop detachment due to the low current intensity. The arc then re-ignites (c). This process is repeated at very regular intervals of approx. 20 to 100 times a second, depending on the shielding gas used. During the short-circuit phase, the current increases (short-circuit current). Due to the small size of the drop, the short-circuit phase is very short, however, and there are no especially high current peaks. In addition, chokes in the welding current circuit slow down the rate at which the current is increased with conventional power sources. This makes the arc re-ignition after the short-circuit gentle and without any significant amount of spatter. With inverters, the software for the power source prevents an excessive rise in the current.

Using a short arc is a relatively “cold” process. It occurs when using all shielding gases for welding root passes, thin panels and out-of-position welding.

6.3 Long arc

The long arc occurs in the upper power range when welding with carbon dioxide or shielding gases with a high CO_2 content. The limit for the CO_2 content in this case is around 25 %. As the arc base is greatly constricted at the wire electrode due to the physical properties of the arc atmosphere using these shielding gases, there is no pinch effect or it is only barely noticeable. Figure 24 clarifies this type of material transfer.

Large drops form on the tip of the electrode (a) that are transferred to the workpiece primarily under the influence of gravity. Short-circuit bridges are often created between the drops and the molten pool during this process (b), in which filler material is transferred into the molten pool. Isolated, very large drops may sometimes also be transferred over (c). In this case the short-circuits are virtually continuous due to the large drop size. This produces very high short-circuit flows resulting in significant spatter formations when re-igniting the arc.

This process, which occurs in the upper current intensity and voltage ranges, produces a large, hot molten bath. The process is therefore only suited to welding in the flat and horizontal vertical positions (Figure 26). Out-of-position welding is not possible.

6.4 Spray arc

When using argon and mixed gases rich in argon, the arc at the start of the drop surrounds the entire end of the electrode so that the pinch effect can be optimally

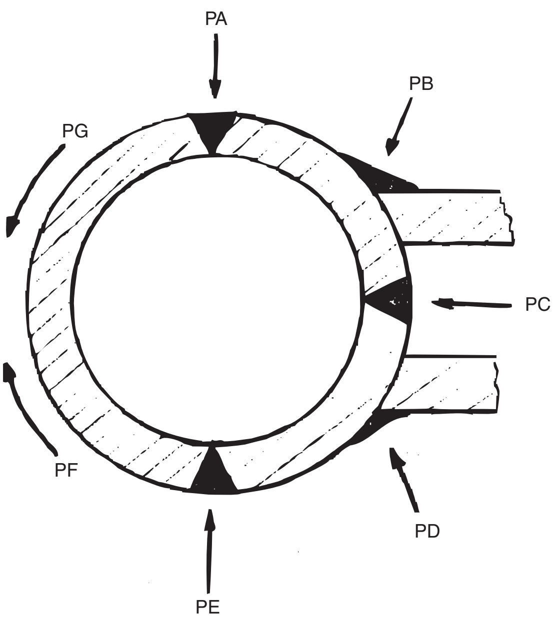


Figure 26 Welding positions as defined in ISO 6947

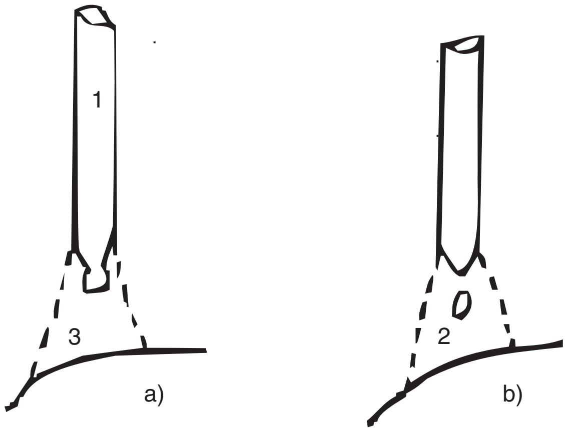


Figure 27 Drop transferwith a spray arc
1: Wire electrode
2: Drop
3: Arc

set with sufficient current intensity (Figure 27). The end of the wire is constricted (a) and individual drops are detached from the electrode (b).

This creates a short-circuit-proof, low-spatter material transfer. The spray arc occurs in the upper power range with shielding gases rich in argon. This type of arc also forms a large, hot molten bath, so that the process is only suitable for out-of-position welding in a limited way.

6.5 Mixed arc

In between the short arc on the one hand and the spray or long arc on the other is an arc shape for which a mixed material transfer is typical partly in the short-circuit and partly in free movement. In this area, however, significant spatter formation is created, even using mixed gases rich in argon. It is therefore advisable to avoid this moderate current intensity range or to use a pulse arc.

6.6 Pulse arc

The pulse arc occurs if a pulse-shaped current is used for welding instead of a uniform current. The setting parameters with this type of arc, are depending on the modulation of the power source, the wire feed speed as well as the base current or the base voltage, the pulse current or pulse voltage, the pulse duration and the pulse frequency. As shown in Figure 28, a drop detaches from the electrode tip due to the pinch effect in the pulse phase. This creates a fine-drop, low-spatter welding process.

With fixed values for the base current (voltage), pulse current (voltage) and pulse duration, the deposition power can be set using the wire feed and the arc length adjusted by changing the pulse frequency. The pulse arc occurs across the entire power range and is also suitable for out-of-position welding in the lower and moderate current intensity ranges.

6.7 Special types of material transfer

In addition to the standard arc types already described, other special types have been increasingly used over the past few years.

With current intensities above those for the conventional spray arc, i.e. with wire feed rates of 1.2 mm wire, e.g. of more than 15 m/min, high deposition power spray arcs occur when using mixed gases. However, this creates such a deep, cutting fusion penetration that faults could occur in the weld metal. It is therefore seldom used. When increasing the voltage, the arc begins to rotate in this power range and the fusion penetration expands. The rotating arc is used to increase the deposition power or to raise the welding speed for filler and final passes with butt welds and fillet welds on thick-walled components.

With high deposition power short arcs, the process has a material transfer in the typical short-circuit transfer mode. It occurs at current intensities in the same range for the conventional spray arc, but

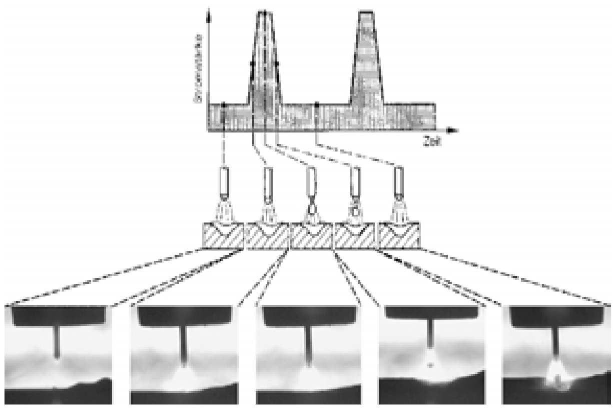


Figure 28 Drop detachment with a pulse arc

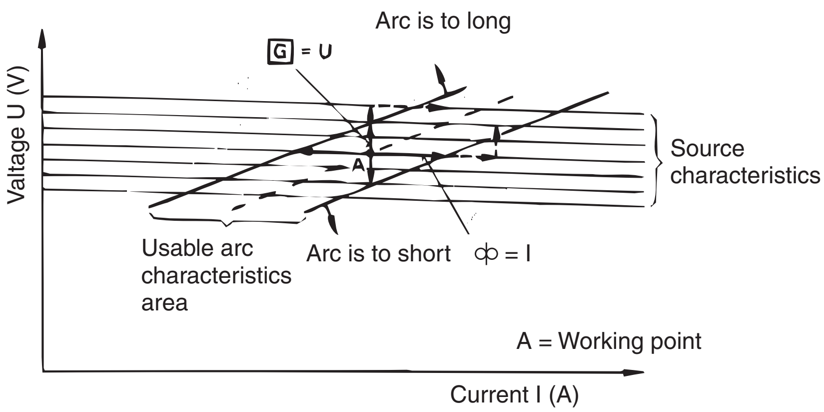


Figure 29 Suitable arc ranges with MIG/MAG welding [1]

at a considerably lower arc voltage.

The high deposition power variants of MIG/MAG welding are only used with full automation, with a few exceptions.

7 Setting the set welding parameters

7.1 Setting with conventional systems

In contrast to manual arc welding and TIG welding, two adjustments are required to set up MIG/MAG systems. This process is described below using the example of setting a step switch machine.

For MIG/MAG welding, constant voltage power sources are used. The required voltage is therefore selected by setting a specific characteristic on the rough and fine step switches for the power source and the most suitable arc is achieved by setting the relevant wire feed speed. Figure 29 shows how changes in the power source setting and the wire feed speed affect the position of the working point.

The working point (A) is the intersection between the source characteristic set and the arc characteristic. It is identified using the current intensity Is and the voltage Us. If the wire feed speed is increased, the arc shortens, the working point moves to the right on the source characteristic and the current intensity rises. The opposite occurs when the wire feed speed is reduced. This means that the potentiometer for the wire feed unit can be used to set the required current intensity. When the current intensity is increased, the arc is shortened, however. The voltage must be increased irrespectively at the same time to ensure that the arc does not become too short. When increasing the voltage, a higher characteristic needs to be set on the step switch, and when reducing the arc voltage, a lower characteristic is required. With the most common, slightly falling shape of the horizontal power source characteristic, adjusting the required parameter will always also result in a slight change in the other parameter. With a completely horizontal form, the parameters do not have a reciprocal effect.

In order to provide optimum conditions for welding, the arc must not be too short or too long. If the arc is too short, increased short circuits and therefore spatter occur. The short circuits can be detected by the rattling noise produced by the arc. As the arc increases in length, there is an increased risk of air penetrating the arc area, producing a greater risk of pores. The tendency to form undercuts also increases. The welder can detect an arc that is too long, because the arc will emit a hissing noise. The line for the ideal working points, i.e. the ideal working characteristic, runs roughly diagonally through the current/voltage diagram. In reality there is one useable arc characteristic. This is the working range that should be used for welding. Figure 30

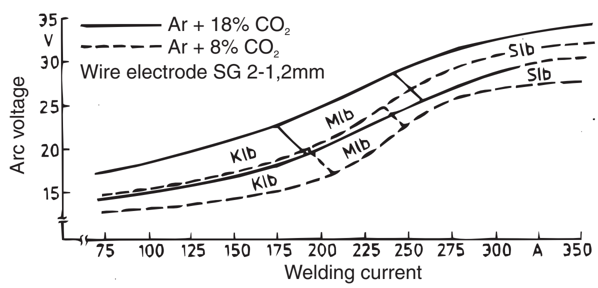


Figure 30 Working ranges for two argon mixed gases [1]
Klb = Short arc
Mlb = Mixed arc
Slb = Spray arc
Wire electrode SG2 = G3Si-EN 440

shows the working ranges for a Si/Mn alloy wire electrode and two different mixed gases.

All working points inside the working ranges represent good welding conditions. Working points falling downwards mean excessively short arcs, and working points above the upper limit line produce arcs that are too long. The working ranges only ever apply for a specific wire electrode. As changing the shielding gas results in different physical conditions in the arc atmosphere, the working range also only ever applies to a specific shielding gas.

When welding with pulse-shaped current, the pulse arc occurs across the entire range. However, as the material transition is short circuit-proof in any case, the range limits at lower and moderate current intensities tend to create higher arc voltages.

7.2 Synergetic setting of set welding parameters

As there are not always sufficient numbers of sufficiently well trained welders available in all sectors, modern MIG/MAG systems offer simplified options for setting the set welding parameters, such as the PHOENIX multiprocess machine (Figure 31).

Figure 31 PHOENIX multi-process machines

It began as early as the 1970s with one-dial operation where a single rotary potentiometer was used to set the deposition power by changing the wire feed, and the same adjusting knob in a specific transmission ratio was connected to an infinitely adjustable characteristic modifying device so that the voltage was modified at the same time. A second knob also permitted specific corrections to be made to the working point.

Today, many MIG/MAG systems provide a more far-reaching simplification of the setting work as standard. The ideal working characteristics for commonly used welding tasks are saved in the machine. All the person operating the system needs to do is to use touch controls, for example, to set the material being welded, the required wire diameter and the shielding gas connected. This will call up the pre-programmed, optimum working characteristic. The output can then be infinitely adjusted using a rotary dial, and a correction knob is available for specific requirements relating to the optimum arc. Figure 32 and Figure 33 show displays from modern welding systems that allow even more complex settings to be made.

In the central section, the welding task can be set using touch controls. In addition to prescribing the material and the wire electrode diameter, as well as the shielding gas, the control can be used to stipulate whether solid wire or cored wire should be used, or whether special tasks such as MIG brazing or GMA surfacing are to be performed. As the system is a multi-process system, this section is also used to change the characteristics required for other processes (TIG, MMA). In

Figure 32 Display on the PHOENIX 300 EXPERT welding machine

Figure 33 Display on the PHOENIX PROGRESS welding machine

the left-hand part of the display, the output can be set on the upper rotary dial, the middle dial is used to set the arc length correction, and the lower to change the arc dynamics using an adjustable choke. The current intensity and voltage appropriate for the working point are displayed on the upper part of the display. The welding data used can be saved and re-used later on as appropriate.

7.3 Regulating the MIG/MAG process

The set welding parameters set should be as constant as possible during welding. The internal control in MIG/MAG welding provides this constancy, and its functional principle is explained below.

The simplest way to explain the sequence involved in a control operation is to assume that the arc starts at a higher stage and is led down. How the current intensity and arc voltage change during this process is shown in Figure 34.

The working point AI corresponds to the parameters at which the arc burns on that stage. During the transition across the stage, the arc lengthens and the working point moves from AI to AII. The current intensity reduces here by the amount $_i$. There is no significant drop in the voltage, as the characteristic for the power source is slightly falling. The internal control is used to return the arc, which is now much too long, back to its original dimension. At the lower current intensity i_{II} less wire melts than previously. As the feed speed of the wire electrode remains unchanged, however, the arc gradually becomes shorter because more wire is being fed into the arc than is currently being melted there. This is how after a short time the original arc length is achieved once more and the arc burns at the current intensity and voltage previously set. This control functions virtually inertia-free and is therefore very fast. This is a self-regulating effect within the system, which is why it is known as internal control or $_i$ control.

8 Performing welding work

The MIG or MAG welder requires good training, not just in practical welding skills, but also in the specific theory aspects of the process. This helps to prevent faults.

8.1 Igniting the arc

After the torch switch is pressed, the wire electrode starts moving at the speed previously set. At the same time, it is made live via the power relay and the shielding gas starts flowing. When touching the surface of the workpiece, a short-circuit is produced. Due to the high current intensity at the tip of the electrode, material starts to turn to vapour at the point of contact and the arc ignites. At high wire feed rates, the still very weak arc may go out due to the wire material pressing onto it, which means that the ignition process may only be successful after the second or third attempt. It is therefore advisable to ignite at a reduced feed speed and only to switch to the actual wire feed

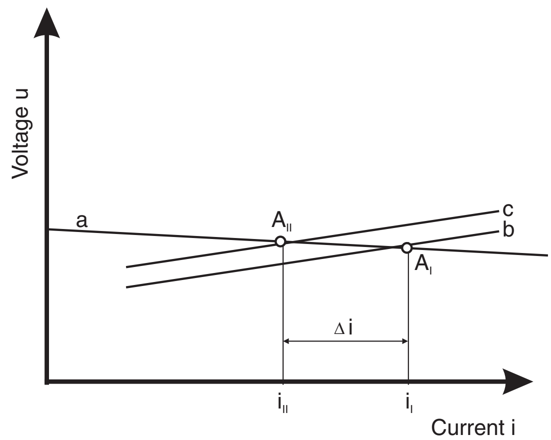


Figure 34 Internal regulation (Δ I regulation) – Characteristic of the current intensity and voltage when pre-welding a stage

speed once the arc is burning steadily. Newer types of MIG/MAG systems provide the option of setting what is known as a “creep speed”. Ignition should never be performed outside the groove and only at points that are melted once more immediately afterwards. Crack formation can be assumed with ignition points which have not been pre-welded due to the high cooling speed of these points of localised heating.

8.2 Moving the torch

The torch is tilted in the direction of welding by around 10 ° to 20 ° and can be moved backhand or forehand (Figure 35).

Its distance to the workpiece should be such that the free wire end, i.e. the distance between the lower edge of the contact nozzle and the start point for the arc, is around 10 - 12 times the wire diameter [mm]. If the torch is tilted too much, there is a risk that air is sucked into the shielding gas. Forehand torch movements are normally used when welding solid wires, and backhand welding is used with cored wire that conveys slag. The torch is normally moved with a slightly backhand motion in the vertical down position. Vertical down welding (pos. PG) is used mainly with thinner panels. With thicker panels there is a risk of fusion faults due to weld metal running ahead. This type of fusion fault 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 vertical up position. The standard weaving movement shape is the open triangle.

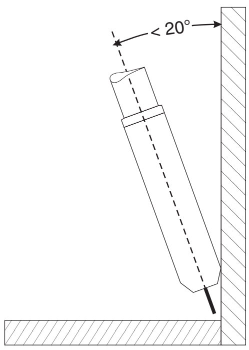


Figure 35 Position of the torch against the parent metal

8.3 Ending the welding process

At the end of the seam, the arc must not shut down suddenly or the torch removed from the end-crater. Especially with thicker panels where deep end-craters may occur in large-volume beads, it is advisable to remove the arc slowly from the bath or, if the system being used permits it, to set an end-crater filling program. With most systems, a specific post-flow time for the shielding gas can also be set, so that the last molten weld metal remaining can embrittle under the shielding gas shroud.

However, this is only effective if the torch is held at the end of the seam for a time.

8.4 Welding parameters

The lower limit for the possible use of the process for butt welds with unalloyed steel is around 0.7 mm, with stainless steel 1 mm and with aluminium materials around 2 mm.

Root passes and thin panels are generally welded using a short arc or using a lower power range pulse arc. With filler, final and backing runs on thicker panels, spray or long arcs are set with higher power range. These welding tasks can also be performed with very low spatter with the pulse arc.

Guidelines for suitable welding data for welding butt welds and fillet welds are given in Table 5 to Table 9.

Panel thickness mm	Groove shape	Opening angle °	Root face distance mm	Position	Wire electrode diameter mm	Wire feed m/min	Current intensity Ampere	Arc voltage Volt	Passes
1	I	-	0	PA	0.8	3.8	70	18	1
2					1.0	4.3	125	19	
			1.5	PG	0.8	7.1	130		
4			2.0	PA	1.0	4.8	135		
			2.5	PG		5.4	160	20	
6	V	50	2.0	PA	1.0	4.3	125	19	
						8.4	205	22	2
				PG		4.7	130	19	1
						5.4	170	20	2
8				PA	1.2	3.1	135	18	1
						8.1	270	28	2
									3
				PF	1.0	3.7	100	17	1
									2
10			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			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				PA		3.8	140	19	1
						9.5	310	29	2
									3
									4
									5
									6

Table 5 **Guideline values for MAG welding butt welds on unalloyed and low-alloy steel. Wire electrode: G3Si1/G4Si1 Shielding gas: Mixed gas M2.1, Values irrespective to [1] and [2]**

Panel thickness mm	Groove shape	Opening angle °	Root face distance mm	Position	Wire electr. diam. mm	Wire feed m/min	Current intensity Ampere	Arc voltage Volt	Passes
1	I	-	0	PG	0.8	4.0	70	15	1
2			1.5	PA	1.0	3.5	100	16	
			2.0	PG		4.0	105	17	
4			2.5	PA		4.3	115		
6	V	60	2.0			3.4	95	15	
						10.0	200	26	2
8						4.4	110	16	1
						10.0	200	26	2
									3
12					1.2	3.0	110	17	1
						8.0	250	28	2
									3
									4

Table 6 **Guideline values for MAG welding butt welds on stainless CrNi steel 1.4541 Wire electrode: G199L, shielding gas: Mixed gas M1.2, values acc. to [2]**

Throat thickness mm	Position	Wire electrode diameter mm	Wire feed m/min	Current intensity Ampere	Arc voltage Volt	No. of passes
2.0	PB	0.8	6.5	100	17	1
	PG		7.0	110	18	
3.0	PB	1.0	9.0	200	24	
	PG		8.8	195	22	
4.0	PB		10.4	220	26	
5.0		1.2	8.0	250	28	
6.0						3

Table 7 **Guideline values for MAG welding fillet welds on stainless CrNi steel 1.4541. Wire electrode: G 19 9 L, shielding gas: mixed gas M1.2, values acc. to [2]**

Panel thickness mm	Groove shape	Opening angle °	Root face thickness mm	Wire electrode diameter mm	Wire feed m/min	Current intensity Ampere	Arc voltage Volt	Passes
2	I	-	2	0.8	5.0	110	20	1
4			4	1.2	3.1	170	22	
6	Y	70	1.5	1.6	6.0			
8					6.8	220	26	2
10		60	2.0		6.2	200		1
					6.0	170	24	2
					7.2	230	26	G
12			1.5	1.2	13.7	240		1
					12.2	220		2
					15.6	250	28	G

*) without root face surface spacing G= backing run

Table 8 Guideline values for MIG welding butt welds on aluminium materials Wire electrode: GRAlMg5, shielding gas: argon, flat welding position, values acc. to [1] and [2]

Effective throat thickness/mm	Position	Wire electrode diameter mm	Wire feed m/min	Current intensity/amperes	Arc voltage Volt	Position no.
1.0	PA/PB	0.8	3.8	65	17	1
	PG					
2.0	PA/PB		7.3	130	19	
	PG		7.1	100	20	
3.0	PB	1.0	10.6	215	23	
	PG		9.0	210	22	
4.0	PA/PB		10.7	220	23	
5.0	PB	1.2	9.5	300	29	
6.0						
	PF	1.0	4.7	115	18	
8.0	PB	1.2	9.5	300	29	3
	PF	1.0	4.8	130	19	2
10.0	PB	1.2	9.5	300	29	3
	PF		4.2	165	19	2

**Table 9 Guideline values for MAG welding fillet welds on unalloyed and low-alloy steel.
Wire electrode: G3Si1/G4Si1,
Shielding gas: mixed gas M2.1,
Values acc. to [1]**

The current and voltage values used for information purposes by the welder are displayed on the measuring devices, which are normally integrated into the machines. With pulse welding, the display instruments show the arithmetic average value of the current intensity and arc voltage produced in the pulse and base phase at the set pulse frequency. The tables can therefore also be used as guideline values for MIG/MAG pulse welding. If no measuring devices are integrated into the machine, external devices can be used for measuring, or the welder needs to refer to the wire feed speed also given in the tables. The correct arc length then needs to be set irrespective to what the welder sees and hears.

8.5 Automation options

With partly mechanised MIG/MAG welding, the addition of the filler material and the shielding gas, and the arc length control are automated, and only the welding movement itself needs to be performed manually.

A simple option for full mechanisation is to clamp the torch and move it over the workpiece at welding speed using a trolley or by affixing the torch in a stationary position and moving a rotationally symmetrical component underneath the torch in a rotating device (Figure 36).

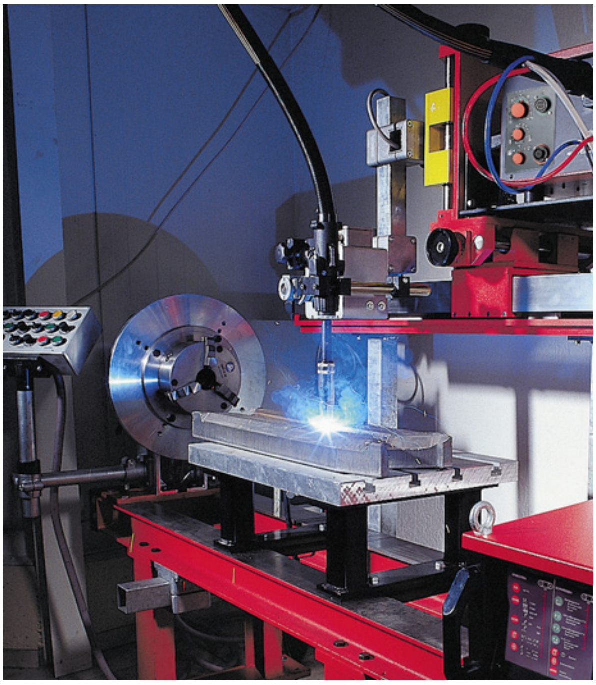


Figure 36 Fully automated welding

The functional principle of the process also makes this procedure suitable for difficult mechanisation tasks where, for example, multiple torches are used simultaneously on one workpiece. Not without reason is MIG/MAG welding therefore also by far the most commonly used process with industrial robots for arc welding.

9 Work safety

In MIG/MAG welding the arc transfers the drop. As a consequence of the high temperatures prevailing there, there is more metal vapour than with the TIG process, for example. More harmful gases and smoke are therefore produced. With cored electrodes, this amount increases due to the filler components being vaporised. It is therefore a requirement that extraction is virtually always used directly at the point of origin, both with extended periods of welding work performed at a fixed position and with short-term usage. With non-localised welding work, fresh air is sufficient, or mechanised ventilation of the room is sufficient, except for welding high-alloy steels and coated materials. An extractor can be integrated into the torch in MIG/MAG welding (Figure 37).

It is important that the extraction nozzle is designed so that the shielding gas is not also sucked away from the welding point.

The welder must also protect himself against radiation from the arc and against electrical dangers. To protect against the infrared and ultraviolet radiation, the MIG/MAG welder normally wears a helmet, which leaves both hands free. The filter glass is integrated into this safety helmet. This filter has recently been defined in DIN EN 169. There are various grades of protection that need to be permanently affixed to the glass. With MIG/MAG welding, filters of protection grades 10 to 15 are used, depending on the current intensity, where grade 10 is prescribed for lower currents and 15 for the higher current intensities.

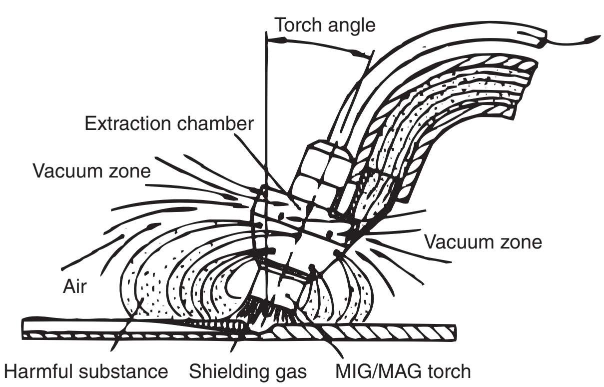


Figure 37 Extraction integrated into the torch

The greatest electrical risk is represented by the open circuit voltage. This is the maximum voltage present on the activated power source between the connection sockets when the arc is not burning. After the arc is ignited, the voltage is much lower; in MIG/MAG welding only around 17 to 30 volts. Irrespective to the relevant German accident prevention regulations, power sources for direct current in normal operation should have an open circuit voltage peak value of max. 113 volts. With alternating current systems, which in recent times have been used in special cases with MIG/MAG welding, this value is also 113 Volts, but the peak value is limited to max. 80 Volts. Where there is an increased risk of electric shock, e.g. when welding in small spaces or on large iron masses, reduced values apply for alternating current, e.g. a peak value of 68 volts and an r.m.s. value of 48 volts. Modern welding power sources meeting these requirements bear the “S” safety sign in conformance with DIN EN 60974-1. Older power sources may still be marked with “K” (d.c.) or “42 V” (a.c.). The safest way for welders to protect themselves against electric shocks is to wear undamaged welding gloves made from leather and well-insulated work clothes including safety shoes.

10 Special features of different materials

As mentioned above, the MIG/MAG process is suitable for welding a large range of materials. The sections below cover various special features of the different materials.

10.1 Un-alloyed and low-alloy steels

Unalloyed and low-alloy steels are welded using mixed gases M1, M2, M3 or using pure carbon dioxide (Figure 38). Due to the low spatter formation, primarily in the upper power range, mixed gases predominate in Germany, however. These steels can normally be welded very well using the MAG process. One exception is grades with a high carbon content, such as E 360 (formerly St. 70), with approx. 0.45 % C. Due to the high fusion penetration of the process, the weld metal absorbs a relatively larger amount of carbon via dilution, creating a higher risk of hot cracks. This can be remedied by all measures that reduce the fusion penetration and therefore also the dilution. This includes low current intensities and welding on forward traveling weld metals - Caution: Risk of fusion faults.

Pores form in unalloyed and low-alloy steels primarily due to nitrogen. This can be due to dilution when welding steels

Figure 38 MAG welding on beams in steel construction work

with a high nitrogen content, e.g. nitriding steels. However, the nitrogen is normally absorbed from the air due to an incomplete shielding gas bell. Safe protection from this is guaranteed if the correct quantity of shielding gas has been set and turbulence in the shielding gas flow, e.g. due to spatter in the shielding gas nozzle or instabilities in the process, is avoided. Carbon dioxide as a shielding gas is less sensitive to this type of pore formation than mixed gases. With mixed gases, the sensitivity is reduced as the CO_2 content increases.

10.2 High-alloy steels and nickel-based alloys

This group of materials can in principle 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 (M1.1) or argon with CO_2 contents of up to 2.5% (M1.2). A significant disadvantage when welding corrosion-resistant steels is the oxide skins which occur after welding and which are left on and next to the seam. These skins need to be removed by brushing, etching or blasting before the component is used in operation, because they impair the corrosion-resistance of the metal. The amount of cleaning work required for MAG-welded seams is greater than with MMA welding, where the slag covering prevents oxygen from penetrating the seam surface at higher temperatures. Part of the economic advantages of part-mechanised welding can therefore be lost due to the amount of clean-up work required. Mixed gases containing CO_2 are more favourable in this respect than those containing O_2. They are therefore being increasingly used. The carbon dioxide content in shielding gas must not be too high, however, as the gas decomposing in the arc causes the weld metal to carbonise, which in turn reduces the corrosion-resistance. The permissible CO_2 content is therefore limited to max. 5 %.

When welding corrosion-resistant steels, any overheating must be avoided because it could result in embrittlement and reduces the corrosion-resistance due to chromium carbide deposits. The heat feeding therefore needs to be checked and it may be necessary to allow the workpiece to cool down by including cooling breaks during work. With materials in the full austenitic steels groups, “cold” welding is also an option to avoid heat cracks.

As austenitic steels do not embrittle under the influence of hydrogen, a few percent of hydrogen can also be added to the argon to improve the deposition power (increase the welding speed). Due to the risk of pore formation, the H_2 content should not be more than 7 %, however. Whereas when using duplex steels with a two-phase structure of austenite and ferrite, a higher risk of crack formation due to hydrogen is present.

Nickel-based alloys are normally MIG-welded using argon. With 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 normally MIG-welded (Figure 39).

Figure 39 MIG aluminium welding in vehicle construction

Argon is generally used as the shielding gas. Due to the aluminium’s high level of heat-conductivity, additional helium is especially useful here. As mentioned above, helium improves the heat conductance and the heat retention of the shielding gas atmosphere. This provides deeper and wider fusion penetration, as shown as a scheme diagram in Figure 40.

When this deeper fusion penetration is not required, e.g. when welding thinner panels, welding can be performed more quickly with the same fusion penetration form. Thicker aluminium needs to be preheated due to the significant heat-conductivity of the material. This not only ensures sufficient fusion penetration, but also reduces the tendency to form pores because the weld metal has more time to release the gas during the embrittleing process. When using shielding gases containing helium – standard content levels are 25 or 50 % - the pre-heating can be reduced, and at smaller wall thicknesses, pre-heating may not be necessary at all. This partly offsets the higher price of gases containing helium.

Difficulties in eliminating the high-melting oxide skin on the bath do not occur in MIG welding because the plus pole is on the electrode (cathodic cleaning). Nevertheless, it is still advisable to remove the oxide skins immediately before welding by scraping or brushing, as they are hygroscopic and therefore carry hydrogen into the weld metal. Hydrogen is the sole cause of pore formation when welding aluminium materials. Aluminium in its molten state has a relatively high level of solubility for hydrogen, but in the solid state, this gas is barely soluble in the metal. Any hydrogen absorbed during

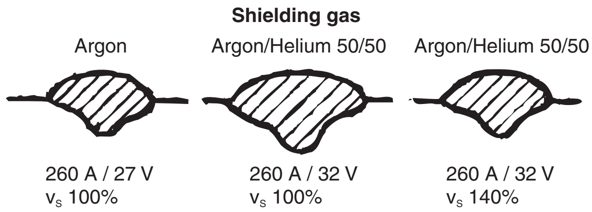


Figure 40 Penetration profile with different shielding gases. Material: AlMg3, Wire electrode: ∅1.6mm

welding must therefore exit the weld metal before embrittleing if no pores are to be formed. This is not always possible, especially with thicker sizes. Completely pore-free seams cannot be achieved with aluminium materials for larger wall thicknesses. The favourable effect of pre-heating has already been mentioned.

AlMg and AlSi alloys tend towards heat cracks during welding at Si contents of around 1% or Mg contents of around 2%. This alloy range should be avoided when choosing the filler material. Wire electrodes with an alloy content one degree higher are therefore better than electrodes of exactly the same type.

10.4 Other materials

In addition to the materials already mentioned, only copper and copper alloys are MIG-welded in any significant quantity. Pure copper needs a relatively high level of pre-heating in order to avoid fusion faults due to its high heat conductivity.

The weld metal for bronze wires, e.g. made from aluminium bronze or tin bronze, has good sliding properties. It is therefore used for GMA-surfacing sliding surfaces. With welds of this type on iron materials, the fusion penetration needs to be kept low using relevant measures, because iron has a low level of solubility in copper. It is included in the weld metal in the form of small balls and reduces the usage properties.

The conditions for MIG brazing are similar. This process is used to connect zinc-plated panels in automobile construction, for example. The fillers used are wire electrodes made from silicon bronze or tin bronze. Due to the low melting point of these bronzes, the zinc vaporisation level is reduced. Fewer pores are produced and the protection provided by the zinc coating is retained right up to near the seam and on the back of the panels. In this situation, too, no fusion penetration should occur in the steel material if possible, but the connection should be made solely via diffusion and adhesion forces, as in brazing. This is achieved by using modified set welding parameters and a special torch position, such that the arc burns only on the molten bath.

11 Applications for MIG / MAG welding

11.1 Uses in manufacturing

Irrespective to recent statistics, the proportion of MIG/MAG welding used on deposited weld metal in relation to all arc welding processes is 80%.

There are virtually no branches of industry where MIG/MAG welding is not used. The main areas of usage are in vehicle construction, where heavy goods vehicles, locomotives and ships are manufactured, for example. Aluminium is increasingly being used as the material for these applications. Other uses are to be found in steel and bridge construction work, and in the construction of ships and machines. In crane and excavator construction, higher strength steels are increasingly being used, something for which MAG welding is particularly appropriate because the weld metal has a lower hydrogen content, allowing no cold cracks to occur. MAG welding is slightly under-represented in boiler, equipment and pipeline construction where, due to the excellent quality of the weld metal, basic stick electrodes are often still used for welding.

MAG welding is not just used for industrial applications, however, but also in the trades it is hard to find a workshop that does not use the process. This applies both to car bodyshops and to metalworking firms and small steel construction operations.

11.2 Example applications

In conclusion, a few selected example applications are used here to clarify the proper use of MIG/MAG process.

Figure 38 shows the use of MAG welding in steel construction work.

On beams such as those shown in the illustration, fillet welds or double bevel butt welds are used on the corners. With longer beams, butt welds also need to be used crosswise to the main load direc-

Figure 41 MIG brazing in assembly vehicle bodywork

tion. Particular specifications apply to these welds with regard to preventing faults.

On car bodies, short MAG seams are used in addition to numerous resistance welding points (Figure 41).

Galvanised panels are also MIG brazed. Bodywork made from aluminium is resistance spot and MIG welded.

Figure 42 shows MIG welding on tanks for tanker vehicles, manufactured from aluminium alloys.

A push/pull unit is used here for welding so that there are no feed problems with the relatively soft aluminium wires.

Figure 42 MIG welding used to manufacture tanks

12 Literature

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From the EWM Knowledge range of publications – All about welding

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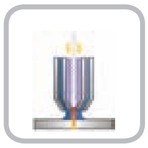
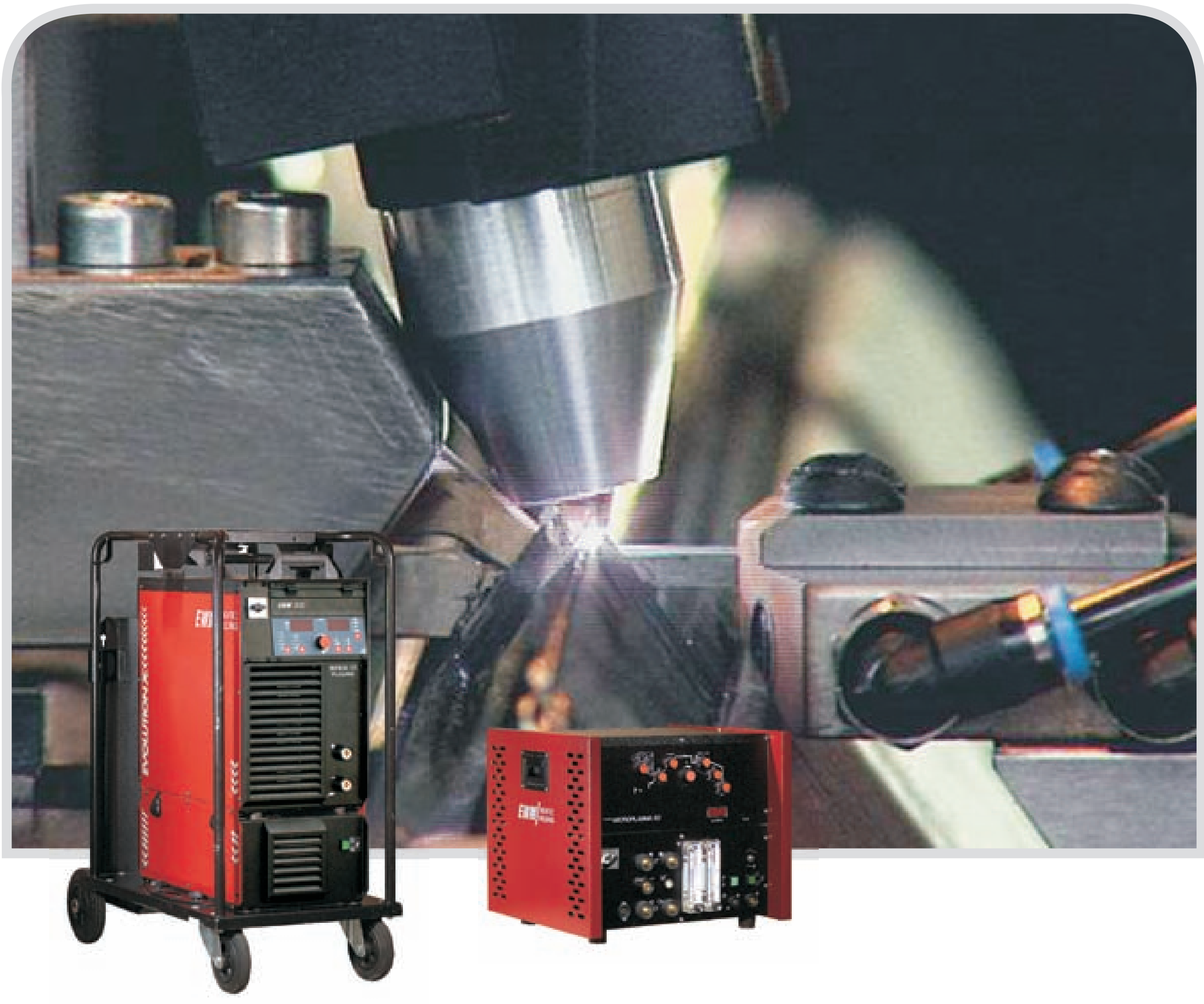
PLASMA PRIMER





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10.09

1 Welding with a plasma arc

1.1 Introduction

Plasma welding is one of the most recent fusion welding processes. It is a tungsten shielded gas welding process (PW) and was not introduced into Germany until the 1960's. The international ISO 857-1 standard describes plasma welding (process no. 15) as follows: Arc welding using a constricted arc.

Very early on it was attempted to increase the power density in the arc by constricting it. Due to the high energy density in this type of arc, the substance reaches a gaseous state in which it moves significantly at high temperatures, has special electrical properties and is very bright. The physicist Langmuir called this state "thermal plasma". It consists of a mixture of ions, electrons, and neutral particles, but is ionised to a great extent. This substance state occurs in the core of any arc, but more so in a constricted arc due to the high energy density. As in the TIG process, the addition of the filler metal in plasma welding is not related to the current intensity, i.e. the setting of the welding parameters can be concentrated on the requirements of the welding process itself. In the field of welding technology, thermal plasma is used for welding, for thermal spraying and for fusion cutting. This brochure will focus primarily on its applications in welding.

2 The process

2.1 General

The arc is constricted via a water cooled copper nozzle with a narrow hole, through which the arc is forced, **figure 1**. This gives it a virtually cylindrical shape and it diverges by just a few degrees. This produces the high energy density. Inside the plasma nozzle, the arc burns on the needle-shaped tungsten electrode. It is surrounded by plasma gas. The gas escaping through the small, constricted hole cannot of course protect the point of welding to any great extent during the welding process. Extra shielding gas is therefore supplied from a second nozzle. Depending on the type of arc, a distinction is made here between the transferring arc and the non-transferring arc, **figure 2**. In the former case the welding current circuit is between the electrode and the workpiece. This variant is also known as plasma arc welding. In the latter case, the arc is ignited between the electrode and the water cooled copper nozzle. The arc then only burns within the torch and the hot gases escape in the form of a beam – plasma beam welding. This variant is not of relevance to welding and cutting, but to plasma spraying.

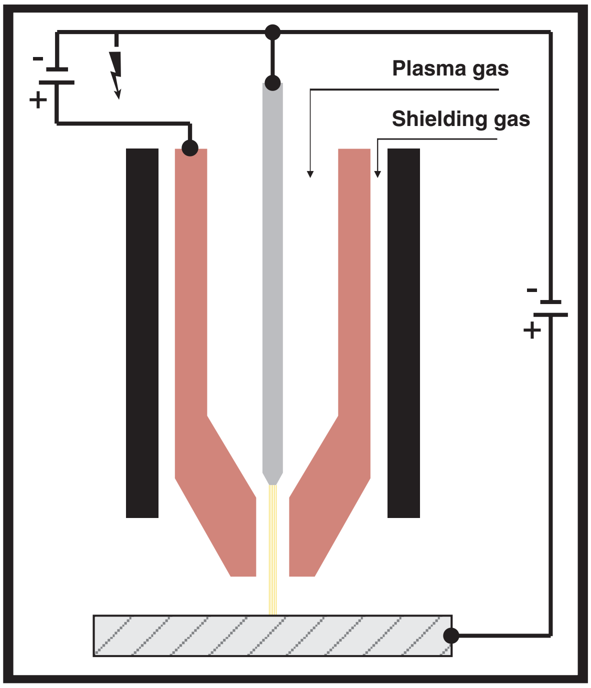
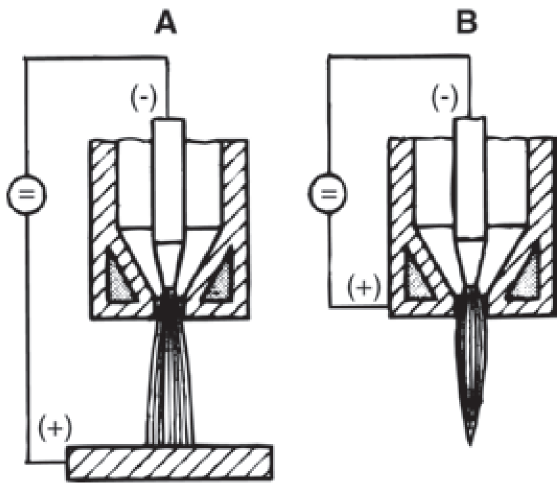


Figure 1: Principle of plasma welding

2.2 Current type

Direct current is normally used for the plasma welding of steel and the minus pole of the current



A = transferring arc
B = non-transferring arc

Figure 2: Arc types

source is on the electrode. In addition to welding with direct current, pulse welding is also used. When welding aluminium materials, welding is carried out on the plus pole due to the lack of cleaning effect in minus pole welding; however, only low current intensities can be used due to the low current loading capacity of the electrode on the plus pole. Alternating current welding represents a compromise here, as it combines an adequate cleaning effect with greater current loading capability. Modern systems for alternating current welding use square waveform alternating current. A more recent variant is the plasma welding of aluminium on the direct current minus pole using shielding gases with a high helium content.

2.3 Electrodes

The same tungsten electrodes are used for plasma welding as for TIG welding. Due to the high melting point of tungsten, the electrodes are produced via powder metallurgy by sintering followed by compression and compaction, and are standardised in DIN EN 26848 (ISO 6848), **table 1**. The diameters are between 1.6 mm and 8mm. The most commonly used diameters are between 1.6 mm and 4 mm. Electrodes with oxidic constituents feature greater current loading capacity and a longer service life in comparison to electrodes made from pure tungsten, as they do not heat up as much at the same current intensities. This has to do with the fact that the electron emitting work from the oxides enclosed in the electrode is lower than from the pure metal. It is also easier to ignite electrons containing oxides. Instead of the thoriated electrons mainly used previously, electrons containing ceroxides have been used increasingly in more recent times. Because thorium is an alpha emitter, electrons containing thorium emit a weak level of radioactive radiation. With direct current minus pole welding, the electrodes are ground to a point as in TIG welding. For direct current plus pole welding and for alternating current welding, which is carried out on aluminium, the ends of the electrodes are in contrast ground to a blunt-ended cone shape only, or not ground at all.

	Composition				
	Oxide additive		Impurities	Tungsten	
Ref.	% (m/m)	Type	% (m/m)	% (m/m)	Colour ID
WP	-	-	≤ 0,20	99,8	green
WT 4	0,35 to 0,55	ThO_2		Rest	blue
WT 10	0,80 to 1,20				yellow
WT 20	1,70 to 2,20				red
WT 30	2,80 to 3,20				violet
WT 40	3,80 to 4,20				orange
WZ 3	0,15 to 0,50	ZrO_2			brown
WZ 8	0,70 to 0,90				white
WL 10	0,90 to 1,20	LaO_2			black
WC 20	1,80 to 2,20	CeO_2			grey

Table 1: Tungsten electrodes conforming to DIN EN 26848

2.4 Gases for plasma welding

Plasma welding also uses gases which are standardised in DIN EN 439. Argon is normally used as the plasma gas in welding, also known as the central gas, because it ionises more readily, which in turn means that it reaches a higher level of ionisation. When welding chrome/nickel steels and nickel-based alloys, small quantities of hydrogen are also added to the argon as this improves the heat transfer and permits faster welding speeds. A similar effect is achieved when welding aluminium, titanium and zircon by adding helium to the plasma gas. Argon or argon/hydrogen mixtures are generally used as the outer shielding gas for unalloyed and high-alloy steels. Active mixed gases based on argon/carbon dioxide or argon/oxygen can also be used for welding unalloyed and low-alloy steels. As well as pure argon, argon/helium mixtures are also used as the shielding gas when welding aluminium, titanium and zircon.

2.5 Filler metals

The filler metal is added for manual welding in the same way as for TIG welding, in other words by feeding in rods. In the fully automated version of the process, a special feed unit is used to melt in wire-shaped filler metal. In plasma powder welding, the filler metal is added in the form of a metal powder; in a separate feed gas flow in deposit welding and using the shielding gas in plasma powder joint welding. The filler metals for plasma welding are the same as for TIG welding.

They should be the same type as the parent metal or slightly over-alloyed.

3 Classification of plasma welding

Plasma welding is carried out exclusively using a transferred arc. Depending on the application type, an initial distinction can be drawn between plasma joint welding and plasma deposit welding. Joint welding is sub-divided again by output level. This is covered in more detail below.

3.1 Plasma joint welding

3.1.1 Micro plasma welding

Previously the focus was always on the high energy density of the process due to the constricted arc, from which one might conclude that plasma welding was only suitable for thicker workpieces. In actual fact, however, it is with very thin materials that other typical advantages of the constricted arc are revealed when compared to TIG welding. When welding foils and minimal thickness sheets, current intensities of just a few amperes or even less than one ampere are required. The TIG arc is highly unstable at such low currents because no defined operating point is set. **Figure 3** shows this as a schematic diagram [1]. The current sources used in TIG welding have a virtually vertically falling characteristic at low current intensities in particular. The characteristics of a non-constricted arc also follow a virtually vertical path at low current intensities, in what is known as the ayrton range. This means that there is no exact intersection point at the operating point but instead only a glancing contact between two characteristics, which results in the arc instability described above. The vertically falling part of the arc characteristic is missing with a constricted arc, which means that this also continues to burn in a stable way on an exact operating point, even at very low current intensities. For example, the plasma arc can be used to join workpieces of just 1/100 mm thickness in the foil range flush, even at currents below 1 ampere. This range up to around 50 amperes is therefore known as micro plasma welding. It is normally carried out manually.

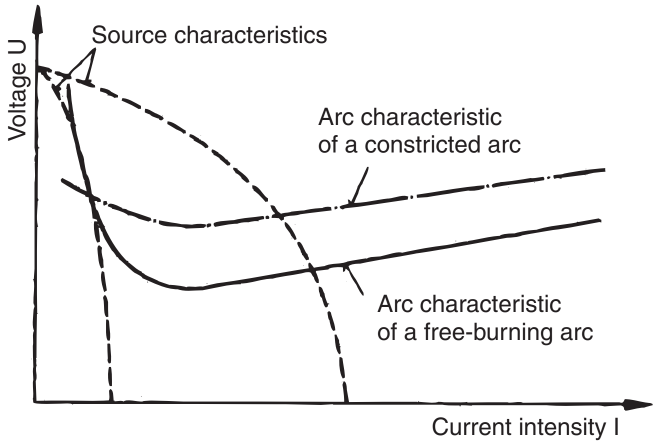


Figure 3: Operating points with free-burning and constricted arcs

3.1.2 Soft plasma welding

If the opening of the constricting nozzle is enlarged slightly in comparison to the nozzle width normally used in plasma torches, an arc is produced which is less constricted and more rich in energy, the effect of which is between the TIG and plasma arc. It offers advantages in manual welding for panel thicknesses between 1 mm and 2 mm.

3.1.3 Thick sheet plasma welding

This range, which ranges up to material thicknesses of up to around 10 mm, must be subdivided into the extrusion range and the keyhole range. The extrusion range is so called because the heat is only supplied from the surface and is forwarded to the lower layers by heat conductance. The weld metal is extruded downwards by the pressure from the plasma arc and forms a root on the backing side. In the extruded range, the welding can be carried out both manually and with full automation. With sheet metal thicknesses over around 2.5 mm, a technique known as keyhole technology can be used. The plasma arc pushes through the entire panel thickness and forms a welding eyelet. The heat is transferred via this eyelet not only from the surface but also across the entire cross-section penetrated by the beam. This improves the efficiency of the process and the potential welding speed increases greatly in comparison to the speeds which can be achieved using the extrusion technique. The liquid pool is pressed to the side by the plasma beam, but flows back together on the rear edge of the eyelet and hardens there to form a welding bead. Naturally everything needs to be right here, such as the distance of the torch and the welding speed. This type of welding can therefore be fully mechanised.

3.1.4 Plasma powder joint welding

A more recent variant of plasma welding is plasma powder joint welding, **figure 4** [2]. Unlike plasma powder deposit welding, which is covered in the section below, no special supply gas flow is required in this process for the powder welding additive. It is added along with the shielding gas. This means that the dimensions of the torch can be kept smaller. When considering the advantages of this process, a comparison

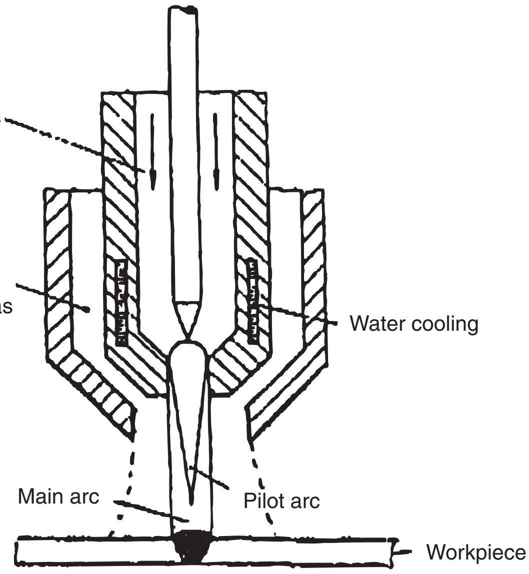


Figure 4: Principle of plasma powder joint welding

with TIG welding is useful. In the manual application the welder has one hand free because it is not necessary to add the filler metal in the form of a rod. This means that the welder can concentrate more fully on the actual welding operation itself. In fully mechanised TIG welding, where the additive wire is normally added after the torch, the entire weld head needs to be moved in curved movements along with the nozzle supplying the wire, because otherwise the wire cannot completely melt in the weld pool. In robot welding this rotating movement carries out the last manual axis, which means that it is not required for other positioning movements of the torch. In plasma powder welding, this rotating

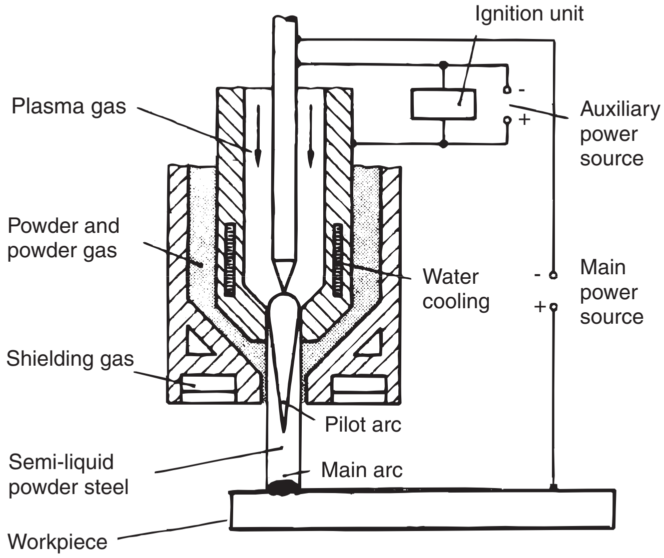


Figure 5: Principle of plasma powder deposit welding

movement of the head is not necessary because the powder additive is added concentrically around the arc.

3.2 Plasma deposit welding

In plasma powder deposit welding, **figure 5** [1], a powder welding additive is added in a separate supply gas flow. It melts in a non-transferring pilot arc, which is already partially burning out between the electrode and the water cooled copper nozzle. The transferred main arc melts onto the parent metal and the melted parent metal and melted additive material mixes to form a weld bead. The optimum composition of the weld metal can be set by matching the current intensity with the quantity of melted powder. In plasma

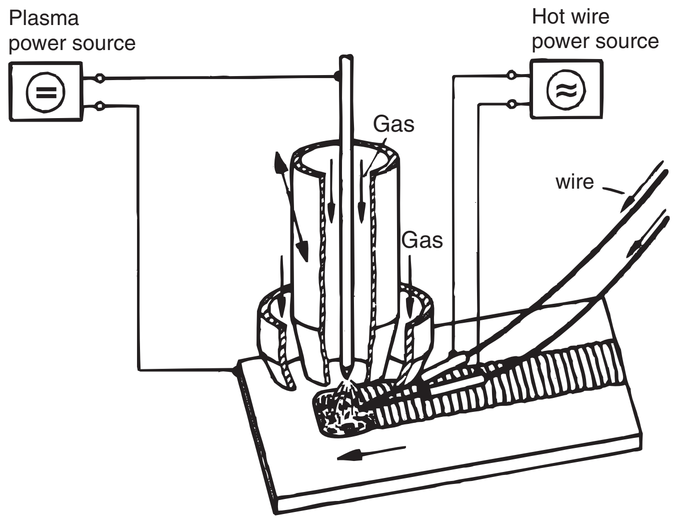


Figure 6: Principle of plasma hot wire welding

hot wire welding, **figure 6** [1] two wires on a separate current source are pre-heated via resistance heating and then melt in the weld pool of a plasma arc. During the onward motion of the weld head in the direction of welding, the entire system is moved to and fro across the direction of welding to form deposit beads of up to 60 mm in width. In this process, and in plasma powder deposit welding, the fusion penetration and thus the mixing is at a low level so that only a few layers are required to achieve the required composition on the surface.

3.3 Plasma brazing

With the increasing use of zinc-plated panels in the automobile industry, arc brazing is being used more and more in place of welding. In addition to MIG brazing, plasma brazing has also recently captured a definite range of applications. This process variant is different from micro or soft plasma welding primarily in the type of filler material. Instead of the steel wires or rods of the same or similar type normally used in welding, copper based alloys are used. For zinc-plated panels, these are silicon or tin bronzes, and aluminium bronzes are used for aluminium-plated panels. Due to the low melting point of these additives, the metallic coatings are damaged far less by vaporisation and combustion than in arc welding. In comparison to MIG brazing, a

Figure 7: Manual torch for plasma brazing

better seam appearance and better solidity and strength values are achieved in the brazing metal.

However, plasma brazing requires a slightly different torch movement in comparison to welding. The arc is directed less onto the parent metal and is positioned more on a portion of forward brazing metal. This largely avoids the panels melting on, but sufficient heat is supplied to the two parts being joined in order to produce a brazed joint via diffusion and adhesion forces. The process can be carried out manually using a rod filler metal added by hand, but the continuous addition of the brazing wire to the torch can also be carried out using a separate feed unit. **Figure 7** shows a plasma torch with cold wire feed for manual brazing. In the fully mechanised application, a machine torch is used where the filler wire is also continually moved onto the brazing point. The torch can also be moved via a welding robot.

4 Setups for plasma welding

A system for plasma welding consists of the power source, the control and the torch.

4.1 Control

Welding machine control INTIG03

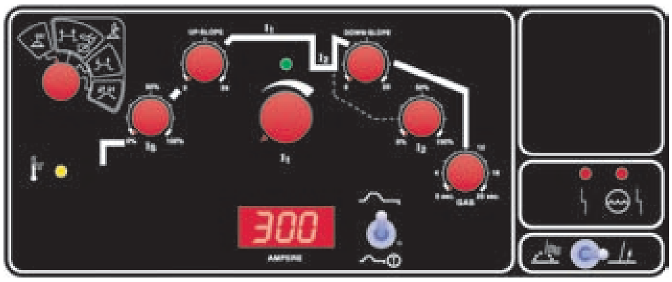


Figure 8: Display on the control of a plasma welding system

The control has the tasks of switching the welding current on and off, regulating it and keeping it constant. **Figure 8** shows the display from a welding system for plasma direct current welding. Several parameters can be preset by this system, like the gas pre-flow time and the pilot arc current. In addition to the main current, the ignition current, the ramped starting and stopping of the current (up-slope/down-slope) and the gas post-flow time can be set. The plasma current source is equipped with a high-voltage pulse ignition unit. Via the high voltage pulses, alternating voltage of several thousand volts, a weak, non-transferring arc (known as the pilot arc) is ignited between the water cooled copper nozzle and the electrode. This remains switched on during the welding process as well. It pre-ionises the subsequent arc path so that the arc can ignite without contact when the main circuit is switched on.

4.2 Power source

The power source is tasked with converting the alternating current coming from the mains at high voltage and lower current intensity into welding current with low voltage and adjustable high current intensity. Modern power sources for plasma welding work in accordance with the inverter principle. The inverter is an electronic power source which functions according to a completely different working principle than conventional power sources (**figure 9**). The

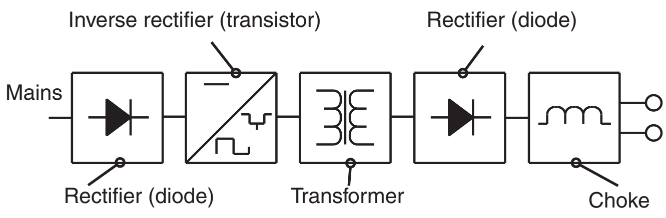


Figure 9: Block diagram of a 3rd generation inverter, clock frequency up to 100 Hz

current coming from the mains is first rectified and then divided into short sections by switching on and off, so that it can be transformed. This process is known as cycling. This is permitted via quick-reaction electronic switches; transistors. The first transistorised inverters work at a cycle frequency of around 25 kHz. Today, cycle frequencies of 100 kHz and more are possible with highly developed transistors. After "cutting up" (cycling) the current, it is transformed to the required high current intensity and low voltage. After the transformer, a square-shaped alternating current is produced which is then rectified once more. The high clock frequency has the advantage that the required mass of the transformer can be kept very small. This is dependent on the frequency of the current being transformed. This means that lightweight current sources can be produced. A recent system for plasma welding for thick panels with an output of 400 A therefore weighs around just 100 kg including all auxiliary units – **figure 10**. Systems for micro plasma welding **figure 14** weigh only some kilograms.

With electronic power sources, much of what is achieved using components such as resistors, chokes and capacitors, is triggered electronically by the control. The control for these power sources is therefore just as important as the power unit. The current is adjusted, for example with switched-mode sources, by changing the ratio between the current input/current output times. The clock frequency can also be changed to adjust the current level. To generate pulse-shaped current, the ratio of the on/off times is changed cyclically by the control. The new technology also means that controlled power sources are possible, which is precisely what welding technology had been waiting for. The electronic control compares the set welding current nominal value with the actual value and maintains this at a constant level even in the case of large changes in the welding voltage. An improved level of efficiency, as well as cos phi and lower open circuit losses in the inverter power sources are produced simply from the lower mass of the transformer. Inverter power sources for plasma welding normally have a vertically falling characteristic (constant current

Figure 10: TETRIX welding system for plasma welding

characteristic) in the operating range, **figure 11** left. With this type of characteristic, the current intensity does not change when the arc length is changed.

For plasma welding with alternating current, electronic current sources are used which emit

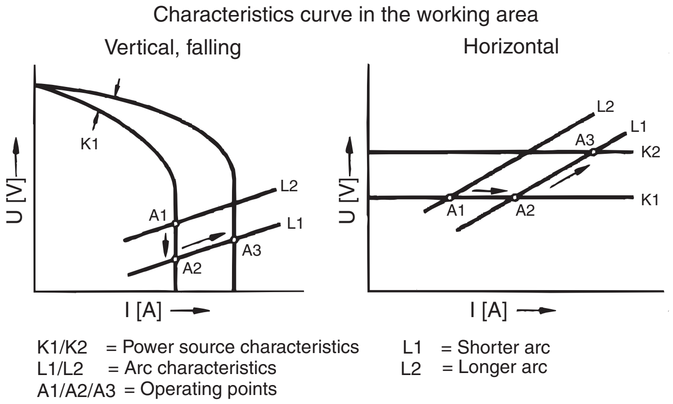


Figure 11: Constant current and constant voltage characteristics

an artificial square-shaped alternating current. This is generated in that the plus and minus poles of a direct current source are alternated in rapid succession on the electrode by electronic switches (these days normally transistors). As the switching operations are carried out in quick succession, this produces a square-shaped alternating current with a very steep crossover when the polarity is changed. The frequency of the alternating current can normally be changed between 30 Hz and 300 Hz. In addition, the balance of the alternating current half-waves can be adjusted, namely between 20% plus/80% minus and 80% plus/20% minus. The proportions of the two half-waves can be used to affect the current carrying capacity of the tungsten electrode and the fusion penetration of the arc.

4.3 Welding torch

For micro plasma welding, which is normally carried out manually, lightweight torches are used which are roughly similar in shape and size to the torches used in TIG welding, **figure 12**. With higher welding currents, intensive water cooling of the torch is required. Thanks to this, and thanks to the two shielding gas flows required, the torch becomes even bigger, which makes the manual application of the process more difficult. For the fully mechanised variant of the plasma welding process, machine torches are therefore used. **Figure 13** shows a machine torch for plasma joint welding.

Figure 12: Manual torch for plasma welding

Figure 13: Machine torch for plasma welding

5 Performing the welding operation

Before starting the welding process, the groove faces in the weld seam area must be cleaned thoroughly. They must be bare metal and free of grease, dirt, oxides and paint residue. The cleaning can be carried out via mechanical processing, grinding or brushing. With corrosion resistant materials, only brushes made from stainless steel may be used.

Suitable solvents should be used for cleaning and degreasing. Warning: Poisonous vapour may be produced when using solvents containing chlorine.

5.1 Setting the shielding gas quantity

The plasma gas quantity depends on the workpiece thickness being welded and thus on the torch size. With micro plasma welding this is between 0.2 l/min and 1 l/min and with thick panel plasma welding between 1 l/min and 6 l/min. The quantity of external shielding gas is between 5-10 l/min and 15-25 l/min. accordingly [1]. The flow quantity can be measured indirectly using manometers which measure the pressure in front of an integrated pitot tube proportional to the throughput. The manometer scale is then calibrated directly in l/min. Measuring equipment which uses glass tubes and suspended bodies directly in the shielding gas flow to the torch. **Figure 14** shows the gas dosing unit on the Mikroplasma 20 welding system.

Figure 14: Gas dosing unit on the "Microplasma 20" microplasma welding system

5.2 Edge preparation

The edge shapes most commonly used in plasma joint welding are given in **figure 15**. Due to the good fusion penetration characteristics, the workpiece edges are often only prepared as butt welds and melted without filler metal being added. With thicker panels which cannot be welded through in one run as a butt weld, a single-V butt weld with broad root face is prepared. The V-shaped upper part of the joint then needs to be filled in with filler metal, however. For this purpose there are plasma torches with integrated cold wire feed – **figure 16**. Raised seam welds, edge welds without seam preparation and corner welds are also used.

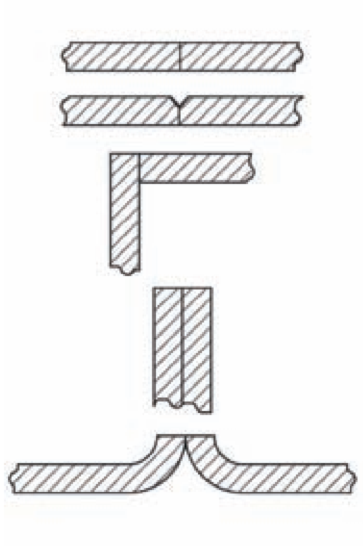


Figure 15: Typical welds in plasma welding

5.3 Forming

This means the additional feeding of shielding gas to the rear of the root, where the material being welded is also in a liquid state, but the shielding gas supplied to the top side does not reach it. Unlike TIG welding, the seam is "burnt" much less in plasma welding due to the higher welding speed if it is not formed. The cold forming gas does assist in forming the rear of the root, however. This gives it the name "forming gas". Forming also prevents the formation of oxide skins and annealing colour on the rear of the root, or at least reduces this. This is important when

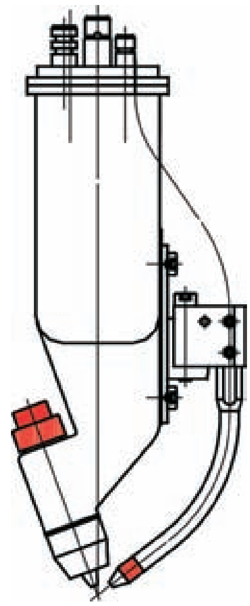


Figure 16: Plasma torch with integrated cold wire feed

welding corrosion-resistant steels, for example, because these oxide skins reduce the corrosion resistance of the welded joint. When welding pipes, the ends can simply be blocked off and the forming gas introduced into the inside. When welding panels, it can be allowed to escape through openings in the backing lines. Argon or an argon/hydrogen mixture can be used as the forming gas. DIN EN 439 standardises more cost-effective forming gases in group F, however. These consist of a hydrogen/nitrogen mixture, for example. Pure nitrogen can also be used for forming in some circumstances.

5.4 Igniting the arc

First the non-transferring pilot arc is ignited in the interior of the torch between the tungsten electrode and the constricting nozzle. This pre-ionises the gas path between the torch and parent metal so that the main arc can ignite without contact after the welding current is switched on, when the torch has approached the workpiece to a distance of a few millimetres. The pilot arc can be seen by the welder behind the dark safety glass, and helps him to find the start of the weld more easily (pilot arc).

5.5 Guiding the torch

In manual plasma welding, welding to the left is preferred, as with TIG welding; in other words the welding rod is moved in the direction of welding in front of the torch. Manual welding is used in micro plasma welding, in soft plasma welding, when using the extrusion technique and in plasma powder joint welding. In the latter case, the welding additive, as already mentioned, is added in powder form concentrically around the plasma nozzle. In contrast, plasma welding is used with the keyhole technique and plasma powder deposit welding normally only with full mechanisation. In this case, additional investment for driving units are required to move the torch in the direction of welding or for moving the workpiece underneath the fixed torch.

5.6 Magnetic arc blow effect

In contrast to the TIG arc, the plasma arc is considerably more stable in direction. It is therefore less affected by external magnetic fields. Despite this, the general rules for avoiding the blow effect should also be observed in plasma welding, i.e. in root welding the tack points should be located very close together and the repelling effect of the opposite pole utilised by the appropriate fitting of the ground connection to the workpiece.

5.7 Welding positions

Plasma joint welding is only used in the manual application in the vertical (flat) and horizontal (horizontal vertical) positions. In fully mechanised welding, longitudinal seams are welded in the flat position and circumferential welds in the horizontal vertical position or as transverse seams in the horizontal position. Plasma deposit welding is normally carried out in the flat position only.

5.8 Ending the welding operation

When ending the welding operation, the current is dropped in a ramp formation to keep the end crater small. This is especially important when welding using the keyhole technique. In this case it may be necessary to drop the gas pressure as well at the end of the seam to close the keyhole.

5.9 Welding parameters

In addition to the electrical parameters welding current intensity and welding voltage, the fusion penetration characteristics in plasma welding is also affected by the welding speed and by the pressure of the plasma gas, i.e. by the quantity of plasma gas added and the diameter of the constricted opening. The welding voltage is higher than in the closely related TIG welding process due to the longer length of the arc.

Tables 2 and 3 [3] contain welding data on micro plasma welding and on thick panel plasma welding on austenitic chrome/nickel steels.

5.10 Work safety

Plasma welding, like TIG welding, is a very clean process. Virtually no poisonous gases or smoke is produced, which means that there is no legal requirement for extraction directly at the point of origin according to the existing work safety regulations. Free ventilation or mechanical ventilation of the room is sufficient. The welder does need to protect himself against the radiation from the arc and against electrical hazards, however. To counteract the infrared and ultraviolet radiation, the plasma welder normally wears a head shield which leaves both hands free for moving the torch and adding the filler metal. The welder's safety filter is integrated into this protective screen. This filter is standardised in DIN EN 169. There are various safety levels which need to be permanently marked on the glass. In plasma welding, filters in safety levels 9 to 14 are used, depending on the current intensity being used, with level 9 for the lower currents, e.g. for micro plasma welding, and 14 for the higher current intensities. The greatest electrical hazard arises from the open circuit voltage. This is the highest voltage, which runs between the connection sockets with the power source switched on, when the arc is not burning. After the arc is ignited, the voltage is much lower, in TIG welding only around 12 to 20 Volts, for example. In accordance with German accident prevention regulations VBG 15, power sources for direct current in normal operation may have a threshold value of the open circuit voltage of max. 113 volts. With alternating current systems, this value is also 113 volts, but the effective value is limited to max. 80 volts. Under increased electrical hazard, such as when welding in small rooms or on large iron masses, lower values apply for alternating current, e.g. a threshold value of 68 volts and an effective value of 48 volts. More modern welding power sources meeting this requirement bear the "S" safety sign in accordance with DIN EN 60974-1. Older power sources may still be marked with "K" (direct current) or "42V" (alternating current). The welder can ensure maximum protection against electric shocks by using undamaged welding gloves made from leather and well insulated work clothes including safety shoes.

Workpiece thickness mm	Welding current A	Welding voltage V	Plasma gas l/min	Shielding gas l/min	Welding speed cm/min
0,1	3	21	0,2	5	30
0,2	6	22	0,2	5	30
0,4	14	24	0,2	6	35
0,5	18	23	0,2	6	20
1,0	40	25	0,3	7	35
Edge preparation:	Butt weld without gap				
Parent metal:	X 5 CrNi 18.10				
Plasma gas:	Argon I1 - DIN EN 439				
Shielding gas:	Argon/hydrogen R1 - DIN EN 439				
Welding position:	Flat				

Table 2: Welding parameters for manual microplasma welding (values from [5])

Workpiece thickness mm	Welding current A	Welding voltage V	Plasma gas l/min	Shielding gas l/min	Welding speed cm/min
2,5	200	24	1,5	15	80
3,0	210	28	2,5	18	75
4,0	220	27	2,5	18	65
5,0	230	29	2,5	20	45
6,0	240	28	2,8	20	40
8,0	290	28	3,5	20	25
Edge preparation:	Butt				
Parent metal:	X 5 CrNi 18.10				
Plasma gas:	Argon I1 - DIN EN 439				
Shielding gas:	Argon/hydrogen R1 - DIN EN 439				
Welding position:	Flat				
Filler metal:	For larger gaps with 3 mm sheet metal thickness and over				

Table 3: Welding parameters for fully mechanised plasma keyhole welding (values from [5])

5.11 Special features of different materials

Plasma welding is suitable for joint welding a large range of steels and non-iron metals and alloys.

5.11.1 Unalloyed and low-alloy steels

Plasma welding is a good choice for use with these materials, assuming certain special features are taken into account. Due to the deep fusion penetration and the typical edge shapes in plasma welding with large ridges which need to be melted, the weld metal consists to a large extent of melted parent material. With unalloyed steels, such as pipe steels containing little silicon, the weld metal can then be disrupted by an in take-of oxygen. The consequence of this is a metallurgic pore formation in the weld metal.

When selecting the batch, care therefore needs to be taken regarding the silicon content, or larger proportions of Si/Mn-alloyed filler metals need to be added.

5.11.2 High-alloy steels

Plasma welding with keyhole technology is ideally suited for use with this material group. The viscosity of the weld metal specific to these materials produces especially flat and finely feathered beads underneath. This means that mechanical backing runs are not normally necessary.

The more intensive heat feeding by the concentrated arc is compensated by the greater welding speed, in comparison to TIG welding, for example, which means that there is no risk of disadvantageous effects in the form of a tendency towards heat cracks or reduced resistance to corrosion. For components subsequently exposed to a high risk of corrosion, the corrosion skins formed by the welding process must at least be removed on the side touching the product by brushing, blasting, grinding or etching because a greater degree of corrosion could occur underneath.

5.11.3 Aluminium and aluminium alloys

It is not possible to weld aluminium materials on the minus pole with argon as the shielding gas. The high-melting oxide layer on the pool cannot be dealt with, therefore. Aluminium oxide (Al2 O3) has a melting point of around 2050°C. The parent metal, e.g. pure aluminium, melts at 650°C on the other hand. Aluminium has such a high degree of chemical relationship to oxygen, which means that even if the surface of the parent metal has been freed of oxides before welding by brushing or scraping, skins form on the surface of the pool quickly again. Due to their high melting point, these skins only partially melt directly underneath the arc. This means that the greater part of the seam surface would be covered with a solid layer of aluminium oxide when welding with direct current (- pole). This makes monitoring the pool impossible and makes it more difficult to add filler metal. This oxide layer can be removed by using flux, as in brazing, but this would mean a lot of extra work.

When welding with direct current on the plus pole, it is possible to take off and remove this oxide layer via charge carriers in the arc. Here only the ions are the issue as the electrons do not have sufficient kinetic energy for this due to their low mass. **Figure 17** shows the flow of charge carriers in the arc. If the minus pole is on the electrode, the electrons move from the electrode to the workpiece and the residual ions from the workpiece to the electrode. Cleaning effect is not possible with this pole setup. With the poles reversed, on the other hand, the heavy ions hit the surface of the workpiece. They can take off and remove the oxide layer thanks to their kinetic energy. Welding on the hotter plus pole results in

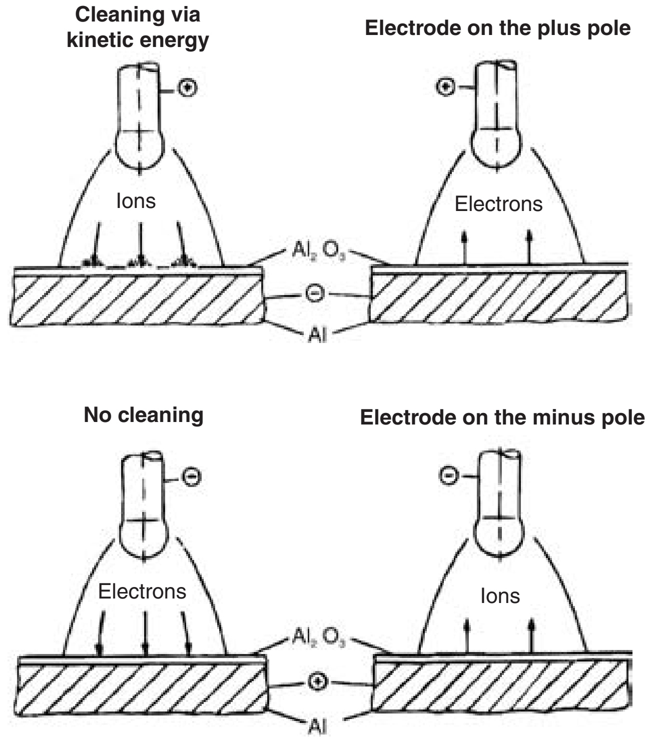


Figure 17: Cleaning effect and electron emission work in welding of aluminium alloys

the current loading capacity of the electrode being quite low, however. Thick electrons must be used with semi-cone shaped ends. The fusion penetration is relatively low due to the low current loading capacity. When welding with alternating current the cleaning effect occurs when the positive half-wave is on the electrode. The electrode can then cool down again in the subsequent negative half-wave. This is therefore also known as the cleaning and cooling half-wave. When welding with alternating current, the current-loading capacity is lower than with direct current minus pole welding. However, it is higher than when welding on the plus pole. It has been shown that for sufficient cleaning effect, the entire positive half-wave is not required at all, but that 20% or 30% of the half-wave is sufficient.

This fact has been exploited in modern current sources in which the balance of the two half-waves can be changed in relation to one another, e.g. from 20% plus/80% minus to 80% plus/20% minus. The lower proportion of the plus pole results in a higher level of current loading capacity of the electrode, or with the same current setting, in a longer service life. With these “square-wave sources” it is normally still possible to change the frequency of the artificial alternating current as well, e.g. between 50 Hz and 300 Hz. Increasing the frequency also improves the level of wear on the electrode.

The square-wave artificial alternating current has another advantage, however. As the current output wave form is very steep when the polarity is changed, the idle times of the arc in the crossover are considerably shorter than with a sine-shaped wave form. The re-ignition is therefore more reliable and the arc is more stable overall. Modern power sources permit the use of direct current in welding, both with sine and square wave-form alternating current.

More recently a variant of minus pole welding has also been used, in which shielding gas with a high helium content is used. In manual welding the proportion of helium in the shielding gas needs to be at least 90 % to ensure sufficient pool monitoring for the welder. In machine welding a helium proportion of 70 % is also adequate. When welding on the minus pole under argon, the oxide skin cannot be broken open, as explained above. Due to the high temperature of the energy-rich helium arc, it can be liquefied, however. This means that it is less of a problem. **Figure 18** [4] shows a comparison of the surface formation and the fusion penetration in plasma welding of aluminium with the variants described above. When interpreting the results it should be noted that the welds have been carried out using different current intensities.

Another special feature in welding the material aluminium is its sensitivity to pores when in the take-up of hydrogen. The relationships are more problematic than when welding steel. Whereas iron can still dissolve hydrogen at 8 cm3/100 g weld metal in the transfer from the liquid to the solid state, aluminium in its solid state dissolves practically no hydrogen at all. This means that all hydrogen taken up during welding must exit the weld metal before it hardens. Otherwise pores will form in the weld metal.

Sources of hydrogen in TIG welding of aluminium are primarily oxide skins on the parent metal. This bind in humidity and must therefore be removed before welding by brushing or scraping. On the other hand, the arc is quieter if there is a thin oxide skin on the surface because this emits lighter electrons than the pure metal. A compromise therefore needs to be found between a stable arc and sufficient protection against pore formation. It has proven useful to remove oxides thoroughly from the workpiece surfaces before welding, but then waiting one or two hours before starting the welding process so that a new thin oxide layer can form. The oxide skins formed on the surface of the welding rods also contribute to pore formation. Filler metals made from aluminium should therefore be stored carefully and not for too long a period.

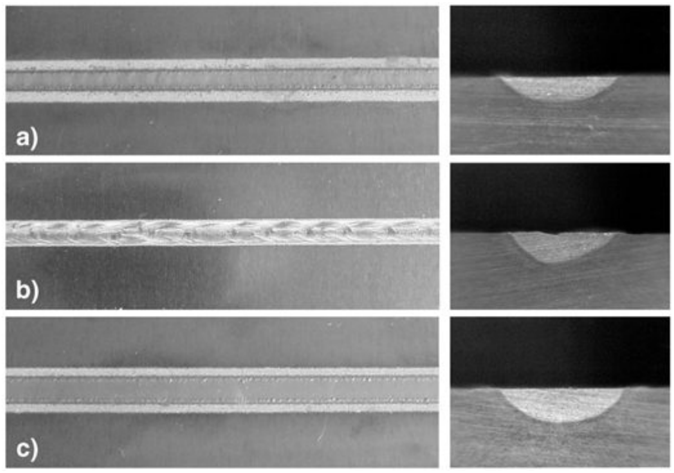


Figure 18: Upper seam sides and fusion penetration in the plasma welding of AlMg3, t=3mm, no filler metal

a) Plasma plus pole welding
I=35A, U=26V, v_S=40cm/min,
Plasma gas: Ar, shielding gas: 70%Ar / 30%He
b) Plasma minus pole welding
I=70A, U=20V, v_S=90cm/min,
Plasma gas: 30%Ar / 70%He, shielding gas: He
c) Plasma alternating current welding
I=45A, U=26V, v_S=40cm/min,
Plasma gas: Ar, shielding gas: 70%Ar / 30%He

5.11.4 Other materials

The concentrated heat feeding of the plasma arc has an especially useful effect with copper and copper alloys in particular, which have a high level of heat conductance. In comparison to TIG welding, it can therefore be possible to reduce or even do without the pre-heating process normally required to ensure sufficient fusion penetration, especially with larger wall thicknesses.

In addition to the metals and alloys mentioned above, nickel and nickel alloys can be successfully plasma welded, as well as titanium and titanium alloys.

5.11.5 Materials for plasma deposit welding

In plasma powder deposit welding, cobalt/chrome/tungsten alloys (stellite) or alloys based on nickel/chrome/boron (colmonoy) are frequently welded on as depositing materials. By the separate setting of the current intensity and the quality of power additive, very low mixtures can be maintained, which means that very thin coatings are sufficient. The plasma hot wire process has previously generally been used to apply corrosion-resistant plating made from CrNi steel, as well as nickel/chrome alloys for protection against wear and tear.

6 Applications for plasma welding and brazing

Plasma welding can be used to weld joints, starting from very thin parts in the foil area (micro plasma welding) up to large workpiece thicknesses. Keyhole technology permits thicknesses of up to 10 mm to be through-welded on steel as a butt weld, for example. With titanium this upper thickness threshold is increased up to 12 mm. In addition to this, a single-V butt with broad root face must be produced.

In deposit welding, on the other hand, a minimum thickness needs to be specified for the parent metal. This is around 4 mm for plasma powder deposit welding, and around 20 mm for plasma hot wire welding.

Plasma joint welding is used in pipe and closed container construction, for example when manufacturing pipes made from stainless steel with longitudinal welds, and for welding containers such as barrels, storage tanks and gas cylinders.

In equipment construction it is ideal for welding compensators, bellows and metal screens. A more recent area of application is in dental technology, where it is used in dental labs instead of brazing.

Applications for plasma powder deposit welding can be found primarily in fittings construction for armour-plating sealing surfaces, and in engine construction when welding on valve seats.

Plasma brazing is used mainly where thin metal-coated panels are processed. A main area of application is in car construction, but also in other sectors of industry where panels in the thickness range of around <1 mm occur.

6.1 Example applications

Figure 19 shows membranes made from black plates, with raised seams welded onto their circumferences using micro plasma welding.

Figure 19: Edge-formed seam on membranes

Another example of micro plasma welding is shown in **figure 20**. In this case there are longitudinal seams on protective grilles for chemical ovens. The thickness of the individual rods is 0.15 mm.

Figure 20: Longitudinal seam on protective grids for chemical ovens

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Figure 21 shows internal and external round seams on fittings for heating unit construction which have been joined using plasma joint welding.

Figure 21: Internal and external seams on fittings for heating unit construction

Figure 22 shows the application of manual plasma brazing in the automobile industry on the door sill of a BMW car body. The filler metal is added manually in this case in the form of rods.

Figure 22: Manual plasma brazing on the door sill of a BMW car body

6.2 Comparison with TIG welding

There is an obvious comparison between plasma welding and the closely related TIG welding process. As well as the high welding speed of the plasma process already mentioned, there are other advantages, which are balanced out by several disadvantages, however. A comparison of advantages of disadvantages are given in **table 4**.

Plasma welding (in comparison to TIG welding)	
Advantages	**Disadvantages**
• Reduced sensitivity in comparison to changes in arc length • Greater arc stability • Deeper fusion penetration and more concentrated heat feeding • Longer service life of the tungsten electrode • Easier to locate the start of the weld seam via a pilot arc	• Higher investment costs • Torches difficult to use at higher output levels • Less suitable for out-of-position welding

Table 4: Comparison between TIG and plasma welding in joint welding

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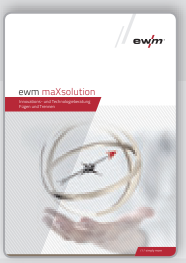

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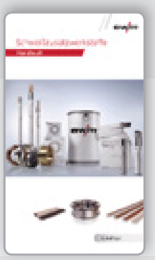

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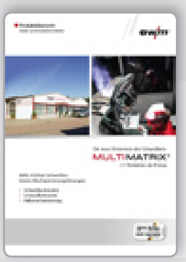

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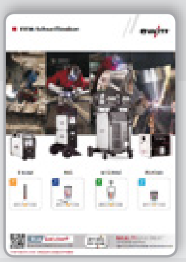

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