Welder's Handbook

For Gas Shielded Arc Welding, Oxy Fuel Cutting & Plasma Cutting

Published by:
Air Products PLC

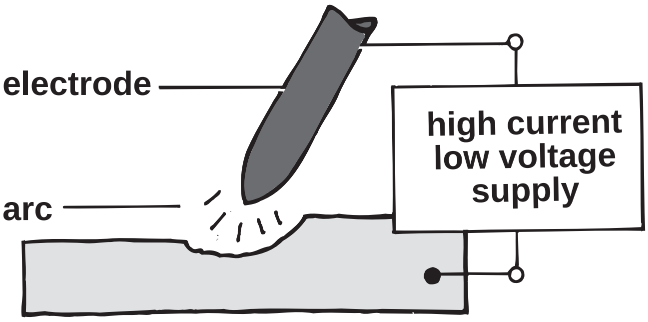
Designed and produced by:
PDF Conceptual Design & Marketing

Fusion welding

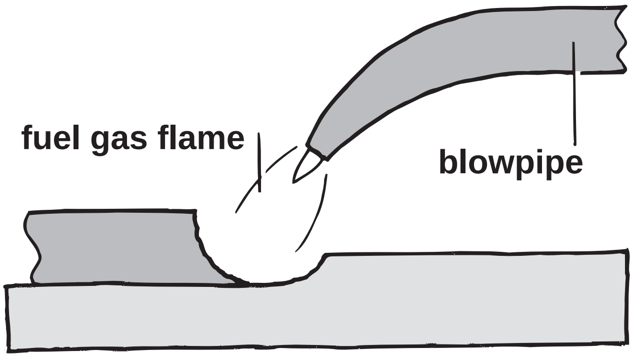
The most widely used welding processes rely on fusion of the components at the joint line.

In fusion welding, a heat source melts the metal to form a bridge between the components.

Two widely used heat sources are:



Electric arc

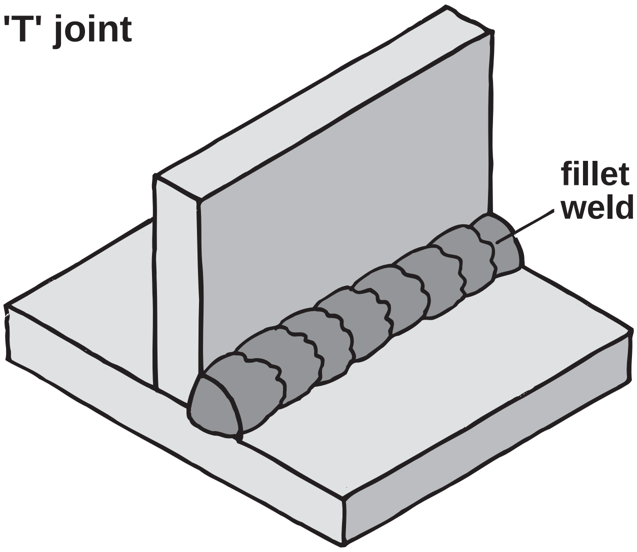


Gas flame

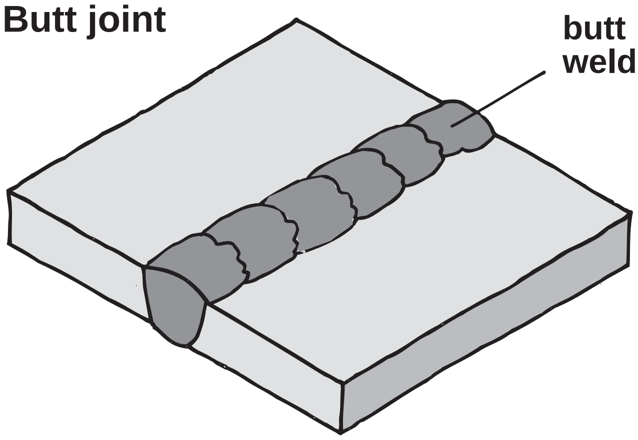
The molten metal must be protected from the atmosphere - absorption of oxygen and nitrogen leads to a poor quality weld.

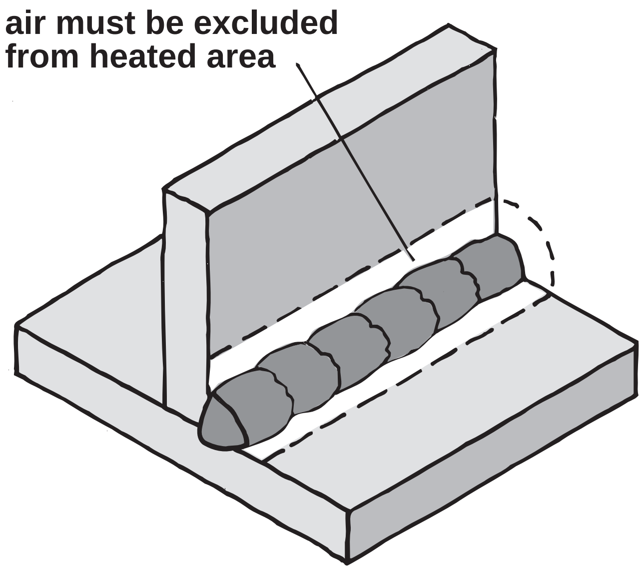
Air in the weld area can be replaced by a gas which does not contaminate the metal, or the weld can be covered with a flux.

'T' joint



Butt joint





Why use welding?

Welding is used because it is:

- one of the most cost-effective methods of joining metal components
- suitable for thicknesses ranging from fractions of a millimetre to a third of a metre
- versatile, being applicable to a wide range of component shapes and sizes

The joints produced by welding are:

- permanent
- strong, usually matching the strength of the components,
- leak tight,
- reproducible,
- readily inspected by non-destructive techniques.

Welding can be used:

- in the workshop
- on site

for

- sheet
- plate
- pipe
- sections

Which process?

A large number of welding processes and techniques are available. No process is universally best. Each has its own special attributes and must be matched to the application.

Choosing the most suitable process requires consideration of a number of factors.

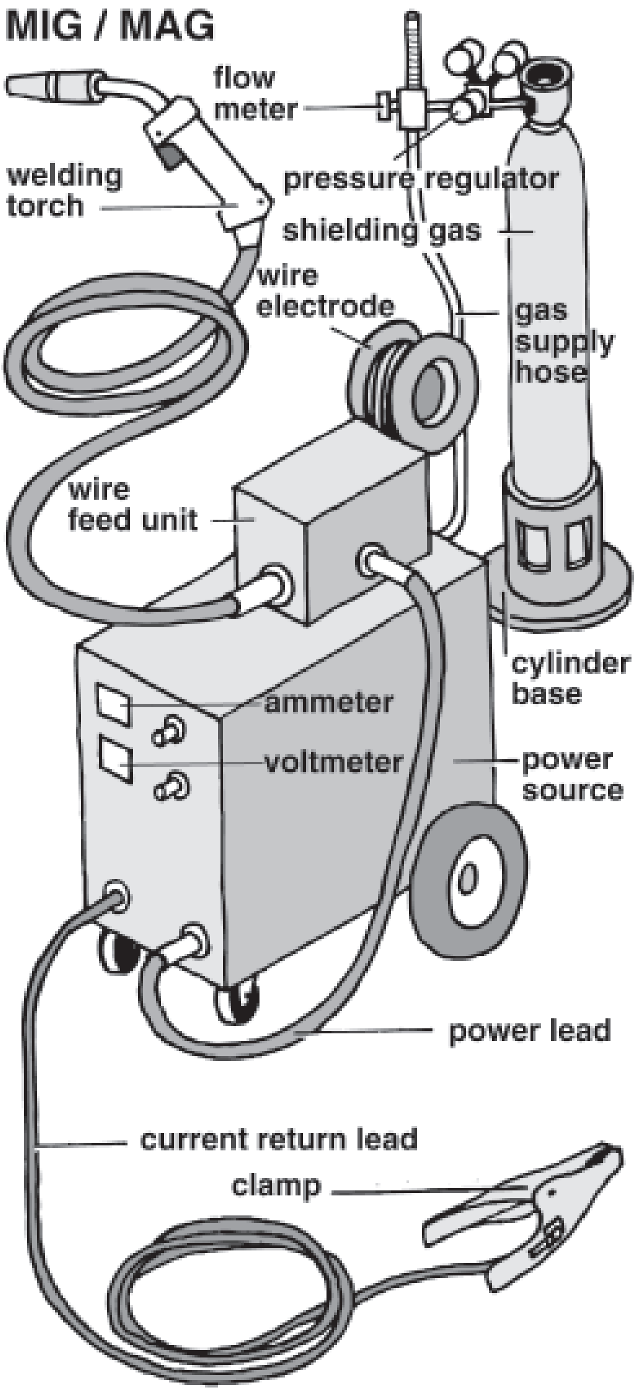
Factors in choosing welding process:

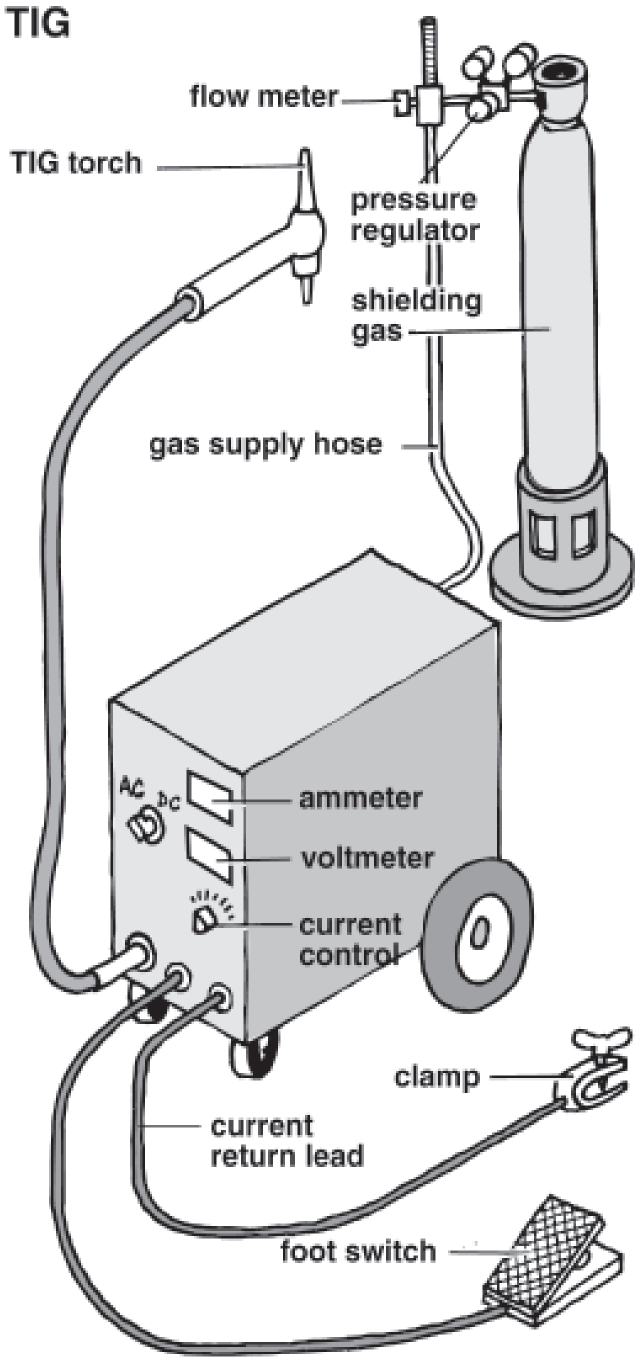
- type of metal
- type of joint
- production constraints
- equipment availability
- labour availability
- health, safety and the environment
- costs of consumables
- labour costs
- material thickness

Arc welding processes

Fabrications involving sheet metal, plate or pipes are commonly welded by an arc process.

Two of the most important processes use a gas shield to protect the weld metal from atmospheric contamination.





Terms commonly used in gas shielded welding

arc length Distance between the tip of the electrode and the surface of the weld pool.

base metal Incorrectly used to describe the metal from which the components of the joint are made. The correct term is *parent metal.*

bead A single run of weld metal deposited onto the surface of the *parent metal.*

burn-off rate The rate at which the wire is melted. Quoted as a linear measurement - m/min (metres per minute) or in/min.

deposited metal Material which is added, either from the electrode or filler wire, to build up the weld profile.

deposition rate The rate at which melted electrode metal is added to the weld pool. Quoted in kg/hr (kilograms per hour). Sometimes incorrectly used in reference to the ratio of metal deposited to the amount of electrode melted - this is the *deposition efficiency.*

electrode The flux coated rod in manual metal arc welding, the tungsten in TIG and plasma welding and the consumable wire in MIG/MAG welding. The arc is formed between the parent metal and one end of the electrode.

filler metal Metal added to the weld pool during welding. For TIG it is supplied as cut lengths of wire.

interpass temperature The temperature of the material adjacent to the joint between each run is the interpass temperature. In some applications, a maximum temperature is specified to avoid metallurgical changes in the metal.

melt run Melting the parent metal by passing a TIG arc along the surface. Filler metal is not used.

nozzle In TIG and MIG/MAG welding - A metal or ceramic tube which confines the shielding gas to the weld area.

parent metal The metal which is to be joined by welding. Often incorrectly called the base metal.

pass or run The metal deposited during one traverse of the joint by an arc. In TIG welding without a filler, the term melt run may be more correct.

preheat temperature The temperature of the parent metal just before welding is started. With some metals the parent metal is heated before welding to avoid problems such as cracking or lack of fusion.

root run The first run deposited in a joint where further runs are needed to fill the groove.

sealing run A run of weld metal deposited on the reverse side of a butt joint, along the line of the root.

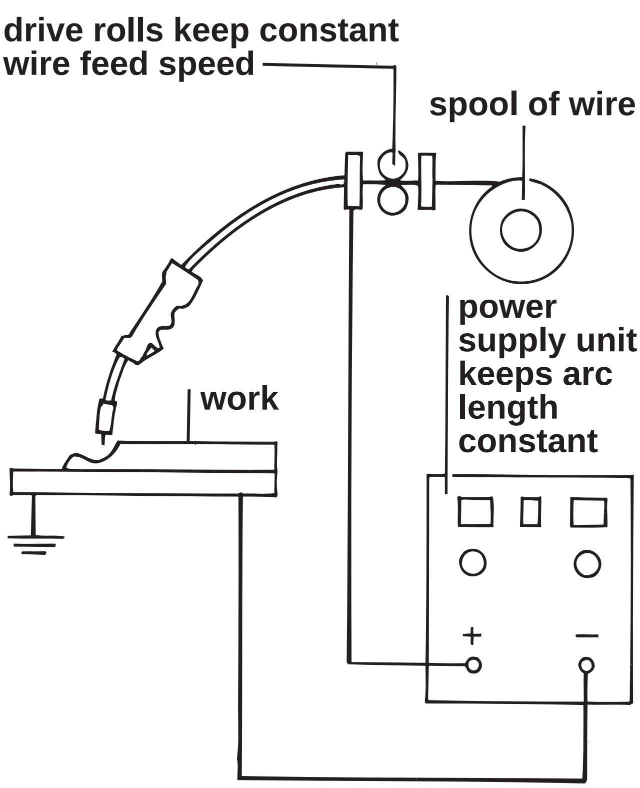
MIG/MAG welding principles

Gas shielded metal arc welding is a semi-automatic process which is suitable for both manual and mechanised operation.

It is known by a variety of names:

- MIG - Metal Inert Gas
- MAG - Metal Active Gas
- CO_2 - carbon dioxide

A low voltage (18–40V), high current (60–500A) arc between the end of a wire electrode and the work provides the heat needed for the welding operation. The arc and the weld are protected from atmospheric contamination by a gas shield.

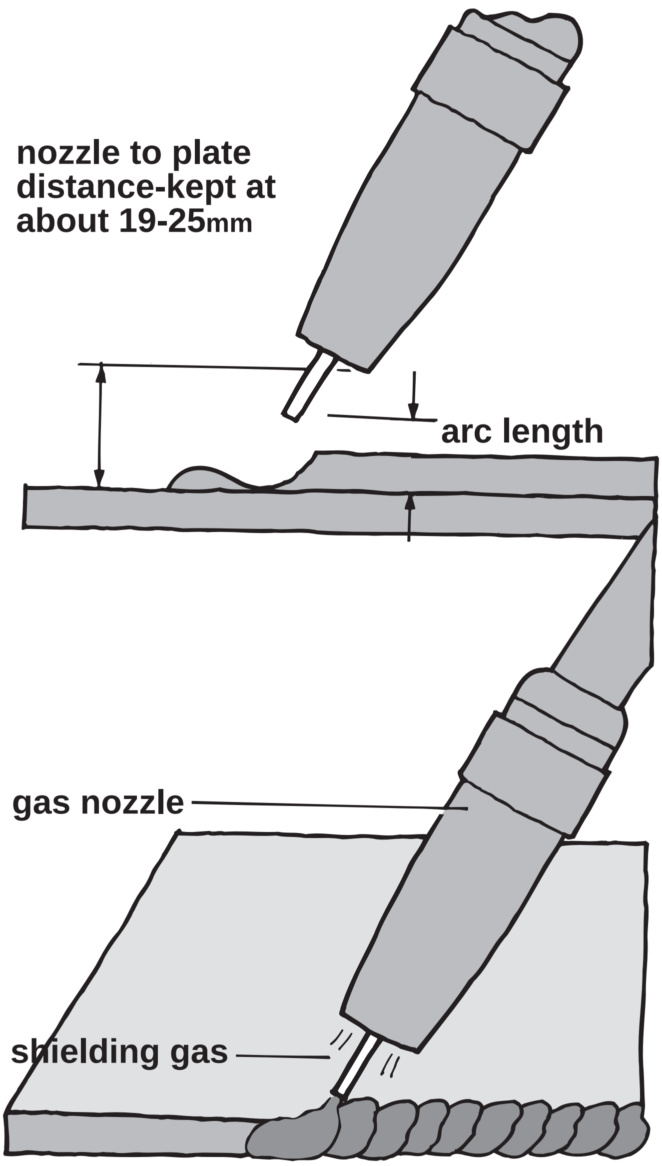


The shielding gas can be:

- pure argon
- argon mixed with small amounts of other gases
- helium or
- carbon dioxide

according to the metal being welded.

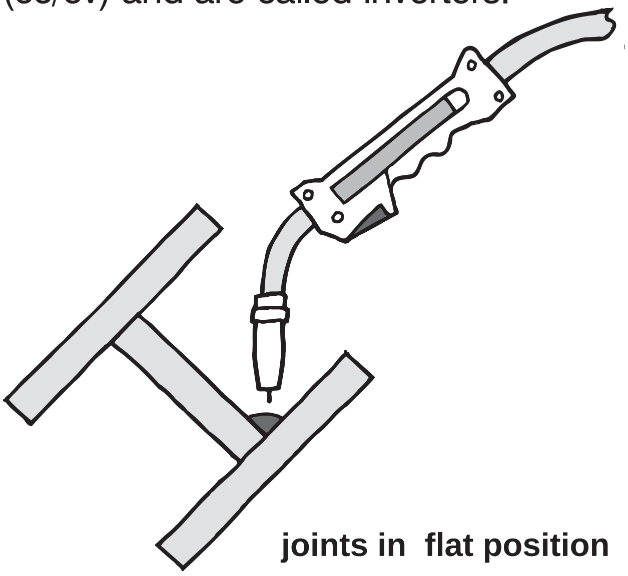
See pages 9 and 26.



Operation

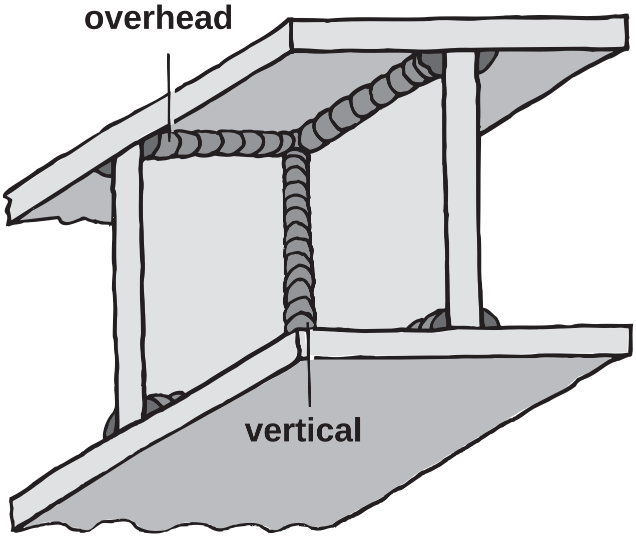
An electric motor feeds the wire into the arc and the power source keeps the arc length at a preset value leaving the welder to concentrate on ensuring complete fusion of the joint.

Power sources for MIG/MAG are called constant voltage or potential, known as the self adjusting arc, and constant current, known as controlled arc or drooping characteristic units. Modern power sources combine constant current and constant voltage (cc/cv) and are called inverters.



The process can be operated at currents within the range 280–500A for welding plates, thick walled pipes and sections in the flat position. The term 'Spray Transfer' is used to describe this type of operation.

Welds which are located in positions where the metal tends to run out of the joint under the action of gravity are welded at lower currents (60/180A).



The appropriate technique for these types of joint is either 'Dip Transfer' or 'Pulse Transfer'.

These two techniques are also used for welding sheet material.

Synergic MIG/MAG is an advanced welding system which incorporates both spray and pulse transfer. Optimum conditions can be established for a range of applications which are readily reproduced by the welder.
Special equipment is required for Synergic-MIG/MAG welding.

Welding data for MIG/MAG applications are given on pages 30 to 33.

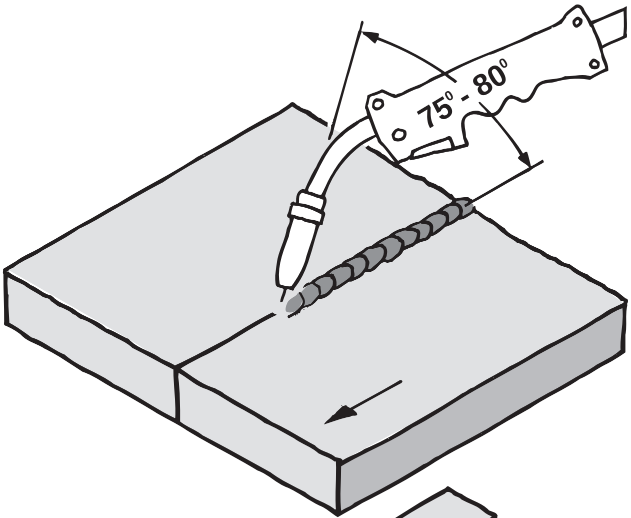
Trade hint

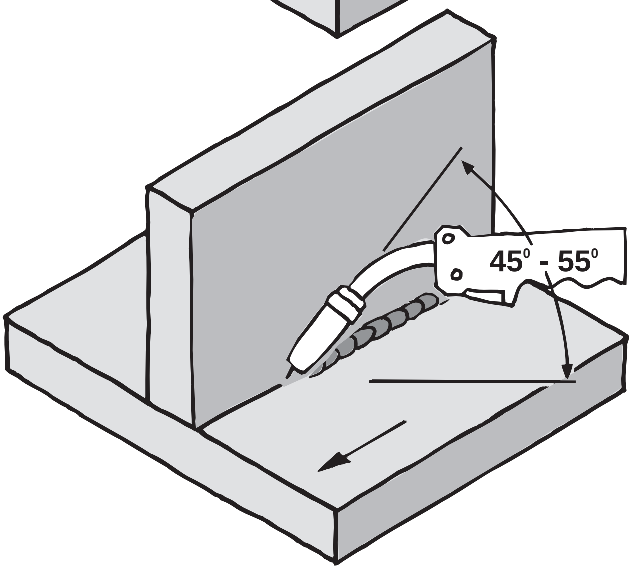
' MIG/MAG welding with a ***Ferromaxx™*** *gas shield gives a low hydrogen content in the weld. This means that lower preheat levels are needed than with MMA welding. '*

Using MIG/MAG welding

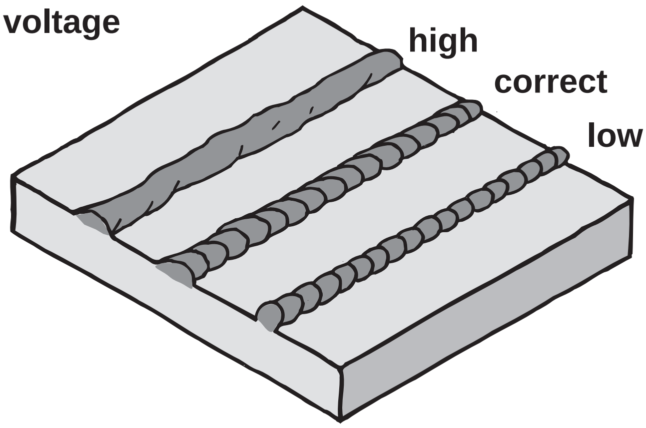
With MIG/MAG, the wire is pointed in the direction of travel (forehand technique). This allows the arc to fuse the parent metal ahead of the weld pool and gives the best penetration. The welder controls the speed of travel to ensure that the weld pool does not run ahead of the arc as this would cause lack of fusion.

Weld quality in MIG/MAG welding is critically dependent on the skill of the welder and selection of the welding variables.





Voltage controls the profile of the weld. **Inductance** (in Dip Transfer) stabilises the arc and minimises spatter. **Wire feed speed** sets the welding current.



Current controls:

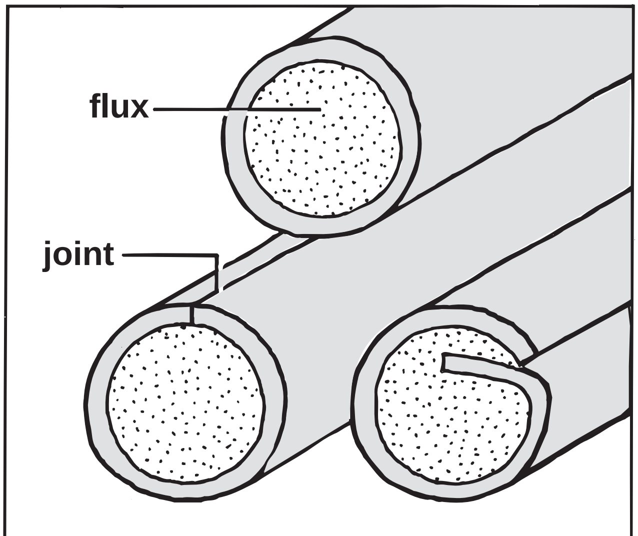
- heat input
- size of weld
- depth of penetration

Wire diameter depends on the current required. The table gives a guide to the selection of wire diameter but the exact relationship depends on the material and the shielding gas.

Diameter (mm)	Current range (A)	Wire feed speed (m/min)
0.6	40–100	2–5
0.8	40–150	3–6
1.0	100–280	3–12
1.2	120–350	4–18

Flux cored wires

Wires for MIG/MAG welding are usually solid. For carbon, carbon-manganese, high strength low alloy steels and stainless steels, flux cored wires can be used. These offer the advantages of higher welding speeds and easier control of fillet weld profiles.



cross section of flux cored wires

Air Products gases for MIG/MAG welding

Air Products welding gases enable the optimum results to be obtained with MIG/MAG welding of a range of metals.

Pure **argon** is particularly effective for welding aluminium and its alloys. Also used for copper and nickel.

Ferromaxx™ is a range of selected mixtures of argon, carbon dioxide and other gases to provide ideal arc conditions for spatter free welding of steels. **Ferromaxx™ 7** is recommended for carbon, carbon-manganese and high strength low alloy steels up to 10mm thick in dip, spray and pulse transfer modes. **Ferromaxx™ 15** is the choice for welding carbon, carbon-manganese, high strength low alloy steels and coated steels in dip, spray and pulse transfer modes for all thickness'.

Ferromaxx™ Plus is the multi-purpose gas for welding carbon, carbon-manganese, high strength low alloy steels and coated steels of all thickness' with solid wires in dip, spray and pulse transfer and with metal and flux cored wires.

Inomaxx™ is a range of gases specially designed for MAG and Pulse MAG welding stainless steels. **Inomaxx™ 2** is recommended for welding ferritic and austenitic grades of stainless steel of all thicknesses in dip, spray and pulse transfer modes.

Trade hint

*'Faster travel speeds with **Ferromaxx™**, **Inomaxx™** and **Alumaxx™** mean reduced welding costs.'*

Inomaxx™ Plus is the choice for welding all thickness' of ferritic and austenitic stainless steels in dip, spray and pulse transfer and with metal cored wires.

Alumaxx™ Plus is the high performance argon - helium shielding gas for MIG welding aluminium and it's alloys of all thickness' in spray and pulse transfer modes (Alumaxx™ Plus is also the recommended gas for TIG welding aluminium and copper).

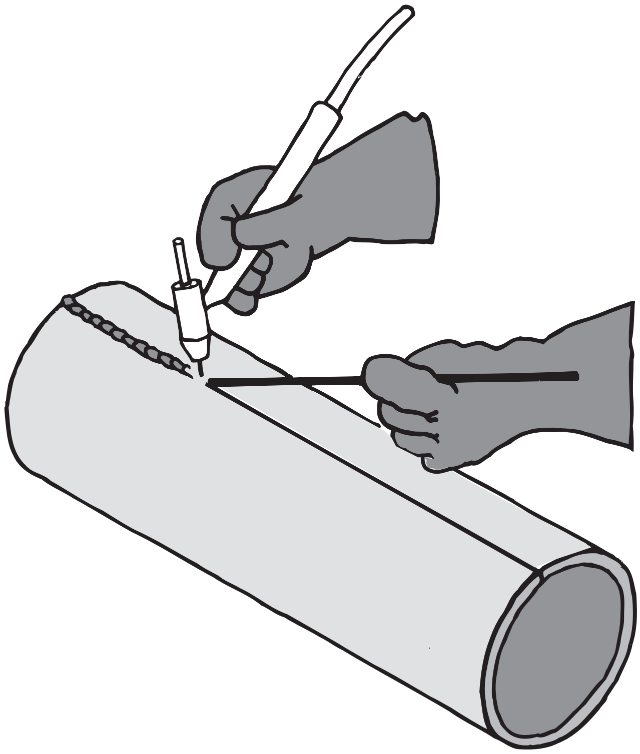
See pages 26–28 for choosing the right gas.

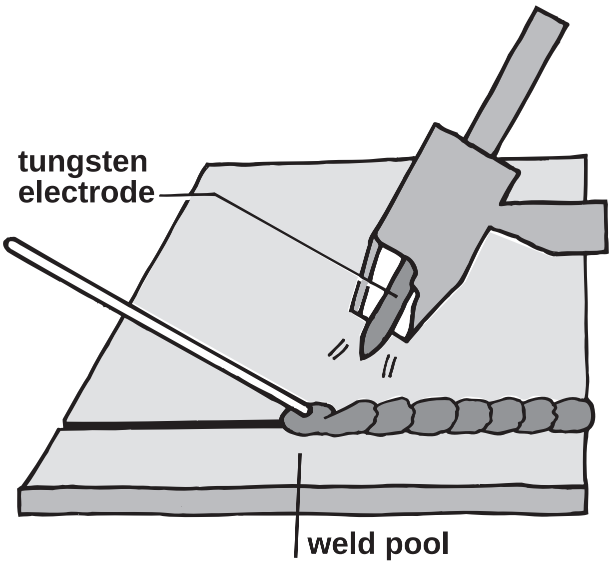
Tungsten inert gas welding

Principles
Tungsten inert gas shielded welding is usually called TIG welding. It uses an arc between a tungsten electrode and the work to fuse the joint. The electrode is not melted and any filler metal needed to build up the weld profile is added separately.

Both the molten metal in the weld pool, the tip of the filler wire and the hot electrode are protected from atmospheric contamination by a shield of inert gas. Usually the gas is argon, but helium by itself or mixed with argon may be used for special applications. Argon - hydrogen mixtures can be used for stainless steel.

See page 29.





Trade hint

'Air Products gases containing helium give better penetration on metals with high thermal conductivity.'

Operation

TIG welding is suitable for both manual and mechanised welding.

In manual welding, the operator points the electrode in the direction of welding and uses the arc to melt the metal at the joint.

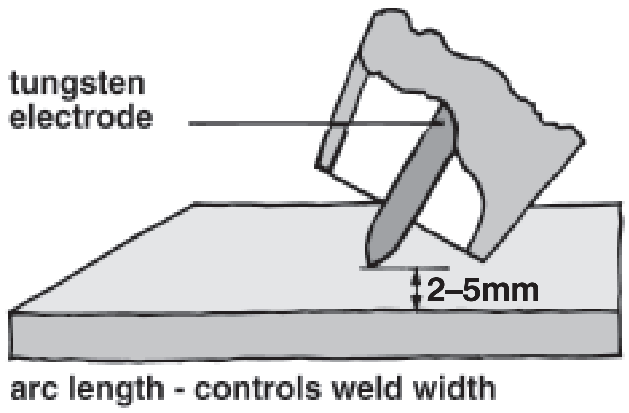
If filler metal is required, for example when making a fillet weld, it is added to the leading edge of the weld pool.

Filler is supplied as cut lengths of wire - usually 1 metre long.

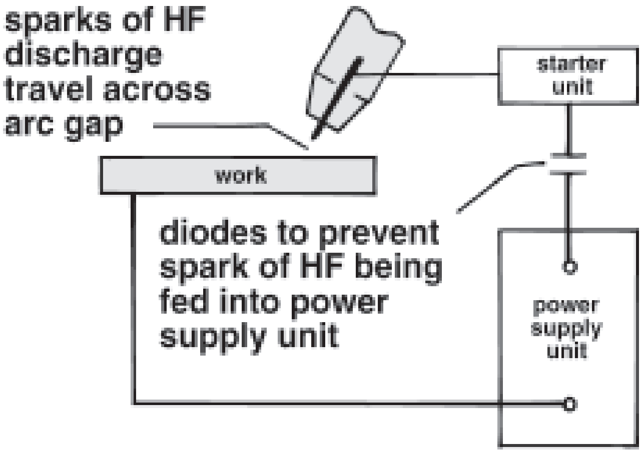
Arc length is controlled by the welder and is usually between 2mm and 5mm.

Heat input to the arc depends on the current chosen by the operator.

Travel speed is adjusted to match the time needed to melt the joint.



Using an arc starting device enables the arc to be struck without touching the electrode to the work.



Choice of current

Both direct current (dc) and alternating current (ac) can be used with TIG welding.

Direct current with the electrode connected to the negative terminal of the power source is used for:

- carbon steels
- copper and its alloys
- stainless steels
- nickel and its alloys
- titanium and its alloys
- zirconium and its alloys

Alternating current is used for welding:

- aluminium and its alloys
- magnesium and its alloys
- aluminium bronze

Power sources for TIG

Power sources for use with TIG welding must be capable of delivering a constant current at a preset value. They are often called 'drooping characteristic' units.

Rectifier units are commonly used for dc welding although motor generators may be more suitable for site use.

Single phase transformer units are almost universally used for welding aluminium. Modern power sources have square waveform.

Combined ac/dc power sources can be used where there is a mix of work.

Modern power sources combine constant current and constant voltage (cc/cv) and are called inverters.

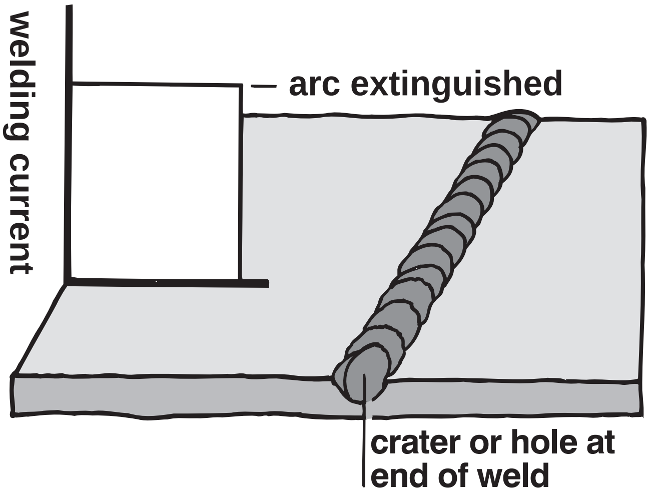
The power source should be equipped with:

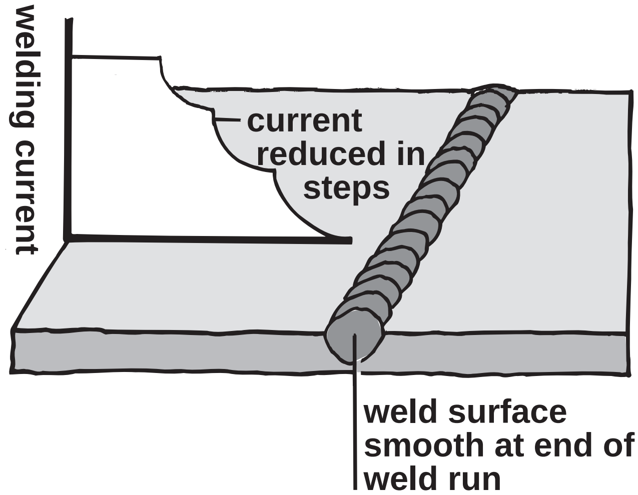
- foot operated on/off switch
- remote control for the current
- crater filling device
- an arc starting device
- gas control valves
- water control valves - for nozzle cooling at high currents.

Welding data for TIG applications are given on pages 34 to 36.

Crater filling

Automatic gradual reduction of the current at the end of a weld run avoids the formation of a crater.





Trade hint

'Use stainless steel wire brushes and wire wool to clean aluminium before welding.'

Electrodes for TIG welding

Pure tungsten electrodes can be used for TIG welding. Thoriated and zirconiated types give easier starting and better arc stability and are generally preferred.

Thoriated tungsten electrodes contain 2% thoria (thorium oxide) and are used for dc welding.

Zirconiated tungsten electrodes contain 2% zirconia (zirconium oxide) and are recommended for ac welding of aluminium.

The diameter of the electrode is chosen to match the current. The minimum current depends on arc stability.

The maximum current a given diameter of electrode can carry is determined by the onset of over-heating and melting.

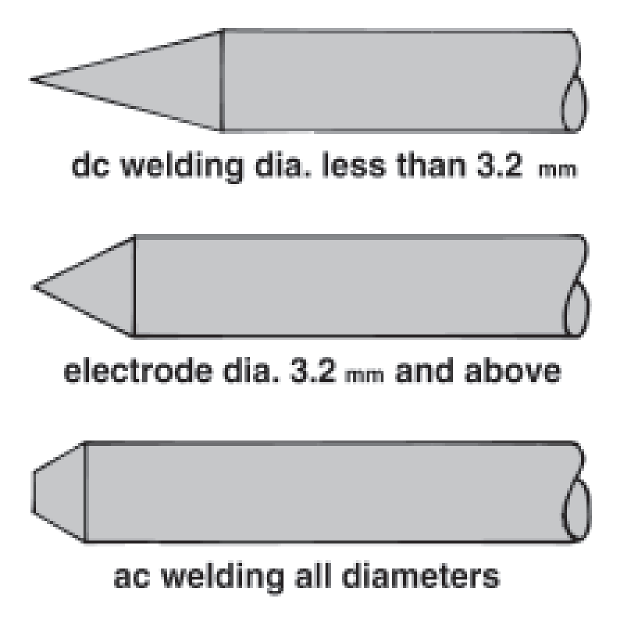
Electrode diameter mm	Maximum operating current (A)	
	Direct Current (dc)	Alternating Current (ac)
1.6	60–150	60–125
2.4	170–250	120–210
3.2	225–330	150–250
4.0	350–480	240–350
4.8	500–675	330–460

Taken from BS EN26848:1991

Before use, the end of the electrode is ground on a silicon carbide wheel to give the most appropriate profile. Contamination with other metals must be avoided as this lowers the melting point of the electrode.

For dc welding a sharp point is required.

For ac welding only a small bevel is needed as the end of the electrode becomes rounded when the arc is operated.



Trade hint

'Do not completely empty a cylinder of gas. Always close the valve before returning a used cylinder to the stores.'

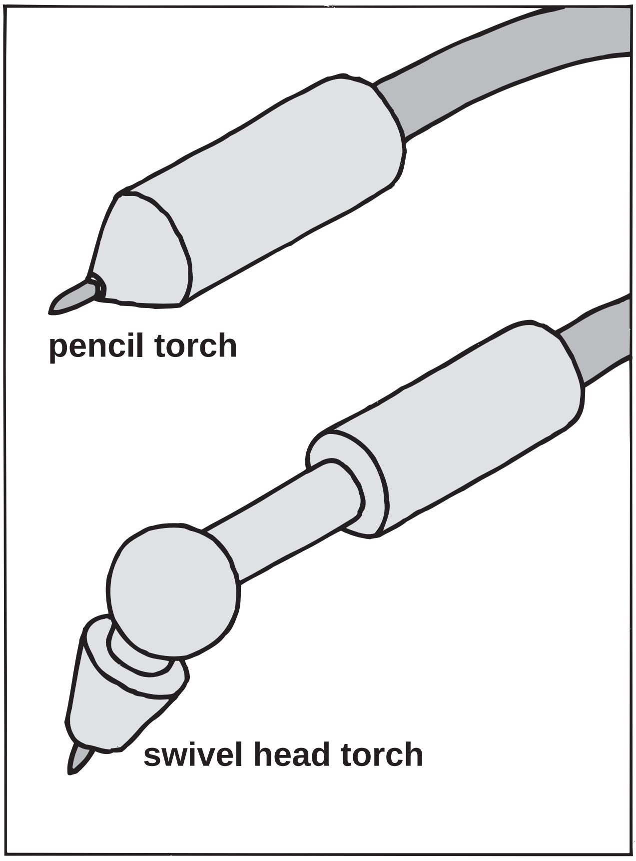
Torches for TIG welding

TIG torches are rated according to the current they can carry without overheating. At currents above 150A the torch body and possibly the nozzle are water cooled.

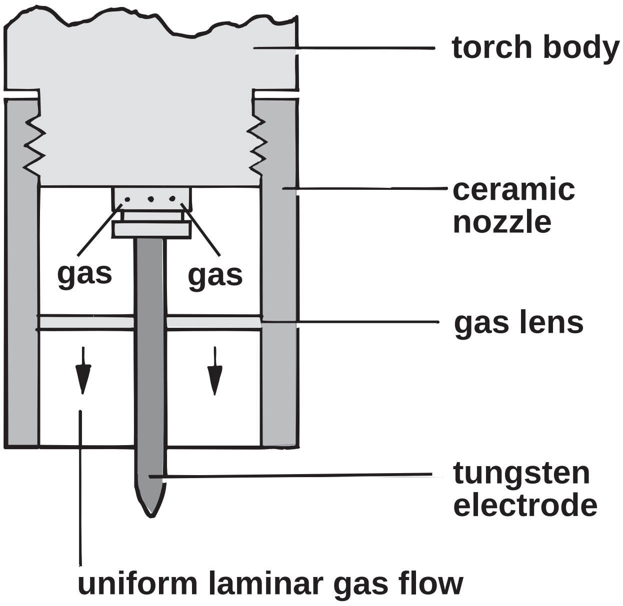
At lower currents, the flow of shielding gas provides sufficient cooling.

An advantage of the TIG process is the availability of a range of torches which enable welds to be made even on small components.

The efficiency of the gas shield is critically dependent on the design of the nozzle.



A gas lens can be used to stabilise the gas shield. With this, the electrode can project further from the end of the nozzle, giving better visibility of the arc and the weld pool.



Gases for TIG welding

Pure argon Suitable for all metals.

Alumaxx™ Plus. An argon-helium mixture which allows faster welding and deeper penetration on aluminium and its alloys and copper and its alloys.

Inomaxx™ TIG. An argon - helium - hydrogen mixture which gives lower ozone emissions, less surface oxidation, improves the weld profile, welding speed and penetration on stainless steel, cupro-nickel and nickel alloys.

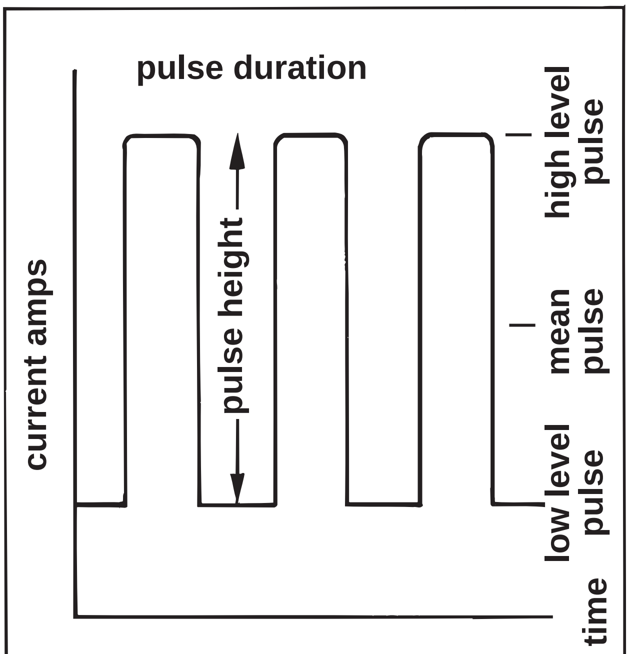
See page 29 for choosing the right gas.

Pulsed TIG

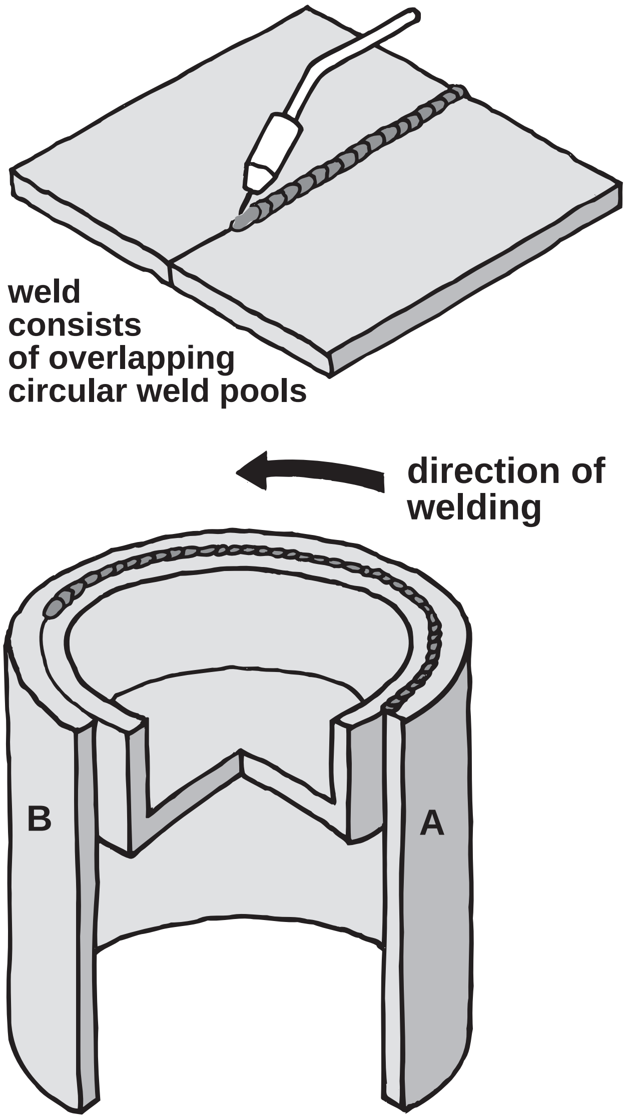
At low currents, a TIG arc becomes difficult to control. Pulsing the current gives stable operation at low heat input levels.

The arc is operated at a low current onto which pulses of high current are superimposed. The frequency of the pulses and their duration are set by the operator to the required heat input and degree of weld pool control.

Conventional torches are used but the power source must be either specially designed for Pulsed TIG or in older equipment supplemented by an adaptor which supplies the pulses.



waveform for pulsed TIG welding



conventional TIG - welding speed progressively increased from A-B

pulsed TIG - constant travel speed

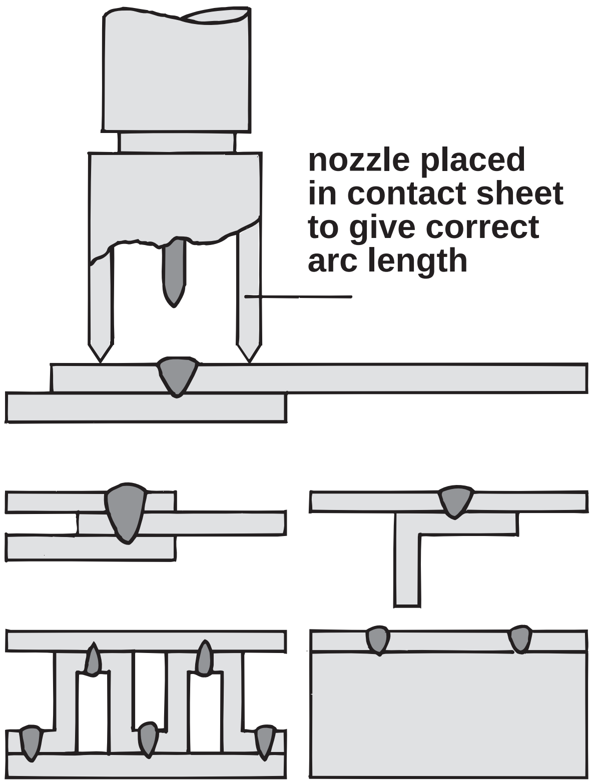
Pulsed TIG is particularly suited to the welding of sheet less than 1mm thick as it reduces the risk of burn through.

Pulsed TIG is also used to weld cylindrical components as it avoids the need to increase travel speed to keep the weld width uniform. This is of great advantage in mechanised welding.

TIG spot welding

TIG spot welding provides an alternative to resistance spot welding where access is from one side only or it is not possible to fit the component between the arms of the spot welder.

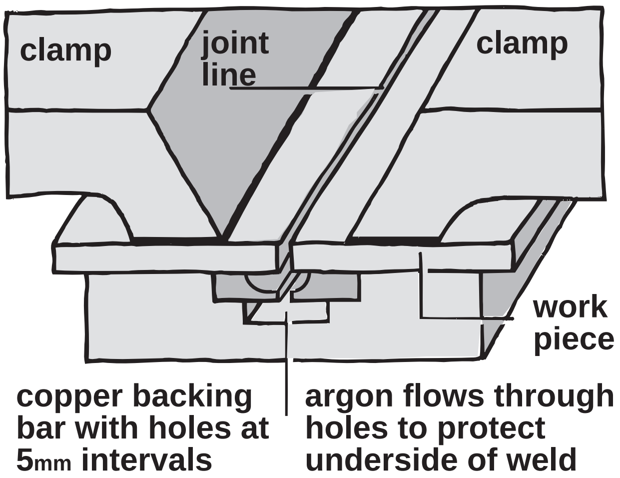
In this technique, the electrode is held at a fixed distance above the surface of a lap joint. The arc melts a circular weld pool which penetrates through the interface between the sheets. After a pre-determined time, usually from 0.4 to 1 second, the current is reduced progressively to allow the weld to solidify without a crater.



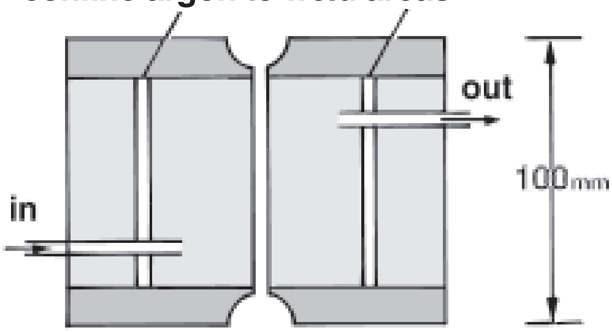
TIG spot welding is not recommended for aluminium

Gas backing

When the weld metal penetrates through the root in a butt joint, it is exposed to air and may become oxidised. This is not normally a problem with aluminium and its alloys, but can cause poor quality welds in steels, especially stainless steel and reactive metals (such as titanium). Contamination can be avoided by providing a gas backing.

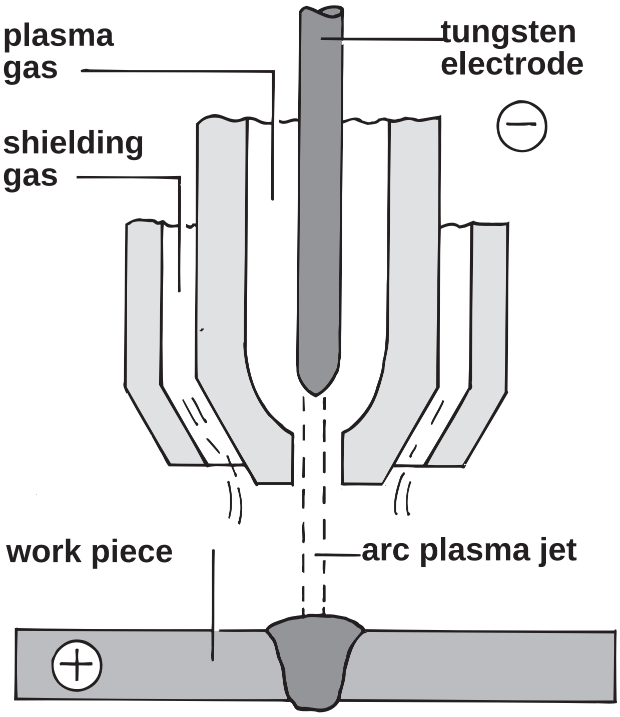


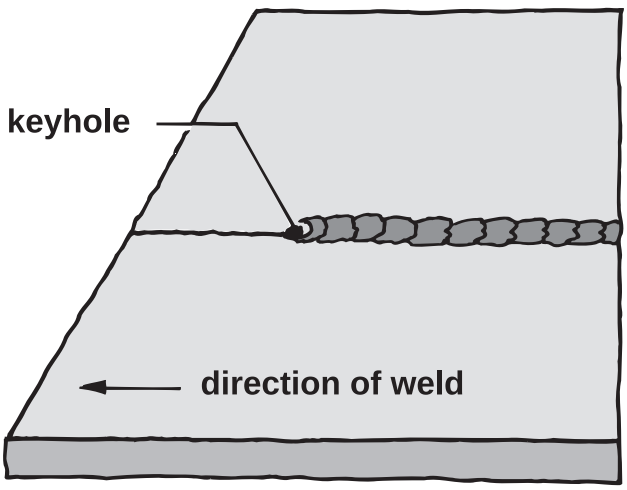
Removable plugs or dams in a pipe confine argon to weld areas



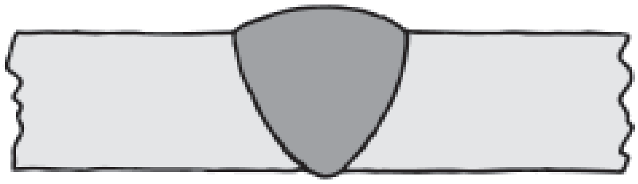
Plasma arc welding

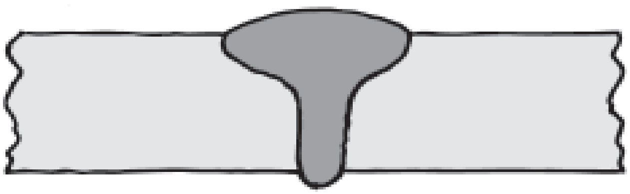
The arc used in TIG welding can be converted to a high energy jet by forcing it through a small hole in a nozzle. This constricts the arc and forms the plasma jet.





Plasma arc welding relies on a special technique known as keyholing. First a hole is pierced through the joint by the plasma arc. As the torch is moved along the joint, metal melts at the front of the hole, swirls to the back and solidifies.


conventional TIG welding


plasma arc welding

Plasma arc welding is mainly used for butt joints in plates and pipes. Its principal advantage is that it gives controlled penetration.

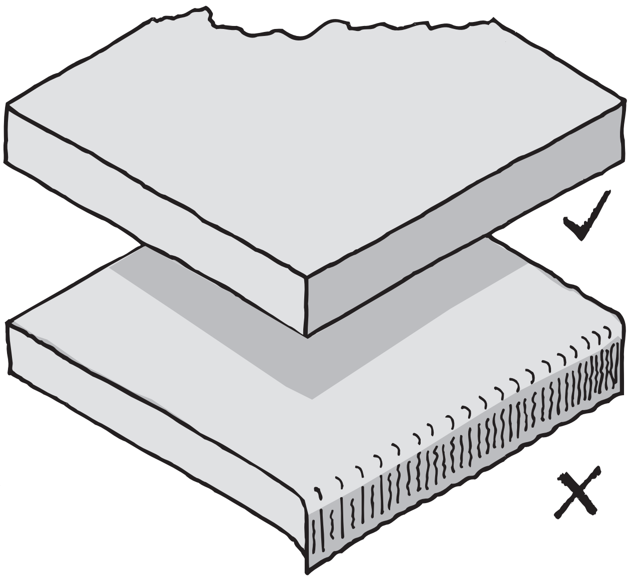
The gas surrounding the electrode is usually argon. Either argon or an argon-hydrogen mixture can be used for the shielding gas.

The plasma arc process is also used for cutting.

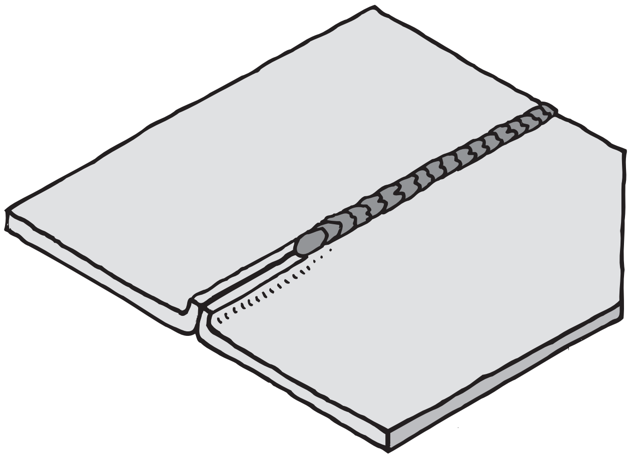
See page 44.

TIG and MIG/MAG welding of sheet

Both TIG and MIG/MAG processes can be used to weld sheet material. With MIG/MAG, dip or pulse transfer techniques must be used.

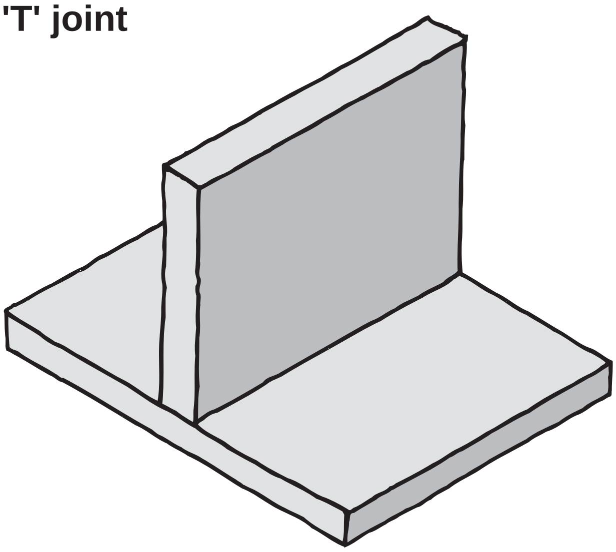


The edges of the sheet are cut square, with no burrs.

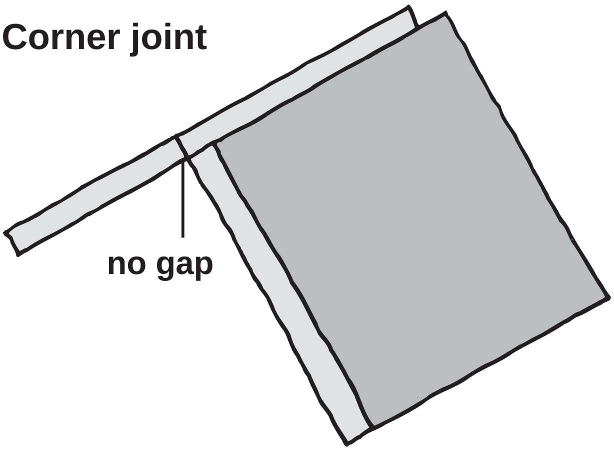


Butt joints in sheet less than 1mm thick are TIG welded. The edges of the sheet can be flanged to avoid the need to use filler metal.

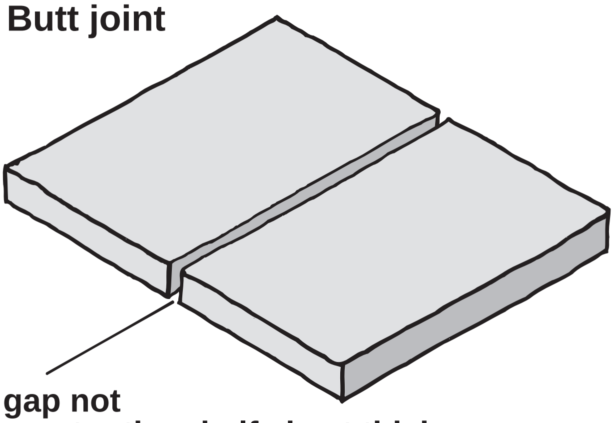
'T' joint



Corner joint

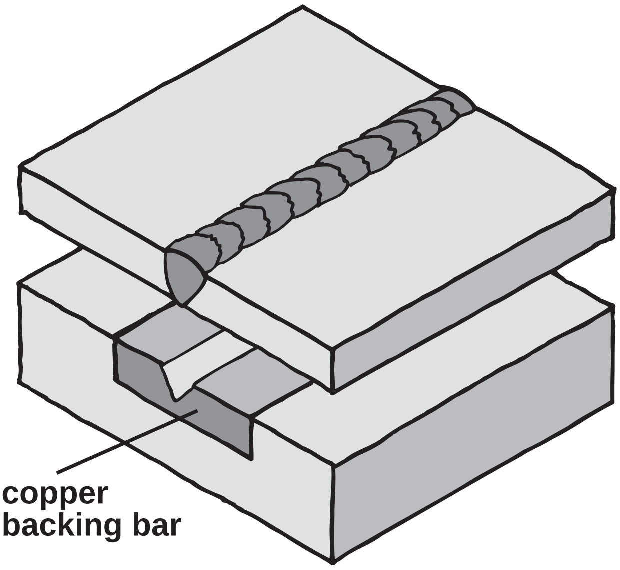


Butt joint

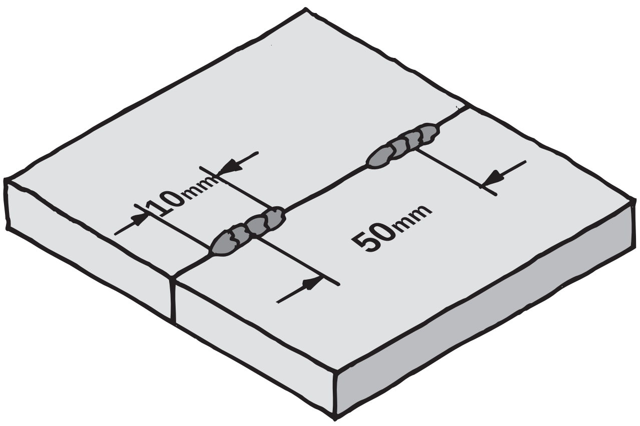


The gap between the edges depends on the joint type and sheet thickness.

The sheets must be held in alignment, preferably by clamping against a backing bar.

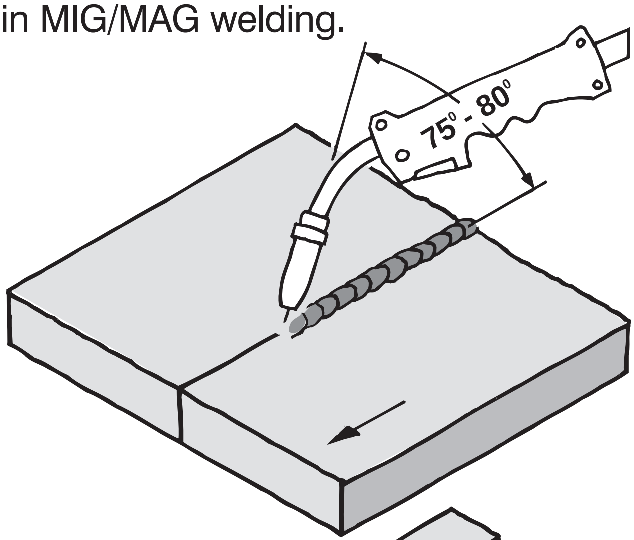


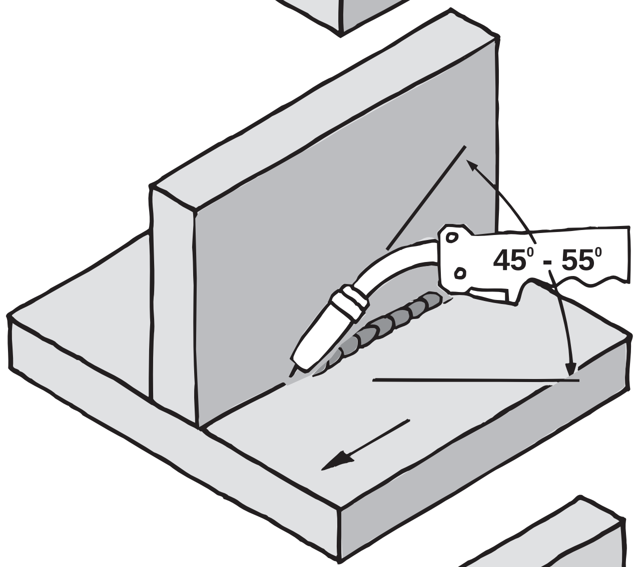
If this is not possible, tack welds about 10mm long should be placed at 50mm intervals. The tacks are melted into the main weld.

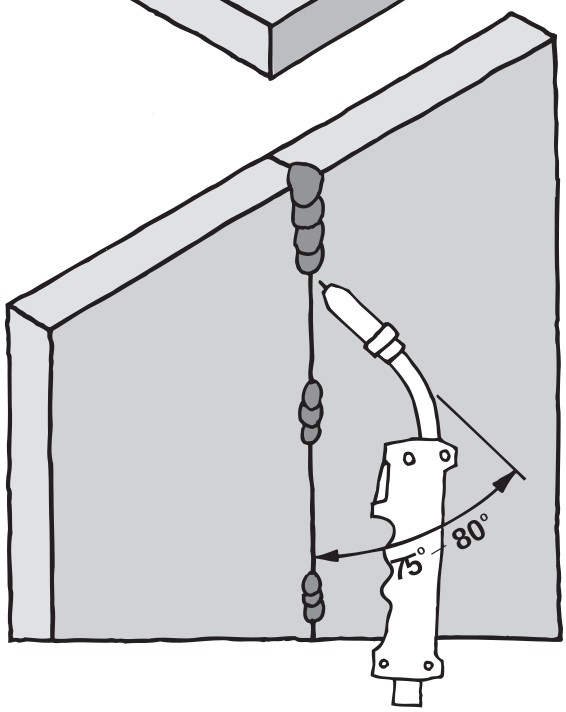


See page 31 for welding conditions.

Control of the angle between the gun and the surface of the sheet is critical in MIG/MAG welding.







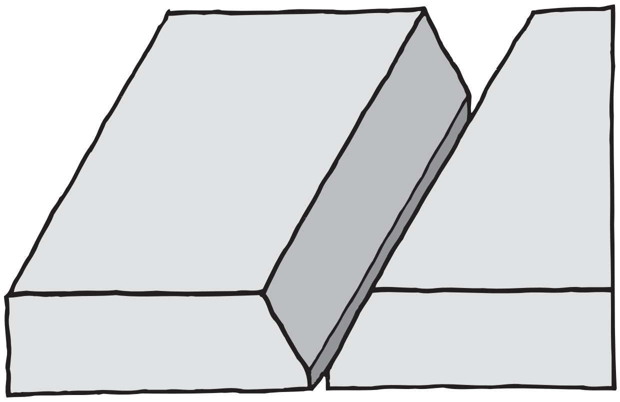
MIG/MAG welding of plate

Spray transfer can be used for butt joints in the flat position and for T-joints in both flat, horizontal and vertical positions. All vertical and overhead welding needs a low current technique — dip or pulse transfer.

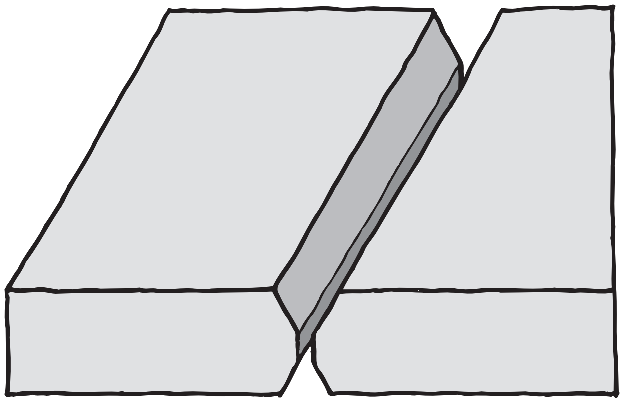
Up to 3mm thickness, the edges of the plate can be cut square.

A single or double bevel is used for greater thicknesses.

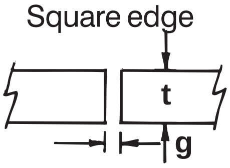
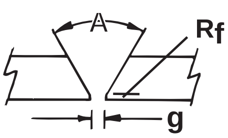
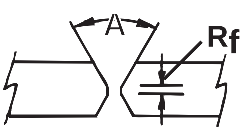
The dimensions of the edge preparation depend on thickness and type of material.



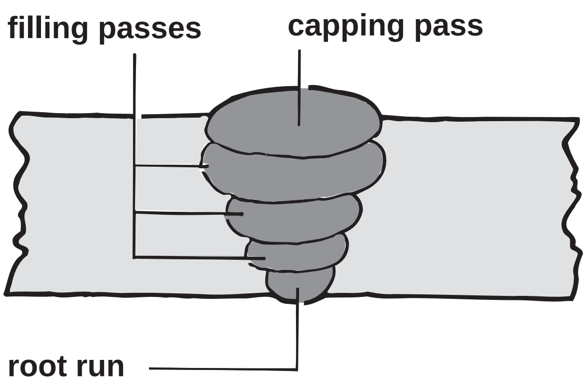
Single 'V'



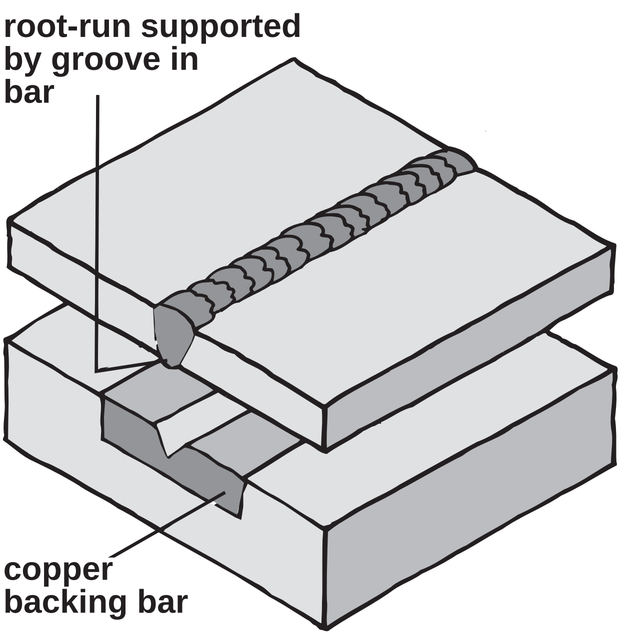
Double 'V'

Type	Thickness	Low carbon steel and stainless steel	Aluminium
Square edge 	Up to 6mm	$g = {}^{1}/_{2}t$	$g = {}^{1}/_{2}t$
Single V 	6mm to 18mm	A = 60° Rf = 1.5mm max g = 1mm max	A = 65-70° Rf = 1.5mm max g = 1.5mm max
Double V 	Above 18mm	A = 50° Rf = 1 to 2mm g = nil	A = 80-90° Rf = 1.5mm max g = 1.0mm max

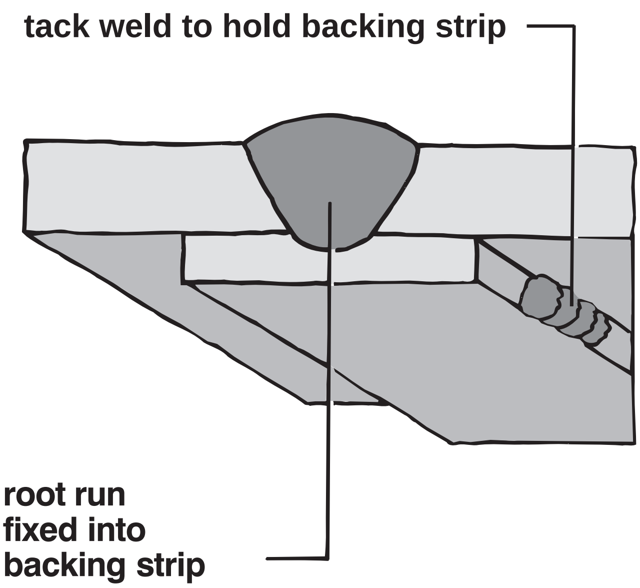
The number of runs needed to fill the groove depends on the thickness.



The deep penetration characteristic of spray transfer makes it difficult to control the molten metal in a root run. The root run can be deposited with dip, or MMA welding can be used.



Alternatively, the underside of the root run can be supported by a backing bar which is removed after welding or a backing strip which is left in place.



See page 32 and 33 for welding conditions.

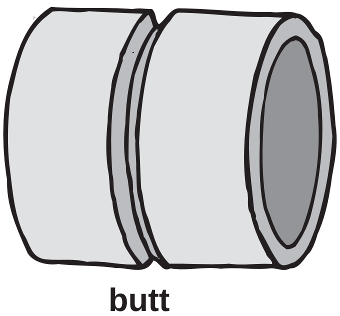
Trade hint

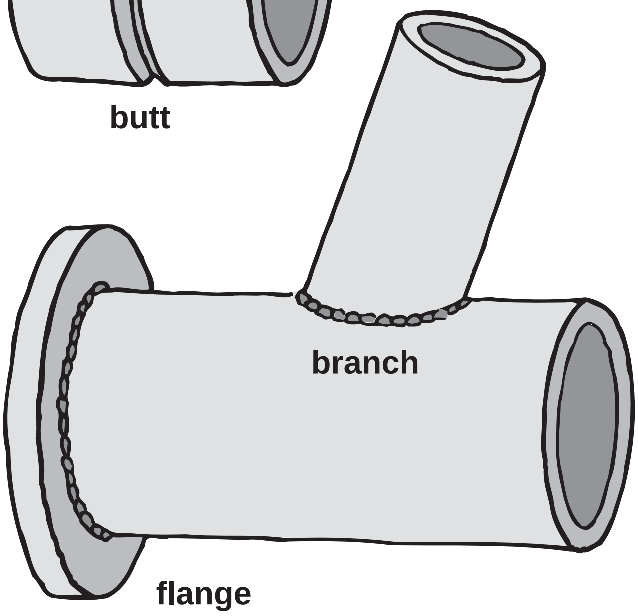
‘Improved metal transfer with argon based gases, as compared to pure carbon dioxide, makes root run control easier.’

Pipe and tube joints

There are three main types of welded joint used in pipework.

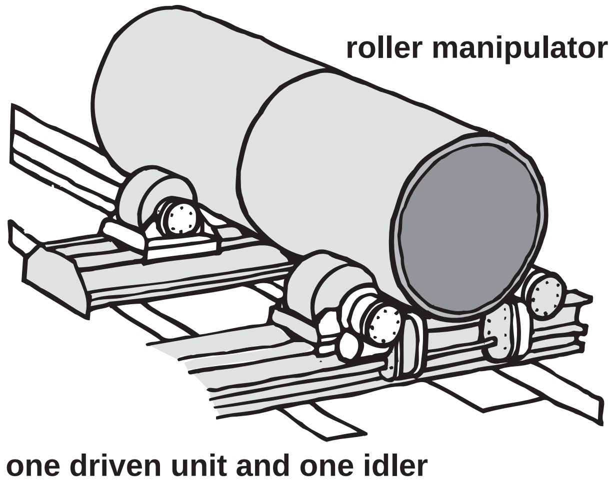
- butt
- branch
- flange

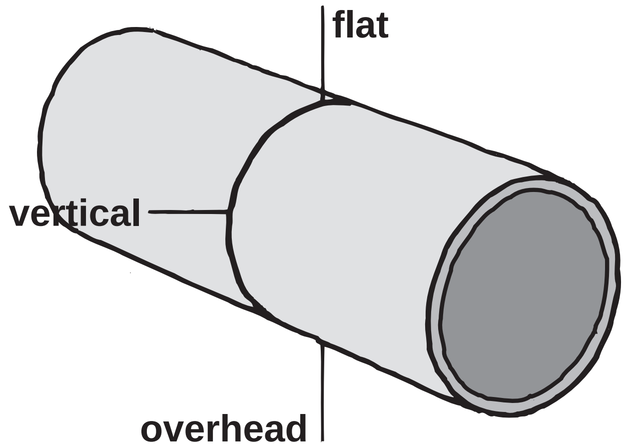




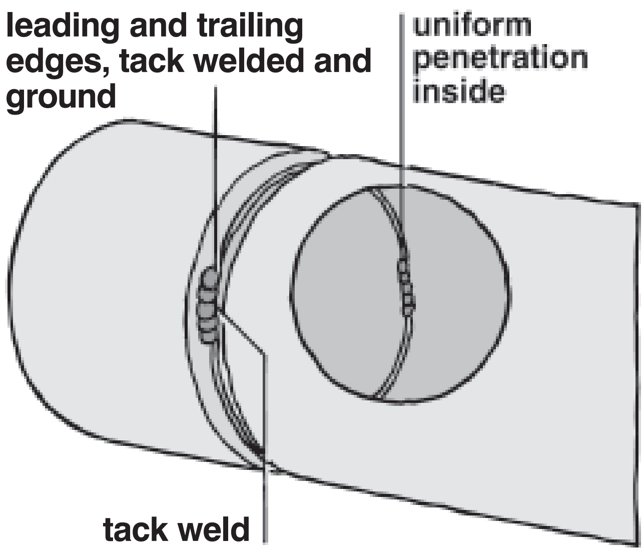
If possible, during welding the pipe should be *rotated* so that the weld is made in the horizontal position - use spray, dip or pulse transfer for MIG/ MAG.

If the weld must be made in a *fixed position* and changes from flat to vertical to overhead as the weld progresses round the joint - use dip or pulse transfer for MIG/MAG.



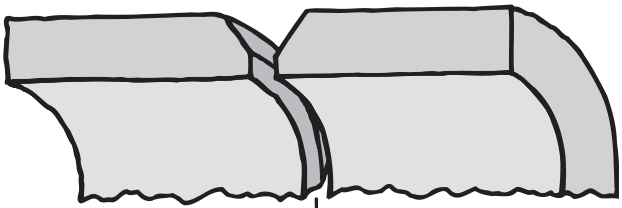


Before welding, the pipes can be clamped or tack welded to maintain alignment.



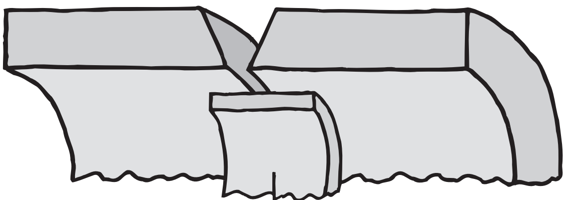
Root runs can be made by TIG or MIG/MAG with dip or pulse techniques or by MMA welding. With TIG welding the bore of the pipe can be filled with argon or nitrogen to protect the penetration bead and to control its profile.

Unbacked butt joint



The edge preparation is chosen to suit the process.

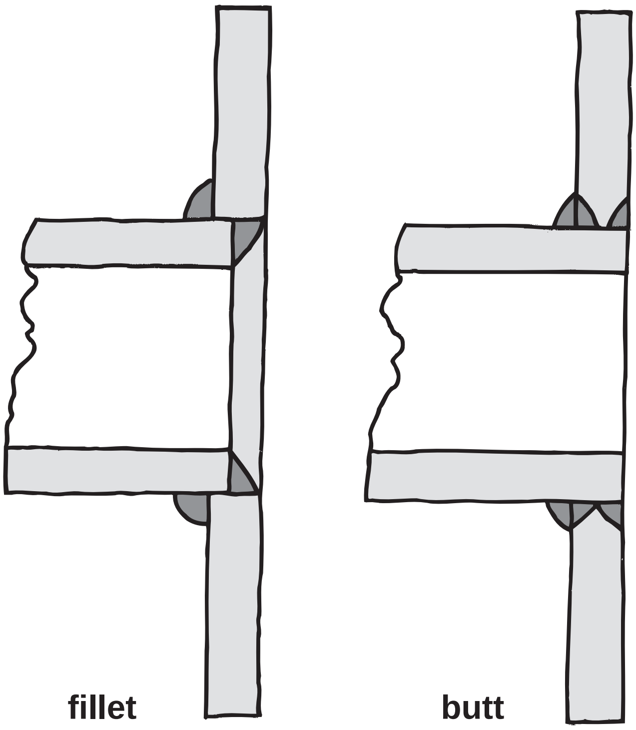
Backed butt joint



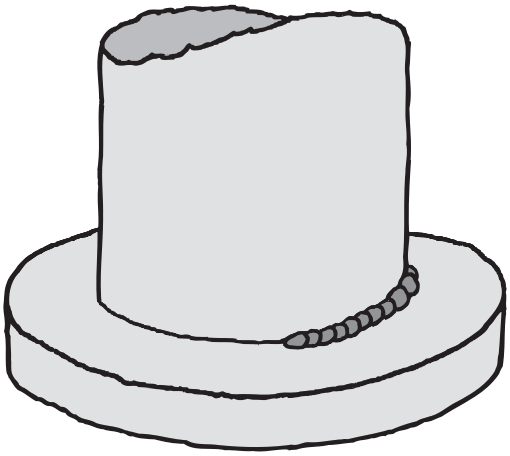
Trade hint

‘Protect the underside of the weld with Air Products argon or nitrogen See page 16’

Flange joints are either fillet or butt welded.



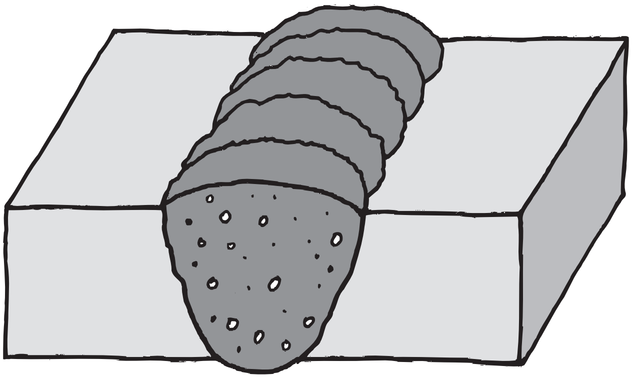
For ease of welding flanges, the axis of the pipe should be vertical and the flange rotated.



Defects in welds

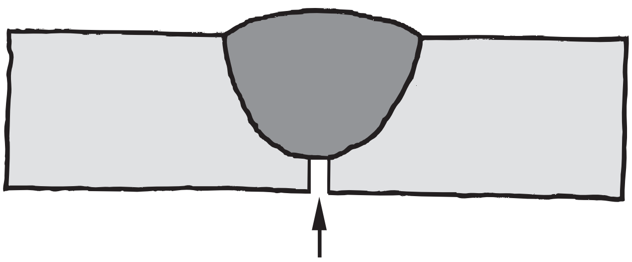
Porosity

- gas flow too high
- blocked nozzle
- draughty conditions
- moisture on work or filler
- paint or grease on surface of metal



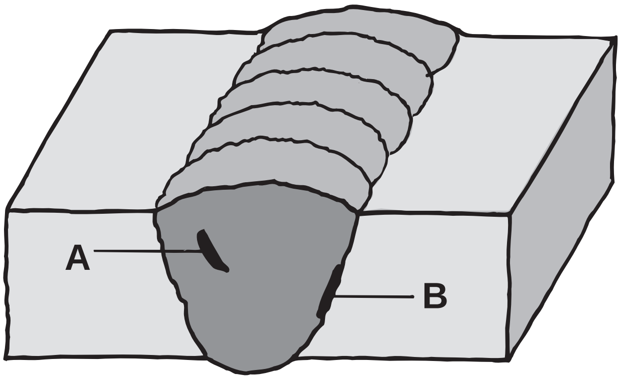
Lack of penetration

- current too low
- root gap too small
- root face too thick
- poor technique
- misaligned joint



Lack of fusion

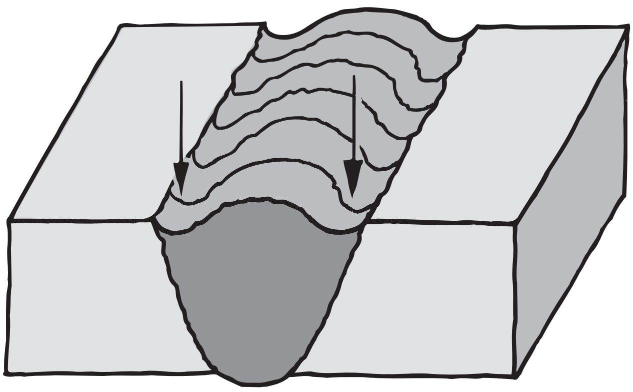
- arc length too short
- current too low
- travel speed too slow in MAG welding
- incorrect inductance setting (MAG)



A-lack of inter-run fusion
B-lack of side fusion

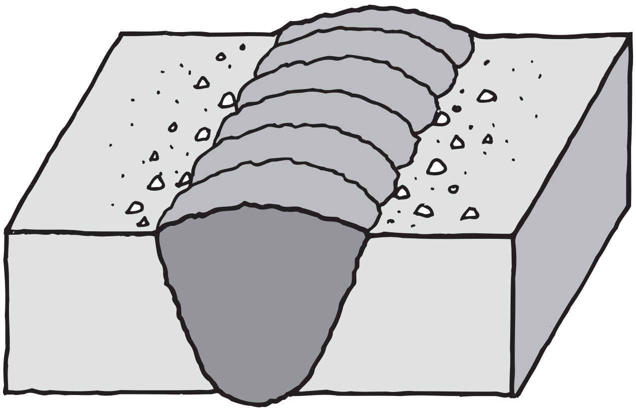
Undercut

- travel speed too high
- current too high
- poor technique



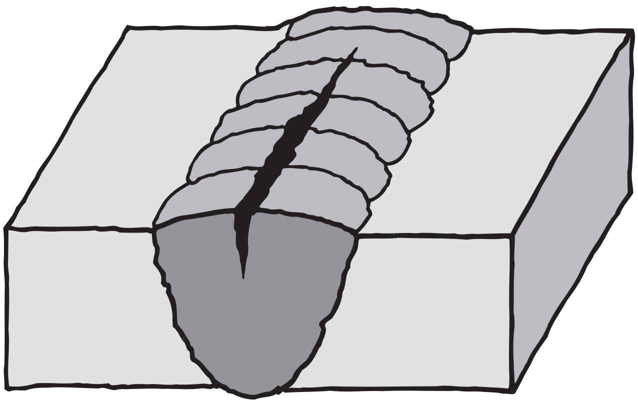
Spatter

- insufficient inductance (MAG)
- short arc length
- voltage too low (MAG)
- rusty plate



Centre line crack

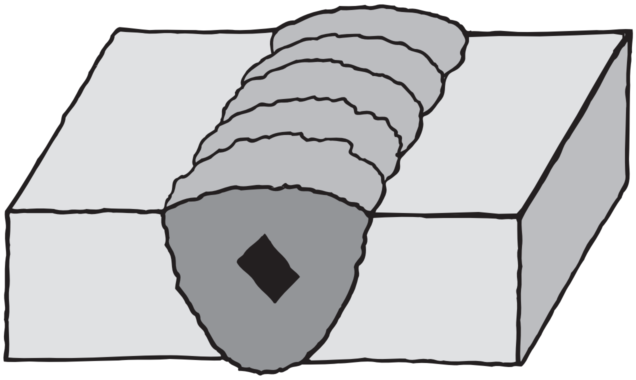
- low voltage, high current
- high sulphur in steel
- incorrect filler
(stainless steel and aluminium)
- incorrect use of preheat
- high restraint



Tungsten inclusions

TIG welding

- electrode tip touching weld pool
- current too high for electrode diameter
- using thoriated electrode for ac



Trade hint

'Acceptance levels for defects are given in British Standards. Check the Standards before you start to weld.'

Gases for MIG/MAG welding

Carbon , carbon-manganese and high strength low alloy steels

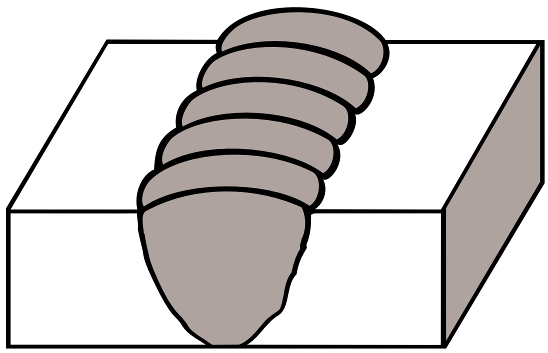
Ferromaxx™ 7, Ferromaxx™ 15, Ferromaxx™ Plus and carbon dioxide (CO_2) are used to weld these steels. The choice depends on the composition of the steel and the operating requirements.

General guidelines:

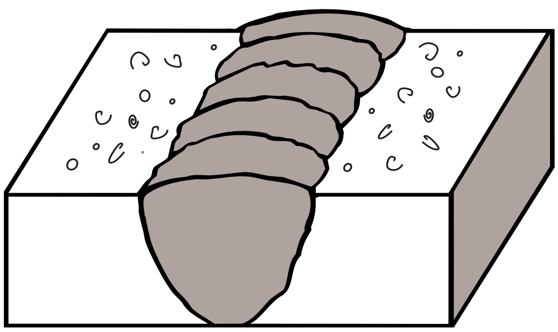
- Penetration increases with the addition of helium. Penetration also increases with higher carbon dioxide contents.
- Choose **Ferromaxx™ 7** if work is wholly thin material. **Ferromaxx™ 15** gives better results on a wider range of material thicknesses with the benefit of reduced ozone emissions. It can be used successfully on thin materials but penetration in butt joints may be more difficult to control.
- **Ferromaxx™ Plus** is the multi-purpose high performance shielding gas which can be used in place of **Ferromaxx™ 7** or **Ferromaxx™ 15** and which also gives exceptionally low ozone emissions.
- Carbon dioxide can be useful for fillet welds in thickplate.
- Spatter increases with increase in carbon dioxide content.
- **Ferromaxx™** gases give a smoother weld surface.
- Steel which contains chromium needs special consideration.

  There is a danger that carbon dioxide in the gas will react with the chromium to form a carbide. This renders the chromium in the steel less effective.

  The amount of carbon dioxide which can be tolerated depends on the chromium content.



Ferromaxx™ Plus



CO_2

Trade hint

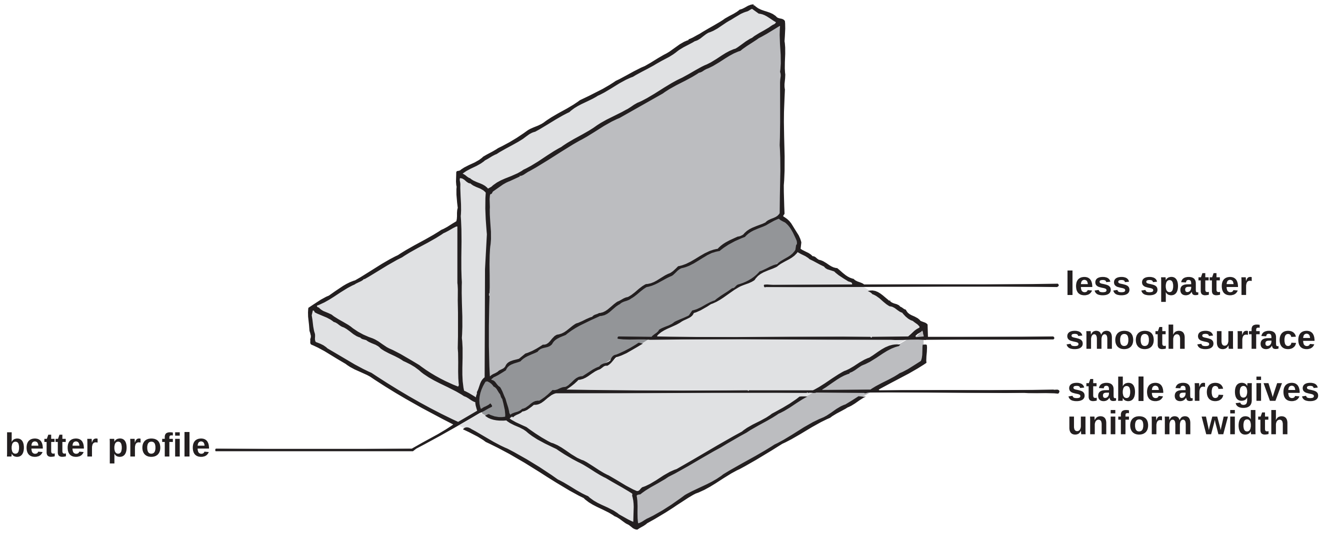
*‘Reduce spatter and improve profile with **Ferromaxx™** and minimise post weld grinding.’*

Gases for MIG/MAG welding

Type of steel	Ferromaxx™ 7	Ferromaxx™ 15	Ferromaxx™ Plus	Carbon dioxide
Carbon, Carbon-manganese Structural	✔	✔	✔	✔
Carbon-molybdenum	✔	✔	✔	✔
1.5%Cr 0.5%Mo	✔	✔	✔	✘
2.5%Cr 1%Mo	✔	✔	✔	✘
5%Cr 1%Mo	See Note	✘	See Note	✘

Notes: In many applications Argon-2% oxygen is preferred for the welding of steels containing 5% Cr. Always seek technical advice before recommending a gas for these steels.

Benefits of Ferromaxx™



Gases for MIG/MAG welding

Inomaxx™ Plus = 63% argon, 35% helium, 2% CO2
Inomaxx™ 2 = 98% argon, 2% CO2
Alumaxx™ Plus = argon 70%, helium 30%

Stainless steel	
Inomaxx™ Plus	Recommended for all material thickness' on dip, spray and pulse transfer. Stable arc conditions offer all-positional capability. Solid and metal cored wires. Excellent weld bead profiles and appearance with very little oxidation. Suitable for manual, automated and robotic welding.
Inomaxx™ 2	Recomended for materials up to 10mm thick on dip, spray and pulse transfer. Offers all-positional capability with solid wires.
argon + 1% to 3% oxygen	Suitable only for spray transfer.
Aluminium and alloys	
Alumaxx™ Plus	Recommended for all material thickness' on spray and pulse transfer. Higher arc temperatures promotes better penetration and increased welding speeds. Produces less porosity. Suitable for manual, automated and robotic welding.
argon + 75% helium	Suitable for very thick sections.
argon	Stable and controllable arc. Suitable for pure alluminium and all alloys.
Copper and alloys	
Alumaxx™ Plus	Recommended for all material thickness' in spray and pulse transfer. Improved welding speeds and penetration profiles. Suitable for manual, automated and robotic welding.
argon + 15% to 25% nitrogen	Spray transfer only.
argon	Use for sheet and metals up to 9mm thick.
Nickel and alloys	
Alumaxx™ Plus	Recommended for all material thickness' in spray and pulse transfer. Enhanced weld bead profiles and increased penetration. Suitable for manual, automated and robotic welding.
argon	Use for sheet and plate up to 9mm thick. Suitable for pulse techniques.

Gases for TIG welding

Shielding gas	Metal
Pure argon	All commercially fabricated metals.
Alumaxx™ Plus	Aluminium and alloys - all thickness' Copper and alloys - all thickness' Nickel and alloys - all thickness' Stainless steels - all thickness' Suitable for manual, automated, orbital and robotic welding.
Helium 75% argon 25%	Thick section aluminium and alloys Thick section copper and alloys.
Inomaxx™ TIG	Austenitic stainless steel - all thickness' Nickel and alloys - all thickness' Suitable for manual, automated, orbital and robotic welding.
argon + 1% to 3% hydrogen	Austenitic stainless steels Nickel and alloys.
argon + 5% hydrogen	Austenitic stainless steels - automated, orbital welding Nickel and alloys - automated, orbital welding.

Alumaxx™ Plus = argon 70%, helium 30%
Inomaxx™ TIG = argon 68%, helium 30%, hydrogen 2%

Benefits of Alumaxx™ Plus gases

- enhanced heat transfer
- suitable for use on metals with a high thermal conductivity especially in thick sections
- deeper penetration
- faster welding speeds
- lower ozone emissions

Benefits of Inomaxx™ TIG gases

- increased welding speed
- improved penetration
- less surface oxidation
- lower gas consumption and overall costs
- less post-weld cleaning
- lower ozone emissions

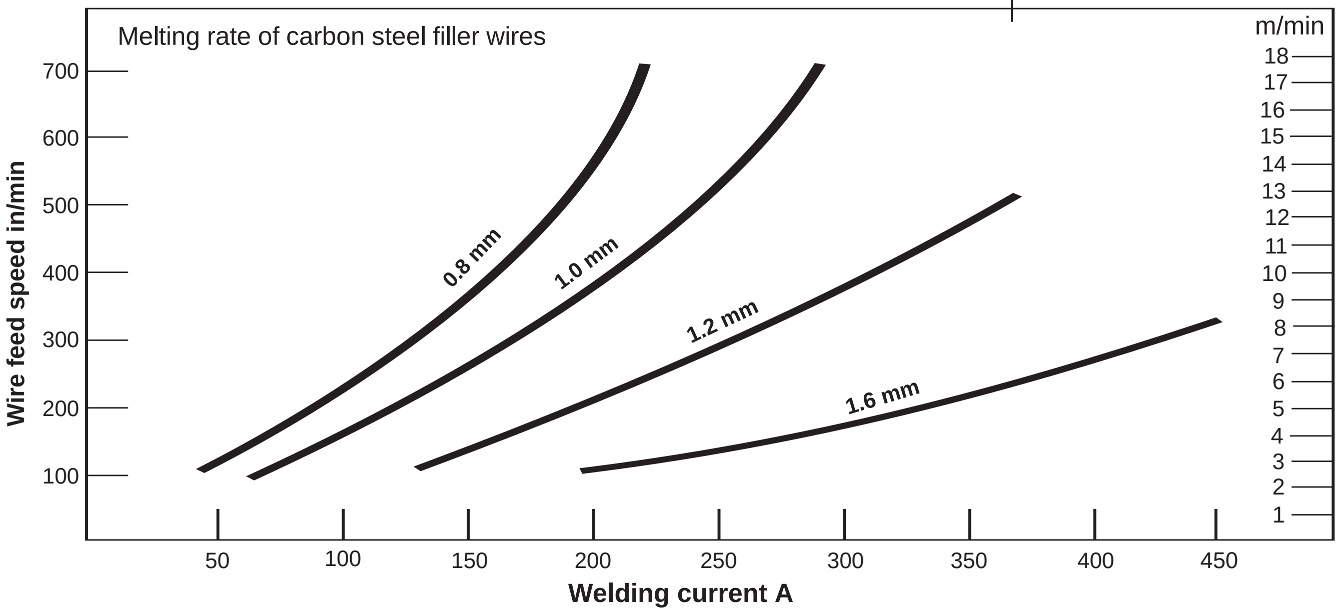
Useful data for MIG/MAG welding

Optimum current ranges for steel wire

Electrode diameter (mm)	Current range (A)
0.6	40–100
0.8	40–150
1.0	100–280
1.2	120–350
1.6	150–450

Length of electrode wire per kilogram

Electrode diam mm	Approximate length per kilogram (metre)		
	Carbon steel	Stainless steel	Aluminium
0.8	125	122	364
1.0	95	93	276
1.2	55	54	160
1.6	30	29	87



Typical conditions for MIG/MAG welding sheet

Sheet thickness			Joint	Electrode	Current	Voltage	Gas (1)
mm	swg	in	gap mm	dia mm	A	V	
Carbon steel							
0.9	20	$^{1}/_{32}$	0.8	0.8	55 - 65	16 - 17	Ferromaxx™ Plus
1.2	18	$^{3}/_{64}$	0.8	0.8	80 - 100	17 - 19	Ferromaxx™ Plus
1.6	16	$^{1}/_{16}$	0.8	0.8	90 - 110	17 - 19	Ferromaxx™ Plus
2.0	14	$^{5}/_{64}$	0.8	0.8	110 - 130	18 - 20	Ferromaxx™ Plus
3.2	10	$^{1}/_{8}$	0.8	1.0	180 - 200	20 - 23	Ferromaxx™ Plus
4.0	8	$^{5}/_{32}$	1.2	1.0	180 - 200	20 - 23	Ferromaxx™ Plus
6.0(2)	4	$^{1}/_{4}$	1.6	1.0	180 - 200	20 - 23	Ferromaxx™ Plus
Stainless steel							
1.6	16	$^{1}/_{16}$	1.0	0.8	70 - 90	19 - 20	Inomaxx™ Plus
2.0	14	$^{5}/_{64}$	1.0	1.0	75 - 95	19 - 20	Inomaxx™ Plus
3.2	10	$^{1}/_{8}$	1.0	1.0	90 - 130	18 - 21	Inomaxx™ Plus
6.0(2)	4	$^{1}/_{4}$	1.6	1.2	180 - 240	22 - 26	Inomaxx™ Plus
Aluminium and alloys							
1.6(3)	16	$^{1}/_{18}$	1.0	1.0	70 - 100	17 - 18	Alumaxx™ Plus
2.0(3)	14	$^{5}/_{64}$	1.0	1.0	70 - 100	17 - 18	Alumaxx™ Plus
3.2	10	$^{1}/_{8}$	1.0	1.2	100 - 130	19 - 20	Alumaxx™ Plus
6.0(2)	4	$^{1}/_{4}$	1.6	1.2	150 - 200	26 - 29	Alumaxx™ Plus

Notes: (1) Gas flow rate: 14 to 16l/min (higher flow rates may be required with gases containing helium)
(2) Welded from both sides
(3) Pulsed transfer

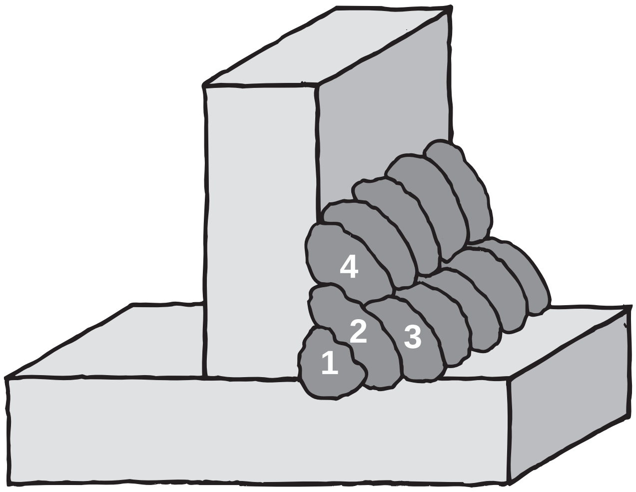
Typical conditions for MIG/MAG welding plate

Butt joints in flat position

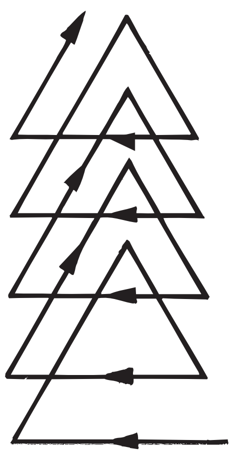
Run	Wire dia mm	Current A	Voltage V
Carbon steel – Ferromaxx™ Plus or Ferromaxx™15			
Root	1.0	90–100	17–19
Second	1.2	260–270	29–31
Filling	1.2	280–300	31–33
Stainless steel – Inomaxx™ Plus			
Root	0.8	80–85	19–21
Second	1.6	220–230	22–24
Filling	1.6	265–275	25–27
Aluminium & alloys – Alumaxx™ Plus			
Root	1.0	85–95	20–22
Second	1.6	210–220	24–26
Filing	1.6	230–240	24–26

Fillet welds in flat position

Leg length mm	Wire dia mm	Current A	Voltage V	Number of runs
6	1.2	300–320	31–33	1
10	1.2	290–310	30–32	2
12	1.2	290–310	30–32	4



Butt and fillet welds in vertical position



use a triangular weave

ensure fusion in the root

Plate thickness or leg lengths mm	Wire Diameter mm	Current A	Voltage V	Number of runs
6	1.0	80–95	17–18	1
10	1.0	70–180	19–20	1
12 (1)	1.0	80–95	17–18	2
12 (2)	1.0	70–180	19–20	2

(1) Root run deposited vertical-down (2) Filling run deposited with weave moving up the joint.

Useful data for flux cored wires

Optimum current ranges for steel electrodes

Wire dia mm	Current range A	Wire dia mm	Current range A
1.2	100 - 280	2.4	300 - 525
1.6	140 - 350	3.2	400 - 650
2.0	200 - 425		

Current ranges vary according to cored wire type.

Typical welding conditions for flux cored wires

Steel plate - **Ferromaxx™ Plus** shielding gases at 20 l/min

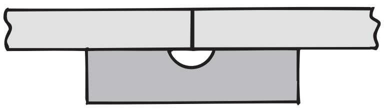
Butt welds - flat position			
Run	Wire dia mm	Current A	Voltage V
Root	1.2	140 - 180	18
Second	2.4	350 - 430	25
Filling	2.4	350 - 430	25
All welds - vertical position all runs			
Run	Wire dia mm	Current A	Voltage V
Root	1.2	130 - 165	18
Second	1.2	150 - 170	18
Filling (weaved)	1.2	170 - 200	20
Fillet welds - flat and horizontal - vertical positions; single pass			
Leg length mm	Wire dia mm	Current A	Voltage V
4.5	2.0	325 - 375	25
6.0	2.4	400 - 450	30
10.0	2.4	450 - 525	32

Note: 10mm leg length fillet weld — flat position only

Typical conditions for TIG welding

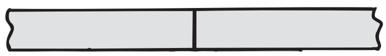
Butt Joints

Recommended joint preparation



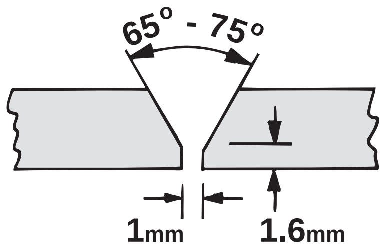
removable backing

up to 3.2mm



no root gap

up to 3.2mm

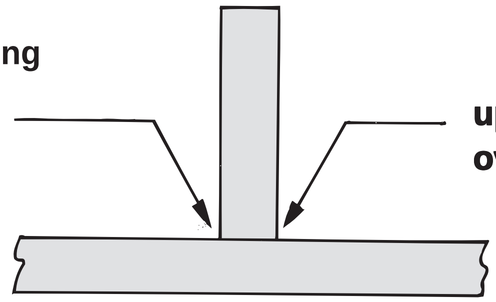


4.8mm and thicker

Metal thickness mm	Electrode diameter mm	Filler rod diameter mm	Welding current A	Shielding gas flow l/min
Aluminium — alternating current — zirconiated electrode				
1.6		1.6	60 – 80	6
3.2	3.2	2.4	125 – 145	7
4.8	4.0	3.2	180 – 220	10
6.0	4.8	4.8	235 – 275	12
Stainless steel — direct current — thoriated electrode				
1.6	1.6	1.6	60 – 70	5
3.2	2.4	2.4	70 – 95	6
4.8	2.4	3.2	100 – 120	7
6.0	3.2	4.0	135 – 160	8
Carbon steel — direct current — thoriated electrode				
1.6	1.6	1.6	60 – 70	5
3.2	1.6 or 2.4	2.4	75 – 95	6
4.8	2.4	3.2	110 – 130	7
6.0	3.2	4.8	155 – 175	8

Typical conditions for TIG welding

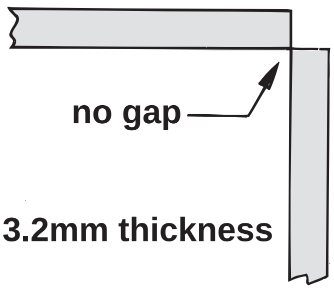
T Joints - fillet welded

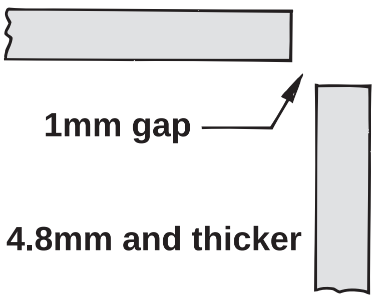


Metal thickness mm	Electrode diameter mm	Filler rod diameter mm	Welding current A	Shielding gas flow l/min
Aluminium — alternating current — zirconiated electrode				
1.6	2.4	1.6	60 – 80	5
3.2	3.2	2.4	130 – 160	6
4.8	3.2 or 4.0	3.2	195 – 230	7
6.0	4.0 or 4.8	4.8	260 – 295	10
Stainless steel — direct current — thoriated electrode				
1.6	1.6	1.6	50 – 70	5
3.2	2.4	2.4	85 – 105	5
4.8	2.4	3.2	120 – 145	6
6.0	3.2	4.0	165 – 180	7
Carbon steel — direct current — thoriated electrode				
1.6	1.6	1.6	50 – 70	5
3.2	1.6 or 2.4	2.4	90 – 120	5
4.8	2.4	3.2	135 – 175	6
6.0	3.2	4.8	170 – 200	7

Typical conditions for TIG welding

Corner joints





Metal thickness mm	Electrode diameter mm	Filler rod diameter mm	Welding current A	Shielding gas flow l/min
Aluminium — alternating current — zirconiated electrode				
1.6	2.4	1.6	50 – 70	6
3.2	2.4 or 3.2	2.4	100 – 120	7
4.8	3.2 or 4.0	3.2	175 – 210	10
6.0	4.0 or 4.8	4.8	220 – 260	12
Stainless steel — direct current — thoriated electrode				
1.6	1.6	1.6	40 – 55	6
3.2	2.4	2.4	50 – 75	7
4.8	2.4	3.2	90 – 110	8
6.0	3.2	4.0	125 – 150	10
Carbon steel — direct current — thoriated electrode				
1.6	1.6	1.6	40 – 60	6
3.2	1.6 or 2.4	2.4	70 – 90	7
4.8	2.4	3.2	110 – 130	8
6.0	3.2	4.8	155 – 175	10

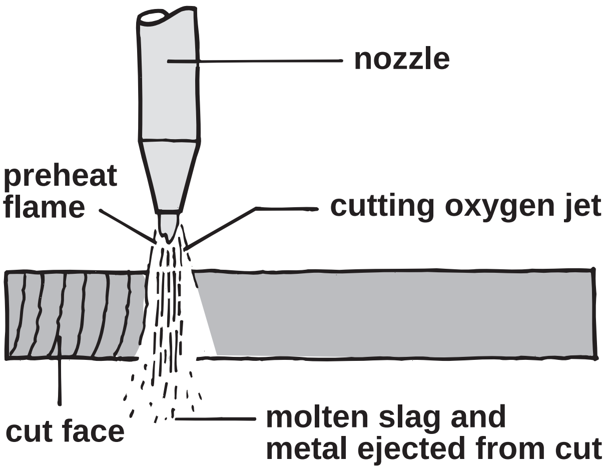
Oxygen-fuel gas cutting

Principles

Oxygen-fuel gas cutting is widely used to cut:

- straight lines and shapes in plates
- pipe end in preparation for welding
- scrap metal

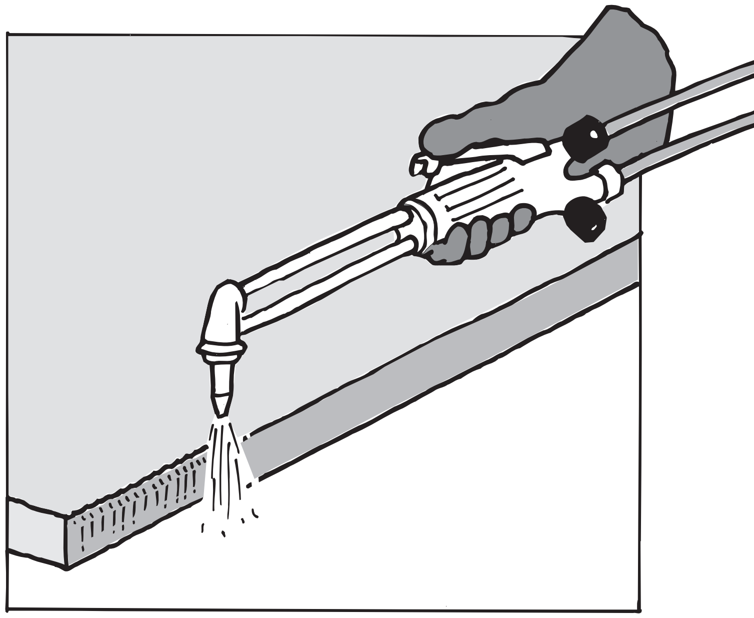
It can produce a variety of edge profiles on plates, pipes and sections



The cutting action depends on a chemical reaction between oxygen and hot iron or steel.

A preheat-flame is used to raise the surface of the metal to the temperature at which the reaction takes place.

The heat from the reaction melts the metal which is blown from the cut by the oxygen jet.



Metal	Cutting response
Mild and low carbon steels	Very good
Stainless steel	Must use flux in oxygen jet. Poor quality cut
Aluminium, copper etc	Unsuitable

Trade hint

'Air Products' oxygen has the right purity for fast cutting. Do not use damaged nozzles if you want the best results.'

Equipment

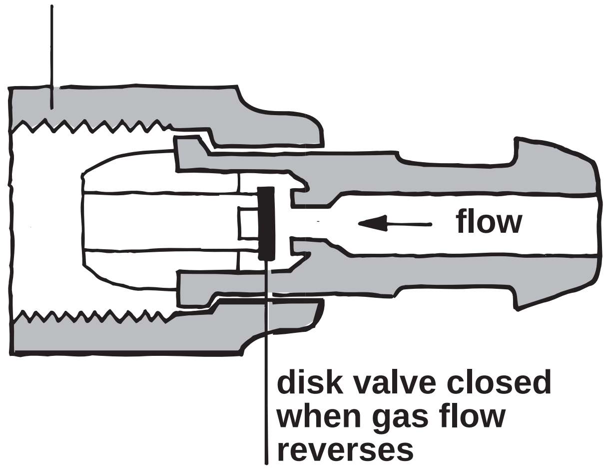
The essential equipment for cutting comprises:

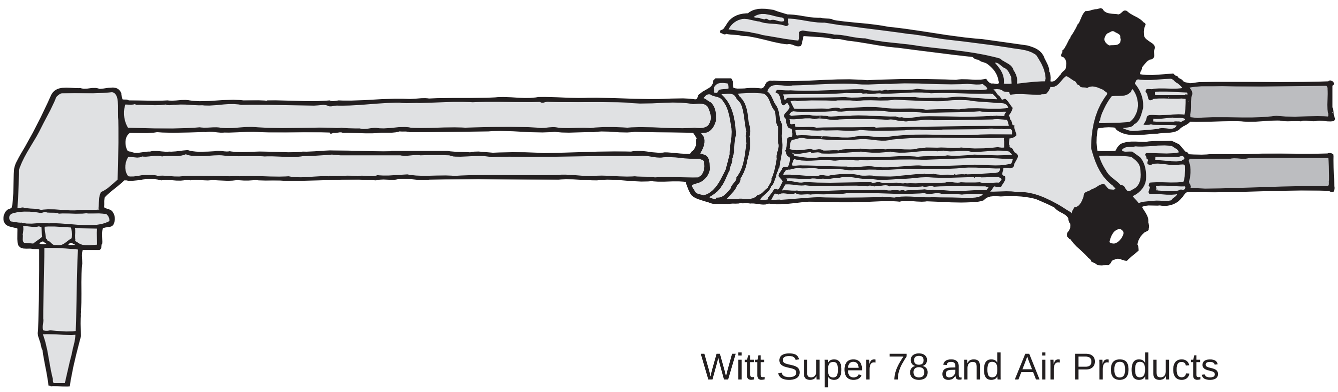
- cutting and torch hoses
- oxygen regulator (14 bar max output)
- fuel gas regulator (2 bar max output)

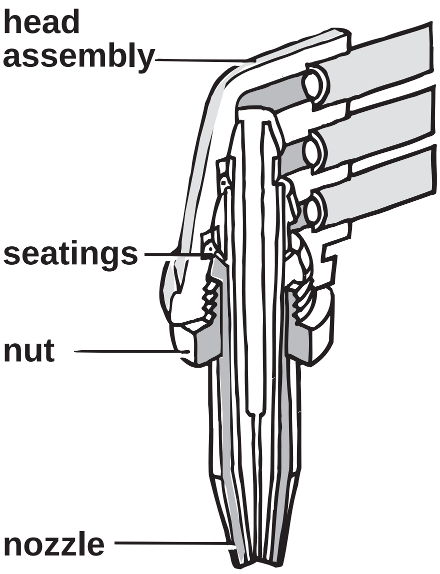
Oxygen and fuel gas for the preheat flame are mixed in the nozzle.

The type of nozzle is matched to the fuel gas.

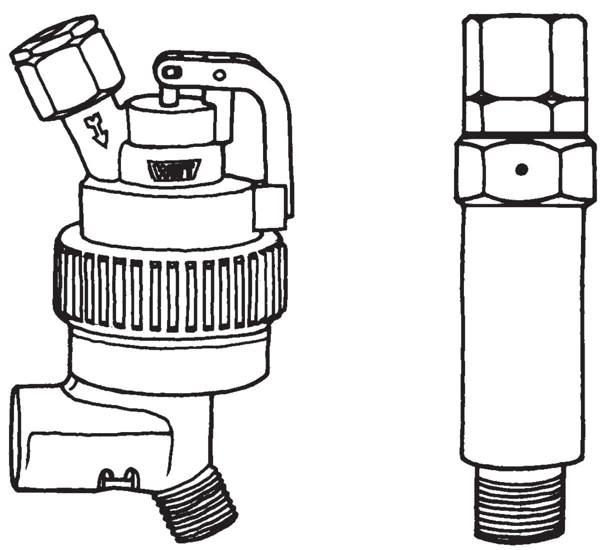
For safety, hoses must be fitted with hose protectors at the torch.







Witt Super 78 and Air Products Flashback arrestors.



Preheat flame

The preheat flame:

- heats the metal to start the cutting action
- heats the surface along the line of the cut to keep the cutting action going
- disperses residual paint and oxide on the surface

Fuel gas can be:

Apachi+™ — propylene based gas, exclusive to Air Products PLC.

Acetylene — colourless unsaturated hydrocarbon.

Propane — liquified petroleum based gas.

Choice of fuel gas depends on:

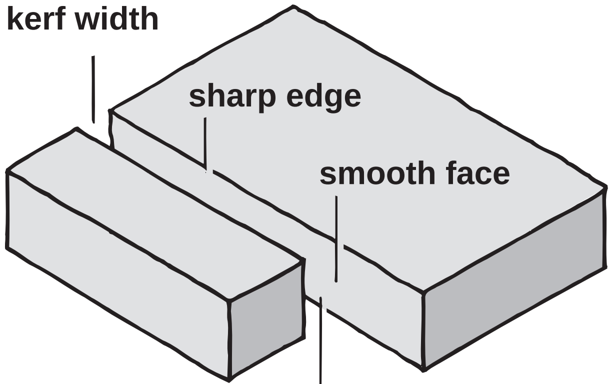
Factor for choice	Apachi+	Acetylene	Propane
Time to start cut	●●	●●●	●
Cutting speed	●●●	●●●	●●
Fuel gas cost	●●	●	●●●
Heating oxygen cost	●●	●●●	●
Ease of handling	●●●	●	●●●

●●● = best choice   ● = worst choice

Quality of cut

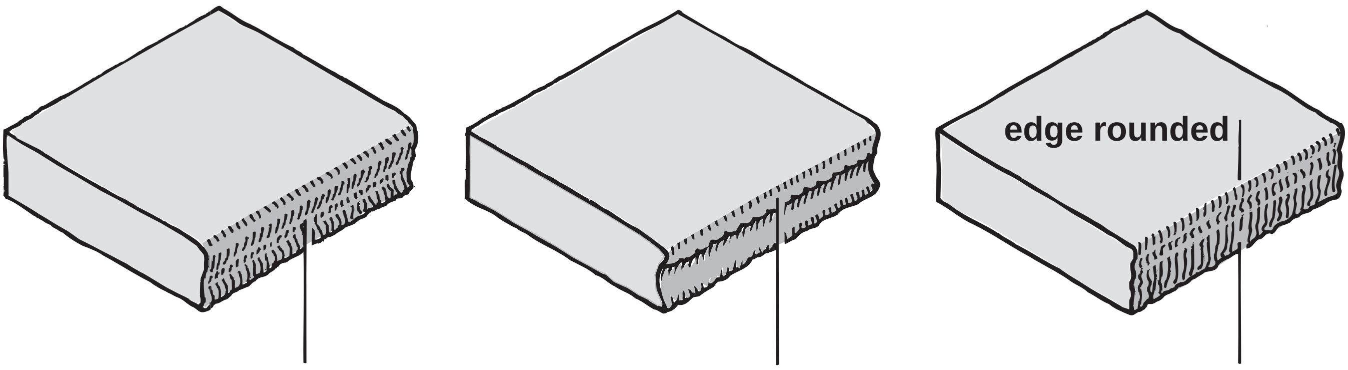
The aim is to produce a cut with:

- a uniform gap (kerf)
- clearly defined edges
- smooth faces
- no adhering slag



The quality of a cut surface depends on a number of variables

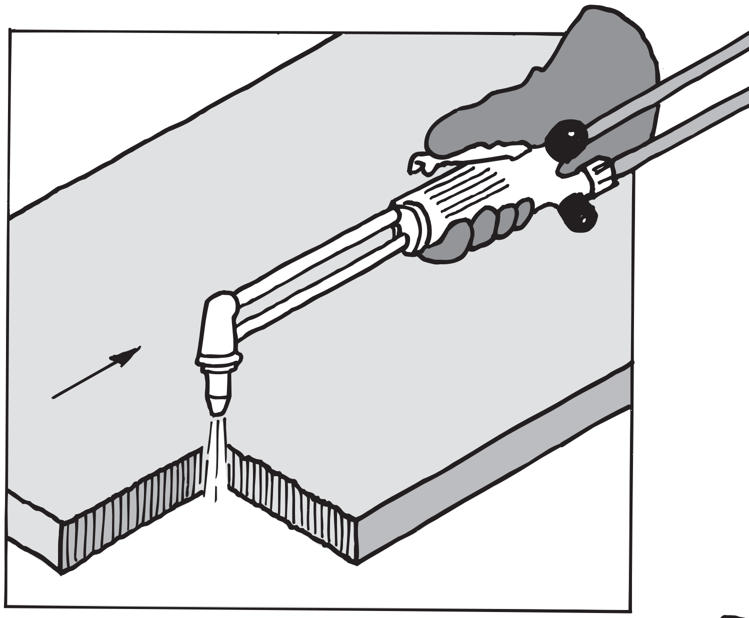
Variable	Condition	Effect
Nozzle-to-plate distance	too low	top edge rounded
	too high	undercutting
Cutting oxygen pressure	too low	cutting stops
	too high	irregular face variable width
Cutting speed	too low	excessive melting; slag adheres to face
	too high	undercut; slag bridges bottom
Preheat flame	too small	cutting stops
	too big	top edge very rounded



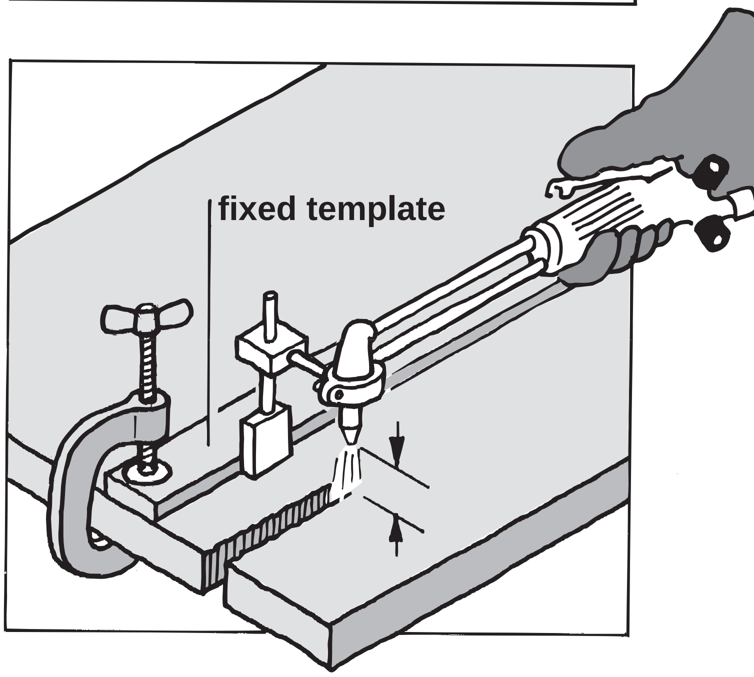
Operating techniques

Manual cutting is used for short cuts and the removal of defective parts.

It is difficult to achieve a uniform cut with manual techniques. Variations in travel speed and nozzle-to-plate distance give irregular cut faces.



Improved results can be obtained by the use of guides for straight lines . . .

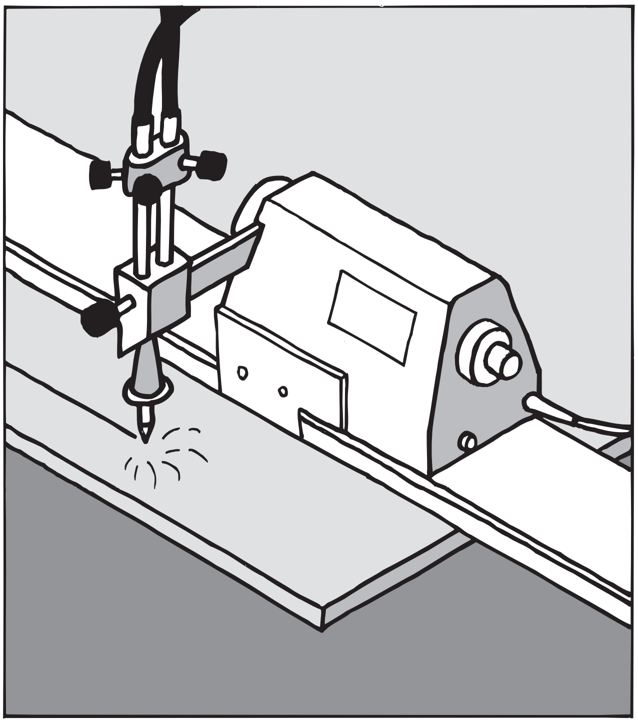


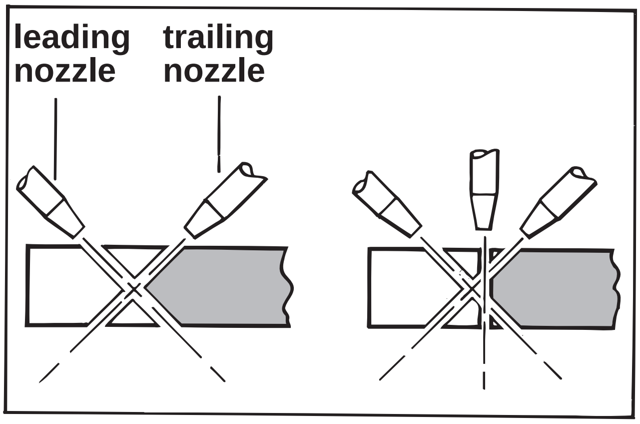
. . . and radius bars for circles.

Operating techniques

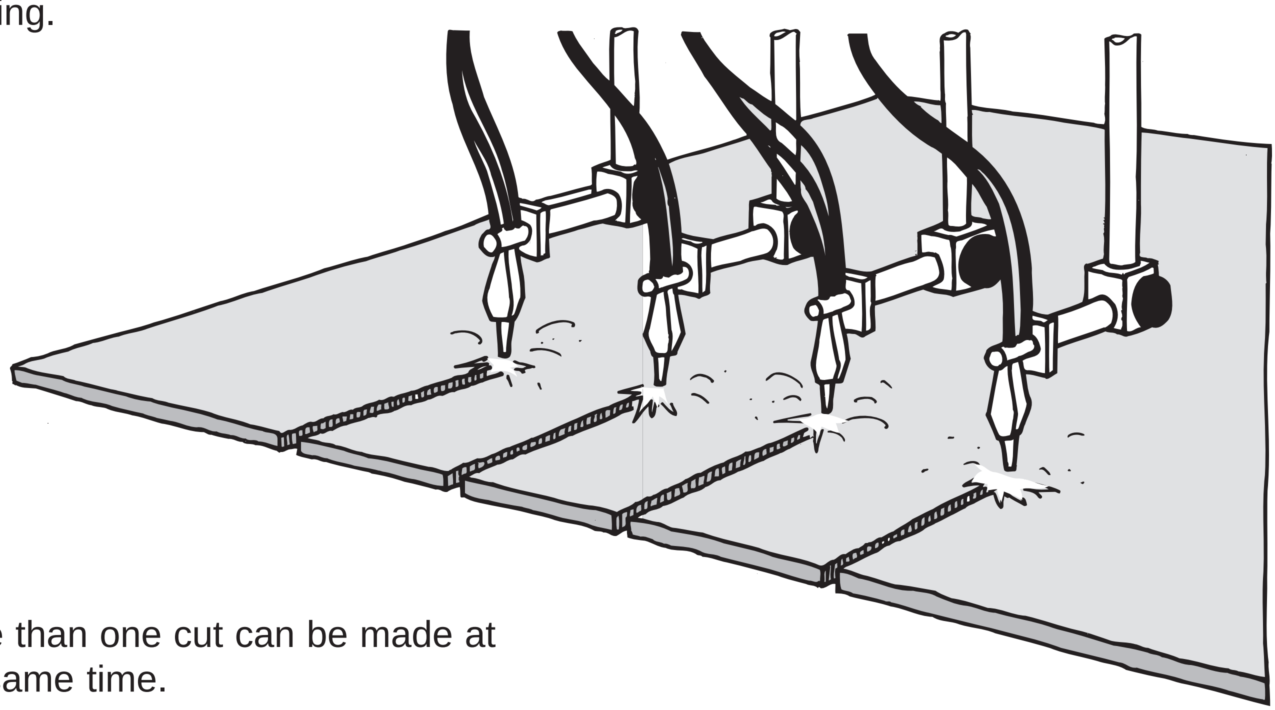
Mechanised cutting produces a superior finish to manual operation.

A variety of mechanised traversing systems are available or the torch can be moved along a straight line or by hand to produce a complex shape.





Mechanised systems can be used to prepare the edges of plate prior to welding.



More than one cut can be made at the same time.

Typical operating conditions

Plate thickness mm	6	9	12	18	25	35	50
Nozzle size - in	1/32	1/32	3/64	3/64	1/16	1/16	1/16
Cutting speed							
in/min	24	22	21	15	13	12	11.5
mm/sec	10.2	9.3	8.9	6.3	5.5	5.1	4.9
Cutting oxygen							
pressure — bar	1.8	1.8	2.1	2.1	2.8	3.2	3.2
psi	25	25	30	30	40	45	45
flow rate l/hr	650	950	1150	1600	2000	2500	3300
Preheat gas							
pressure — bar	.14	.21	.21	.21	.30	.30	.30
psi	2	3	3	3	4	4	4
flow rate l/hr							
Apachi+	250	260	295	295	340	400	400
oxygen	900	950	1025	1025	1150	1350	1350
Acetylene	310	320	340	340	400	430	430
oxygen	340	355	375	375	440	475	475
Propane	255	265	300	300	350	400	400
oxygen	1080	1125	1275	1275	1475	1720	1720

Note: These conditions provide a starting point. Precise settings depend on the type of nozzle, nozzle-to-plate distance and the condition of the plate surface.

Plasma arc cutting

Accurate cuts can be made in stainless steel and non-ferrous metals such as aluminium by plasma arc cutting.

The cuts are made by a high temperature, high velocity gas jet generated by constricting an arc between a tungsten electrode and the component.

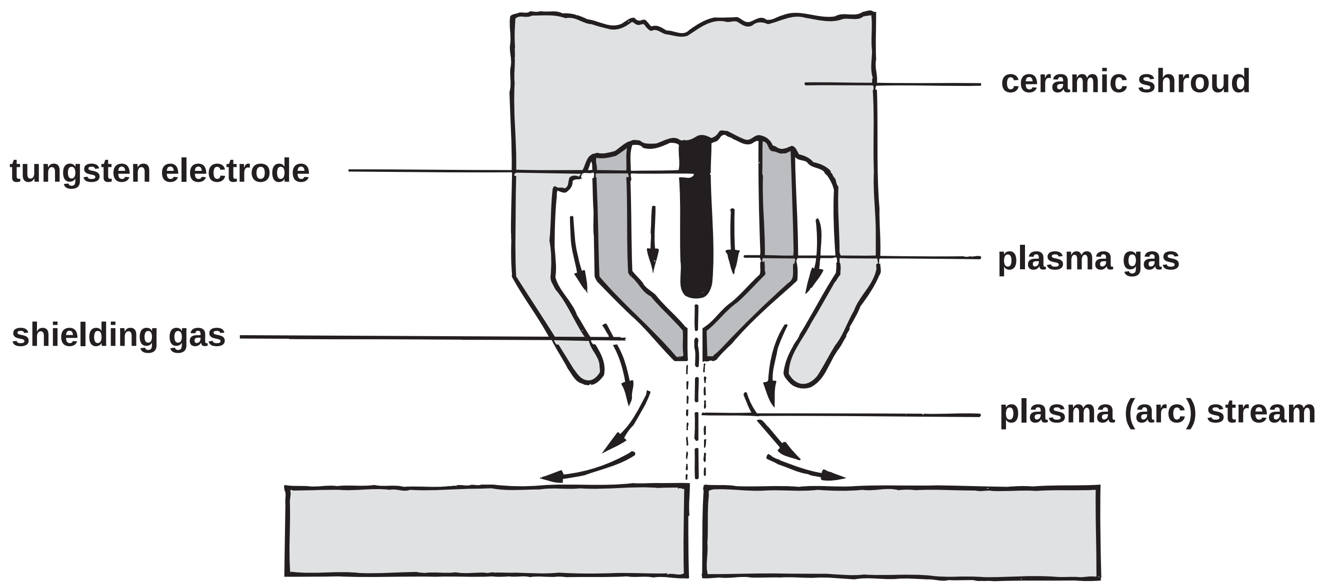
The heat from the arc melts the metal and the gas jet removes the molten metal from the cut.

The arc operates in an inert inner shield, whilst an outer shield provides protection for the cut surface.

Argon, helium, nitrogen and mixtures of these gases are used for both the inner and outer shields.

Plasma arc cutting is characterised by fast cutting speeds and is mainly used in mechanised systems.

The cutting is accompanied by a high noise level which can be reduced by operating the torch under water.



Hytec 35

Hytec 35 is a gas mixture which has been specially formulated for plasma arc cutting. It contains 65% argon and 35% hydrogen.

Hytec 35 is used as the plasma gas. The shielding gas can be nitrogen or argon.

Benefits of Hytec 35

- Increased cutting speed
- Reduced oxidation
- Narrow kerf — less metal wastage
- Clean cut surface
- Handles thicker section material

Hytec 35 - plasma cutting parameter guide

	Plate thickness mm	Speed mm/min	Orifice size mm	Power kW	Flow rate l/min
Aluminium	6	7607	3	60	82.6
	12	2536	3	70	82.6
	25	1268	4	80	94.4
	50	507	4	80	94.4
	75	380	5	90	94.4
	100	304	5	90	94.4
Stainless Steel	12	2536	3	60	70.8
	25	1268	4	80	80.2
	50	507	4	100	94.4
	75	406	5	100	94.4
	100	203	5	100	94.4

For specific parameters and gas flow rates consult your equipment manual.

Golden rules for safe handling of welding and cutting gases

Safety always — accidents never

Always understand the properties and hazards associated with each gas before using it.

Always wear suitable eye and face protection when dealing with gas.

Always store cylinders in the vertical position, and ensure that they are properly secured.

Always protect your hands! Wear stout gloves when handling gas cylinders.

Always use a proper trolley for moving cylinders, even for a short distance.

Never attempt to repair or modify cylinder valves or safety relief devices.

Never remove or obscure official labelling on a gas cylinder and always check the identity of a gas before using it.

Never smoke when dealing with gas.

Never use direct heat on a cylinder. Keep cylinders cool.

Never allow oil or grease on cylinders and valves and always close the valve when not in use.

Never lift a cylinder by its cap, guard or valve. Always replace caps and guards.

Air Products Welding Specialists provide technical advice to companies and individuals in the welding industry throughout the UK and Ireland.

Why not let our team of experts assist you with your welding queries.

Our trained staff are on hand to provide the answers you need, ensuring you get the best weld every time.

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