Handbooks in welding technology series

TIG and PLASMA Welding

Process techniques, recommended practices and applications

W Lucas

Published in association with Huntingdon Fusion Techniques

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ABINGTON PUBLISHING

Woodhead Publishing Ltd in association with The Welding Institute
Cambridge England

Published by Abington Publishing
Woodhead Publishing Limited, Abington Hall, Granta Park
Great Abington, Cambridge CB21 6AH, England
www.woodheadpublishing.com

First published 1990
Reprinted 2008

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

ISBN 978-1-85573-005-2

Printed by Victoire Press Ltd, Cambridge, England

Foreword

With ever increasing attention to quality control and automation in welding, TIG and plasma processes are becoming more widely used.

Huntingdon Fusion Techniques Limited has specialised in providing precision welding equipment and accessories since 1975 and are delighted to be associated with this informative book.

Dr Lucas touches on most aspects of TIG and plasma welding which should give this work a wide appeal to all people wishing to use a high quality controlled heat input welding process.

We commend 'TIG and Plasma Welding' to all people involved with teaching, design and manufacturing as an easy to read and comprehensive book, which should not date.

Ron A Sewell
Managing Director
Huntingdon Fusion Techniques Ltd

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Part II PLASMA WELDING

Preface

The tungsten arc welding processes are currently exploited widely for precision joining of crucial components and those which require controlled heat input. The small intense heat source provided by the tungsten arc is ideally suited to the controlled melting of the material. As the electrode is not consumed during welding, as with the MIG (GMA) or MMA (SMA) welding processes, autogenous welding can be practised without the need for continual compromise between the heat input from the arc and the deposition of the filler metal. Because the filler metal, when required, can be added directly to the weld pool from a separate wire feed system, all aspects of the process can be precisely and independently controlled, i.e. the degree of melting of the parent metal is determined by the welding current with respect to the welding speed, whilst the degree of weld bead reinforcement is determined by the rate at which the filler wire is added to the weld pool.

Within the context of gas tungsten arc welding two quite distinct processes have emerged - TIG and plasma welding. Whilst both are equally suitable for manual and mechanised welding, certain operating modes can be exploited for specific applications. These unique modes are derived almost exclusively from the electrode/torch configuration and the gas flow system. However, within the two welding processes there are a number of important operating techniques or process variants which can almost be considered as welding processes in their own right. The variants of interest include:

Pulsed current (TIG and plasma);
Micro-TIG;
TIG-hot wire;
Narrow gap TIG;
Keyhole plasma.

To aid a full understanding of the operating features of the TIG and plasma processes and their variants, i.e. with a view to exploiting the advantageous features, information is initially presented on the fundamental electrical, arc and process characteristics. However, because of the similarities in their operating characteristics, the welding engineer often has to make a difficult choice between techniques. Practical experience gained at The Welding Institute in evaluating the techniques, together with the production experience of its Research Members, have shown that there are areas where the special features of each technique offer specific advantages. Thus, considerable emphasis is placed on describing current applications including operating data, in a wide range of components from the various sectors of industry. It is hoped that by elucidating the reasons for the choice of a particular technique, readers will be better placed to make the best use of TIG and plasma welding in their own company.

The author acknowledges process research and development data and helpful discussions on the technical aspects of TIG and plasma welding with colleagues at The Welding Institute, in particular J C Needham, G A Hutt, M R Rodwell, I D Harris and M D F Harvey. Particular thanks are extended to D Patten, B O Males and M G Murch for guidance on the practical techniques described and the information provided on the application of the TIG and plasma welding processes.

Help with the preparation of the manuscript and the drawings by Mrs J M Lucas, M J Lucas and W B Lucas is gratefully acknowledged. Abington Publishing would also like to thank Mr R Sewell for his helpful advice.

The following companies have kindly agreed to the publication of technical information and photographs of applications: Air Products plc, British Alcan Ltd, Babcock Energy Ltd, Foster Wheeler Power Products Ltd, ESAB, Huntingdon Fusion Techniques Ltd, Precision Systems Ltd, APV Paramount Ltd, Skomark Engineering Ltd, Devtec Ltd, William Press Ltd, Darchem Engineering Ltd, SAF Welding Products Ltd, Abia, BOC Ltd, Arc Machines Inc, Saipem SpA, Equipos Nucleares SA, Kobe Steel Company, Sciaky Bros Ltd, Rolls Royce Plc (Rodney Fabrication Facility), Jet Joint Undertaking.

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Printed in the United Kingdom
by Lightning Source UK Ltd.
118622UK00001B/184-189

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Chapter 1

The TIG welding process

Most forms of electric arc welding make use of the fact that shorting and then separating conductors connected to the positive and negative poles of an electric current source creates an arc, and thus an area of concentrated heat. If this arc occurs in air the metals being welded can become oxidised, and to some extent vaporised, by the uncontrolled intense heat produced. This unwanted effect can be reduced by use of a flux or, in the case of TIG, an inert gas shield. The power source thus controls the short circuit, directs the arc and allows the molten metal to flow evenly without oxidation.

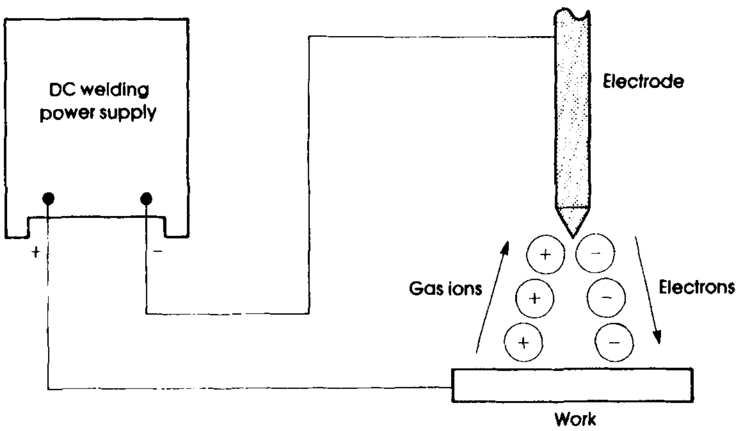
Terminology

The process is known by various names as follows:

- *TIG* - Tungsten inert gas, the best known name in Europe but generally understood world-wide;
- *GTAW* - Gas tungsten arc welding, mostly in the USA;
- *WIG* - Wolfram (tungsten) inert gas, German definition.
  For the purpose of this book only the first definition is used.

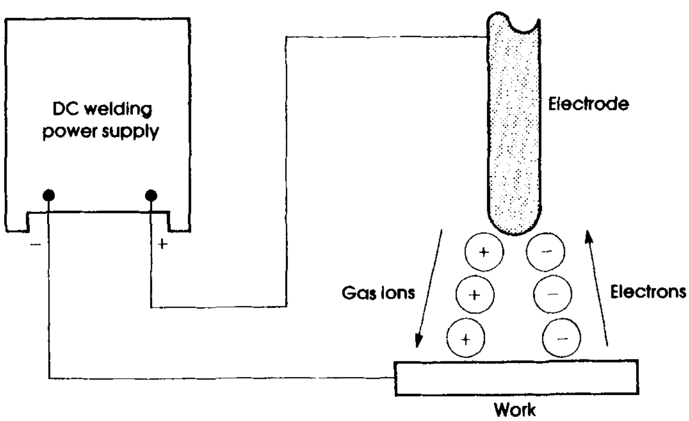
Modes

- *DC* – direct current, electrode negative, work positive. Sometimes known as straight, *i.e.* unpulsed DCEN (or DCSP in the USA), Fig. 1.1.



1.1 DCEN polarity.

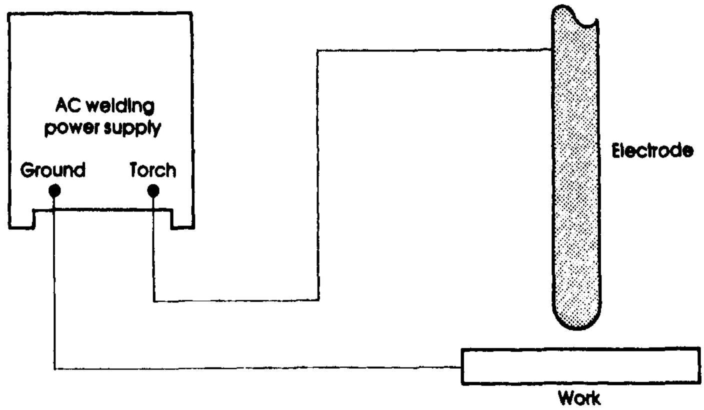
- *DC reverse polarity*, electrode positive, work negative (not used as widely), DCEP (or DCRP in the USA), Fig. 1.2.



1.2 DCEP polarity.

Note: The terms DCEN and DCEP are preferable as they indicate electrode polarity for both the above.

- *AC* – alternating current. In this mode arc polarity rapidly changes giving some cathodic cleaning effect, ideal for aluminium where oxides rapidly develop in the weld bead, and for some stainless steels. An AC/DC power source gives the ability to select either DC or AC as the occasion arises and would be the best purchase for a general fabrication shop where many different metals of varying thickness to weld would often be encountered, Fig. 1.3.



1.3 AC operation.

- *Pulsed DC* - This mode allows the arc to be pulsed at various rates between selectable high and low current settings and gives greater control of heat in the arc area.

TIG welding is clean, cost-effective, albeit a bit slow compared with metal inert gas (MIG) and metal active gas (MAG) welding, can be used by hand or automated and will weld a vast range of metals and thicknesses in several different modes. Whatever mode is used, the process remains the same, namely that the metals to be joined are fused together by the heat of an electric arc within a shield of inert gas which surrounds the arc and prevents undue oxidation of the metal. The arc is struck between the electrode and the workpiece and, in all but a very few cases, the electrode is made from tungsten, often with small quantities of a rare metal alloyed into the finished electrode rod.

A TIG arc is very hot and localised providing a means of applying maximum heat for welding in a small area, allowing an experienced welder to produce neat, compact weld beads with excellent penetration and strength.

Other terminology

AUTOGENOUS

A common term in TIG welding which means that the weld is formed by fusion of the parent metal(s) only and that no additional filler rod or wire has been introduced into the weld bead. It is generally considered that the *maximum* thickness for autogenous butt welding of mild and stainless steels by TIG is 2.5 mm (0.100 in) with other metals pro rata, depending on their heat conducting properties.

Note - a situation where the electrode touches the weld pool and welding ceases is known by expressions such as touch down, stub in or plough in, amongst others (often unrepeatable).

BACK PURGE

This is a condition in which additional shielding gas is piped to the underside of the weld bead, and some high quality power sources have an extra gas circuit and controls specifically for this purpose. It ensures that the underbead has a clean smooth surface with minimum or zero porosity. It is essential when fabricating vessels and welding tubing circuits for the food and drink processing industries where porosity could occur and harbour dangerous micro-organisms. It also serves to keep the underbead as small as possible, as large porous underbeads can affect the smooth flow of liquids through pipes and tubes.

CRATER

An imperfection or dimple at the end of a weld seam which can occur if the weld is suddenly terminated at full current. Craters can be eliminated, particularly in automatic welding by correct use of slope-down. With manual welding, craters are filled by use of the current control pedal.

DOWNSLOPE

Opposite of upslope, allowing the arc to die away or decay gradually. Also known as slope out and, in the USA, ramp out.

DUTY CYCLE OF A POWER SOURCE

A term used to define the period of time for which a power source can be used at a particular current level without overloading. Stated as a percentage, generally related to a ten minute period, or in the form of a graph, see Fig. 1.4.

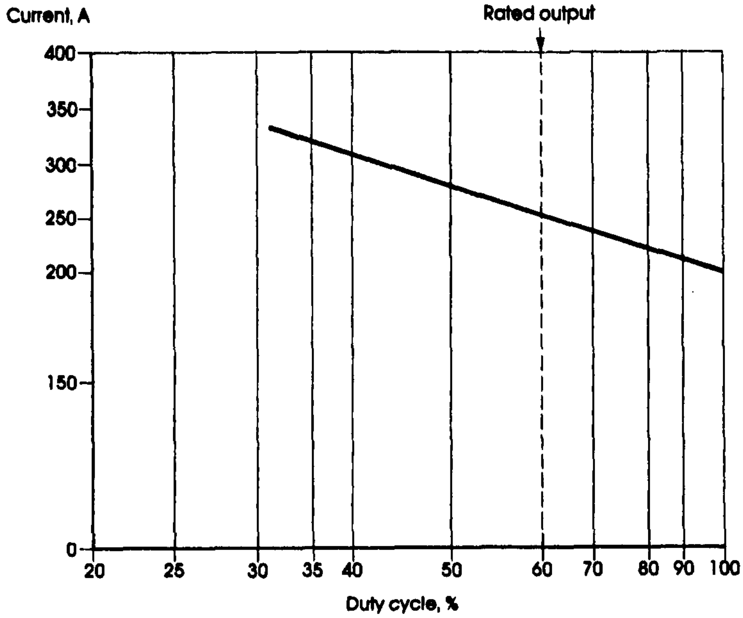
A typical power source may be rated as follows:

Nominal rated* current 250 A at 60% duty cycle giving:

	315A at 35% duty cycle	...	3.5 min
*	250A at 60% duty cycle	...	6.0 min
	200A at 100% duty cycle	...	10.0 min (continuous)

Welding shop use is nearly always intermittent, so the set usually has a chance to cool to normal operating temperature. Overload trips are often fitted to avoid electrical damage. These trips are either manually or automatically reset. When purchasing a set do not be misled by maximum current, pay attention to the stated duty cycle and select a unit with power above your normal needs.

Note: arc voltage generally increases slightly as duty cycle decreases. AC/DC TIG sets can be marginally less efficient than AC or DC *only* models.



1.4 Duty cycle of a power source.

EARTH OR GROUND

These are misnomers but have become normal reference terms in all welding processes and should correctly be called welding 'current return'. The terms refer to the return circuit to the power source. Critical to the welding process, the return circuitry should carry the *full rated output* of the set.

HEAT AFFECTED ZONE (HAZ)

A term used to describe the region immediately around the weld bead. This area should be kept as small as possible and heat sinks are commonly used. Keeping the HAZ small reduces discoloration in the area around the weld zone and thus minimises finishing and polishing times.

HIGH FREQUENCY ARC START (HF)

In the past, HF pulses were used at the electrode tip to provide an ionised air bridge across which the welding current flowed from the tip to the work and established an arc. Once the arc was established the HF was terminated after a few milliseconds only. Now largely replaced by specialised electronic systems which eliminate, or at least minimise, RF and HF interference with peripheral equipment such as computers and DC motor control systems.

RF interference

RF stands for radio frequency and interference with electronics circuits and DC thyristor motor control systems can be caused by airborne RF. It generally results when electromagnetic waves combine either to reinforce each other or to cancel each other out, depending on their relative phases. It is rather difficult to eliminate when caused by HF arc start systems using spark gaps, but these are gradually being replaced by modern electronic devices which minimise both HF and RF interference. The effect of RF on welding system peripherals is similar to that caused by unsuppressed automobile ignition systems (very rare these days).

Computer programs have been known to be completely obliterated by both HF and RF but advanced technology has come to the rescue. Interference with TIG peripherals is usually caused by spikes from HF entering the electrical mains supply circuit.

NUGGET

A slang term, mostly used in the USA, to describe a complete weld bead, particularly between two adjoining, butt welded sheets.

OSCILLATION OF THE ARC

Sometimes known as weaving, this is lateral traversing of the arc from side to side across the seam over a short distance at a fixed speed whilst the torch travels longitudinally along the seam. It is best carried out by mechanical means, although highly skilled operators achieve excellent results by hand. Its purpose with heavier welds is to obtain good melt-in or sidewall fusion at the edges of the seam where the metal is thickest and it is particularly advantageous for capping runs when using a V or J edge preparation.

POST-PURGE

The condition in which shielding gas continues to flow through the ceramic nozzle on the torch for a period *after* the arc is extinguished. It is advisable always to allow a reasonable post-purge time as the electrode tip cools whilst still in an inert gas atmosphere, making for longer tip life between regrinds. The post-flow period also blankets the weld area whilst it is cooling, preventing undue oxidation and giving a better cosmetic appearance to the finished weld. The post-purge period is also often specified for certified welds.

PRE-PURGE

The condition is which the flow of shielding gas through the ceramic nozzle on the torch commences *before* an arc is struck. The period of pre-flow, usually variable at the gas valve on the power source, is mostly fairly short but serves to ensure that there is a minimum of free oxygen remaining in the arc area when welding commences. Extra long pre-purge periods are often specified for critical and certified welds.

UPSLOPE

Used extensively with thin metal sections, this is the condition where the arc is first struck at a low current and then increased on a timed basis up to the full required welding current level. It is ideal for automatic welding, particularly for critical circumferential or orbital applications. Also known as slope in and, in the USA, ramp up.

The following definitions do not strictly apply to this book but are included for interest:

GAS METAL ARC WELDING (GMAW)

The preferred term for MIG/MAG welding in the USA.

METAL INERT GAS (MIG)

Using argon or mixes for shielding.

METAL ACTIVE GAS (MAG)

Using CO_2 or mixes for shielding.

MOG

A rather ambiguous term. Stands for metal 0 (zero) gas although a shielding gas *is* produced from the heating of a flux core contained in the consumable wire electrode.

Note: the above are all semi-automatic processes using a continuously fed consumable wire electrode and a flow of shielding gas.

MANUAL METAL ARC (MMA)

The layman's general view of welding, using consumable stick electrodes with a flux coating.

SUBMERGED-ARC WELDING (SAW)

The weld is carried out using a wire fed through a gun similar to MIG/MAG but with the arc taking place under a continuously spread flux powder blanket (from a hopper) which can be recovered and reused to some extent. Useful for very heavy welds in thick carbon steels.

Part I TIG (GTA) WELDING

CHAPTER 1
Process fundamentals

DC TIG

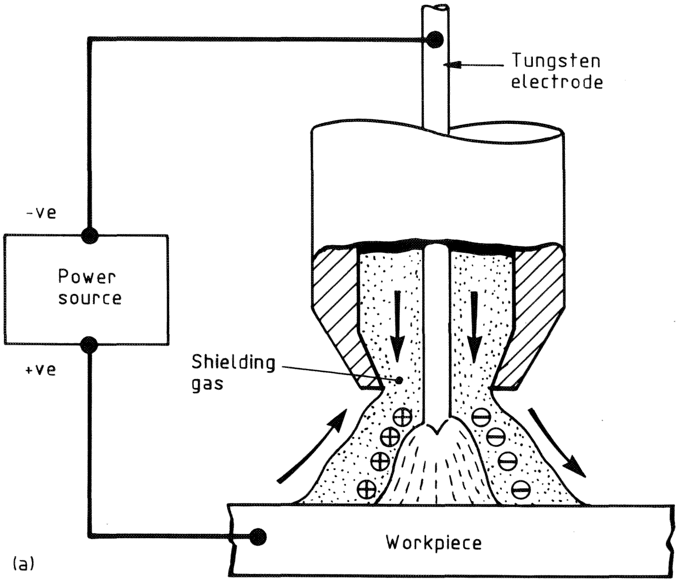
In tungsten inert gas (TIG or GTA) welding the arc is formed between a pointed tungsten electrode and the workpiece in an atmosphere of argon or helium, Fig. 1. In DC welding, the electrode usually has negative polarity (US nomenclature is DC straight polarity) - its electron thermionic emission properties reduce the risk of overheating which may otherwise occur with electrode positive polarity (Fig. 1a). The ionised gas or plasma stream thus formed can attain a temperature of several thousand degrees centigrade, at least in the central core of the arc near to the electrode. Consequently, within the normal range of welding currents from a fraction of an ampere to several hundred amperes (selected according to the thickness of the material) rapid melting can be effected. However, the operation of tungsten arc processes in practice is essentially very simple as the heat required to melt the metal is determined merely by setting the welding current relative to the welding speed, generally within the range 0.1-300A.

As the electrode is not consumed during welding, additional metal e.g. when required to fill a joint, must be added separately in the form of a wire rod (Fig. 1b).

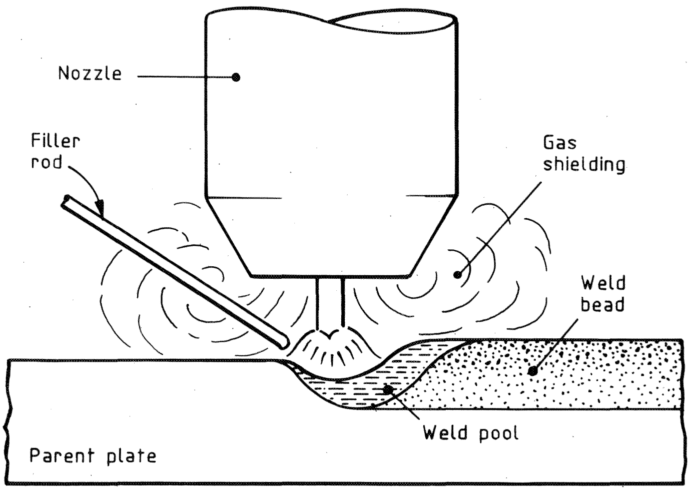
The gas supplied to the arc has two functions; it generates the arc plasma, and it protects the electrode weld pool and weld bead from undesirable oxidation. The arc is in the form of a cone (Fig. 1b), the size of which is determined by the current, the electrode diameter and vertex angle, but the penetration characteristics are primarily determined by the current level and the shielding gas composition.

Electrode

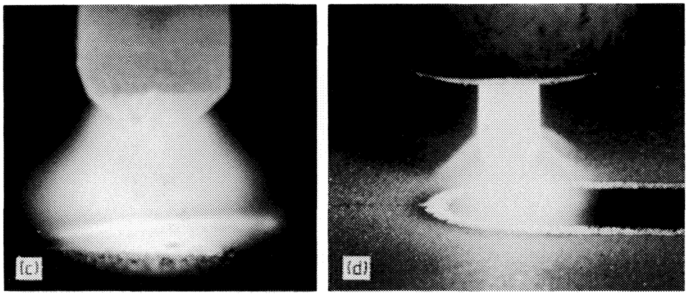
Selection of electrode composition and size is not completely independent and must be considered in relation to the operating mode and the current level. Electrodes for DC welding are pure tungsten or tungsten with 1, 2 or 4% thoria, the thoria being added to improve electron emission which


Tungsten electrode
-ve
Power source
+ve
Shielding gas
Workpiece

(a)


Nozzle
Filler rod
Gas shielding
Weld bead
Weld pool
Parent plate

(b)



1 *The TIG welding process: a) Torch and power source arrangement; b) TIG welding operation; c) Characteristic appearance of the DC TIG arc and weld pool; d) Characteristic appearance of the AC TIG arc showing cathodic cleaning of the plate surface.*

facilitates arc ignition. Alternative additions to lower the electron work function are lanthanum oxide or cerium oxide, which are claimed to improve starting characteristics, provide excellent arc stability, lower electrode consumption and replace thoria which is radioactive. When using thoriated electrodes it is recommended that precautions are taken in their handling and storage and if possible avoid contact with grinding dust and smoke. In DC welding, a small diameter, finely pointed (approximately 30°) electrode must be used to stabilise low current arcs at less than 20A. As the current is increased, it is equally important to readjust the electrode diameter and vertex angle. Too fine an electrode tip causes excessive

Table 1 Recommended electrode diameter and vertex angle for TIG (GTA) welding at various current levels

	DC, electrode negative			AC	
Welding current	Electrode* diameter		Vertex angle	Electrode† diameter	
A	mm	in	degrees	mm	in
<20	1.0	0.040	30	1.0–1.6	0.040–1/16
20–100	1.6	1/16	30–60	1.6–2.4	1/16–3/32
100–200	2.4	3/32	60–90	2.4–4.0	3/32–5/32
200–300‡	3.2	1/8	90–120	4.0–4.8	5/32–3/16
300–400‡	3.2	1/8	120	4.8–6.4	3/16–1/4

* Thoriated tungsten

† Zirconiated tungsten, balled tip, electrode diameter depends on degree of balance on AC waveform; for balanced waveform use larger diameter electrode

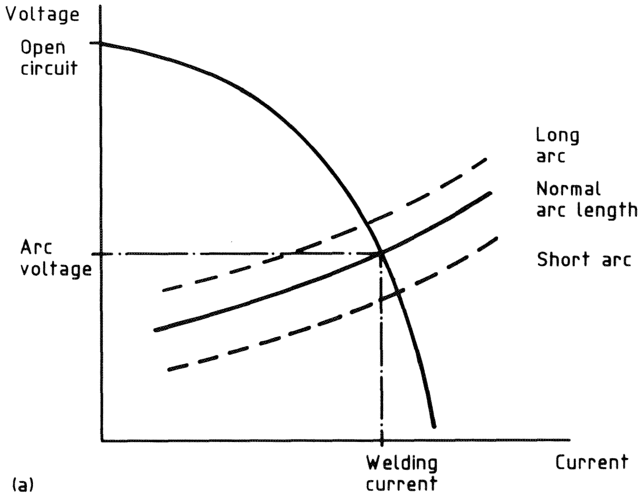
‡ Use current slope-in to minimise thermal shock which may cause splitting of the electrode

broadening of the plasma stream, due to high current density, which may result in a significant decrease in the depth to width ratio of the weld pool. More extreme current levels result in excessively high erosion rates and eventually in melting of the electrode tip. Recommended electrode diameters and vertex angles in argon shielding gases for the normal range of currents are given in Table 1.

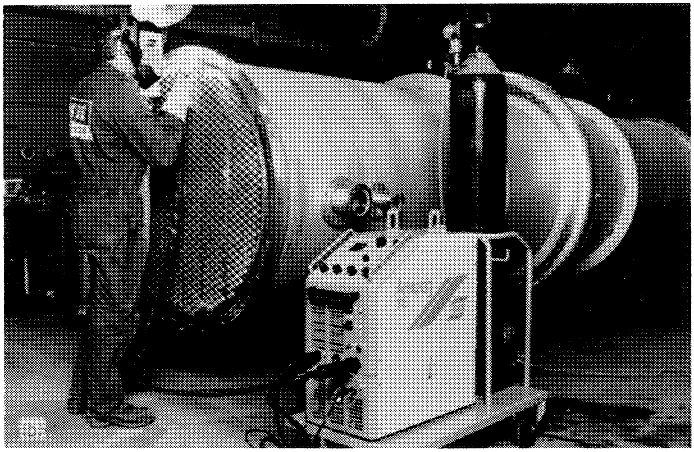
In AC welding, where the electrode must operate at a higher temperature, the positive half-cycle generates proportionally more heat in the electrode than when operating with electrode negative polarity. A pure tungsten or tungsten-zirconia electrode is preferred, as the rate of tungsten loss is somewhat less than with thoriated electrodes. Furthermore, because of the greater heating of the electrode, it is difficult to maintain a pointed tip and the end of the electrode assumes a spherical or 'balled' profile (Fig. 1d).

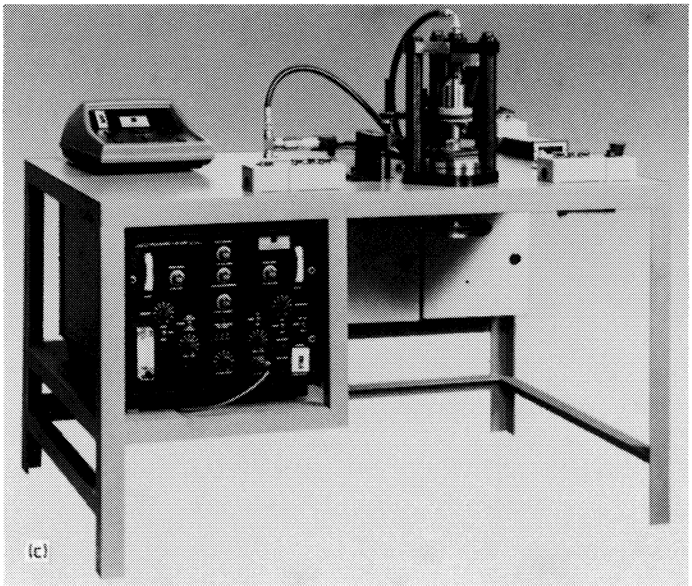
Power source

The power source necessary to maintain the TIG arc has a drooping voltage-current characteristic which provides an essentially constant current output even when the arc length is varied over several millimetres (Fig. 2a). Hence, the natural variations in arc length which occur in manual welding have little effect on welding current level. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited on to the workpiece. Otherwise, excessively high currents are drawn, damaging the electrode and even fusing the electrode to the workpiece.



(a)





2 Power sources for TIG welding: a) Operating characteristics of a constant current power source; b) Inverter power source for manual welding (courtesy of ESAB); c) Transistor (100A) power source for mechanised welding of precision components (courtesy of Huntingdon Fusion Techniques Ltd).

In practical operation the power source is required to reduce the high voltage mains supply, 240 or 440V, AC, to a relatively low open circuit voltage, 60-80V, AC or DC. In its basic form, the power source comprises a transformer to reduce the mains voltage and increase the current, and a rectifier, placed on the secondary side of the transformer to provide the DC supply. Traditional power source designs use a variable reactor, moving coil or moving iron transformers, or a magnetic amplifier to control the welding current. Such equipment has the highly desirable features of simple operation and robustness, making it ideally suited to application in aggressive industrial environments. The disadvantages are relatively high material costs, large size, limited accuracy and slow response. More recently, electronic power sources have become available which do not suffer from these disadvantages, but at their present stage of development are more expensive. The various types of electronic power source are:

- Thyristor (SCR), phase control;
- Transistor, series regulator;
- Transistor, switched;
- AC line rectifier plus inverter.

The major operating features of these systems, with their advantages and disadvantages, are given in Table 2. Of the power source designs listed, the transistor based, series regulator control systems offer greater accuracy and reproducibility of welding parameters, but tend to be wasteful of electrical energy. The AC line rectifier plus inverter type offers the combination of high electrical efficiency and small size. Examples of compact commercially available power sources for manual and mechanised operation are shown in Fig. 2b and c.

Shielding gas

The shielding gas composition is selected according to the material being welded, and the normal stage of commercially available gases is given in Table 3. In selecting a shielding gas it should be noted that:

1 The most common shielding gas is argon. This can be used for welding a wide range of materials including mild steel, stainless steel, and the reactive metals—aluminium, titanium and magnesium.

2 Argon-hydrogen mixtures, typically 2% and 5%H_2, can be used for welding austenitic stainless steel and some nickel alloys. The advantages

Table 2 Major operational features of electronic power sources compared with conventional variable reactor or magnetic amplifier power sources

Control type	Method of control	Advantages	Disadvantages
1 Thyristor (SCR) phase	SCRs replace diodes on secondary output of the transformer Alternatively, triacs or inverse parallel SCRs used in the primary of the transformer	**1** Better accuracy of current and time settings **2** Can be used to produce square wave AC waveform **3** Can be used for pulsed operation	**1** High ripple unless large amount of inductance is placed in series with output **2** Pulsed response normally limited to 100Hz
2 Transistor series regulator	Power transistors in parallel, analogue control from low current input signal	**1** Very stable and accurate control of current level – better than 1% of set level **2** Pulsing over wide range of frequencies, up to 10 kHz, and pulse shape can be varied	**1** Poor electrical efficiency **2** DC supply only
3 Transformer with secondary (transistor) chopper	Transistor, high frequency switching of DC supply	**1** Accuracy and control similar to series controller **2** Less wasteful of energy compared with series controller **3** Greater arc stiffness can be exploited for low current operation	**1** Although similar output to series controller, pulse frequency and wave shaping less flexible
4 AC line rectifier plus inverter	Mains supply rectified to high voltage DC then converted by transistors or SCRs to AC operating at 2–20 kHz. Final output produced by small mains transformer and rectified to DC	**1** Because transformer operates at high frequency, the size and weight of the mains transformer can be greatly reduced **2** Because of its small size, cost of raw materials significantly reduced **3** High electrical efficiency and high power factor	**1** Response rate not as high as transistor controlled power source

Table 3 Recommended shielding gases for TIG welding

	Shielding gas mixtures					
Metal	Argon	Argon $+H_2$	Helium	Helium-argon	Nitrogen	Argon-nitrogen
Mild steel	●					
Carbon steel	●			○		
Low alloy steel	●			●		
Stainless steel	●	●	○	○		
Aluminium	●		●	●		
Copper	●		●	●	○	○
Nickel alloys	○	●		○		
Titanium and magnesium	●		○			

● most common gas
○ also used

of adding hydrogen are that the shielding gas is slightly reducing, producing cleaner welds, and the arc itself is more constricted, thus enabling higher speeds to be achieved and/or producing an improved weld bead penetration profile, i.e. greater depth to width ratio. It should be noted that the use of a hydrogen addition introduces the risk of hydrogen cracking (carbon and alloy steels) and weld metal porosity (ferritic steels, aluminium and copper), particularly in multipass welds.

3 Helium and helium-argon mixtures, typically 75/25 helium/argon, have particular advantages with regard to higher heat input; the greater heat input is caused by the higher ionisation potential of helium which is approximately 25eV compared with 16eV for argon. As the helium based shielding is considerably 'hotter' than an argon based gas, it often promotes higher welding speeds and improves the weld bead penetration profile. The reluctance to exploit the benefits of helium is directly associated with its cost, which in special gas mixtures may be as much as three times that of argon. A secondary disadvantage in employing helium rich gases is the difficulty often experienced in initiating the arc, which can be particularly severe in pure helium.

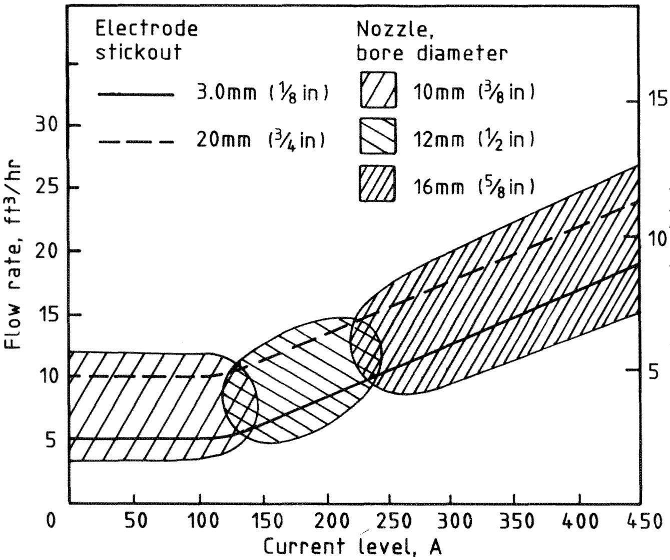
4 As nitrogen is a diatomic gas, on re-association at the workpiece surface, it is capable of transferring more energy than monatomic argon or helium. Hence its addition to argon can be particularly beneficial when welding materials such as copper, which have high thermal conductivity; the advantages of nitrogen additions cannot be exploited when welding ferritic and stainless steels, because nitrogen pick-up in the weld pool would cause a significant reduction in toughness and corrosion resistance.

Flow rate setting

Because of the inherent risk of porosity in TIG welding, the importance of efficient gas shielding cannot be stressed too highly. The shielding gas flow rate is influenced by the following factors:

- Nozzle diameter;
- Current level;
- Type of current;
- Electrode stickout;
- Shielding gas composition;
- Type of joint;
- Welding position.

Recommended shielding gas flow rates for various practical situations are given in Fig. 3. It should be noted that the flow rate should be increased



3 *Recommended shielding gas flow rates.*

when the electrode stickout, welding current or nozzle diameter is increased. In AC operation, as the arc is generally broader and the current reversals have a greater disturbance effect on the shield the flow rates should be increased by approximately 25% compared to DC welding at the same current level.

The effectiveness of a gas shield is determined at least in part by the gas density. As the density of helium is approximately one tenth that of argon, difficulties can be experienced in protecting the weld pool, particularly when welding under draughty conditions or at high currents, which may induce turbulence in the gas shielding stream. However, effective shielding can be maintained by increasing the gas flow, typically by a factor of two.

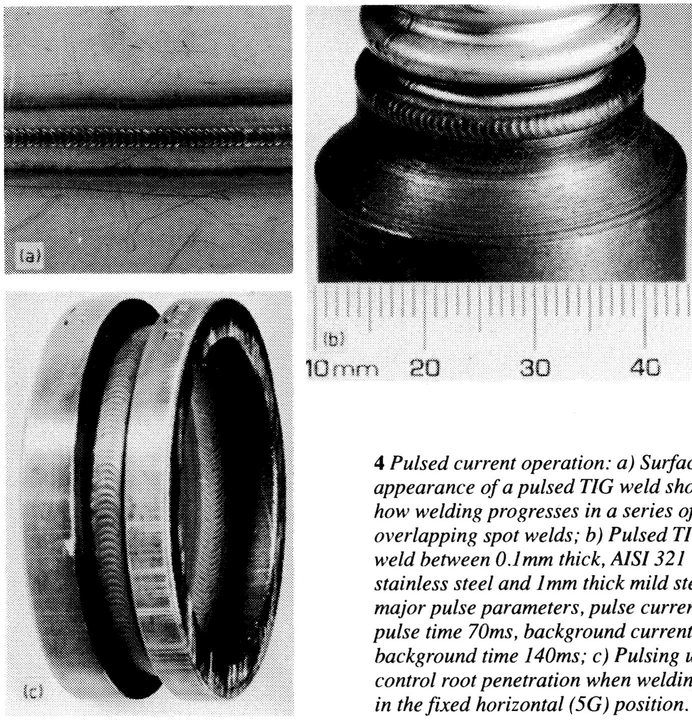
Shielding of the weld pool area can also be improved by the use of a gas lens, which is inserted into the torch nozzle to ensure laminar flow. Adoption of this technique is strongly recommended when welding in positions other than flat and for welding curved surfaces. When welding corner or edge joints, excessive flow rates can cause the gas stream to bifurcate which may result in air entrainment. The effectiveness of the gas shield can often be improved by reducing the gas flow by approximately 25% and here the use of a gas lens is considered essential.

Pulsed current

Principles

Particular mention must be made of the pulsed current technique as applied to TIG welding. The essential feature is that a high current pulse is applied causing rapid penetration of the material. If this high current were maintained, excessive penetration and ultimately burn-through would occur. Therefore, the pulse is terminated after a preset time and the weld pool is allowed to solidify under a low background or pilot arc. Thus the weld progresses in a series of discrete steps with the pulse frequency balanced to the traverse rate to give approximately 60% overlap of the weld spots. The surface appearance of a typical pulsed current weld is shown in Fig. 4a.

The pulsed technique has been found to be particularly beneficial in controlling penetration of the weld bead, even with extreme variation in heat sink. Such variations are experienced either through component design, thick-to thin sections, or from normal production variations in component dimensions, fit-up, clamping and heat build-up. In conventional continuous current welding, where a balance must always be achieved between the heat input from the arc, the melting to form the weld pool and the heat sink



4 *Pulsed current operation: a) Surface appearance of a pulsed TIG weld showing how welding progresses in a series of overlapping spot welds; b) Pulsed TIG weld between 0.1mm thick, AISI 321 stainless steel and 1mm thick mild steel; major pulse parameters, pulse current 75A, pulse time 70ms, background current 15A, background time 140ms; c) Pulsing used to control root penetration when welding pipe in the fixed horizontal (5G) position.*

represented by the material or component being welded, penetration is greatly influenced by these variations. However, in pulsed operation, rapid penetration of the weld pool during the high current pulse and solidification of the weld pool between pulses markedly reduce the sensitivity to process variation through the effects of heat build-up and/or disparity in heat sink.

An example of pulsed TIG welding between thin wall convoluted stainless steel tube and relatively thick wall mild steel tube is shown in Fig. 4b. Pulsing is also used to control root penetration when welding pipe in the fixed horizontal (5G) position, as shown Fig. 4c.

Parameter settings

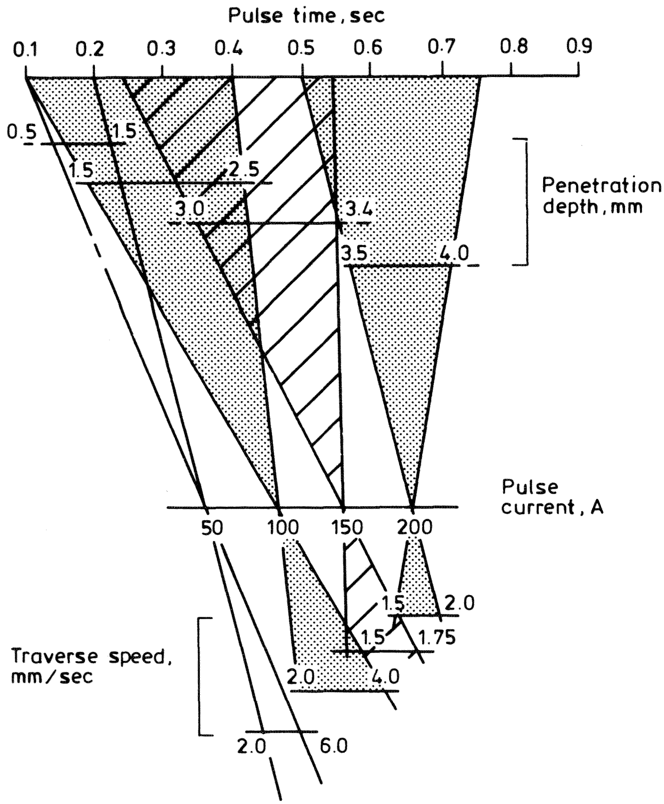
Despite the obvious advantages of the pulsed process in production, the technique may appear to be a further complication in that a greater number of welding parameters must be considered, i.e.:

- Pulse time;
- Pulse level;
- Background time;
- Background level.

The technique can be simplified in the first instance from the knowledge that, for a given material, there is a preferred pulse level which is based on its diffusivity and, to a lesser extent, on its thickness. The preferred currents are approximately 300A for copper, 150A for carbon steel, 100A for cupro-nickel and 50A for lead. Thus, for a given component, the operator need only set the pulse time to achieve penetration which is determined solely by thickness. For example, for welding 2.5mm (0.1in) stainless steel at 100A, a 0.4sec pulse would be demanded, whilst for a 1.5mm (0.06in) thick material, the pulse time would be reduced to 0.1sec at the same current level. The background parameters are considerably less critical in the pulsing operation. The background level is normally set at approximately 15A, which provides the greatest possible heat dissipation during this period whilst being high enough to maintain a stable arc. The background period is normally equal to the pulse period but may be some two or three times greater in welding thicker sections.

This approach is presented only as a guideline for the initial selection of welding parameters, and must be treated with caution, particularly when welding at the extremes of the thickness range, i.e. sections of greater than 3.0mm (0.12in) and less than 1mm (0.04in). In both instances, the preferred pulse current level will be outside the above theoretical operating ranges. For example in welding stainless steel, practical trials have established that for a thickness of 4mm (0.16in) the preferred pulse parameters are 200A/0.75sec, whilst for 0.5mm (0.02in) thick material, the preferred pulse parameters are 50A/0.1sec (Fig. 5).

Welding thick sections at too low a pulsed current can result in loss of most of the advantages of pulsing (controlled depth of penetration and tolerance to variation in heat sink) as the weld pool takes a long time to penetrate the material and thermal diffusion occurs ahead of the fusion front. In welding thinner sections with too high a pulsed current, the excessive arc forces may cause cutting and splashing of the weld pool, resulting in a poor bead profile and electrode contamination.



5 *Nomograph as an aid to the selection of pulse parameters in TIG welding.*

The capacity to use lower pulsed currents and longer pulse times is also of particular importance when using power sources which have a limited response, i.e. a low rate of rise and fall of the current between the background and the pulsed current levels. For instance, power sources in which the current is controlled by a magnetic amplifier are generally limited to pulses of 0.2sec duration, whilst in thyristor controlled types the response is markedly improved and pulses as short as 0.03sec can be generated. However, for complete flexibility, transistor controlled power sources are used which can generate pulses within an almost unlimited frequency range up to 10kHz. An added advantage of these power sources is the capacity to reproduce accurately complex pulse waveshapes which can be of benefit in controlling the weld pool and solidification structure.

AC TIG

Sine wave arc

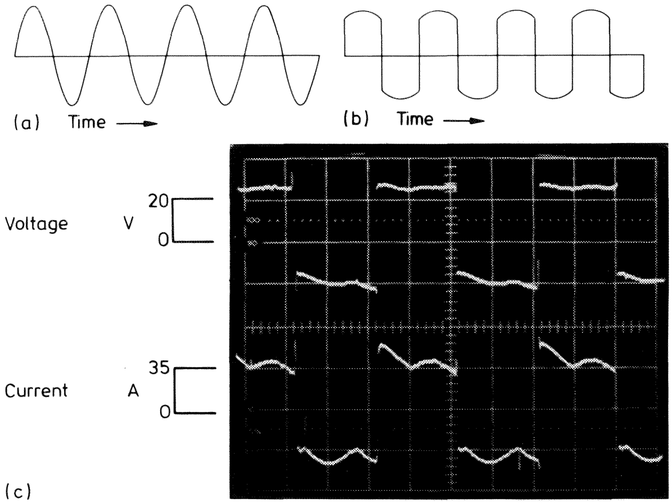
TIG welding is also practised with AC, the electrode polarity oscillating at a frequency of 50Hz. The technique is used in welding aluminium and magnesium alloys, where the periods of electrode positive ensure efficient cathodic cleaning of the tenacious oxide film on the surface of the material (Fig. 1d). Compared to DC welding, the disadvantages of the technique lie in the low penetration capacity of the arc and, as the arc extinguishes at each current reversal, in the necessity for a high open circuit voltage, typically 100V and above, or continuously applied HF, to stabilise the arc. Low penetration results in particular from the blunt or 'balled' electrode which is caused by the high degree of electrode heating during the positive half-cycle. Where deep penetration is required, use of DC with helium as the shielding gas, which does not suffer from these disadvantages and is somewhat tolerant to surface oxide, may be an alternative. Use of helium, however, is not particularly attractive because of its high cost and, in the absence of the cleaning action of the arc, the weld pool/parent metal boundaries can be somewhat indistinct, thus making it difficult to monitor and control the behaviour of the weld pool.

Square wave arc

A new generation of AC power sources has recently become available; their principal feature is that the output current assumes a more square waveform, compared with the conventional sine wave (Fig. 6). Two types of power source are available, differing in the manner in which the square waveform is produced. Whilst a 'squared' sine waveform is generated by using inverted AC, a more truly square waveform is produced by a switched DC supply.

In either case the importance for TIG welding is that the current is held relatively high prior to zero and then transfers rapidly to the opposite polarity. In comparison, the current developed by sine wave power sources decreases more slowly to current zero and likewise the current built up after re-ignition is at a much lower rate.

The benefit of square wave AC is that, aided by the inherent high surge voltage associated with the rapid current reversal, AC TIG can in some instances be practised at 75V without the need for HF spark injection to be superimposed for arc re-ignition.



6 Characteristic re-ignition waveforms for: a) Sine wave supply at 100 OCV; b) Switched DC supply at 75 OCV; c) Square wave AC power source.

An additional feature of square wave AC power sources is the capacity to imbalance the current waveform, i.e. to vary the proportion of electrode positive to electrode negative polarity. In practice, the percentage of electrode positive polarity can be varied from 30-70% at a fixed repeat frequency of 50Hz. By operating with a greater proportion of electrode negative polarity, heating of the electrode can be substantially reduced compared with that experienced with a balanced waveform. Although cleaning of the oxide on the surface of the material is normally sufficient with 30% electrode positive, the degree of arc cleaning may be increased by operating with a higher proportion of electrode positive (up to a limit of approximately 70%).

Further reading

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5 Yoryachev A P and Zelenin V A 'Mechanical deep penetration arc welding with a tungsten electrode'. *Automatic Welding* 1964 12.

6 Needham J C 'Joining metals by the pulsed TIG process - a solution to many welding problems'. *Australian Weld J* 1972 16 5.

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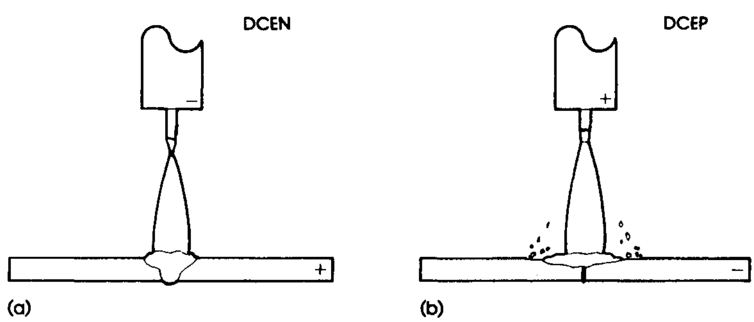
8 Yamamoto H: 'Recent advances in arc welding equipment and their application'. Welding Technology Japan, The Welding Institute, 1984.

Chapter 2

Advantages and applications

From an operator's point of view the main advantage of TIG welding is the fine control of the arc. The process also produces very little spatter so that cleaning after welding is minimised. In addition, very little fume and smoke are produced during welding, although fume removal is recommended in most cases other than perhaps ultra-low current precision work. The TIG process lends itself readily to machine or automatic application, a subject which will be discussed in detail in a later chapter.



2.1 Arc effect: a) DCEN produces maximum workpiece heating; b) DCEP produces maximum workpiece cleaning.

Arc effect

When TIG welding the operator has three choices of welding current, two of which are shown in Fig. 2.1. They are direct current electrode negative (DCEN), direct current electrode positive (DCEP), and alternating current with high frequency stabilisation. Each of these current types has its applications and advantages and disadvantages. A look at each type and its uses will help the operator select the best current type for the job.

The type of current used has a great effect on the penetration pattern as well as bead configuration.

Typical applications for various metals

ALUMINIUM

Used in the AC mode the TIG process is ideal although some grades of aluminium alloys and pure aluminium are weldable using DCEN on thin sections. Heavy fabrications are possible, *e.g.* tanks, silos, pipes and structural framework.

STAINLESS STEELS

Heavy sections can be fabricated using the DCEN mode, giving a very good weld appearance which often needs no further fettling or polishing. Low current TIG is very suitable for the precision welding of stainless alloys in the manufacture of such items as bellows, diaphragms, load cells and transducers, often by mechanical means using pulsed TIG.

MILD STEELS

Not always as suitable for welding as the stainless alloys, mild steels are more prone to weld porosity and distortion.

Note: for both mild, carbon and stainless steels free-machining alloys can be a problem. Certain shielding gas mixes, special filler wires and rods and attention to heat sinking can often help with these metals but they should be avoided if high class welds are required.

Free-machining alloys can be taken as carbon and stainless steels with above average percentages of sulphur, manganese and phosphorus and lower than average carbon and silicon. These alloys *will* weld autogenously with careful attention to welding current pulse rate and heat sinking but are best avoided. They do save machining time and reduce tool point wear. However, check their weldability before embarking on batch production. The most common welding defects are brittleness and extensive porosity.

OTHER METALS: TITANIUM, ZIRCONIUM ALLOYS, NICKEL ALLOYS, COPPER AND ITS ALLOYS, TUNGSTEN

It may seem strange that tungsten can be welded using a tungsten electrode but it is, in fact, very weldable and is used in the fabrication of laser beam projector assemblies for example.

TITANIUM AND ZIRCONIUM

These are best welded and allowed to cool in a purge chamber to avoid oxidation and porosity, but they melt and flow easily to give a good cosmetic appearance. Both are considered to be reactive metals and great care should be taken to ensure good purging at all times. A trailing shield on the torch should be used in addition to the standard gas cup/nozzle assembly.

Some typical applications and components

- Bellows and diaphragm welding
- Transducer bodies and load cells
- Encapsulation of electronics
- Seam welds in tubes and sheets
- Sealing battery can tops
- Filter bodies and assemblies
- Jet engine blade and fin repairs
- Thermocouples and electronic probes
- Metal cabinet corners
- Valve housings and tube fittings
- Cladding and hard surfacing

Plasma versus TIG welding

It is not the intention of the writer to describe or discuss plasma-arc welding in this book. However, it could be useful to list a few of the advantages and disadvantages of plasma welding as compared to TIG.

ADVANTAGES OF PLASMA

- The tungsten electrode is sited well away from the work within the torch and is the cathode of an ionised inert gas column directed through a fine orifice in a copper nozzle. The plasma column thus formed is an incandescent, highly directional stream of gas. This means that coated metals can often be welded without removing the coating or unduly contaminating the tungsten.

- A pilot arc can be left running between bursts of full welding current.
- Metals above 3 mm thickness can be autogenously welded using a square butt presentation and the keyhole technique.
- Arc gaps are not too critical.
- The plasma arc is self-cleaning but careful cleaning of components should still be carried out.

DISADVANTAGES

- Plasma welding needs *two* different gas supplies. One, generally pure argon, is needed to form the plasma stream and the other, often an argon/hydrogen mix, is the shielding gas. This involves two sets of gas control equipment and very careful control of the gas flow rates.
- Watercooling of the torch is essential even at low currents to avoid overheating and erosion of the nozzle and orifice.
- Plasma equipment, particularly torches, is more expensive than that for TIG welding and needs more careful maintenance.
- A plasma arc is often too narrow and stiff, which does not compensate for component inaccuracies and leads to need for more accurate and thus more expensive fixturing. The slightly conical TIG arc can be a positive advantage in such cases.
- The plasma process is sometimes slower than TIG and often requires a second weld run, *e.g.* for bellows manufacture.
- Plasma equipment is generally bulkier and less portable.
- Nearly all bellows manufacturers have abandoned plasma and returned to TIG, particularly pulsed TIG.
- AVC (arc voltage control) cannot be successfully applied to plasma. For autogenous welds this does not always matter but it does if filler wire is being used. Surfacing build-up operations are much more easily carried out using TIG.
- Ninety five per cent of all microwelding can be just as satisfactorily carried out using TIG without the extra complications of plasma.
- Standard machine type torches are not readily available for plasma.
- Plasma cannot be easily applied to orbital pipe welding because of the additional complexity of pipework and cables to supply the weld torch with welding current and gas.
- Plasma arc starting nearly always needs HF which can interfere with computers, microprocessors and DC thyristor drives.

Note: Neither the TIG nor plasma processes are suitable for outdoor use except in very still air or with the welding arc securely curtained off to avoid draughts.

Summary

Whilst plasma scores on thicker and coated metals, nearly all microjoining operations are more easily and cheaply carried out using a precision pulsed TIG power source. For general welding TIG is more convenient.

For further information and advice on the plasma process see part 2 of 'TIG and plasma welding' by W Lucas, TWI, published by Abington Publishing UK, and other literature produced by The Welding Institute.

CHAPTER 2

Applying the TIG (GTA) process

Practical considerations

The TIG process is used extensively in all branches of industry e.g. chemical and nuclear plant and aero-engineering industries. The principal type of application is one in which quality is paramount such as welding thin material down to 0.5mm (0.02in) thickness, and for precision welding heavier components. The relatively small arc can be precisely positioned on the joint and heat controlled to minimise distortion. In butt welding of material within the thickness range 0.5–3mm (0.02–0.12in), welding is normally carried out autogenously, i.e. without the addition of filler material. However, if the joint configuration contains a gap, weld bead reinforcement is required, or if the material is sensitive to weld metal cracking or porosity, filler must be applied. It can be added in wire or rod form with composition either of a matching analysis, or of a specific composition to overcome a metallurgical problem, e.g. containing deoxidants to prevent formation of porosity in the weld metal.

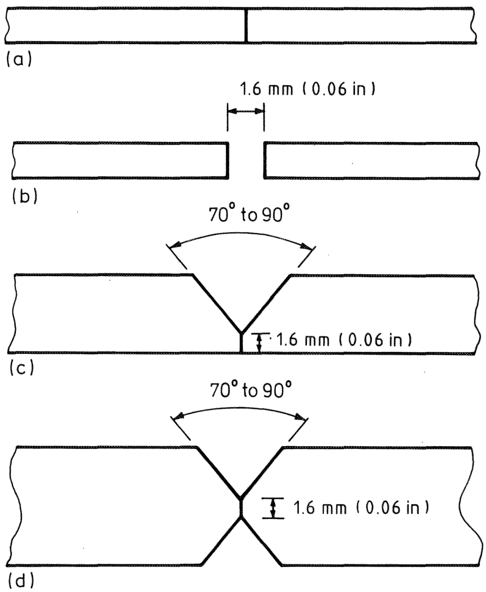
Joint preparations

Sheets of thickness less than 3mm (0.12in) are welded with a simple square edge butt joint configuration, see Fig. 7a and b. Sheet and plate thicker than 3mm (0.12in) require an edge preparation and typical joint configurations are given in Fig. 7c and d. The root may be completed autogenously, provided that there are no metallurgical problems, and the joint is then completed with the required number of passes with filler added to the weld pool.

Alternative joint preparations are available for tubular components and these are discussed separately in Chapter 3.

Backing systems

For fully fused welds, sheets should be clamped to a rigid, temporary, backing bar which supports the penetration bead during welding. Use of a

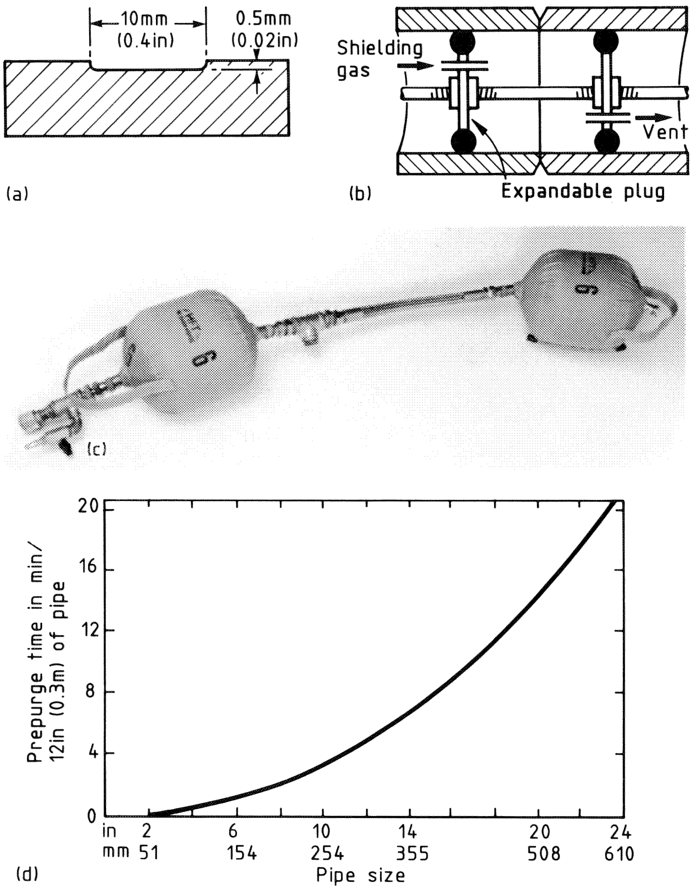


7 Typical butt joint configurations for sheet and plate material: a) Square edge closed butt <3mm plate thickness; b) Square edge open butt <3mm plate thickness; c) Single V butt, 3–10mm plate thickness; d) Double V butt, >10mm plate thickness.

backing bar is advisable when welding with an open root joint preparation. The bar normally contains a shallow groove along its length, as shown in the typical design in Fig. 8a, which is suitable for section thicknesses up to 1.5mm (0.06in). Bars may be stainless steel, copper or mild steel. When fabricating components for service in specific environments, choice of material may be restricted to avoid contamination of the weld metal. For example, in nuclear applications where copper contamination must be avoided, bars of a similar composition or ceramic coated steel strip have been successfully employed.

When welding high integrity components, a shielding gas is normally used to protect the underside of the weld pool and the weld bead from atmospheric contamination. Several techniques are available such as gas ports in the backing bar, localised gas shrouds for sheet, or total coverage of the tubular joints using dams or plugs; a commonly used technique for tubular components is shown in Fig. 8b.

When using the plug technique the plugs must be at a sufficient distance from the joint to avoid damage from the heat generated during welding. It is



8 *Typical backing systems used in TIG welding: a) Temporary backing bar for sheet material; b) Gas backing for protection of the underside of a tubular weld; c) Pipe purging bladder system; d) Recommended pre-weld purging time (c and d courtesy of Huntingdon Fusion Techniques Ltd).*

also essential with all gas backing systems that the vent hole is sufficiently large to accommodate the gas flow, thus eliminating any tendency to pressurise the weld pool during or on completion of welding. Failure to take account of the pressure build-up results in a concave underbead profile and even expulsion of the weld pool on completion of the weld.

The backing gas used when welding ferritic steels,stainless steels and nickel alloys is normally argon. Nitrogen can be used as a general purpose backing gas for copper. The flow rate depends on the diameter and length of the pipe and is set to ensure five to six volume changes of the pipe system, which should ensure that the oxygen content is reduced to less than 1%. The gas flow rate increases with increased pipe diameter, from typically 10 l/min (20cfh) for a 75mm (3in) diameter pipe to 17 l/min (35cfh) for a 500mm (20in) diameter pipe.

When welding aluminium a backing bar is almost always used in preference to gas backing. For most applications, mild steel is used for the bar, but for high production rates and where weld quality is critical, stainless steel can be used. If the backing is not grooved, it is necessary to back chip to sound metal and to re-weld the root with a sealing run.

Material considerations

The TIG process is more widely applied for welding alloyed steel, nickel alloys, aluminium and the reactive metals titanium and zirconium, and less extensively for mild and carbon steels. Rimming steels, in particular, can suffer from outgassing and porosity unless a filler wire containing deoxidants is used.

Although the choice of shielding gas is largely influenced by the material composition (Table 3) it is worth emphasising that whilst argon is the most common shielding gas, argon-hydrogen and helium-argon mixtures can often increase welding speed. The addition of hydrogen produces a cleaner weld but its use for welding thick section low alloy and high carbon steels is not recommended because of the risk of hydrogen cracking.

Cleaning

Because of the inherent risk of porosity in TIG welding, thorough cleaning of the joint area is essential to remove all traces of oxide, dirt and grease. The normal practice is to use a stainless steel wire brush for carbon, low alloy and stainless steels. A bronze wire brush can be used for copper and its alloys, whilst chemical etch cleaning of aluminium or scraping of the immediate joint area can be particularly effective when welding the reactive metals e.g. aluminium, titanium and zirconium.

It is recommended that the wire brushes used for cleaning the joint preparations should be reserved for the various material types.

Immediately before welding, the weld area should be first degreased with petroleum ether or alcohol and again after wire brushing; degreasing before wire brushing prevents contamination of the wire brush. It is also desirable to scratch brush the joint after each weld pass to remove any oxide film formed during welding.

Finally, it is noteworthy that equal attention should be paid to cleaning the filler wire which must be degreased. Wire baking should not be necessary if stored correctly.

Manual welding

The compactness and lightness of the torch make the TIG process ideal for manual welding of thin components where there is a prime requirement for precise control of the behaviour of the weld pool. High quality welds can be readily achieved even where there is limited access to the joint.

Welding techniques

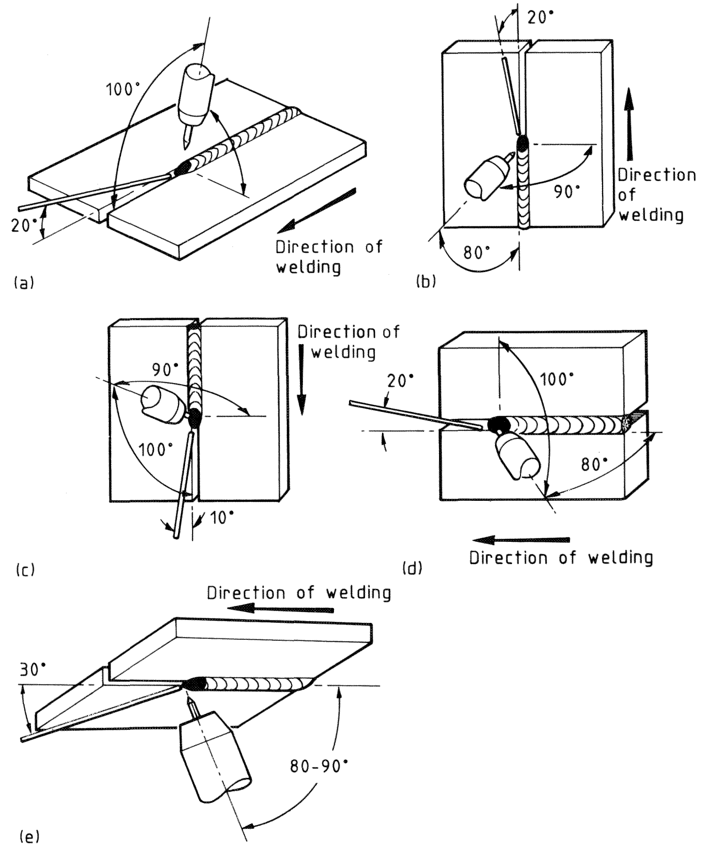
Significant welder skill is demanded by the TIG process, as the operator must maintain a constant electrode to workpiece distance of approximately 1.6mm (0.06in). Because of the conical arc, torch to workpiece variations as small as 0.5mm (0.02in) can vary the effective area of the arc by as much as 15%. The protrusion of the electrode from the end of the gas shield also gives a risk of electrode contamination, or tungsten inclusions in the weld metal from touching either the weld pool or the filler wire.

When using filler, the rod or wire must be positioned so that its tip is heated by the arc but final melting and transfer of metal occur when the rod is dipped into the weld pool. Thus, to avoid oxygen and nitrogen pick-up, the welder must always ensure that the hot tip of the rod is held within the protective envelope of the gas shield.

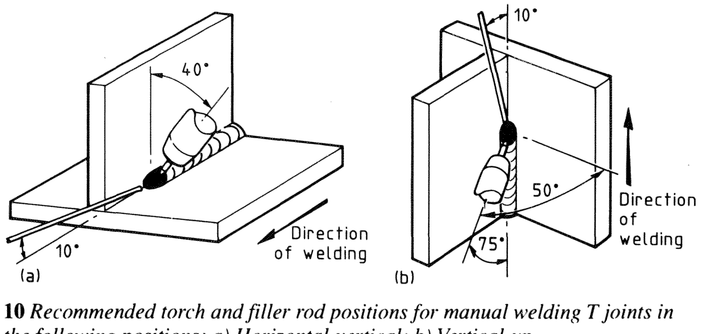
The recommended welding techniques i.e. torch and filler rod angles for the various positions for butt welding are shown in Fig. 9 and for T joints in Fig. 10. Welding is preferably carried out in the flat position where gravity has a minimal effect on the behaviour of the weld pool and the highest speeds can be achieved.

In manual welding of pipes the recommended torch and filler rod positions are shown in Fig. 11 for the rotated pipe (1G position) and the fixed pipe (5G position) operations. In this case welding is normally carried out from the six o'clock to the 12 o'clock position.

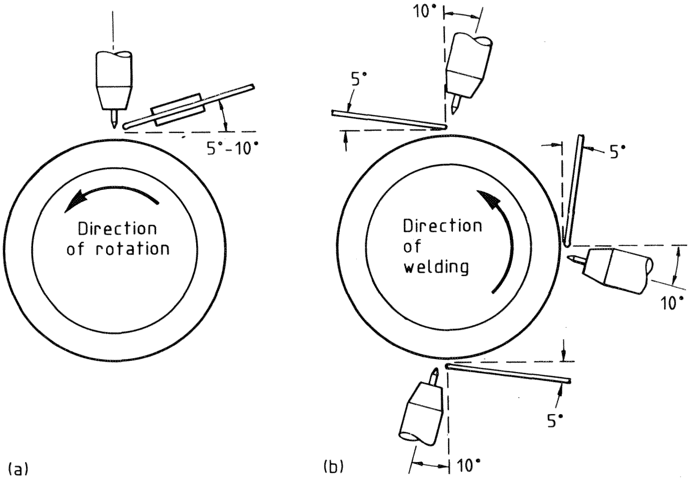
Special mention must be made of the two-operator technique which is similar to that used in gas welding. It can be employed when welding large components in the vertical position; section thickness must generally be greater than 5mm (0.2in), and the advantages over single operator welding are:



9 *Recommended torch and filler rod positions for manual welding butt joints in the following positions: a) Flat; b) Vertical-up; c) Vertical-down; d) Horizontal-vertical; e) Overhead.*



10 *Recommended torch and filler rod positions for manual welding T joints in the following positions: a) Horizontal-vertical; b) Vertical-up*



11 *Recommended torch and filler rod positions for manual welding of pipe: a) Pipe rotated (1G) position; b) Fixed pipe (5G) position.*

1 Higher welding speeds;

2 Lower overall welding currents;

3 Smaller weld beads;

4 Reduced joint preparation;

5 Lower distortion.

Welding speeds are approximately twice that of single-operator welding and because the joint preparation is generally smaller filler rod consumption is significantly reduced; a square edge preparation can be used for thicknesses up to 8mm (0.3in) with a double V, 70–80° included angle, for thicker plate material.

Typical welding parameters

Typical welding parameters are given in Table 4a and b for welding butt joints in the flat position in mild steel and stainless steel, respectively. Standard data are also presented on the amount of filler rod consumed, weight of weld metal deposited and arc time per metre of weld.

Applications

Noteworthy examples are welding of aluminium-magnesium alloy piping in chemical plant construction (Fig. 12a) and fabrication of aeroengine

Table 4 Typical welding parameters and standard data for welding butt joints in the flat position

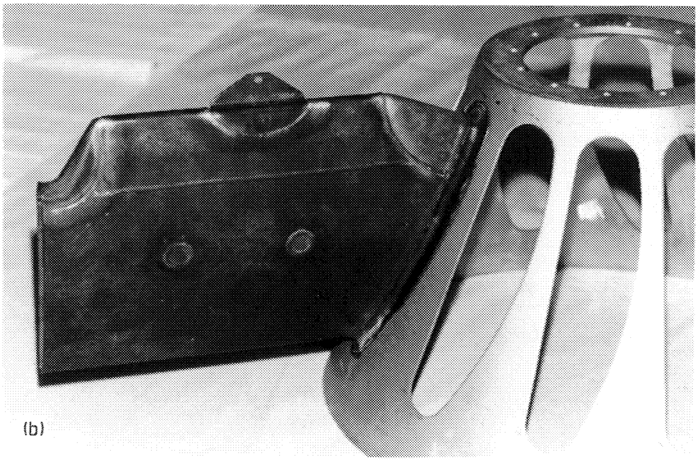
a) Mild steel

Sheet thickness, mm	0.7	0.9	1.0	1.2	1.6	2.0	2.5	3.0
Gap, mm	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
Filler rod diameter, mm	1.6	1.6	1.6	1.6	1.6	1.6	2.4	2.4
Current, A	45	65	70	85	105	125	155	155
Voltage, V	8	9	9	9	9	10	10	10
Filler rod consumed per								
metre of weld, m, mean	0.79	0.99	1.05	1.20	1.40	1.61	1.54	1.54
, range	1.12	1.33	1.38	1.53	1.74	1.94	1.77	1.77
	0.46	0.66	0.71	0.86	1.07	1.27	1.32	1.32
Weight of weld metal deposited								
per metre, g, mean	8.2	9.7	10.4	11.8	14.7	17.6	44.0	47.6
, range	14.1	15.6	16.3	17.7	20.6	23.5	49.9	53.5
	2.4	3.8	4.5	5.9	8.8	11.7	38.1	41.7
Arc time per metre								
of weld, min, mean	3.87	3.33	3.46	3.41	3.75	3.98	4.27	5.27
, range	4.74	3.86	3.97	3.81	4.09	4.28	4.82	5.85
	3.35	3.00	3.15	3.15	3.52	3.78	3.93	4.90

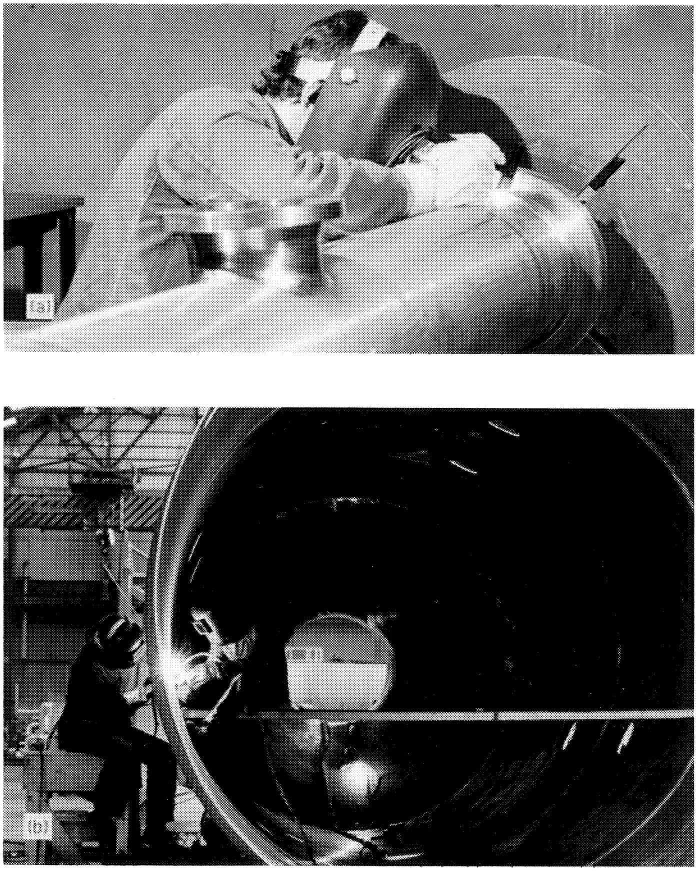
b) Stainless steel

Sheet thickness, mm	0.7	0.9	1.0	1.2	1.6	2.0	2.5	3.0
Gap, mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Filler rod diameter, mm	1.6	1.6	1.6	1.6	2.4	2.4	2.4	2.4
Current, A	55	95	105	135	175	185	195	195
Voltage, V	9	10	10	10	10	11	11	11
Filler rod consumed per								
metre of weld, m, mean	0.83	1.08	1.14	1.33	1.02	1.06	1.10	1.10
, range	1.12	1.36	1.43	1.61	1.21	1.25	1.29	1.29
	0.55	0.79	0.86	1.04	0.83	0.87	0.91	0.91
Weight of weld metal deposited per metre								
of weld, g, mean	8.3	9.1	9.5	10.3	29.9	31.5	33.6	35.6
, range	13.4	14.2	14.6	15.5	35.1	36.7	38.8	40.8
	3.1	3.9	4.3	5.1	24.7	26.4	28.4	30.4
Arc time per metre								
of weld, min, mean	2.91	1.82	1.83	1.62	1.70	2.26	2.92	3.78
, range	3.47	2.07	2.06	1.79	1.83	2.40	3.07	3.95
	2.53	1.65	1.68	1.50	1.61	2.16	2.81	3.64

Note: 1 Shielding gas argon, 2 Joint preparation, square edge



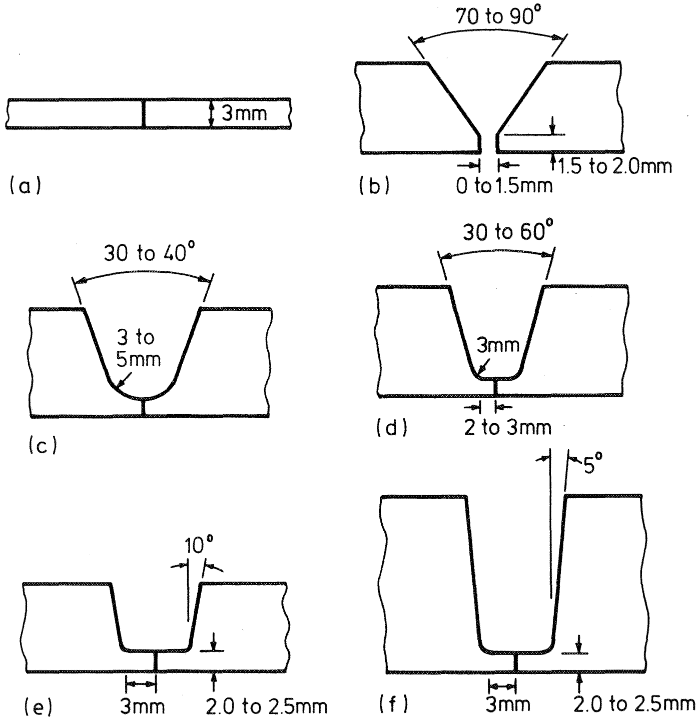
12 *Manual TIG welding applications in a fixed position: a) Aluminium – magnesium alloy piping (courtesy of Air Products Ltd); b) Exhaust diffusion vane to cone manufactured in a nickel based alloy (courtesy of Rolls-Royce Plc).*



13 *Manual TIG welding in which the component or vessel can be rotated: a) Cylinder for a vacuum chamber; joint preparation as shown in Fig. 14c. Welding conditions: shielding gas – argon, backing gas – argon, electrode diameter – 2.4mm, electrode tip angle – 60°, welding current, root – 130A, welding current, fill – 170A, filler rod diameter, root – 1.6mm, filler rod diameter, fill – 2.4mm; b) Aluminium – magnesium pressure vessel using the two-operator technique (courtesy of Air Products Ltd).*

components (Fig. 12b) where in each case the welder has to contend with the problem of difficult access to the joints. Because of precise control over penetration of the weld pool, a skilled welder can produce 'defect free' welds with close control of the weld bead profile.

A typical example of high quality pipe welding for a vacuum chamber is shown in Fig. 13a. Welding was carried out using the simplest technique,



14 *Typical joint preparations used in welding tubes. The joint configurations are for guidance only as the dimensions may vary, and other configurations are shown in succeeding figures to illustrate specific applications: a) Simple butt, <3mm wall thickness, manual or mechanised; b) V type, >3mm wall thickness, manual or mechanised operation; c) U type, >3mm wall thickness, usually manual; d) U type with extended 'land', usually mechanised; e) U type orbital welding, mechanised operation; f) Narrow gap, mechanised operation.*

i.e. by rotating the pipe under a fixed torch position. The joint preparation was of the U type, Fig. 14c, which enabled the underbead profile to be controlled precisely and minimised the filler required to complete the joint.

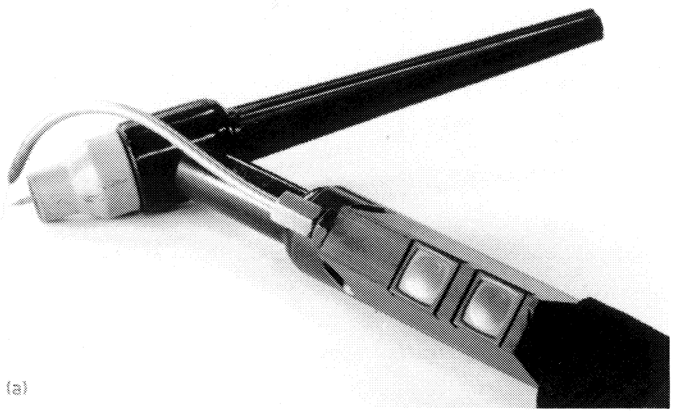
In an example of two-operator welding of a 6mm (0.25in) wall, aluminium magnesium pressure vessel, Fig. 13b, the vessel was rotated so that welding could be carried out in the vertical position.

The TIG process is often used for the root pass only, with subsequent joint filling carried out using MMA or MIG. By adopting this approach, complete root fusion can be more readily achieved, and the use of a higher deposition rate process for the filler passes ensures that the joint is filled as efficiently as possible.

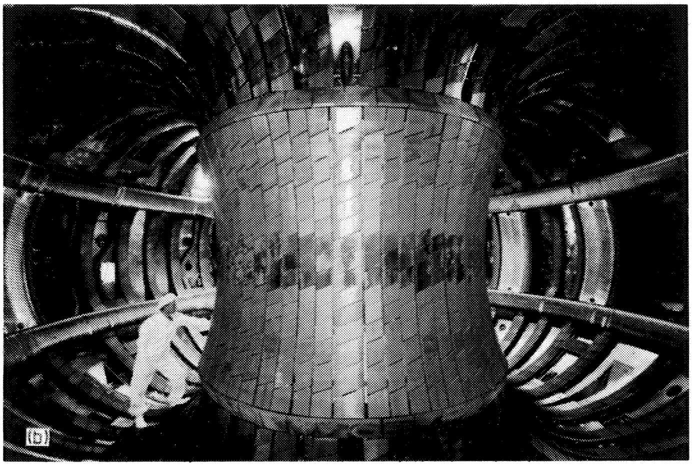
Automatic wire feed

Special mention should be made of the use of equipment which automatically feeds the filler wire into the weld pool. This is often referred to as semi-automatic welding; typical commercially available equipment is shown in Fig. 15a.

Whilst the technique hinders manipulation of the weld pool to some extent, e.g. using the wire to push the weld pool through in the root pass, it can be used effectively in the filler passes to achieve a continuous welding operation. An application which exploited the advantage of automatic feed to increase the duty cycle was the strengthening of the vacuum vessel, Fig. 15b, of the Joint European Torus is shown in Fig. 15c. The seams required



(a)



15 *Semi-automatic TIG welding: a) Equipment for automatic feeding of the filler wire; b) Vacuum vessel of the Joint European Torus (JET) ; c) Manual TIG welding of the stainless steel inner lining of the toroid vessel (b and c courtesy of the JET Joint Undertaking).*

continuous welding of typically 12mm (0.5in) thick stainless steel and Inconel over 10m (33ft) in length; at a welding current level of 180A, wire feed speeds of over 1000 mm/min (40 in/min) were achieved in the vertical position using a 1.2mm (0.048in) diameter wire.

Mechanised operation

Welding techniques

The TIG process is used extensively in mechanised welding, where high weld quality must be consistently achieved. For instance, in the chemical, aeroengine and power generation industries, the compactness of the torch has been fully exploited in the design and construction of specialised welding equipment. However, because of the inflexibility of mechanised systems compared with manual welding, closer tolerances must be placed on component dimensions and joint fit-up. As a general guide, joint fit-up (gap and vertical mismatch) should be $\not>$15% of sheet thickness for the normal range of materials and $\not>$10% for material of less than 1mm. Consequently, when welding thin material it is prudent to devise a good clamping arrangement, preferably using 'finger' clamps to ensure a uniform heat sink along the joint. Whilst joint gap variation is not normally a problem, in butt welding of tubes it is sometimes necessary to size the ends of the tubes to remove excess ovality.

In tube welding standard equipment which can accommodate a wide range of tube sizes is currently available for butt welding in all positions. Whenever possible, welding is carried out with the torch in the fixed vertical position, i.e. with the tube rotated beneath the torch (1G welding position) or with the tube positioned vertically (2G welding position). Integral filler, a ring insert or a separate wire feed addition can all be used to enable tolerances on component fit-up to be relaxed. For example, in welding 32mm (1.28in) OD, 3mm (0.12in) wall thickness boiler tubes, whilst the maximum wall thickness variation, without filler wire, was found to be 0.125mm (0.005in), the addition of filler material allowed the variation to be increased to 0.5mm (0.02in).

The simple butt, V and U type joint preparations, (Fig. 14) are all used for welding tube in the flat position; V and U type joints must be adopted for wall thicknesses above 3mm (0.12in) and the U type joint, although more expensive to machine facilitates control of weld bead penetration in the root and reduces the number of weld passes, particularly in thicker wall material. The preferred joint preparation for wall thicknesses above 3mm (0.12in) has a root face of 2mm (0.08in) and a total land width of typically 6mm (0.25in). The wide land is essential to avoid weld pool touching the sidewalls when the pool surface tension could cause suck-back especially in positions other than the flat.

Pulsed current operation

The pulsed current technique has several advantages in mechanised welding especially with regard to improving tolerance to material and production variations. Specific advantages of pulsed operation are as follows:

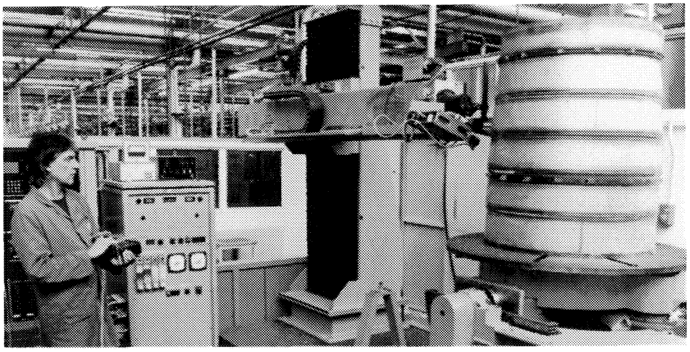
1 It aids control of weld bead penetration by increasing tolerance to process variations (component dimensions and joint fit-up).

2 It reduces the sensitivity to a disparity in heat sink, for example, in components requiring a weld to be made between thin and thick sections.

3 In certain materials it can reduce the sensitivity to surface oxides and to cast to cast compositional variations.

4 It helps to reduce distortion in thin section material or through poor clamping.

It should be noted, however, that pulsing the welding current inevitably reduces welding speed as the weld pool is allowed to freeze between pulses. For example, with continuous current operation 2.5 mm (0.1in) thick,



16 *Mechanised welding of a heatshield assembly in a nickel based alloy (courtesy of Rolls-Royce Plc).*

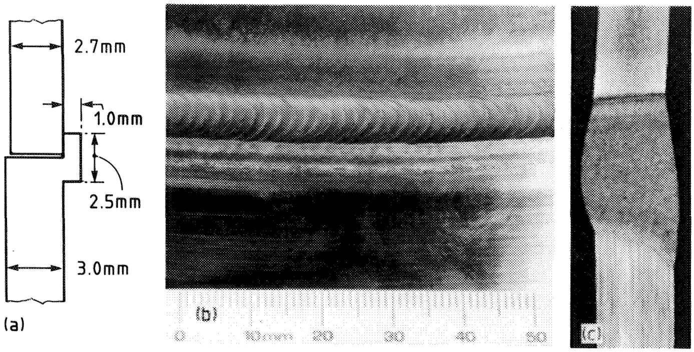
stainless steel sheet can be welded at 0.5 m/min (20 in/min) travel speed, but with pulsed current operation, and allowing the weld pool to solidify between pulses, the travel speed would be reduced to 0.12 m/min (5 in/min). Typical pulse parameters for a range of thicknesses of stainless steel are given in Fig. 5.

Applications

Compared with manual welding, mechanised welding is used as a means of increasing welding speed and to achieve more consistent results over long lengths or in mass production. However, if a high level of weld quality is to be maintained, greater attention must be paid to the accuracy of joint fit-up and the welding parameters. A typical example of precision mechanised welding in aero engine manufacture is shown in Fig. 16.

As described in Chapter 1, pulsing is often used in welding thin sheet material, for the root pass of thicker material, and in difficult welding positions, as a means of improving the tolerance of the process. Applications in tube and tube to plate welding are described more fully in subsequent chapters.

A notable example in which pulsing was used to control the weld pool profile when welding in the more difficult 2G position was joining a pendant liner to a fueling standpipe extension and the reheater tube to tubeplate welds for the AGR. The joint configuration for the pendant liner is shown in Fig. 17a. The joint had to be welded on site in the 2G position; an integral filler was provided to ensure that no thinning of the wall occurred. In the initial technique a ceramic covered backing strip was attached to the outside of the joint to protect and support the weld pool during welding. Because of variations in the underbead profile through localised contact



17 *Pulsed TIG welding of pendant liner to fueling standpipe extension using a gas backed technique: a) Joint configuration; b) General appearance of weld; c) Section through weld (courtesy of Darchem Engineering Ltd). Typical welding parameters: shielding gas – argon, pulsed current – 100A, pulsed time – 1sec, background current – 20A.*

with the strip, a two run technique was required to even out weld bead penetration. A conventional gas backing system was found to be preferable, as not only could the weld be completed in a single pass but the underbead surface had a much cleaner appearance. The resultant surface appearance and cross section through the pulsed TIG weld (gas backed) are shown in Fig. 17b and 17c respectively.

Typical defects

The type of defects and their characteristic appearance are listed in Table 5. Information is also presented on the likely cause of the defects and possible remedial actions.

The main problem in TIG welding is maintaining a uniform degree of penetration. Difficulties occur if adequate attention is not paid to minimising variations which may arise in production such as:

Process parameters	Welding parameters
Component dimensions	Welding current
Joint fit-up	Electrode – workpiece distance
	Electrode dimensions
	Shielding gas composition
	Shielding gas flow rate
	Welding speed

Table 5 Typical defects

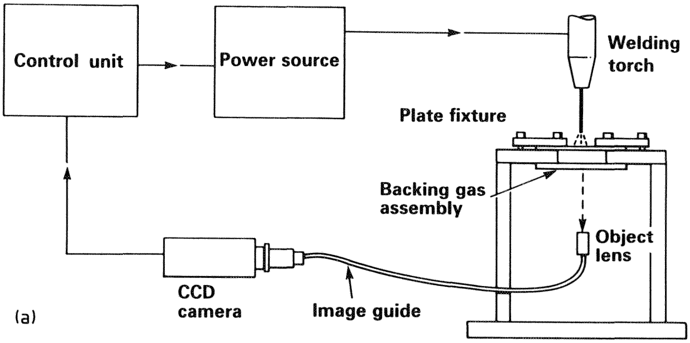
Defect	Appearance	Cause	Remedy
Lack of root penetration	Notch or gap	Current level too low	Increase current
		Welding speed too high	Decrease welding speed
		Incorrect joint preparation	Increase joint angle or reduce root face
		Arc too long	Reduce arc length
	Concave underbead	Tacks not fully fused	Reduce size of tacks
		In flat position, backing gas flow too high	Reduce backing gas flow rate
		In position, intolerant joint preparation	Use U preparation and ensure weld pool does not bridge the sidewalls
Lack of side-wall fusion	Not normally visible, detected by NDT (radiography and ultrasonic examination) or side-bend tests	Current level too low	Increase current level
		Welding speed too high	Decrease welding speed
		Incorrect torch angle	Incline torch backwards and hold arc on leading edge of weld pool
		Incorrect joint preparation	Increase joint angle
		Too large rod/wire diameter for plate thickness	Reduce rod/wire diameter
		Insufficient cleaning	Clean plate surface
Undercut	Groove or channel along one edge of weld	Welding current too high	Reduce welding current
		Welding speed too high	Reduce welding speed
		Torch inclined to one side	Incline 90° to plate surface
Porosity	Severe case, surface pores but normally sub-surface detected by radiography	Insufficient shielding	Increase flow rate (see Fig. 3 for correct flow rates)
		Turbulence in the shield	Decrease flow rate
		Disturbance of the shield through draughts	Shield joint area
		Dirty plate material, e.g. oil, grease, paint	Clean surfaces and remove degreasing agent
		Dirty wire material	Clean wire and remove degreasing agent
		Contaminated gas	Change gas cylinder. Purge gas lines before welding. Check connections. Use copper or Neoprene tubing
Weld metal cracks	Crack along centre of weld	Excessive transverse strains in restrained welds	Modify welding procedures to reduce thermally induced strains
		Low depth to width ratio (D:W)	Adjust parameters to give D:W of 1:1
		In autogenous welding, incorrect parent metal composition	Reduce sulphur, phosphorus contents to <0.06% total
		Surface contaminants	Clean surfaces, particularly remove cutting lubricants
		Large gaps in fillets welds	Improve joint fit-up

Material

Cast composition
Surface cleanness

In manual welding, weld quality is very much in the hands of the welder and skill is required to ensure that full penetration is achieved without lack of fusion or porosity defects in the body of the weld.

In mechanised welding, where the operator has little control of the behaviour of the weld pool, greater control must be exercised over the component dimensions and fit-up. It is also essential that stringent control over the equipment settings and welding parameters is assured by means of



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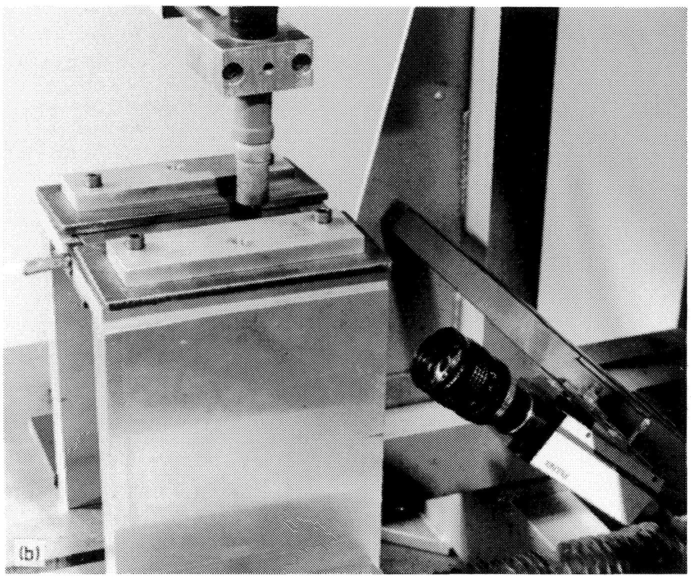

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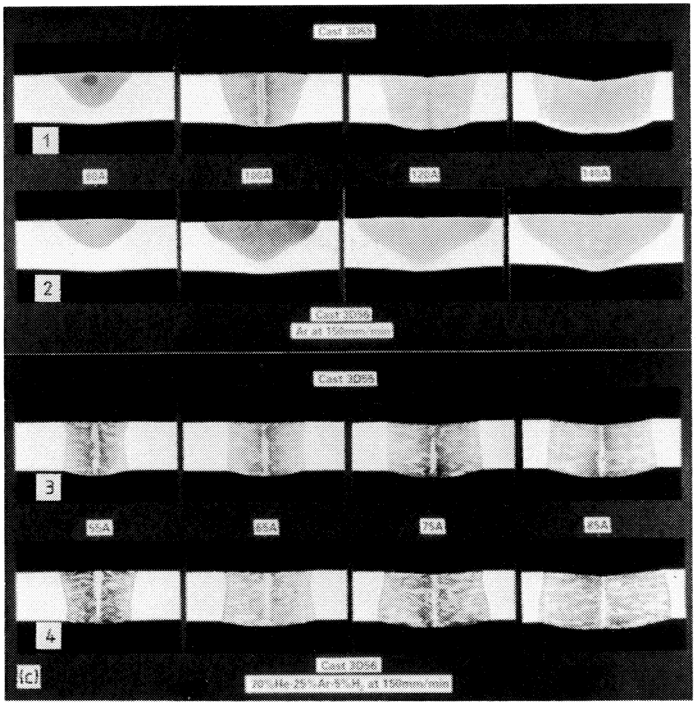

18 *Control of penetration in TIG welding: a) System arrangement for backface control; b) Direct observation of backface of weld using CCD camera; c) Sections through 'good' and 'poor' casts of stainless steel showing the beneficial effect of helium based shielding gas on weld bead penetration profile: 1 – 'Good' cast argon shielding gas, showing effects of current level on depth of penetration; 2 – 'Poor' cast, argon shielding gas, depth of penetration for the same range of welding currents; 3 – 70% helium – 25% argon – 5%H_2 shielding gas showing penetration behaviour for the 'good' cast; 4 – 70% helium – 25% argon – 5%H_2 shielding gas showing 'poor' cast to have almost identical penetration behaviour as 'good' cast.*

a quality control scheme. Instrumentation packages are now available commercially for monitoring the performance of welding equipment during production. Weld pool penetration control systems are also available commercially which are capable of ensuring that the weld pool completely penetrates the material. A novel technique is the use of a CCD camera focused on to the back of the weld as shown in Fig. 18 a and b. The control system chops the peak current pulse in response to a preset quantity of light emanating from the weld pool. The system has applications in the manufacture of critical components for the nuclear and aero engine industries where full fusion must be guaranteed.

Material variation

Special mention must be made of variations in penetration which are caused by minor differences in material composition. Generally known as cast to cast variation, two heats of material conforming to the same nominal specification may produce vastly differing weld bead shapes when welded with exactly the same welding procedure. The problem has been attributed to small differences in the level of impurity elements in the material. For example, casts of austenitic stainless steel which are low in sulphur, typically less than 0.008% tend to display poor penetration behaviour; transverse sections through orbital TIG welds of good (0.014%S) and poor (0.002%S) casts of stainless steel are shown in Fig. 18c, 1 and 2, respectively.

Two process techniques which are capable of improving the tolerance of the TIG operation to variations in material composition are low frequency current pulsing (see Chapter 1) and the selection of the shielding gas composition. With regard to the latter, helium based mixtures have been found to be very effective, especially a three component shielding gas, 70% helium/25% argon 5% hydrogen. As shown in Fig. 18c, 3 and 4, the penetration behaviour of the above two casts now performed almost identically when welded using the helium based shielding gas.

However, it must be emphasised that helium rich gases are not always successful in overcoming the effect of material variation, and it is advisable to investigate other shielding gas mixtures, for example argon-H_2 mixtures, and other combinations of welding parameters especially lower welding speeds.

Further reading

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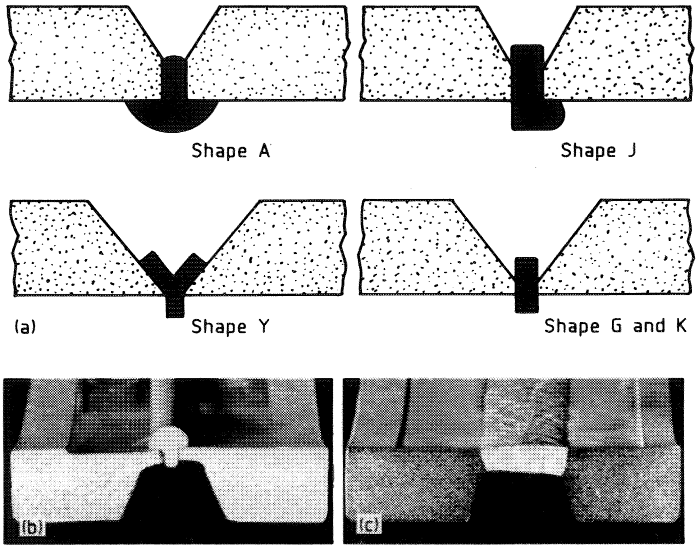
CHAPTER 3

Mechanised orbital tube welding

Welding techniques

When it is not possible to rotate the tube, as in the construction of chemical plant or boilers, orbital welding techniques can be applied.

Although a simple V preparation of 70–90° included angle and 0.5 (0.02in) to 1.0mm (0.04in) root face (Fig. 14b) can be used, a pre-placed insert can be employed to improve the uniformity of the root penetration. A number of inserts are shown in Fig. 19a, and whilst some of the designs are self-locating, it is prudent to match the tube ends and to tack the insert in position before welding. The appearance of the more common EB insert pre-tacked into the joint is shown in Fig. 19b. Despite the use of a simple V



19 *The use of a consumable insert in butt welding tubes to improve the uniformity of root penetration: a) Insert designs; b) General appearance of Shape A, often referred to as an EB insert, tacked into place; c) Appearance of penetration bead in the overhead position.*

preparation, the additional material provided by the insert was sufficient to avoid suck-back of the root pass in the overhead position, Fig. 19c.

However, if the welding parameters are not carefully set, typical root defects which can still be experienced, include:

- Incomplete root fusion;
- Uneven root penetration profile;
- Root penetration concavity (suck-back).

The most tolerant joint preparation for wall thicknesses above 3mm(0.12in) is the U-shaped preparation (Fig. 14e) with a root face of 2.0 (0.08in) to 2.5mm (0.1in) and a total land width of 6mm (0.25in) between the sidewalls. This preparation not only reduces the filling required (in thicker wall tube) but also assists in containing the weld pool in the vertical position. However, because of the closeness of the sidewalls, the torch must be accurately tracked along the joint; poor tracking may result in suck-back in the root pass or lack of sidewall fusion defects in the filler passes.

Pulsing the welding current is particularly useful in ensuring that a positive penetration bead is obtained in all welding positions. However, when suck-back problems are experienced additional process techniques can be adopted. For example, pulsing the wire feed in synchronism with the background current period has been found to be especially effective for the following reasons:

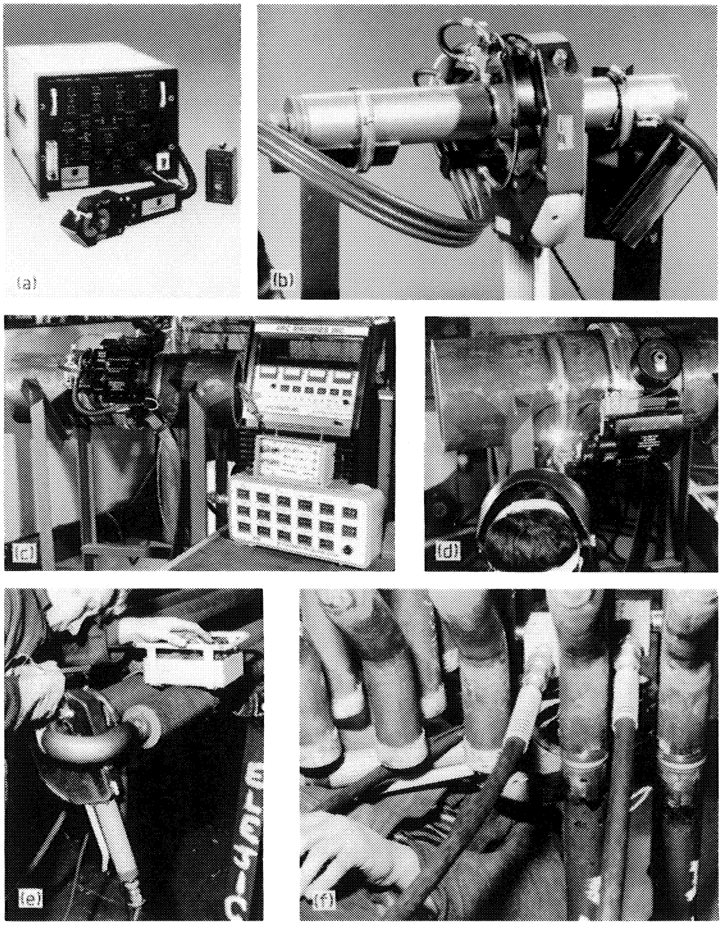
- When no filler wire is added during the high current period the arc current can be held at a level sufficient to give penetration;
- Feeding of wire during the background period rapidly freezes the weld pool;
- Weld penetration bead is pushed through and supported whilst it freezes.

The disadvantage of this technique is that, as the welding procedure is more difficult to set up, greater operator training is required.

Another process technique which has been successfully applied in production is negative purging. In this technique the backing gas is reduced to slightly less than atmospheric pressure, so that in effect the weld pool is drawn into the bore of the tube.

Equipment

Standard commercial welding systems are currently available for butt welding in all positions, for a wide range of tube sizes, and the associated



20 *Typical commercially available orbital tube welding equipment: a) General arrangement of basic function system (courtesy of Huntingdon Fusion Techniques Ltd); b) Basic function welding head (courtesy of ESAB Ltd); c) Full function welding system; d) Full function welding head (courtesy of Arc Machines Inc); e) Production welding of boiler tubes; f) Production welding with restricted access (courtesy of Foster Wheeler Power Products Ltd).*

power sources have the capacity to programme the welding parameters for various welding positions (vertical, overhead, etc) around the joint and to pulse the welding current; examples of commercially available systems are shown in Fig. 20.

The welding equipments vary quite considerably both in terms of the operating features and indeed the price. The simple systems have been termed basic function and are characterised by the restriction to stringer bead welding i.e. no electrode oscillation, although current pulsing is usually provided (Fig. 20a). The full function systems contain the following features:

1 Electrode oscillation;

2 Pulsed current synchronised to electrode oscillation;

3 Pulsed wire feed;

4 Pulsed travel;

5 Multi-level programming;

6 Automatic arc voltage control (AVC).

Intermediate systems contain several but not all of these features. Examples of typical welding heads for the basic function and the full function systems are shown in Fig. 20b, c and d respectively.

The most important limitation of the basic function systems is that the operator is restricted to a stringer bead welding technique, in comparison to the intermediate and full function systems. This necessitates more welding passes, reduction in the tolerance to variation in joint dimensions and fit-up and the increased weld contraction may cause excessive bore constriction.

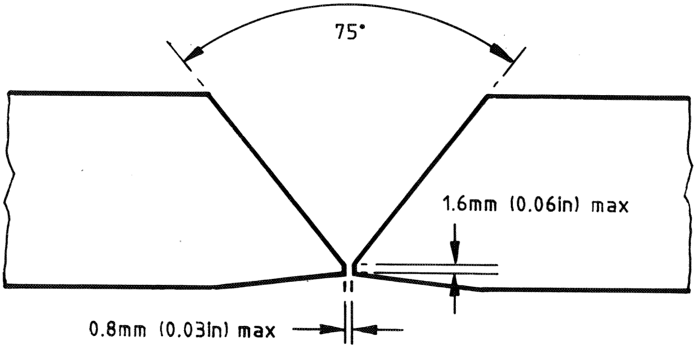
In addition to the benefits of electrode oscillation, the full function systems, in particular, allow the following beneficial welding techniques in control of the weld pool:

- In the root pass, pulsed wire feed with the wire added during the background period promotes rapid freezing and control of the weld pool during this part of the cycle.

- In the hot pass, synchronised pulsing of the current so that a high current level is applied during the end-dwell period improves sidewall fusion; the synchronisation of the low current period on the centre of the joint reduces the risk of re-penetration through the root pass.

- When filling the joint the use of arc voltage control is especially useful as the arc length can be maintained despite the pipe ovality and variations in the weld bead contour.

Table 6 Typical joint preparation and welding parameters for welding 50mm (2in) OD, 4mm (0.16in) wall thickness, carbon steel pipe in the flat (5G) position (courtesy of Foster Wheeler Power Products Ltd)



			1st pass	2nd pass
Current	, peak	A	110	160
	, background	A	60	15
Pulse	, peak	s	0.2	0.2
	, background	s	0.5	0.5
Slope	, in	s	2	2
	, out	s	8	8
Rotational speed		s/rev	150	150
Wire feed speed		mm/min	26-30	26-30
Wire size, diameter		mm	0.8	0.8

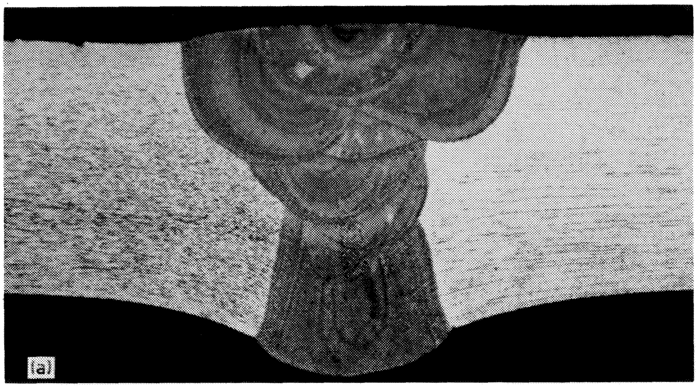
The special techniques afforded by these additional control features facilitate the production of sound welds but it should be noted that in addition to the higher price, the heads are larger and greater operator training is required.

Special purpose equipment is also available for example, for welding tubes with as little as 50mm (2in) clearance between them, and despite the restricted access automatic arc length control and wire feed features have been included in specific designs.

Applications

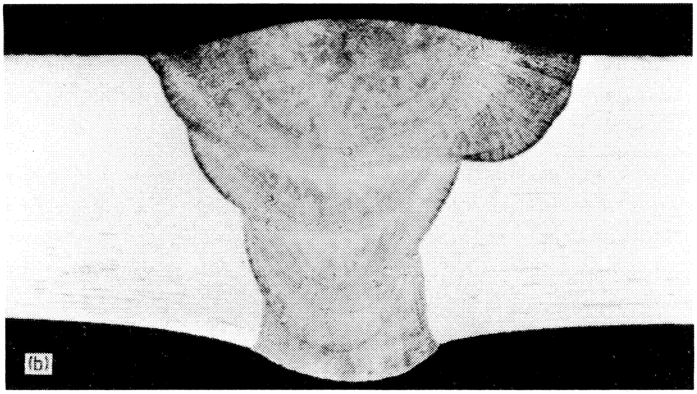
Mechanised orbital welding techniques are used to achieve a more consistent level of weld quality, the tube edge preparation should always be machined so that close tolerances are achieved. Examples of the use of basic function orbital TIG welding in the manufacture of boilers are shown in Fig. 20e and Fig. 20f with the latter being an application with very restricted access; typical joint preparation and welding parameters are given in Table 6. Welding of typically 50mm (2in) OD x 4mm (0.16in) weld thickness, carbon steel pipe was carried out using a basic function system and the weld was completed in two passes.

Electrode oscillation has been used when welding 60mm (2.5in) OD x 5.7mm (0.23in) wall stainless steel pipe to reduce the number of passes from 8 to 4, in Fig. 21. Furthermore, using the stringer bead procedure (basic function system) the bore constriction of typically 1.9mm (0.076in) was outside the maximum of 1.5mm (0.06in) permitted by BS 4677: 1984.



Welding parameter	Unit	Pass number 1	2	3	4	5	6	7	8
Wire diameter	mm	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
Wire feed rate	m/min	0.26	0.26	0.31	0.31	0.25	0.21	0.13	
Pulsed peak current	A	72	76	98	100	100	100	100	70
Pulse time	sec	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Background current	A	29	30	40	40	40	40	40	28
Background time	sec	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Motor delay	sec	5	5	5	5	5	5	5	5
Slope up	sec	1	1	1	1	1	1	1	1
Slope down	sec	6	6	6	6	6	6	6	6
Rotation speed	sec/rev	160	160	160	160	160	160	160	160
Shielding gas flow rate	l/min	7	7	7	7	7	7	7	7
Purge gas flow rate	l/min	3	3	3	3	3	3	3	3

Electrode type	2% thoria
Electrode diameter	2.4 mm
Electrode angle	60°
Electrode polarity	DC–
Shielding gas	Ar-1%H_2
Purge gas	Argon



Welding parameter	Unit	Pass number 1	2	3	4
Wire diameter	mm	0.8	0.8	0.8	0.8
Wire feed rate	m/min	0.75	0.75	0.90	0.75
Welding current	A	81	95	105	80
Weave amplitude	mm	2.0	2.5	3.0	5.0
Weave rate	mm/sec	10	10	10	10
Weave frequency	Hz	0.36	0.38	0.48	0.52
End dwell	sec	0.4	0.3	0.3	0.3
Motor delay	sec	6	6	6	6
Slope up	sec	1	1	1	1
Slope down	sec	6	6	6	6
Rotation speed	sec/rev	165	165	165	200
Shielding gas flow rate	l/min	7	7	7	7
Purge gas flow rate	l/min	3	3	3	3

Electrode type	2% thoria
Electrode diameter	2.4 mm
Electrode angle	60°
Electrode polarity	DC–
Shielding gas	Argon
Purge gas	Argon

21 *Sections through tube welds in 60mm OD and 5.7mm wall (2in NB Schedule 80), type 304 stainless steel pipe in the 5G position: a) Weld with basic function head; b) Weld with electrode oscillation.*

Sections through the welds and the major welding parameters are given in Fig. 21a and b for the stringer and weaved welds respectively.

Because of the reduction in the number of passes there are also significant cost benefits to be gained from using electrode oscillation. A detailed cost analysis using The Welding Institute's WELDVOL and WELDCOST microcomputer program is shown in Table 7. The stringer bead technique requires almost twice as long as the electrode oscillation technique principally because of the extra number of filler passes, and the greater indirect time used to recoil the welding bead cables, modify the welding parameters, clean off the surface oxide between passes and regrind the electrode.

Table 7 Comparison of cost per metre, consumables used and weld times for welding 60mm OD × 5.7mm wall (2in NB, Schedule 80) type 304 stainless steel, using stringer bead and electrode oscillation procedures. (Data produced using The Welding Institute's WELDVOL and WELDCOST programs.)

Stringer bead

Welding cost per metre

Gas	1.0%	1.21
Wire	1.9%	2.27
Electrode		0.00
Rods		0.00
Flux		0.00
Labour	85.1%	100.00
Plant	11.9%	13.95
Power	0.1%	0.08
TOTAL welding cost per metre (pounds)		117.52

Consumables used

Shielding gas used/metre (litre)	= 540.0
Cost (pound/metre)	= 1.08
Backing gas used/metre (litre)	= 66.7
Cost (pound/metre)	= 0.13
Mass of wire used/metre (kg)	= 0.23
Cost (pound/metre)	= 2.27

Weld times

Arc time (min/metre)	= 90.00
Indirect time (min/metre)	= 210.00
Total time (min/metre)	= 300.00

Electrode oscillation

Welding cost per metre

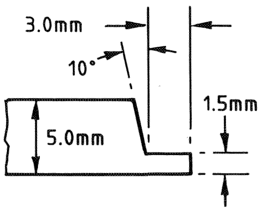
Gas	1.0%	0.92
Wire	2.4%	2.27
Electrode		0.00
Rods		0.00
Flux		0.00
Labour	72.9%	69.44
Plant	23.7%	22.61
Power	0.1%	0.05
TOTAL welding cost per metre (pounds)		95.30

Table 7 *continued*

Consumables used	
Shielding gas used/metre (litre)	= 375.0
Cost (pound/metre)	= 0.75
Backing gas used/metre (litre)	= 83.3
Cost (pound/metre)	= 0.17
Mass of wire used/metre (kg)	= 0.23
Cost (pound/metre)	= 2.27
Weld times	
Arc time (min/metre)	= 62.50
Indirect time (min/metre)	= 145.83
Total time (min/metre)	= 208.33

Table 8 Parameters for orbital TIG welding of 21.4 mm diameter 70/30 Cu-Ni tube

Constants	
Filler composition	70/30 Cu-Ni
Filler diameter	1.2 mm
Shielding gas	argon/5%H_2
Backing gas	argon
Electrode/workpiece gap	2.4 mm
Traverse mode	steady speed
Electrode diameter	1.2 mm
Electrode tip	30° cone

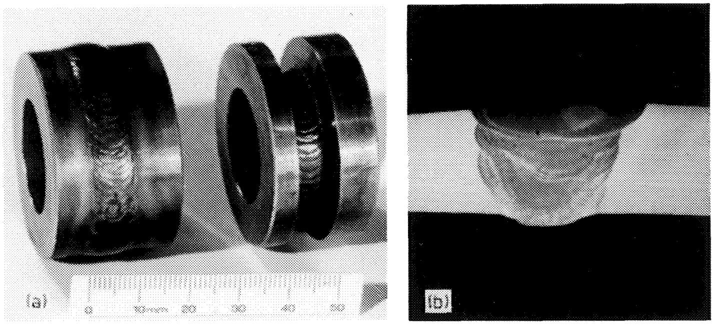


	Root	Filling pass 1	2	3	4
Start position, o'clock	11	12	11	12	11
Slope up, A/sec	5.0	20	20	20	10
Pulsed current, A	90	199	199	199	60
Pulse time, sec	0.7	0.2	0.2	0.2	DC
Background current, A	30	30	30	30	DC
Background time, sec	2.0	1.0	1.0	1.0	DC
Filler addition rate, mm/min	140	225	225	225	225
Weave amplitude, mm*	None	None	None	None	5.6
Weave frequency, cycles/min	N/A	N/A	N/A	N/A	50
Weave delay at extremities, sec	N/A	N/A	N/A	N/A	None
Current decay, A/sec	2.5	9.99	9.99	9.99	2.5
Cutoff at, A	30	60	60	60	30
Sequence terminates, A/sec	5.0	12	12	12	5.0
Final current, A	5.0	5.0	5.0	5.0	5.0
Time per revolution, min†	1.1	1.1	1.1	1.1	1.1

* Weave amplitude measured at electrode tip

† The rotational speed was kept constant, and therefore the actual welding rate increases as the weld preparation is filled

N/A Not applicable



22 *Orbital TIG (GTA) weld in 70/30 Cu-Ni tube; 21.4mm OD, 5.0mm wall thickness: a) Root and completed weld; b) Section through weld. Welding parameters are given in Table 8.*

Another example of orbital welding with the U-shape joint preparation is shown in Fig. 22 where 21.4mm (0.86in) OD, 5.0mm (0.2in) wall thickness 70/30 CuNi tube was welded in the 5G position (welding conditions and parameters are detailed in Table 8). Filler wire was used in the root pass to prevent porosity, and current pulsing was employed throughout, at a frequency of approximately 0.5Hz, to ensure good sidewall fusion. While the pulse current was required to spread the weld pool and to enable the arc to 'bite' into the sidewall, a background period up to 2sec was used to allow the large weld partially to solidify to a more controllable size. Weaving at a frequency of 50 cycles/min was used in the capping pass to spread the weld pool and to prevent undercutting along the edges of the weld bead.

Further reading

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3 Sewell R A: 'Orbital pipeline welding techniques' *Welding and Metal Fabrication* 1989 57 9.

4 Carrick L, Hick A B, Salmon S and Wareing A J: 'A new welding technique for stainless steel pipe butt welds'. *Metal Construction* 1985 17 6.

5 Scott-Lyons R and Middleton T B: 'Orbital TIG system simplifies underwater welding'. *Metal Construction* 1985 17 8 also 'Underwater orbital TIG welding' *Metal Construction* 1984 16 10.

6 Blake M A W, Carrick C and Paton A: 'Automatic TIG welding in site fabrication'. *Metal Construction* 1983 15 5.

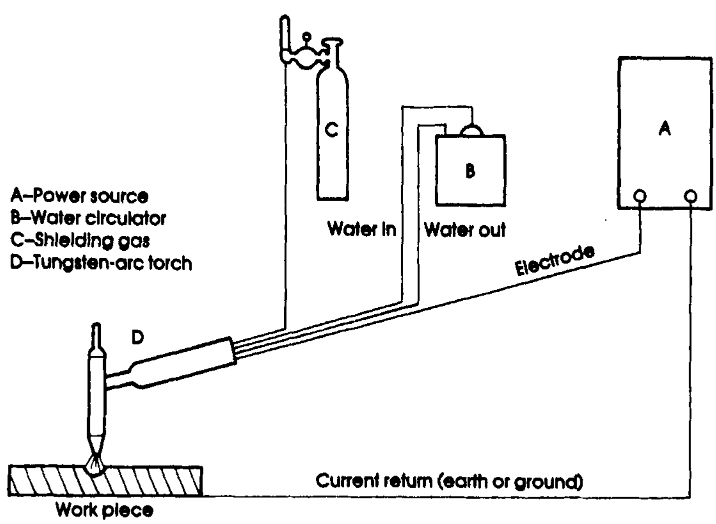
7 WELDVOL and WELDCOST - microcomputer packages available from The Welding Institute, UK.

Chapter 3

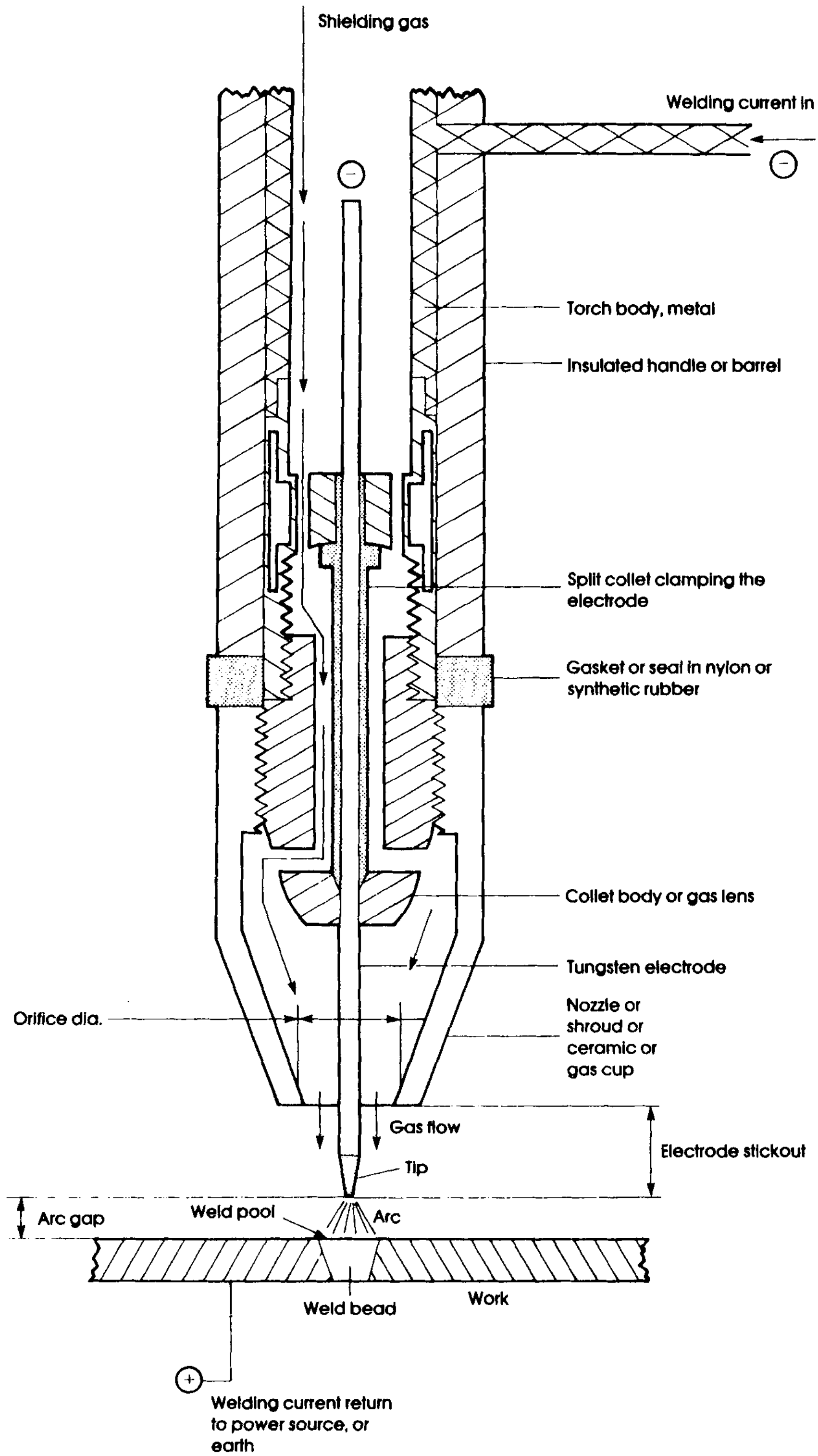
Basic TIG welding requirements

The basic requirements for all TIG welding processes are similar, *i.e.* a power source, a hand held or machine manipulated torch, a pressurised supply of a suitable inert gas from cylinders or bulk containers and cables of the correct size to conduct welding current from the power source to the torch, Fig. 3.1.

This chapter covers torches, electrodes, shielding gases and cables.



3.1 Basic TIG welding components.



3.2 Gas cooled TIG welding torch assembly.

Torches

Delineation here is simple as there are only two basic kinds, hand and machine (straight). The torch carries the non-consumable tungsten electrode in an adjustable clamp arrangement and can be fitted with various ceramic nozzles to guide the gas flow to the arc area.

There has been little change in torch design since the inception of the commercial TIG process except that introduction of modern plastics and synthetic rubbers of lighter weight and with superior insulating properties has allowed torches to be made smaller, lighter and easier to handle. Manual TIG welding requires a steady hand, so a lightweight torch is a great advantage. However, torches should always be selected with due regard to capacity. Use a torch which will carry the *maximum* welding current that is likely to be needed, a manufacturer or stockist will give assistance, and ensure that the nozzle and electrode assembly allow full access to the area being welded. It is, of course, preferable to weld in the flat (downhand) position to take full advantage of the effect of gravity. This is particularly so when additional metal is being introduced into the weld pool by means of wire or rod. Further advice on suitable approach and position will be given later.

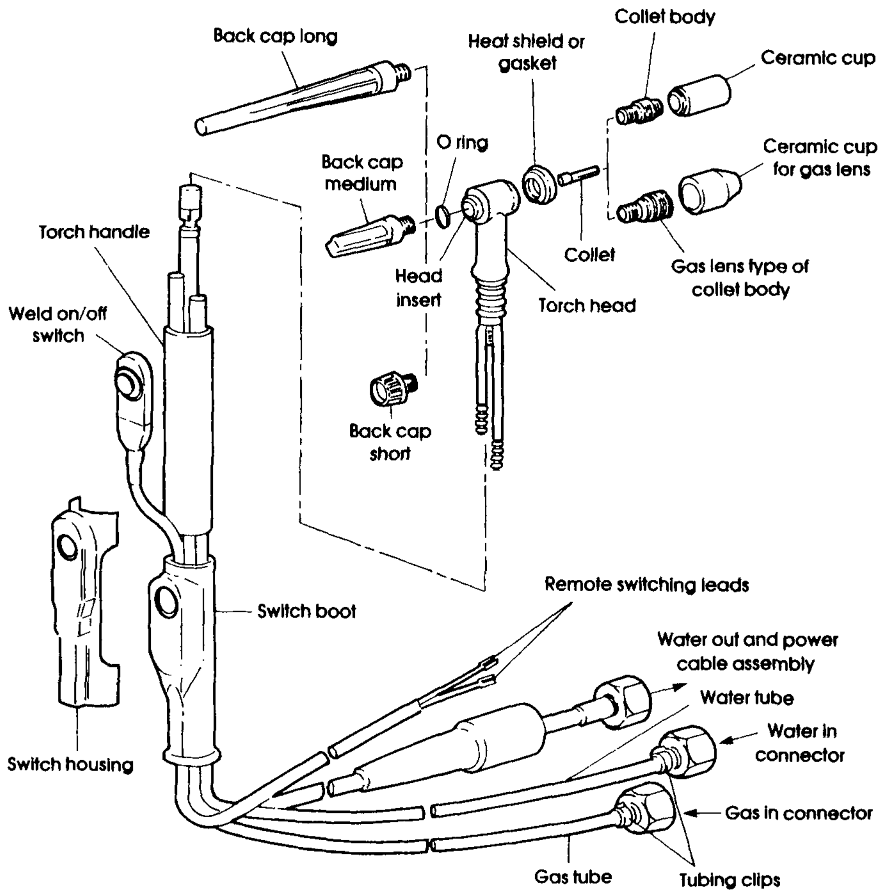
The various components of TIG torches are shown in Fig. 3.2, 3.3 and 3.4 which also give the most used names of the respective parts.

An extremely large variety of ceramic gas cups is available and it is often difficult for beginners to decide which is best for a particular job. Ceramics are graded by orifice size and a rough guiding rule would be that the smaller the electrode and the lower the gas flow the smaller the orifice. Gas flow rate depends on the type of gas and cup orifice diameter. For most hand welding about 7 l/min (15 ft^3/hr) is a good amount.

Always keep a selection of nozzles handy with a good range of orifice sizes, Fig. 3.5. The flow of shielding gas through the torch has some cooling effect which is sufficient for low production rates. For reasons of economy, however, it is better that the gas flow is kept to a minimum, but it reduces the cooling effect. This means that the torch could become uncomfortably warm during continuous use and need watercooling. Torches above 125 A capacity are generally available as either gas- or watercooled. For a busy fabrication shop watercooling can be essential.

Figure 3.2 shows the component parts of a TIG torch and also indicates the usual position of the watercooling gallery. In some cases the water is directed in and out of the torch by separate tubes, but it is not uncommon for the cooling water to be concentrically piped away from the torch via the current input cable, which cools the cable as well. The flow of cooling water needs only to be fairly small (about 1.5 l/min) and for reasons of economy it is best if the watercoolers are of the recirculating type. Mention of these cooling units will also be made in a following chapter.

Manufacturers have taken much trouble to ensure that TIG torches are



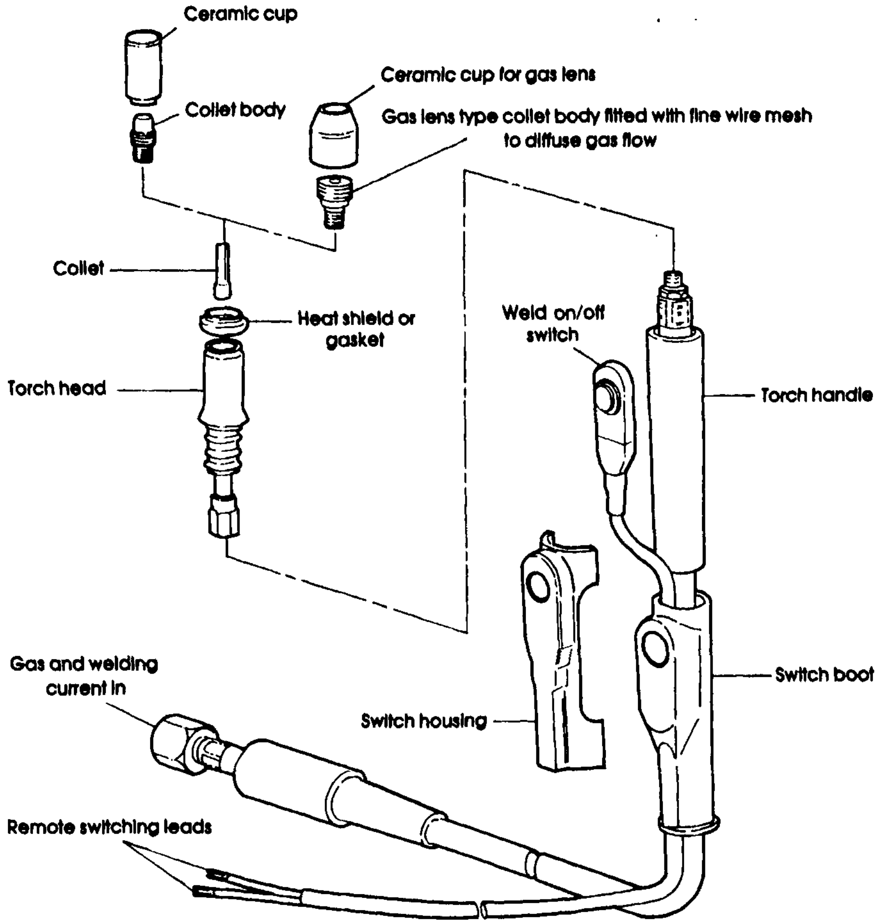
3.3 Watercooled TIG welding torch and fittings.

easy to handle and also that the various component parts are easily changed or replaced. On most designs the ceramic nozzles can be changed in a matter of seconds and it should not take much longer to change or replace the tungsten electrode.

The metal component parts of a good quality TIG torch should always be made from copper or a good quality low resistance brass.

To summarise, when choosing a TIG torch always ask yourself:

- Does the torch have sufficient capacity for the maximum welding current to be used?
- Is it comfortable for the operator if hand welding?
- Is it suitable for welding where access is awkward or restricted?
- Is the cooling method adequate for the production rate required?



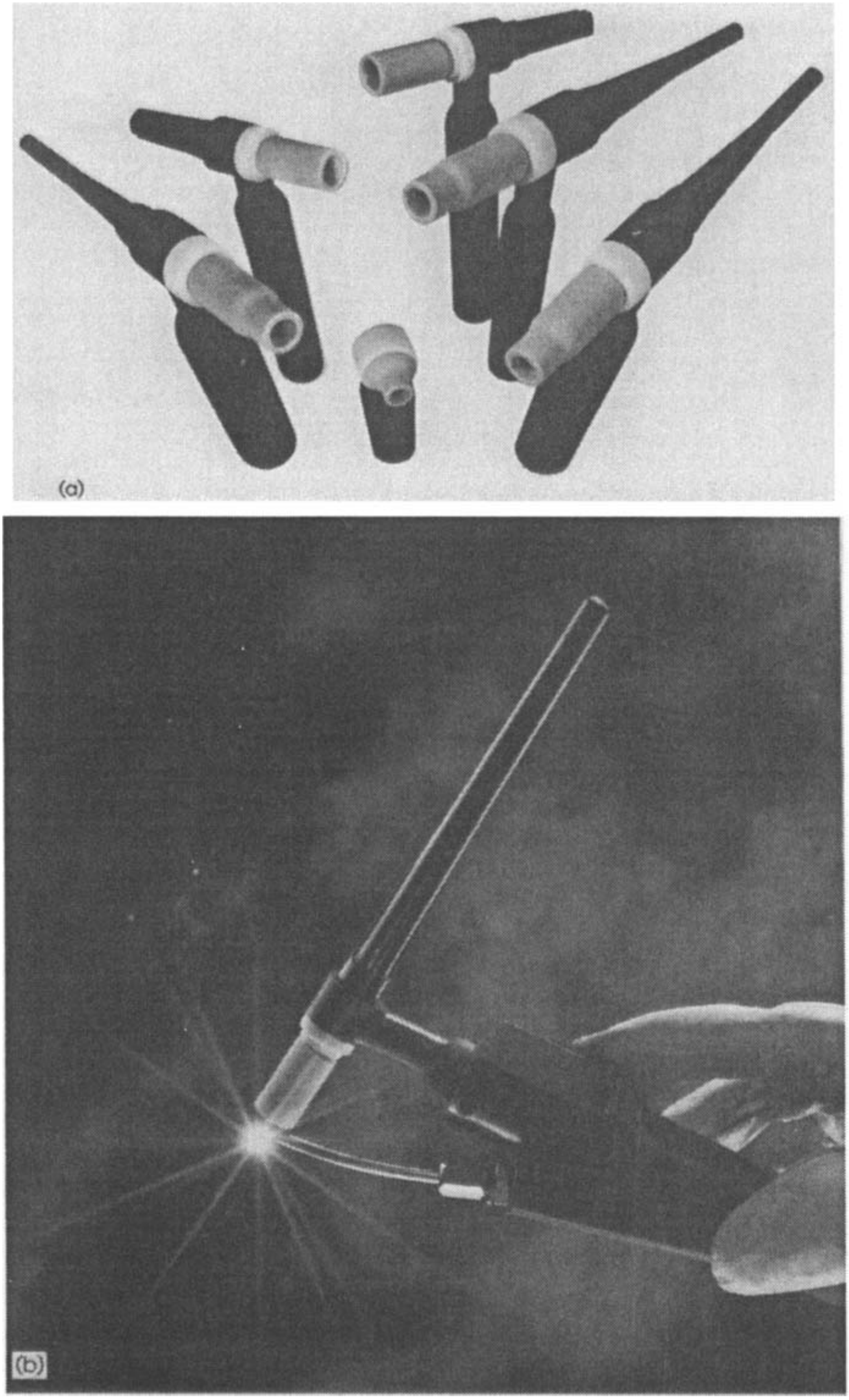
3.4 Gas cooled TIG welding torch and fittings.

- Does the nozzle-to-body sealing method prevent air ingress into the gas flow? At this point a synthetic rubber seal is better than nylon or similar material.

The flow of current to a TIG torch used in hand welding is usually controlled by a pedal switch, leaving one hand free to apply filler wire if necessary, or by a small push button on the torch itself which only switches the weld current on and off.

There are also some TIG torches available which have a flexible neck. These are useful where access to the weld is very difficult, although they are not otherwise extensively used.

TIG torches are fairly robust but should be kept clean and free from oil in particular. Lay the torch down carefully when not in use or, better still, have



3.5 a) Selection of manual TIG welding torches and gas cups; b) TIG torch with built in wire feed and operator's stop-start button.

an *insulated* hook handy to hang it on. This will keep the torch ready to hand and prevent it from falling to the floor, a simple tip which could save the cost of a replacement unit. Keep all torch connections, *i.e.* welding current, shielding gas and cooling water, tightened. A loose current connection within the torch can cause internal arcing with subsequent overheating and, obviously, gas and water leaks are *not* wanted. With care a torch can last a long time and give good service throughout its working life.

Electrodes

TIG electrodes are the final link in the chain between the power source and the weld and critical to the whole process. They are classified as non-consumable, which is not strictly true. What *is* true, however, is that they should last as long as possible for economic reasons, that they should carry the highest required welding current and that they should not disintegrate at the tip whilst welding, thus contaminating the weld pool. All this makes the selection of a suitable electrode of paramount importance. Electrodes for TIG welding are almost entirely made from tungsten (which has a melting temperature of 3370 C (6000 F) and boils at 6135 C (11000 F). They are generally obtainable in round rod form about 150 mm (6 in) long. The rods are mainly products of powder metallurgy produced by compression and/or sintering and come in a variety of diameters starting at about 0.25 mm (0.010 in) up to 6 mm (0.25 in). Larger diameters can be obtained if required. Table 3.1 gives some advice as to which size to use for a particular weld current range and is based on 2% thoriated electrodes, although ceriated and lanthanated tungstens have very similar characteristics. Table 3.2 gives electrode weights for specific diameters.

Table 3.1 TIG electrode current carrying capacity. Tungsten 2% thoriated, 60% duty cycle, in argon

Diameter, in		Diameter, mm	DCEN or DCSP	DCEP or AC	Popular sizes
			Current capacity, A	Current capacity, A	
	0.010	0.25	up to 5	N/A	
	0.020	0.5	up to 15	N/A	✔
3/64	0.040	1.0	15–50	up to 20	✔
1/16	0.064	1.6	50–100	20–50	✔
3/32	0.080	2.0	50–150	50–100	✔
	0.096	2.4	50–200	50–150	
1/8	0.128	3.2	200–300	150–200	✔
3/16	0.180	4.8	250–400	200–300	✔
1/4	0.250	6.4	400–600	300–400	✔

For greater currents consult your electrode supplier

Table 3.2 Nominal weight of standard length tungsten electrodes

Standard diameters,	Nominal weight per electrode in grams for standard lengths of		
mm	75 mm (3 in)	150 mm (6 in)	175 mm (9 in)
1.0	1.1	2.3	2.7
1.2	1.6	3.3	3.8
1.5	2.6	5.1	6.0
1.6	2.4	5.8	7.0
2.0	4.5	9.1	10.6
2.4	6.5	13.1	15.3
3.0	10.2	20.5	23.9
3.2	11.7	23.3	27.2
4.0	18.2	36.4	42
4.8	26.2	52	61
5.0	28.4	57	66
6.0	41	81	95
6.4	47	93	109
7.0	56	111	130
8.0	73	145	170
10.0	114	227	256

To improve the flow of electrons through the formed rod to the tip it is common practice to include in the tungsten electrode powder mix small quantities, seldom more than 4%, of various metallic oxide powders mixed and distributed as homogenously as possible within the structure of the rod. These include oxide powders of zirconium, thorium and, latterly, lanthanum and cerium in various percentages. All these inclusions greatly improve arc striking, particularly when low current DC welding is being carried out and assist with tip shape retention and arc stability. Thorium dioxide (ThO_2) has until recently been the most common oxide used and for most purposes is still by far the best. However, factors other than long tip life and thermal efficiency now weigh against its use and equally good substitutes have been made available. In order of preference for arc striking only, in the author's opinion and based on several years' usage and experiments, are:

1st Thorium 4%, 2% is also satisfactory;
2nd Cerium 1% (cerium is the most abundant lanthanide element);
3rd Lanthanum 1% (lanthanum is the first of the series of rare earth metals).

With regard to lasting properties during DC welding there is not much difference between these three but experience shows that thoriated electrodes last longer between regrinds for currents above 100 A, with all the three lasting well at currents below this figure. For ultra-low current welding (below 3 A) the author's personal preference is for the ceriated type which strikes well and holds a very fine point for long periods. Zirconiated (0.8%) electrodes are mainly used for AC welding as are those of pure tungsten.

IDENTIFICATION OF ELECTRODE TYPE

Electrodes are identified by colour and a DIN standard has assigned a colour code. However some of the colours, particularly orange and the pinks and reds (marked*) are often difficult to distinguish one from the other, so be very careful when a particular type *must* be used. Table 3.3 shows the colours suggested in the DIN standard which, however, is not as yet universally accepted.

The attempt to colour code electrodes by a standard is an excellent idea but for this to become universally used some acceptable international standard should also be assigned to the various colours to avoid confusion.

Table 3.3 Electrode data to DIN 32528 specification

General use	Composition, %	DIN	Material No.	Colour
AC	Tungsten, pure	W	2.6005	Green
AC and DC	Tungsten +1 thorium	WT10	2.6022	Yellow
DC	Tungsten +2 thorium	WT20	2.6026	Red*
DC	Tungsten +3 thorium	WT30	2.6030	Lilac
DC	Tungsten +4 thorium	WT40	2.6036	Orange*
AC	Tungsten +0.8 zirconium	W28	2.6062	White
DC	Tungsten +1.0 lanthanum	WL10	2.6010	Black
DC	Tungsten +1.0 cerium	WC10	–	Pink*
DC	Tungsten +2.0 cerium	WC20	–	Grey

* *Colours not easy to distinguish*

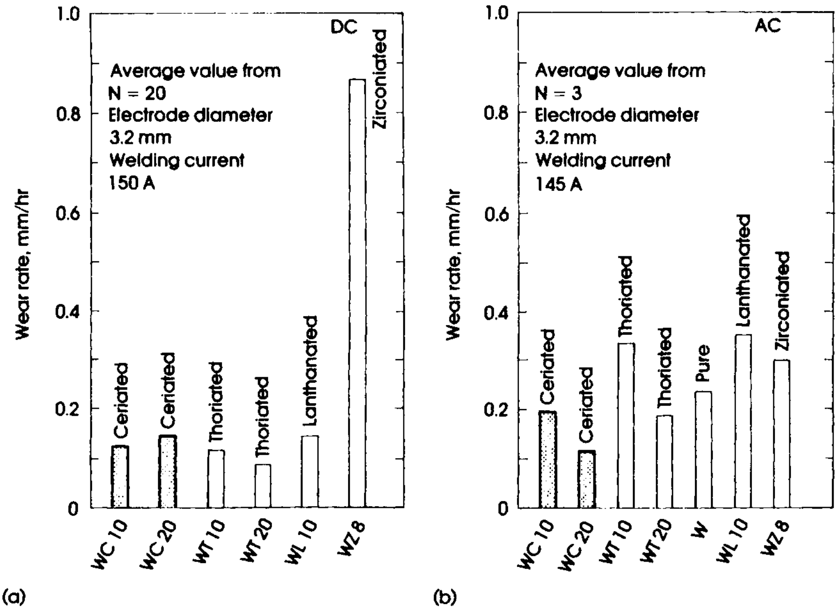
WEAR AND LIFE PROPERTIES

The two histograms, Fig. 3.6, were produced from results of experiments carried out by a major manufacturer of tungsten TIG electrodes. Four different types of alloyed rod were used, all 3.2 mm (0.125 in) diameter at a continuous current of 150 A in both DC and AC modes. The results appear to confirm the author's opinions with regard to tungsten life, and the fact that ceriated electrodes last well in relation to the thoriated type removes many problems regarding dangerous grinding dust and its disposal.

Assuming that the results were obtained with a fixed electrode to work distance, or arc gap, a consistent flow rate and identical TIG torches, the data would probably apply only to mechanised welding. Hand welding in a busy fabrication shop can give very different results.

ARC GAP

A TIG arc is extremely hot, about 20 000 C (35 000 F). This hot spot occurs in the arc at a point close to the electrode tip, but not in the electrode itself, so for optimum penetration and economy the arc gap must be kept as small as is practicable, fairly easy to maintain in mechanised TIG welding but entirely due to the steady hand of the operator in manual TIG. The width of the arc gap has considerable effect on the amount of heat going in to the



3.6 Wear rate for various electrode compositions when TIG welding: a) Steel with DCEP polarity; b) AlZnMgl with AC.

weld pool, as variations in the gap give variations in total heat. The relationship is simple:

Amps × volts × time (seconds) = joules (or watt-seconds).

Where filler wire is being used the arc gap must be greater than for an autogenous weld. Also, the wire or rod has to be melted, so a weld *with* filler will need at least 20% more current than one without. The heat input for any TIG weld can easily be found by experiment but experience will often indicate what approximate current is required before welding starts. No attempt has been made in this book to advise on arc gaps, keep them as small as possible.

The passage of current through the electrode and the heat of the arc will eventually cause the tip to degrade. Some metals out-gas during melting and this can occasionally coat the tip, making repeat arc strikes difficult to achieve. In fact some of the more exotic metal alloys can cause coating of the tip to such an extent that a state of one weld, one regrind exists. When the electrode tip has degraded or become coated it is time to regrind.

ELECTRODE POINTS – TIP GRINDING

Generally the rule here is: the higher the weld current the larger the electrode diameter and the greater the included tip angle, within a 30 – 120° range for most TIG welding use. Tips with an included point angle as low as 10° or less are used for such precision TIG applications as the fusion of thermocouple wires and for edge welded bellows and diaphragms. Regarding grinding of electrode points, the surface finish of the tip is critical only in precision and microwelding applications and in these instances it is a definite advantage to use a mechanical tip grinder. These machines give finely finished, and sometimes polished, tips with first class repeatability and are simple to use, although a good one can be rather expensive. Tungsten grinders will be further discussed later. A capable TIG welding operator rapidly learns to grind tips to an acceptable standard for hand welding on a standard bench grinder but this *must* be fitted with suitable hard, fine grit wheels and an eye shield. Tungsten is very hard and grinding will rapidly destroy softer wheels with subsequent dust problems and increased replacement expense. Purchase of grinding wheels suitable for prolonged use with tungsten electrodes will save money in the long run; consult a reputable supplier.

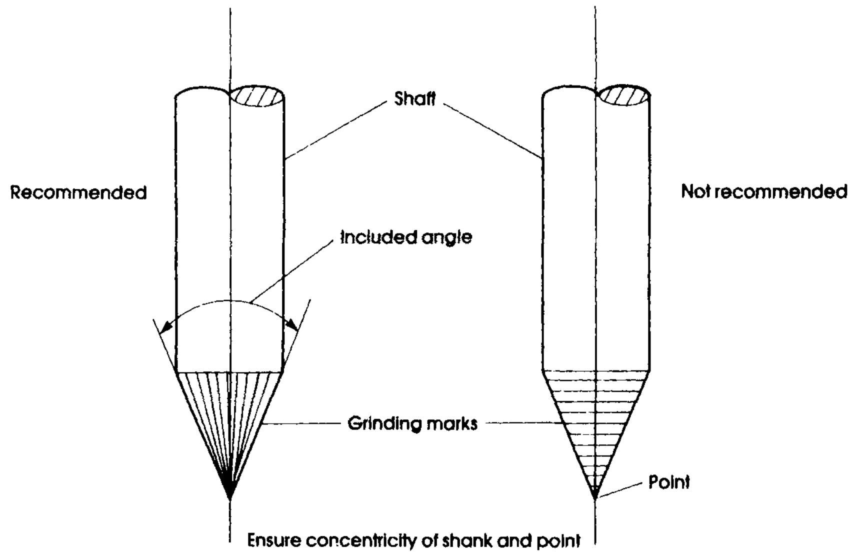
One final comment. To assist the welding current electrons to be emitted from the very tip of the electrode point, ensure that any marks left by grinding run longitudinally *towards* the tip, *not* circumferentially, (Fig. 3.7) and keep points concentric with the tungsten shaft centreline.

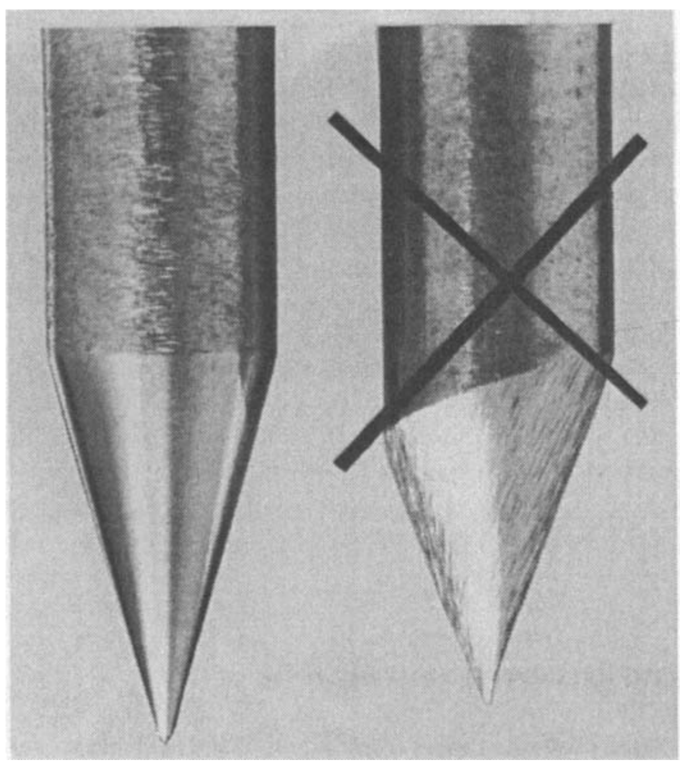
GRINDING DUST

Dust generated by grinding can be considered a severe health hazard and most countries' health authorities recommend that all metal grinding machines be fitted with a transparent eye shield, filter and dust extractor. Where tungsten grinding is concerned, thorium, although present in only small quantities, has two particularly unwanted characteristics, *i.e.* it is slightly radioactive and is also regarded by some medical authorities to be carcinogenic. All dust created by the grinding of thoriated electrodes should be collected and disposed of with extreme care. In the UK an addition of thorium greater than 2% brings these electrodes into the province of the 1985 radiation regulations. *No* dust produced by grinding should be breathed in, as any dust can cause pulmonary illness over long periods of inhalation, so it is only commonsense to provide greater protection. Always wear goggles or industrial spectacles when grinding anything. If there are any doubts about the efficiency of a grinder's dust extraction system, operators should also wear face masks.

Shielding gas types and mixtures

A wide variety of inert gases and mixes of gases is available, either in pressurised cylinders or as liquids contained in special insulated bulk tanks. If large quantities of gas are being used the bulk tank is the most economical method but, of course, such tanks are for static mounting and are not portable.





3.7 Correctly and incorrectly ground electrode points for DC TIG welding.

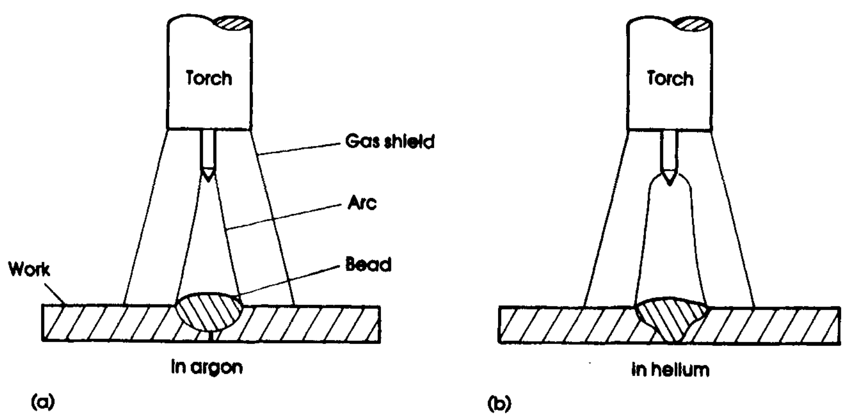
These liquid gases are held at very low temperatures, in the case of argon at −300 F, so the siting of bulk cryogenic tanks is critical. Consult your supplier for advice on which is most suitable for you. Notes on the various gases now follow:

ARGON

This is the most common and economical gas used in TIG welding and is obtained as a by-product when air is liquefied to produce oxygen; argon being present in air at about 0.9%. The advantages of argon are its low ionisation potential and thermal conductivity. Also, being about 1.5 times denser than air it maintains good blanket coverage at the arc for longer periods than helium.

The ionisation potential of argon is around 15.5 electron volts. This is the voltage necessary to remove an electron from a stable atom and convert it into a charged atom or positive ion, making the gas in the area of the arc into a plasma. The remainder of the shielding gas around the arc excludes the active components of the surrounding air and prevents, or at least minimises, metal oxidation.

Argon gives a high arc energy density, *i.e.* a high concentration of energy within the arc area, Fig. 3.8. This allows production of narrow weld seams and it can be obtained at a purity of better than 99.90%, which is essential for welding. It can be used for a great variety of metals and is particularly good for mild and stainless steels, but equally useful for aluminium and magnesium alloys.



3.8 Arc shape using: a) Argon; b) Helium.

A range of argon mixes is available combined with hydrogen additions of between 1 - 5%. These gases concentrate the arc and can increase welding speed but they are more often used to give a better appearance to the finished weld. Hydrogen is classed as a reducing gas. It should be noted that inclusion of hydrogen can give rise to weld porosity, so the rule here is to use the lowest ratio of hydrogen to argon consistent with a good weld both for strength and appearance, Table 3.4. Your gas supplier will assist with the choice of mix.

Table 3.4 Shielding gases for various metals

Gas mix, %	Mild steels	Low alloy steels	Stainless steels	Nickel alloys	Aluminium and alloys	Copper and alloys	Remarks
Commercial argon 99.995	•	•			•	•	General use
High purity argon 99.998	•	•	•	•	•	•	Fine precision welding
Ar75/He25	•	•	•		•	•	Very suitable for aluminium
Ar70/He30	•	•	•	•	•	•	Very suitable for aluminium
Ar50/He50	•	•	•	•	•	•	Very suitable for aluminium
Ar99/$H_2$1	•		•				Not for use with martensitic s/steels
Ar98.5/$H_2$1.5	•		•	•			Not for use with martensitic s/steels
Ar98/$H_2$2			•	•			Not for use with martensitic s/steels
Ar97/$H_2$3			•	•			Not for use with martensitic s/steels
Ar95/$H_2$5			•	•			Not for use with martensitic s/steels
Special Ar/H_2 mixes			•	•			Not for use with martensitic s/steels
Commercial He 99.993				•	•	•	Not for use with any steel
Ar/N						•	Not for use with any steel

HELIUM

Helium is an ideal shielding gas but more expensive in the UK and Europe and not therefore so widely used, in particular for hand welding. Its ionisation potential is 24.5 electron volts, with excellent thermal conductivity, and it gives deeper penetration than argon for a given current and arc gap.

Figure 3.8 shows the general TIG arc forms obtained with argon and helium when used for *mechanised* welding.

With an equivalent arc length, helium has a higher arc voltage than argon. The relationship (amps × volts × time = joules) shows that an increase in arc voltage considerably increases heat input to the weld, so helium or mixtures of argon and helium will score when welding thick metals or using high travel speeds, whilst minimising porosity. However, arc lengths must be held to a very close tolerance when using helium and this means that it is more suitable for machine welding, seldom being used for hand welding unless by a highly skilled operative.

Other disadvantages of helium are the necessity for high flow rates, with an accompanying increase in cost, and the fact that it can inhibit arc striking at low currents. Above 150 A it has some distinct advantages for thicker metals.

Helium/argon mixes are available with argon percentages ranging from 50–75%. These are ideal for most metals and alloys, particularly copper and aluminium.

When used in an automatic welding system helium can, in some circumstances, entirely inhibit an open-gap arc strike and will almost certainly have an adverse effect on arc pulsing. If it is absolutely necessary to use pure helium, a solution could be first to establish an arc in high purity argon and then rapidly change to helium when an arc is established.

NOTES:

- The purity percentages are for gas in cylinders only. Bulk and liquid gases tend to be less pure. Consult your supplier;
- Gas mixes containing hydrogen require a special cylinder regulator usually with a left hand (LH) connecting thread. Again consult your supplier;
- Keep cylinders at room temperature (about 20 C) when welding. If your cylinder storage area is colder than this, allow cylinders to warm to room temperature *before* using;
- Ensure that all piping and connectors are airtight and moisture free. Argon in particular has a slight tendency to be hygroscopic and can collect slight traces of water vapour through piping, leaks, *etc*;
- Argon with 3 or 5% hydrogen is particularly suitable for automatic use, giving increased heat input and thus higher welding speeds;
- Argon with 1% hydrogen gives a clean and shiny cosmetic appearance to the weld bead or seam, a big advantage to the appearance of instruments, *etc*. Major gas producers and suppliers produce Ar/H_2 mixes at a customer's request to his specification. Gas producers also give advice on gas mixes for specific applications;
- Argon with a small addition of nitrogen can help in welding copper as it increases heat input at the arc. *Never* use an argon/nitrogen mix with

ferritic metals as it reduces weld quality and strength. If in doubt consult your gas supplier;

- For very special purposes a gas supplier can provide a mix of more than two gases but this is unusual and costly for small amounts.

BACK PURGING

The finish of the underside of a weld bead is as important as the top surface and can be improved by back purging using the same gas as that flowing through the torch, see later chapters.

Cables

In general the only independent cable used in TIG welding is the current return (earth) and by far the best for this purpose is stranded copper, covered with a natural or synthetic rubber (rather than plastic) which will remain flexible over a wide temperature range. Use good quality cable from a rep-utable manufacturer and keep to the maximum current capacity stated. Always ensure that the connectors at both ends are tight and will not work loose in use. Keep cables as clean as possible and away from possible damage by welders' boots, fork lift trucks or heavy components.

TIG welding produces very little spatter and a suitable natural or synthetic rubber covering is the most resistant to heat damage. PVC and other plastic coverings have adequate insulation properties but are more prone to heat damage and are not so flexible, particularly in cold conditions.

COMPOSITE TIG TORCH CABLES

Composite current cables are often the most troublesome part of a TIG welding system often through failure of the connections, allowing water leaks or the introduction of air into the shielding gas. Many users buy torches with regard only to cost which usually dictates the type of cable fitted. For gas cooled torches there are two styles of cable available, the first a two piece type which uses insulated welding cable to carry the current and a separate hose for the shielding gas. The main advantage with this system is that it is easy to repair and generally long lived. To its detriment are loss of flexibility and comparatively high cost. The most popular option is the use of monocable incorporating the copper conductor inside a larger hose through which also passes the shielding gas. This has the advantage that the hose acts as an insulator for the copper strands while simultaneously supplying shielding gas, and flexibility is improved considerably although ease of maintenance is lost. Monocables are sold in three main forms: PVC hose, reinforced PVC hose and overbraided rubber hose. Rubber hose is by far the superior material combining excellent flexibility with unsurpassed heat

Table 3.5 Sheaths and coverings for composite cables

Material	Rating	Comments
Natural rubber sheathing	★★★	Good all round performance; resists abrasion well and protects against spatter and grinding sparks. Swells in contact with oil. Thicknesses less than 1.5 mm tend to tear in use.
Neoprene sheathing	★★★★	Has similar properties to natural rubber. Less liable to tear and is self-extinguishing.
Unreinforced PVC monocable	●	Low quality: very likely to leak when hot. Flexibility poor, especially when cold.
Reinforced PVC monocable	★★	Reasonable resistance to leakage when correctly crimped. Good flexibility. Be wary of operating gas cooled torches at maximum current for long periods.
Two piece power cables (rubber or PVC)	★★★	Easily maintained. Not as flexible as monocables but hardwearing especially when rubber coverings are used.
Rubber monocable (natural and synthetic)	★★★★★	Extremely flexible, hardwearing and unlikely to leak. *Note*: rubber hoses should always be overbraided or reinforced as plain hose might burst when pressurised.
Nylon zip covers	★★★★	Very flexible with good abrasion resistance. Protection against oil, water and spatter not good.
Glass fibre zip covers	★★★	Very good heat resistant and flexibility, poor life in abrasive conditions.

resisting properties. The PVC hose suffers from heat ageing which in certain conditions rapidly causes leakages around the crimped areas, especially with unreinforced hoses, Table 3.5. The choice, which will probably depend upon the finance available, should also pay attention to the cable ends to ensure that the outer ferrules are of a length to give an effective and reliable water/gas seal. This is the most common point of failure. A 20 mm long ferrule can be considered to be sufficient.

With watercooled torches the construction of current cables is usually of the mono style. In these the cable acts as the drainpipe for the cooling water. The effect of this is twofold; heat ageing of the hose is not such a problem and the cross sectional area of the copper strands in the cable can be reduced because of the watercooling. The weight reduction is also an advantage when using watercooled torches in comparison with similarly rated gas cooled torches which require a much heavier cable. Again the use of rubber hose is of benefit to flexibility and torch life.

SHEATHS

Although it adds weight an overall sheath should be considered for composite power cables to provide protection for the leads and prevent damage as they are dragged across workshop floors. Sheaths come in many forms, dependent upon the torch manufacturer, the best type being made from rubber, fitted at the point of manufacture. This gives good resistance against abrasion and spatter, dependent upon the material. It may also be fire retardant. Available as a retrofit item is a zipper cover which is normally made from a nylon or glassfibre material and is zipped up over the length of the cables. This type is generally more expensive but has its advantages in use as the cover can easily be removed and replaced.

The choice of cables to be fitted to a TIG torch is dictated first by the application and second by price. Table 3.5 gives short lists of available types as a rough initial guide to price and performance.

The star rating indicates the merits and wearing properties of various materials for cable coverings, the more stars the better.

CABLE CONNECTORS

Table 3.6 gives brief descriptions of type and use.

Most countries' standards associations have recommendations both for cables and connectors but considerable confusion still exists as to the production of a *world* standard for such items. The associations meet regularly to try and resolve the matter (particularly European and American) but at the time of writing no firm agreement has been reached. Until such a happy day arrives, use suitable conversation units and adapt as required.

Table 3.6 Cable connections

Type	Use	Description	Comments
BSP female	Mainly European power sources	Standard end fittings of a basic type as stocked by most distributors	Tighten well and insulate with a suitable rubber or plastic boot
American fittings	USA imports to Europe	Torch leads can be made up to this specification for the UK but often at a high price	Normal method used in the USA and readily available there. High current capacity
Central adaptor	Fitted to a number of European machines (Advantage: quick torch connection)	Produced by a number of manufacturers but pin size and position may vary	Quick fit and release. ESAB proprietary type, *etc*
Central connector	Most European power sources and cable extension connectors	Available to order. Ensure that the correct type is specified. A number of different types are available rated on size and current capacity	Quick fit and release. Becoming increasingly popular in Europe. BINZEL proprietary type plus DIN, *etc*
Stud fittings	Older UK and USA machines	Use standard torch cable adaptors (spade type)	Tighten well and insulate
Dual purpose	UK and USA machines easily available	Carry both welding current and cooling water	Very popular for USA machines, orbital weld heads, *etc*

Whatever type of fittings are used, great care must be taken to ensure that *all* cable connections are tight and well insulated with no bare live metal parts. In particular check that your connectors are insulated against HF leakage when HF is being used, by ensuring that rubber boots, *etc*, are adequate, fit tightly and overlap all mating parts. When clamping fittings to cables all wire strands must be clamped by the ferrule. A good ferrule is essential to eliminate stray arcing and overheating at the clamped joints.

CABLE MARKING

Good quality cable should have its size and current rating printed on the insulated sheathing at intervals along its length. However, many equally good cables do *not* have this marking so always buy from a reputable supplier and hold him responsible if not satisfied.

Chapter 4

TIG welding power sources

The power source is the heart of all welding systems; reliability, accuracy and long life being the desirable characteristics governing the selection of a set. Price does, of course, enter into the choice but with TIG power sources, as with any electromechanical device, you get what you pay for. When considering purchase, pay great attention to duty cycle, spares availability and the speed with which servicing can be obtained if required. In small workshops there is seldom a back-up set, so choose wisely. An enormous range is available and most reputable suppliers will arrange a free trial.

The power source must convert mains electricity, with its inherent variations, into as stable a welding current as possible. It does this by using a transformer to reduce mains voltage and proportionally increase current through the secondary windings and convert this to welding current using a rectifier. Early welding sets were bulky, heavy and often unreliable, although it is remarkable how many old sets are still giving good service, probably because of their heavy, sound, construction and relatively low duty cycle. Duty cycle is measured on the basis of how long maximum current can be used over a percentage of a given period, without overheating or internal damage. Modern sets now use overload trips, *etc*, to minimise damage.

Modern power sources are much lighter and less bulky through use of solid state electronics, efficient cooling and modern materials such as plastics and light alloys in their construction. It is generally considered that the four main basic types are as follows:

Type 1 Transistor series regulator power sources - DC only

These use power transistors for current regulation, with analogue control from a low current signal. They are low in efficiency but give accurate and very stable control of the welding current and provide pulsing with varying waveforms and frequency.

Type 2 Switched transistorised power sources - usually DC only

Using power transistors with HF switching of the DC supply, these power sources give similar current control characteristics to Type 1, are more electrically efficient but give a smaller range of pulsing frequency and waveforms.

Type 3 Thyristor (SCR) power sources - AC/DC

Very advanced electronics, using thyristors instead of diodes on the transformer output side. These power sources give excellent current and weld time accuracy, square AC waveforms, and can be used in the pulsed mode, albeit with limited pulsing frequency response.

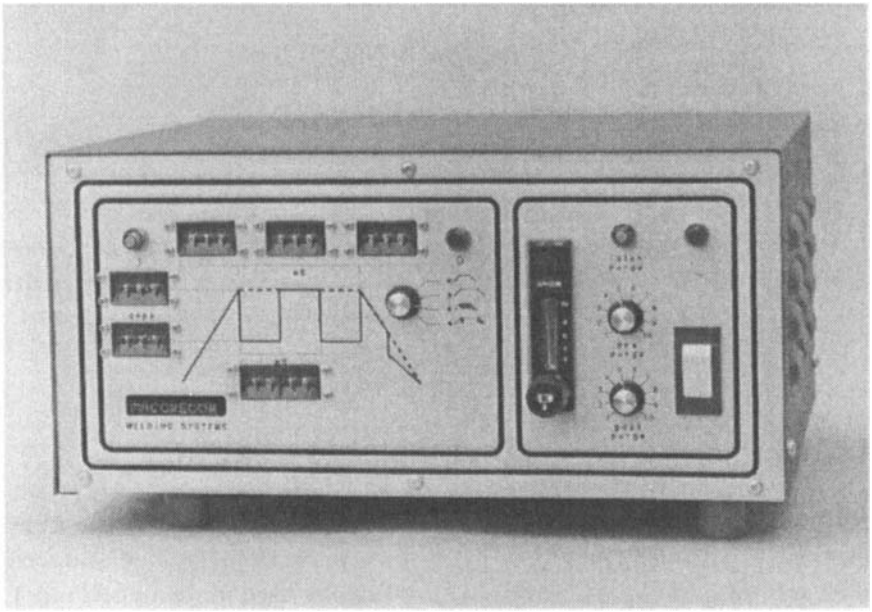
Type 4 AC rectifier plus inverter power sources - AC/DC

These sets are up and coming in the welding industry, very versatile, light in weight and can have many add-on features. Very cost effective and small in size with high efficiency. The response rate is generally lower than transistorised power sources, but then you can't have everything. Watch future progress in development of these undoubtedly commercially attractive sets.

The above type descriptions are in no way comprehensive, neither are they in any order of preference. Every manufacturer issues technical explanatory literature and will advise on suitability for purpose. The author does not intend to go further into technicalities but, to assist with choice (for this book only), three basic categories have been assigned to power sources to help purchasers. These are not based on any standards either national or international but are merely given to list some of the minimum features a purchaser should expect from equipment from each of the categories in addition to the basic current controls and meters:

CATEGORY A - TYPE 2

These are precision solid state, transistorised units and almost always for special and automatic use when extremely stable and consistent arcs are required. They are comprehensively specified and can be very expensive. They range down to 0.1 A up to a maximum of 100–150 A, Fig. 4.1.



4.1 Precision solid state TIG welding power source, category A (type 2).

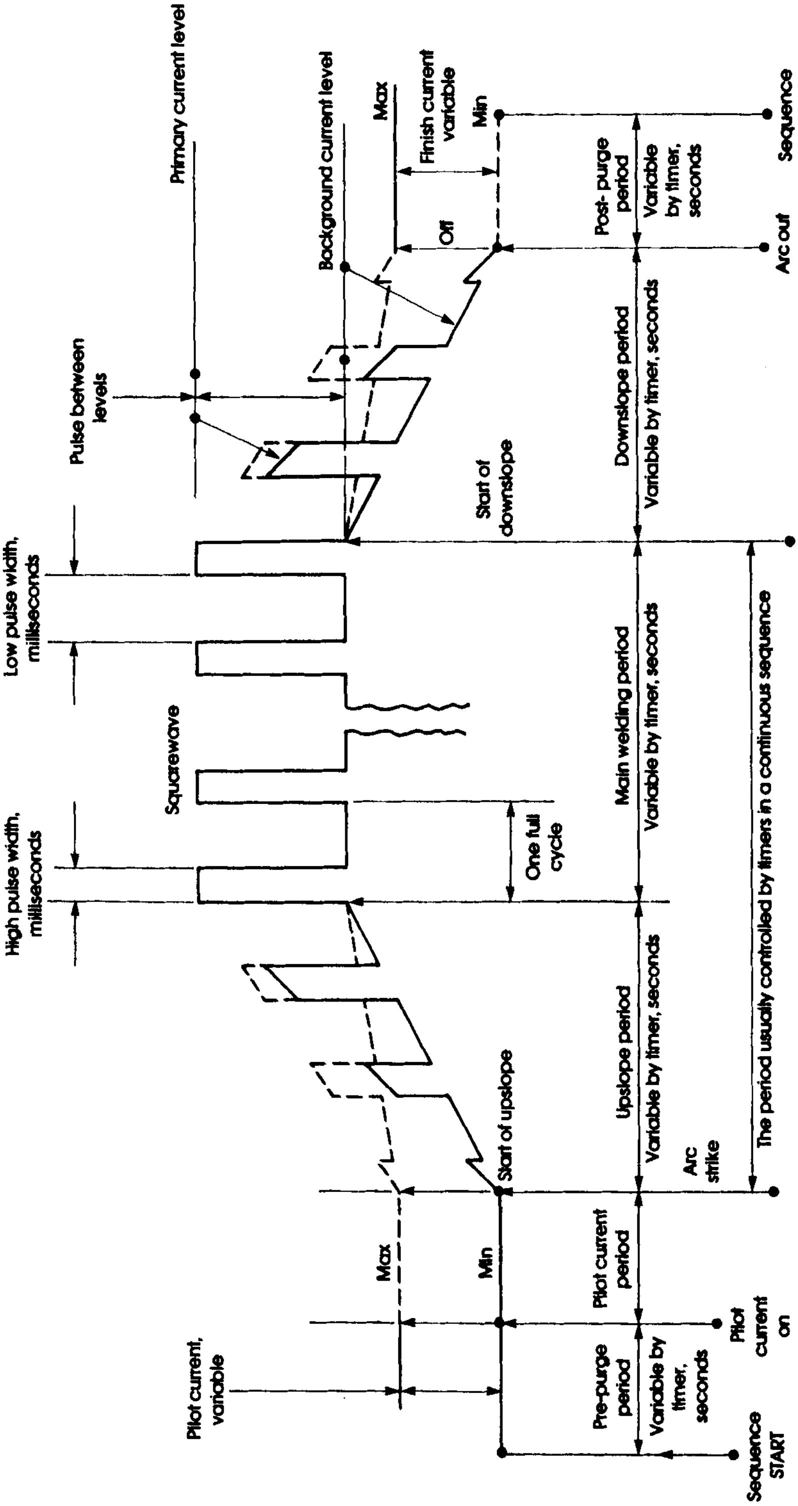
Features

Remote arc sequence switching;
Mains and output current stabilisation;
Arc strike by HF or similar system, *i.e.* computer friendly;
Pre-and post-purge gas flow and time controls;
Additional gas flow circuits for back purge, *etc*;
Current upslope and downslope time controls;
Pulse controls both for current levels and times;
Weld timer accurate to 0.1 s minimum;
Hand welding facility and remote current control;
Compatibility with arc length control systems, robots, computers, *etc.*

Figure 4.2 shows a welding sequence which should be available from these power sources.

Applications

Stainless and alloy edge welded bellows and diaphragms;
Transducer and load cell body welding;
Battery can top and end cap welding;



4.2 Typical welding sequence available from a category A (type 2) power source.

Mechanised and automatic welding machine use, including jewellery welding;
Operation of rotary and orbital welding heads;
Welded encapsulations of electronics;
Filter body and media assemblies in exotic metals;
Jet engine blade and seal fin repairs;
Thin section automatic aluminium welding.

CATEGORY B TYPES 1, 3 AND 4

High quality units mainly used for manual AC/DC welding. Also suitable for building in to mechanised, robotic and semi-automatic welding stations for welds of moderately high quality. Range up to a maximum of around 450 A, stable down to 8–10 A. Particularly suitable for welding aluminium and its alloys.

Features

Current level meters and controls;
Upslope and downslope time controls;
Gas flow controls;
Changeover switching, TIG to MIG/MAG;
Arc strike by HF or similar;
In-built or scope for add-on units such as pulse control, *etc*;
Pre- and post-purge gas weld timer, *etc*;
Remote arc switching.

Applications

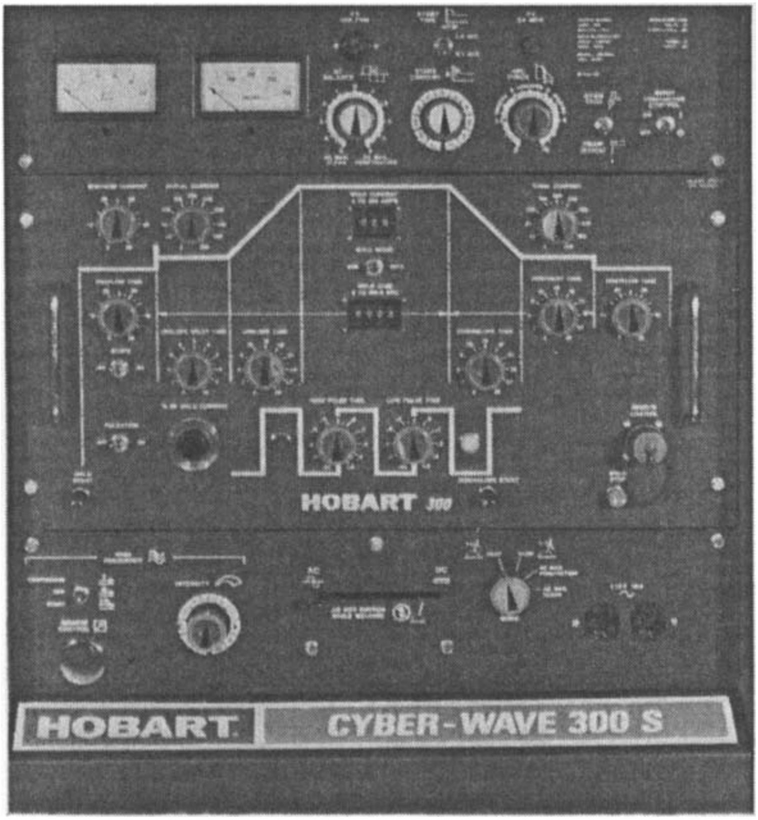
High class workshop welding both AC and DC;
Heavy duty aluminium welding;
Edge and seam welding of canisters, air reservoirs, *etc*;
Mechanised welding machines;
Mild and stainless medium size pressure vessels;
Nuclear fit-up and repair welding.

CATEGORY C USUALLY TYPE 3

Many excellent value for money power sources come within this category and, as in category B, some can be retrofitted with pulsing and timing controls. Ideal for general and jobbing shop use. A very wide range is available and the equipment on the market is usually competitively priced. Beware of too many features, look for a good rugged build quality and service/sales availability.

Note

These Categories by no means represent the full range on the market. TIG power sources are available with capacities up to 1200 A or more and many



4.3 Category B TIG/MIG/MAG 300 A welding power source.

specialised machines are also on sale. A reputable manufacturer or agent should be consulted once your demands are established. If any doubt exists a professional welding society will assist you.

Installation and maintenance

Unless absolutely necessary it is best to install a power source in a convenient spot and *leave it there*, thus avoiding trailing mains supply cables, gas and water hoses, *etc*. All connections should be kept as short as possible. Make sure if you are using cylinder gas that there is adequate space near to the power source to change heavy cylinders easily and quickly (chain cylinders back to a wall if possible). Dust is prevalent in almost every welding shop and accumulates inside a power source in considerable quantities. During routine maintenance remove covers and blow out dust or remove by suction, taking care not to damage circuit boards, *etc*.

Considering the type of work it has to do a modern TIG power source can take considerable punishment and still keep working, but don't unnecessarily give it a hard life.

Calibration

Certain government, ministry, nuclear and aerospace weld procedures call for regular calibration of the welding system used, which can sometimes be a bone of contention as the meters and measuring equipment used must *themselves* be calibrated against a reference standard. Specialist companies exist to carry out checks on a contract basis as and when required and will guarantee their work.

Modern power sources are not as prone to deviate from specification as the old types so calibration and certification should only need to be carried out about once every 12 months unless the procedural contract states otherwise.

CHAPTER 4

Tube to tubeplate

Welding techniques

The TIG process is widely applied to welding tubes into a tubeplate. Possible joint configurations are shown in Fig. 23. In comparison with other TIG operations, good quality tube to tubeplate welding, with either a front or back face technique, requires greater attention to the initial cleaning of the component surfaces, joint fit-up and to the condition of the electrode tip. With regard to cleaning, low porosity can be achieved by using ultrasonic techniques with final degreasing in a solvent immediately before insertion of the tube into the tubeplate. The fit-up can affect the consistency of penetration, and here roller or hydraulic expansion of the tube into the tubeplate has been shown to be particularly beneficial when using the front face welding technique.

When design considerations permit a front face technique should be employed because:

1 Fewer restrictions are imposed on the design of torch;

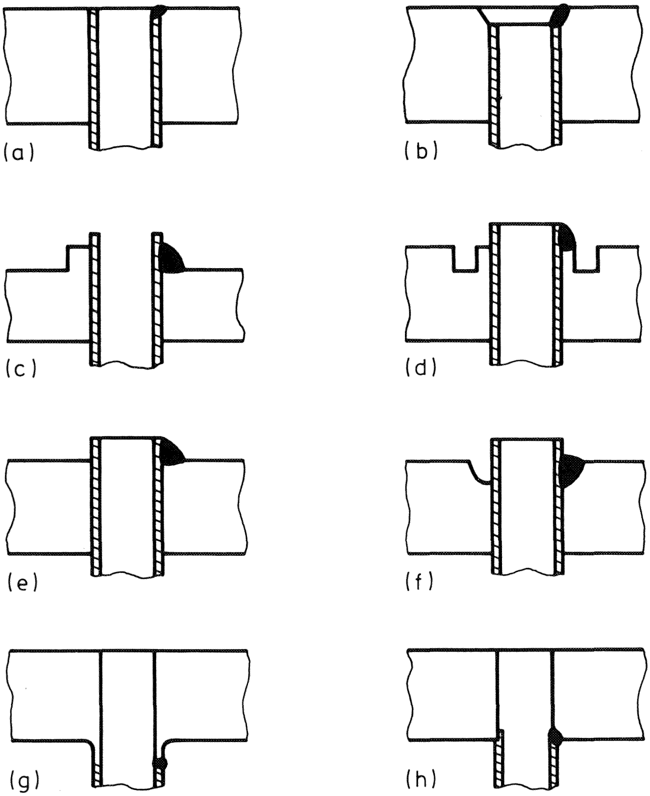
2 The electrode is more readily positioned on the joint line;

3 Welding can be directly observed by the welder;

4 Filler can be added easily to the weld pool.

Equipment

Equipment for tube to tubeplate welding usually consists of special purpose machines. The machine for front face welding usually comprises a rotating torch with a means of locating on the edge of the tube. A typical production machine is shown in Fig. 24a. In this case the welding head is located on the tube to be welded by means of a centre mandrel and then fixed in position by means of pneumatically operated 'pull-in' cylinders; the equipment in production use is shown in Fig. 24b.



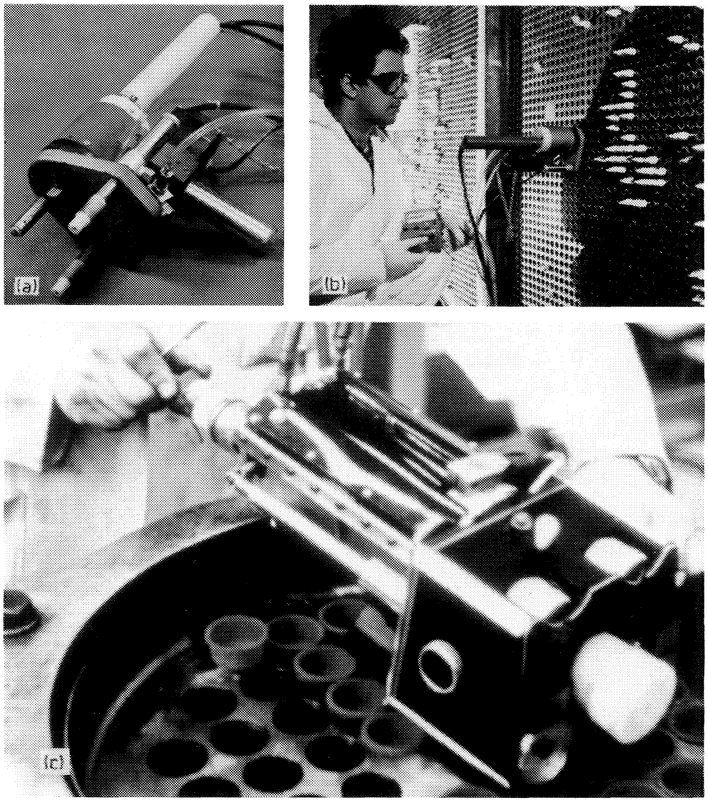
23 *Typical joint configurations for tube to tubeplate welding: a) Flush tube; b) Recessed tube; c) Added ring; d) Trepanned tubeplate; e) Fillet; f) Extended tube; g) Tube to boss; h) Recessed (backface) tube.*

Back face machines are normally more complex as they often incorporate sensor systems for pre-setting the electrode to joint distance; a bore welding torch which was used for welding the steam generator for the advanced gas cooled reactor is shown in Fig. 24c.

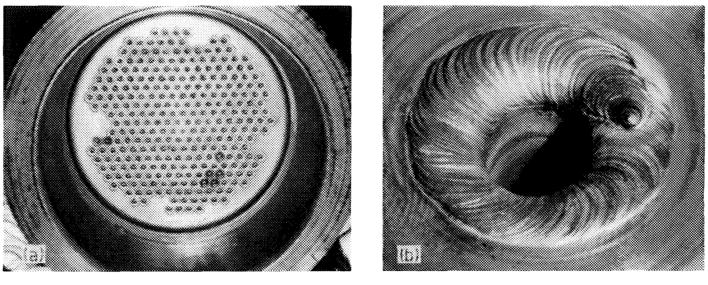
Applications

Front face welding

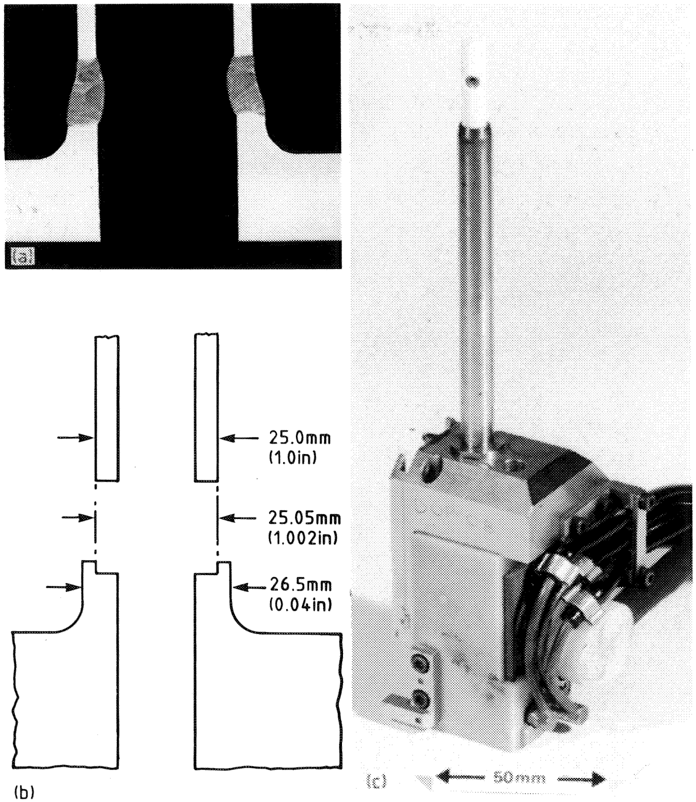
A typical example of front face welding is shown in Fig. 25, in which 13mm (0.5in) OD 2.5mm (0.1in) wall thickness carbon-manganese tube was welded into the tubeplate using the flush tube joint configuration (Fig. 23a). Welding was carried out using argon-helium shielding and a two pass



24 *Examples of tube to tubeplate welding heads: a) Front face torch; b) Front face torch in production use; c) Back face torch (courtesy of Babcock Energy Ltd).*



25 *Front face welded in 13mm OD carbon-manganese tube and tubeplate, joint configuration as shown in Fig. 22a: a) General view; b) Finished weld. Welding conditions: shielding gas – 60% helium/40% argon, electrode diameter – 2.4mm, electrode tip angle – 40°, welding current – 110A, welding speed – 30 sec/rev.*



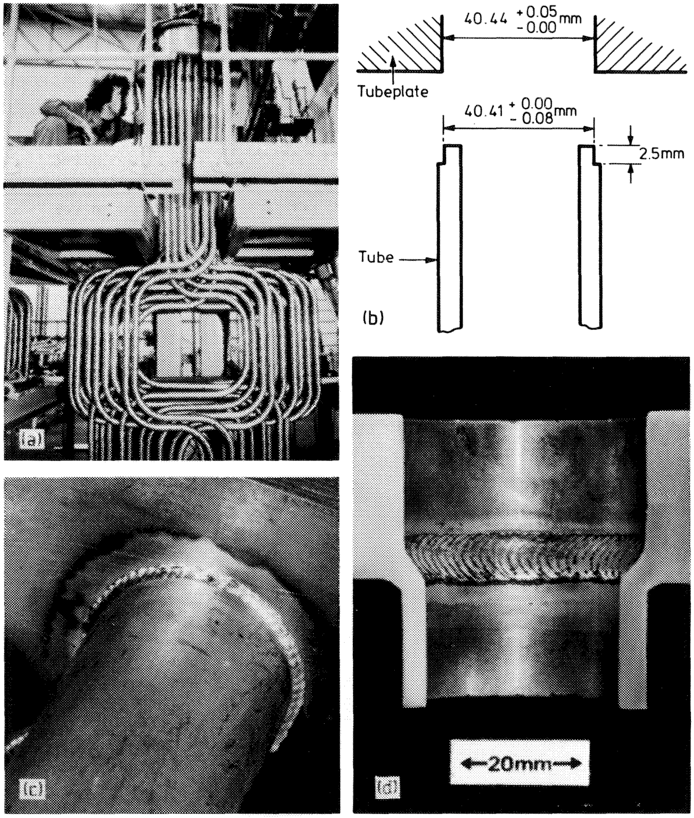
26 *Back face weld in small diameter tube, 25mm (1in) OD x 2.4mm (0.1in) wall thickness, type 347 stainless steel tube to type 347 stainless steel tubeplate: a) Section through weld; b) Joint configuration; c) Welding torch (courtesy of Foster Wheeler Power Products Ltd). Welding conditions: welding speed – 60 sec/rev, welding current – 50A, voltage – 13V, delay – 5sec, rundown – 5sec, arc gap – 12mm (0.5in), electrode position below joint line – 0.04mm (0.002in), welding position – tube vertical.*

technique to avoid weld sinkage, which would have resulted in unacceptable bore protrusion.

Back face welding

Where the major requirement is for a crevice free joint, the back face technique must be adopted using one of the joint configurations shown in Fig. 23g and h. The tube to boss type is more expensive to prepare, and wasteful of material, but it facilitates butt welding and the joint is more readily inspected non-destructively.

An example of a small diameter bore weld in stainless steel is shown in Fig. 26a which required a small precision torch (Fig. 26c) capable of operating within a bore of approximately 25mm (1in.) The joint and welding parameters (given in the figure) were designed to control the degree of bore protrusion and to obtain a smooth external profile with no thinning of the



27 *Tube to tubeplate weld for the reheater pod in the Advanced Gas Cooled Reactor: a) General arrangement of the tubes and tube plate; b) Joint configuration; c) Appearance of back of weld; d) Section through weld (courtesy of Babcock Energy Ltd). Typical welding parameters: shielding gas – helium/argon/5%H_2, pulsed welding current – 120A, pulsed time – 2.6sec, background current – 25A.*

tube wall. The outer wall is protected from oxidation by a layer of submerged-arc flux or argon shielding gas.

The reheater feed water pods for the advanced gas cooled reactor are a notable example of TIG welding of tube to tubeplate joints. The general arrangement of a pod is shown in Fig. 27a and the joint configuration in Fig. 27b. Welding was carried out using a sophisticated bore welding torch (Fig. 24c) which, despite the relatively small bore of the tubes (approximately 40mm (1.6in) OD), had facilities for remote setting of the electrode position relative to the end of the tube.

The essential quality requirements of these joints were zero porosity on radiography, no undercutting of the tubeplate wall and no bore protrusion. Inconsistent results were obtained with the continuous current TIG technique, with the weld pool often failing to penetrate or the incidence of excessive penetration and undercutting. The observed variations in the weld bead penetration profile were caused, at least in part, by the inability of the TIG process to accommodate the variations in heat sink (from variations in ligament thickness), arc position and arc length (through distortion of the shape of the tube hole) which inevitably occur in welding this type of joint configuration.

The pulsed mode of operation, however, largely overcomes these difficulties, particularly if the rotation of the torch was also pulsed. Movement of the torch was carried out during the pulse period, i.e. when the arc forces were still effective, so as to minimise the risk of the molten weld pool flooding back on to the electrode. Uniform weld bead penetration was consistently achieved as shown in the general appearance of the back of the weld, Fig. 27c, and the section through the weld, Fig. 27d.

Further reading

1 Schwartzbert H 'In-bore gas tungsten arc welding of steam generator tube to tubesheet joints'. *Weld J* 1981 60 3.

2 Moorhead A J and Reed, R W 'Internal bore welding of $2\frac{1}{4}$ Cr-1Mo steel tube to tubesheet joints'. *Weld J* 1980 59 1.

CHAPTER 5

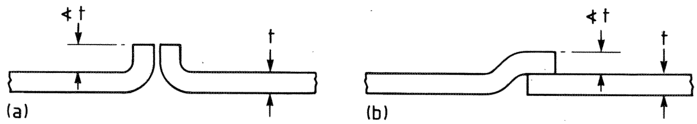
Micro-TIG welding

Welding techniques

The advent of transistor controlled power sources has facilitated the design of very low current power sources; welding currents of less than 1A can now be reliably initiated and held to an accuracy of ±0.5%. To stabilise the arc it is also necessary to use small diameter 2 or 4% thoriated electrodes and the recommended minimum electrode size for various current ranges are given in Table 9.

A small tip of 8–10° is normally used which facilitates arc initiation and arc stability at the low current levels.

To achieve uniform fusion in thin sheet material, i.e. without burn-through, it is essential that the component edges are accurately machined and that the clamping provides a uniform heat sink. It is also necessary to ensure that the two faces are in intimate contact along the entire length of the joint. Tolerance to joint fit-up can be improved by overlapping the sheets or by preforming the edges as shown in Fig. 28.



28 *Edge preparation for welding thin sheet materials: a) Flanged edge; b) Micro-lap.*

Table 9 Recommended electrode diameter and vertex angle for micro-TIG welding at various current levels

Electrode diameter mm	in	Current range A
0.25	0.010	0–2
0.5	0.020	3–8
1.0	0.040	8–20

A tip angle of 8–10° is normally recommended

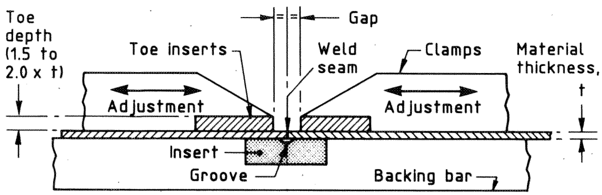
Equipment

A suggested clamping arrangement for butt joints in thin sheet is shown in Fig. 29. The recommended jig design and setting dimensions are given in Table 10. The clamps and backing bars should be made of copper or steel with copper toes or inserts. Clamping should be even over the entire seam length and 'finger' clamps are often used to ensure this.

Specialised mechanised equipment is available with such features as automatic electrode positioning, as shown in Fig. 30a.

Applications

Micro-TIG is now replacing micro-plasma for welding thin section components such as diaphragms and bellows, for single-shot spot welding of wires on to pins and for rounding off surgical catheter guide wire ends. A typical example of a micro-TIG welded application is shown in Fig. 30b

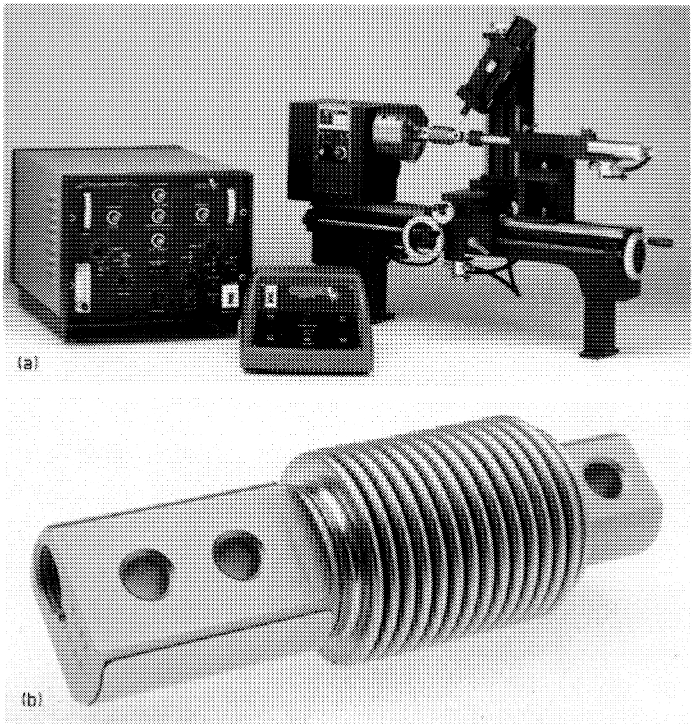


29 Clamping arrangement for welding thin sheet material (courtesy of Precision Systems Ltd).

Table 10 Recommended clamping arrangement for micro-TIG welding thin sheets (courtesy of Precision Systems Ltd)

Material thickness		Clamp spacing			
		Min		Max	
mm	in	mm	in	mm	in
0.075–0.5	0.003–0.020	0.75	0.030	2.0	0.080
0.5–2.0	0.020–0.080	2.0	0.080	4.0	0.160
>2.0	>0.080		1.5–2.0 × t		

t – thickness of sheet
Toe depth – 1.5 to 2.0 t
Groove width – 2 × t
Groove depth – 1 × t (or 0.025 mm (0.010 in) whichever is the mean)



30 *Micro-TIG welding of a load cell: a) Welding equipment showing power source, workpiece handling and electrode positioning; b) Location of joint between the bellows and the end sections (courtesy of Huntingdon Fusion Techniques Ltd).*

which is a load cell made up of a bellows (50mm (2in) OD, 0.08mm (0.003in) wall thickness) wall stainless steel section welded to an Armco body.

Further reading

1 P W Muncaster: 'Developments in low current DC TIG precision welding'. 'Advanced Welding Systems', int conf, London, Nov 1985, publ The Welding Institute.

2 Donath V: 'How can TIG microwelding be mechanised?'. *Schweisstechnik Berlin* 1977 27 2.

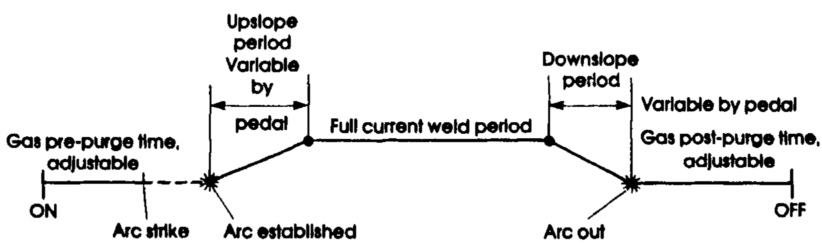
Chapter 5

Unpulsed/pulsed TIG welding

Unpulsed current AC and DC (straight)

In this mode the output current from the power source remains stable and only varies, as in *both* modes, when the arc gap is increased or decreased. Nearly all hand welding is carried out in this mode, as viewing a pulsed arc for long periods can be distressing to the operator. Figure 5.1 shows the usual welding sequence which can be expected from a good quality category B power source.

During the up and down slope periods the welding current is increased or decreased as required by the operator using a variable pedal or hand control on the torch. Operators can become extremely skilled at maintaining and repeating consistent welding parameters, keeping heat input to the required minimum. Some welds can be carried out by an expert *without*



5.1 Sequence from category B power source for hand welding, with pedal control of upslope and downslope.

even using a pedal, with maximum current required set on the control panel and the operator varying the heat input by slightly increasing or decreasing the arc gap, although this cannot be done over a wide current range. The writer recommends use of a pedal current control for all manual welding as this allows full range heat variation in addition to leaving both the operator's hands free to work.

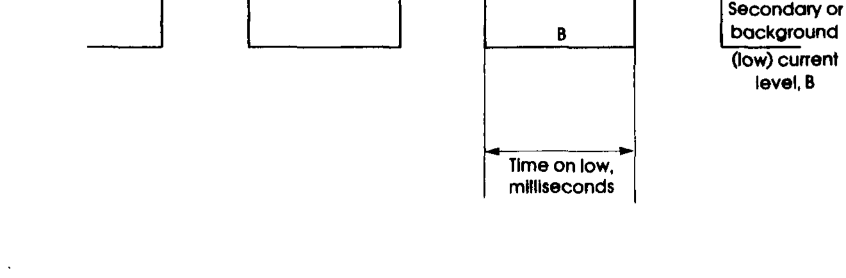
Not all power sources have controls for varying the shielding gas pre- and post-purge times, the gas being on at all times which is wasteful, so *always* try to select a set which has these functions if possible.

Metals which readily conduct, and thus lose, heat, *e.g.* copper are best welded without pulsing, as the aim is to get as much heat into the weld area as possible, particularly for thicknesses in excess of 0.5 mm.

WHY PULSE?

The advantages of pulsed DC TIG are best realised when welding metals which readily melt and flow, such as stainless steels (one possible exception being very thin, *e.g.* 0.05 mm sections and convolutes for edge welded bellows which are often better welded without pulsing). The aim of pulsing is mainly to achieve maximum penetration without excessive heat build-up, by using the high current pulse to penetrate deeply and then allowing the weld pool to dissipate *some* of the heat during a proportionately longer arc period at a lower current. Modern power sources provide a square waveform for the pulse cycle, Fig. 5.2.

In the USA the low level time B is sometimes known as the keep-alight period, an apt term. Thicker metals, say above 1.0 mm, generally require a



5.2 Square waveform pulse current details.

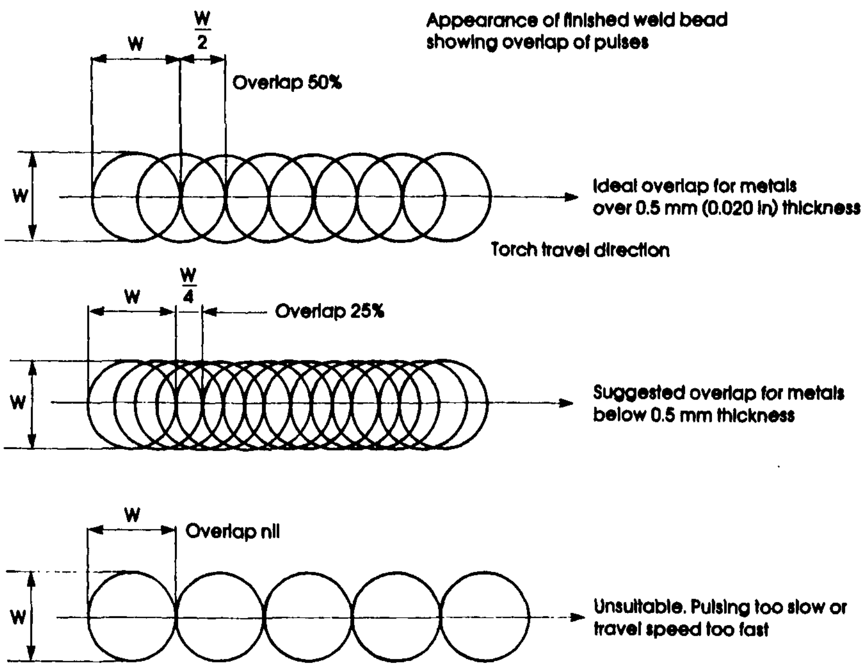
lower pulse rate than thin metals but the rate should always be what best suits a particular application. Trial and error is still the order of the day.

Pulsing can be defined as the consistent overlapping of a progressive series of spot welds. There are no rules governing pulse rate but some starting point is necessary. For stainless steel welding with a closed butt seam, a good average pulse ratio would be 1 high to 3 low: in other words A = 25% B = 75% whilst C = 66% and D = 33%, a ratio of 2 to 1. Then vary the current proportionately up or down until the required weld is achieved. It has been previously mentioned that most pulsed welding is used in automated systems as these give consistent pulse overlaps.

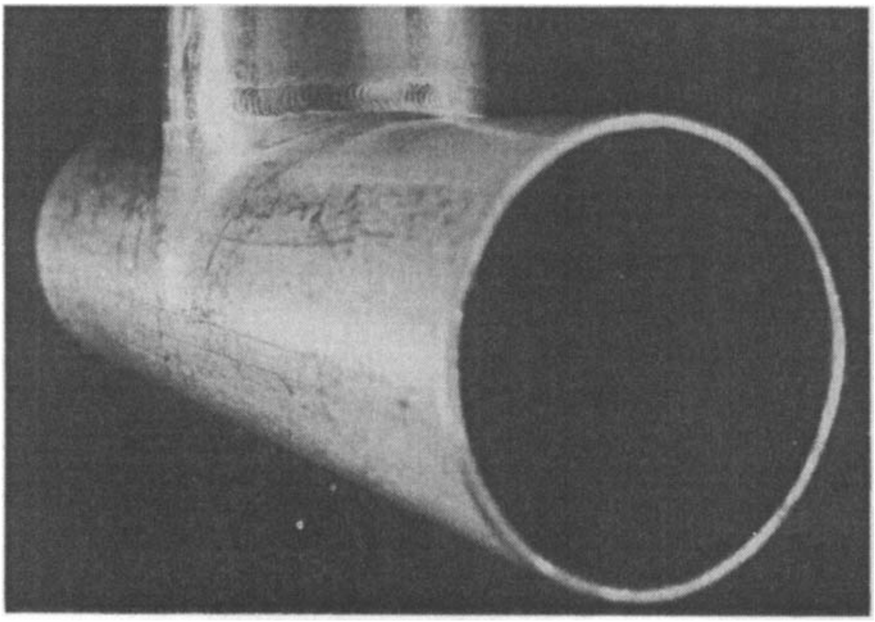
To achieve overlap consistency, the means of moving either the torch or the weldment along the seam must be both smooth and stepless which gives the seam a not unattractive fishscale appearance, Fig. 5.3 and 5.4.

Variations in motion cannot be tolerated particularly in precision welding as such variations increase heat input to the spots, spoiling both the strength and the cosmetic appearance of the finished weld.

One other advantage of pulsing is that the pulse action agitates/stirs the weldpool bringing impurities to the surface thus reducing inclusions and porosity.



5.3 Weld spot overlap appearance.



5.4 T joint produced using pulsed TIG welding.

Average heat input to an unpulsed weld is the product of the power source dial current setting × voltage × time. To find this value for pulsed welding proceed as follows referring to Fig. 4.2.
To calculate average welding current in amps
First add high pulse time to low pulse time, both in milliseconds. This is the total weld *cycle* time (100%).

1 Divide the high pulse time by the weld cycle time which gives a high pulse figure as a decimal of 1.
2 Multiply result (1) by 100 = high pulse time percentage.
3 Subtract result (2) from 100 = low pulse time percentage.
4 Multiply primary current by (2)% = primary current proportion.
5 Multiply background current by (3)% = background current proportion.
6 Add (4) to (5) = average weld current in amps.
Then result (6) × arc voltage × complete weld time (sec) = heat input in joules.

EXAMPLE:

C Primary current = 16 A
D Background current = 8 A
A High pulse time = 50 millisec.
B Low pulse time = 150 millisec.
Total time taken for complete weld sequence taken as, say, 20 seconds arc time.
Arc voltage taken as 11 V

Then: 50 + 150 = *200 millisec* = total weld cycle time (single cycle only) or 5 complete cycles per second, i.e. 5 Hz.

Next: 1 $\frac{500}{200} = 0.25$

2 100 × 0.25 = 25% (high pulse time, %)

3 100 − 25 = 75% (low pulse time, %)

4 16 × 25% = 4.0 A

5 8 × 75% = 6.0 A

6 4.0 + 6.0 = 10.0 A average current

Then 10 A × 11 V × 20 secs = 2200 J.

VIABILITY

Pulsed TIG welding has a drawback in that it is slower than using unpulsed current but its great advantage is that heat build-up in the component is much reduced. Indeed pulsed current is even used to weld end caps to seal the ends of small detonator cans after filling with explosive. Pulsed current also does not permit too much build-up of residual heat in circumferential or orbital welding especially where, at the end of a run, the weld seam overlaps the start.

To make the most use of arc pulsing it can be coupled to, and synchronised with, wire feed, travel speed and oscillation. This gives a more even heat spread, particularly at the seam edges of a V or J preparation and gives better fusion at these edges. Sychronisation can also be allied to arc length control and improves all the characteristics of a weld, including increased deposit rate which is most economically desirable. Many top class TIG power sources have this facility built-in to use if required.

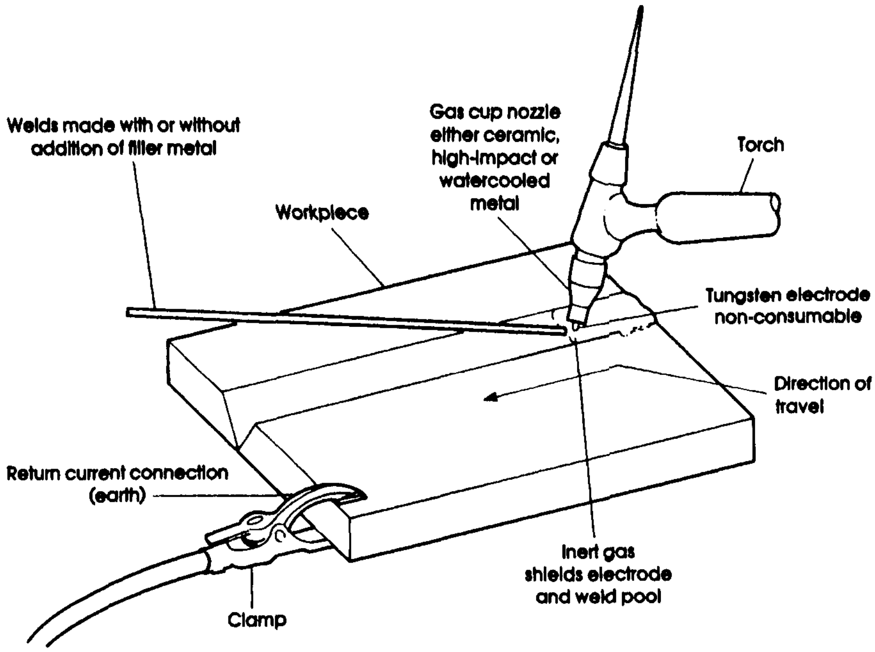
Chapter 6

Hand welding with TIG

Manual TIG welding, like any engineering skill, needs judgement and a steady hand. The judgement is in deciding what heat input is necessary to melt the metal and achieve penetration, the steady hand guides the electrode along the seam, keeping it within the area required. Some welders attain exceptional skill and can weld very thin metals with ease, but most thin sections are best welded mechanically. Figure 6.1 shows the principles of TIG hand welding.

Preparation for welding – component

- Ensure that the correct joint preparation has been made at the weld seam;
- Remove all traces of oil or swarf from the seam edge by solvent and brushing. A brush with stainless wires or stainless wire wool must be used for mild or stainless steels. For copper, use a bronze wire brush if available;
- Wipe the seam edges with a solvent-impregnated, lint-free cloth and, important, allow to dry off thoroughly. Petroleum and other spirits are usually suitable. Check suitability of any proprietary solvents;
- Obtain the correct size and grade of filler wire or rod and degrease before using.

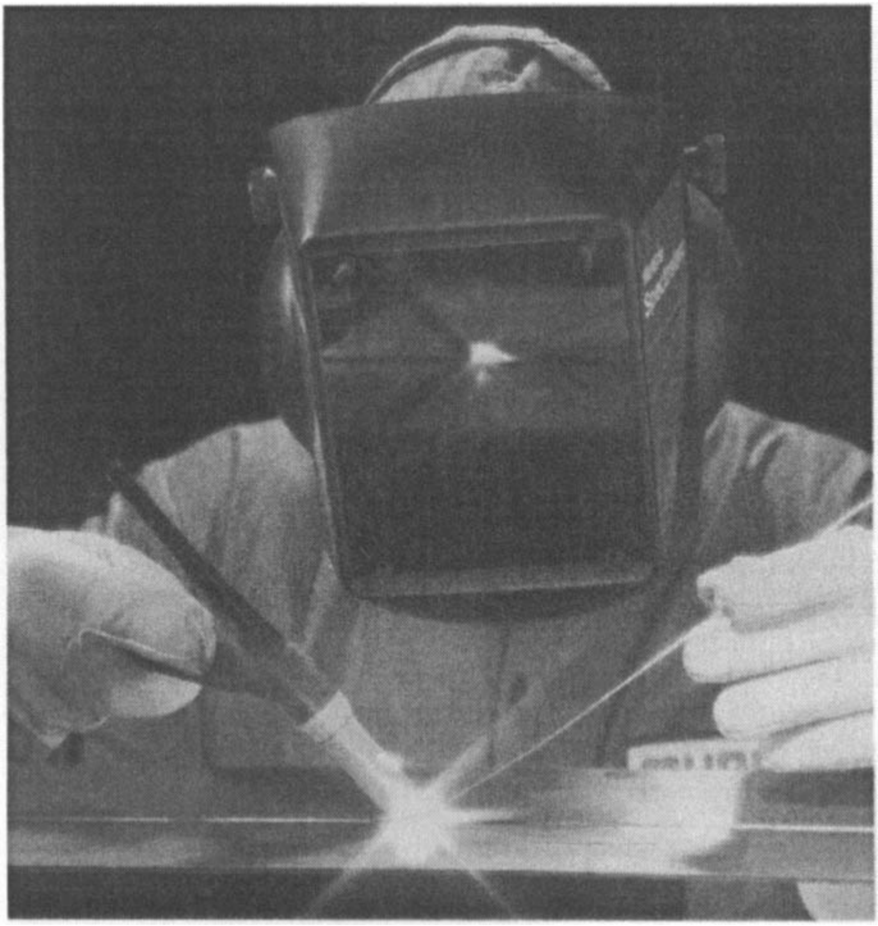


6.1 Manual TIG welding set-up.

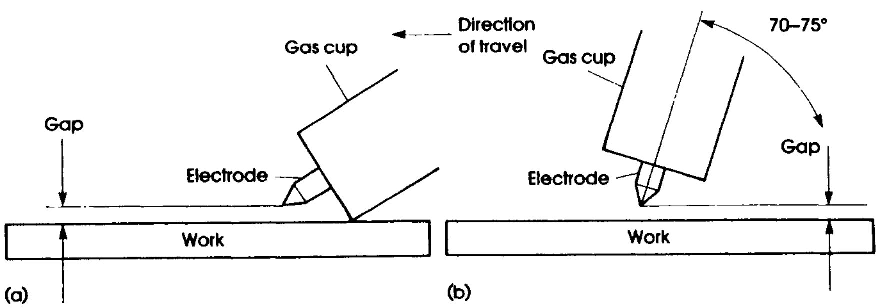
Preparation for welding - operator

- Set the controls on the power source. It is suggested that when using a pedal current control that action be taken to set the maximum current to a safe level which cannot be exceeded, to avoid accidental burnthrough.
- Check that the correct shielding gas is available at the required flow rate. A good average amount is 7 l/min (15 ft^3/hr);
- Adjust the torch, ensuring that the correct size electrode with a suitable ground tip is fitted, electrode stickout is correct and that the type of gas cup used has the optimum orifice size;
- Clear the worktable area and/or access to the component;
- Check that the current return (earth) cable is of the correct rating and securely connected to the component being welded. This is more important than is usually considered;
- Ensure that your helmet is comfortable, fits well and that the visor screen is of sufficient density. Put on gloves and protective clothing. Check that the fume extraction equipment is working if fitted;
- Arrange for gas back purge of the seam wherever possible;
- Get in there and weld, Fig. 6.2.

The booth or welding area should be screened by curtains or similar so that the open arc cannot be seen by other personnel in the workshop.



6.2 Ideal manual TIG welding conditions.



6.3 Position for: a) HF arc striking; b) Welding.

Operation

Try if possible always to weld in the flat (downhand) position and start the arc with the electrode positioned as in Fig. 6.3(a) when using HF or other open arc strike methods. A satisfactory rule of thumb when hand welding is to make the arc gap about one electrode diameter, particularly when welding aluminium. The greatest skill in TIG welding is to maintain a constant arc gap and, as far as possible, electrode-to-work angle, Fig. 6.3(b). Variations in either affect heat input and weld quality. Try never to touch-down and thus contaminate the weld pool. Always brush the weld seam after each pass to remove unwanted oxides or scale.

Weld seams

Tables 6.1 and 6.2 show a comprehensive range of butt and fillet joint preparations for stainless and alloy steels some of which can also be used for autogenous welding. It is essential that, except for some open gap root runs, the edges of the weld seam are held tightly together, perhaps by a preliminary tacking operation. Table 6.3 gives some suggested joints and procedures for spot welding. Considerable practice is needed to acquire the art of welding when using filler wire or rod. The correct position of the wire tip should be well within the shielding gas, touching the weld pool but *not* the electrode.

If it can be arranged when welding with the component on a metal topped bench, either support the gloved hand holding the torch on a smooth wooden rest or on a cool part of the work itself. Try to achieve a short weaving movement from side to side across the weld seam, closing the arc gap slightly at the extremes. This will assist by heating the metal in the proximity of the seam edges, thereby improving penetration at the seam itself. This technique is particularly useful with aluminium which requires a high heat input but can also help with any other metal.

It is advantageous and economical not to use filler wire with stainless steels of around 2.5 mm (0.100 in) thickness or less using a square butt preparation. However, the quality of most welds in carbon steels is often improved by using a compatible wire or rod as this can reduce porosity. If in doubt consult a reliable supplier who will provide wire and rod samples for test welds.

Finally, remember that practice makes perfect.

Table 6.1 Butt welding conditions for stainless and some carbon steels, DCEN, flat position

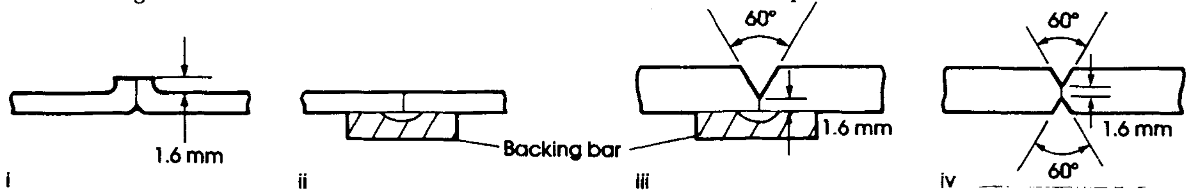
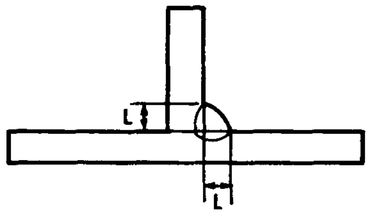


Plate and joint				Welding conditions							Consumables		
Thickness, mm	swg	Sketch	No. of passes	Nozzle bore, mm	Wire dia, mm	Electrode dia, mm	Argon flow l/min	ft^3/hr	Current, A	Speed m/hr	Wire con'n kg/m	Argon con'n l/m	Arc time min/m
0.25	33	i	1	6.4 or 9.5	—	0.8	2	4.2	8	23	—	5.2	2.6
0.35	28	i	1	6.4 or 9.5	—	0.8	2	4.2	10–12	23	—	5.2	2.6
0.56	24	i or ii	1	6.4 or 9.5	1.2	1.2	3	6.3	15–20	23–18	0.013	7.8 or 9.9	2.6 or 3.3
0.9	20	ii	1	6.4 or 9.5	1.2 or 1.6	1.2 or 1.6	3	6.3	25	15	0.015	12	4.0
1.2	18	ii	1	9.5	1.6	1.6	3	6.3	35	15	0.018	12	4.0
1.6	16	ii	1	9.5	1.6	1.6	4	8.5	50–60	12	0.022	20	5.0
2.0	14	ii	1	9.5	1.6 or 2.4	1.6	4	8.5	75	12	0.037	20	5.0
2.6	12	ii	1	9.5 or 12.7	2.4	1.6	4	8.5	85–90	9	0.045	27	6.7
3.3	10	ii or iii	1 2	9.5 or 12.7	2.4 or 3.2	1.6 or 2.4	5	10	125 90	9	0.074	67	13.4
4.8	3/16	iii	2	12.7	3.2	2.4	5	10	1st 100 2nd 125	9	0.30	67	13.4
6.4	1/4	iii	*3	12.7	3.2	2.4	5	10	1st 100 2nd 150 3rd	9	0.45	100	20.1
6.4	1/4	iv	**3	12.7	3.2	2.4	5	10	1st 125 2nd 150 3rd	9	0.30	100	20.1

* *Root run - no filler*
** *Root run - no filler, and one filling run each side*

Table 6.2 Fillet welding conditions for stainless and some carbon steels, DCEN, horizontal-vertical and flat position



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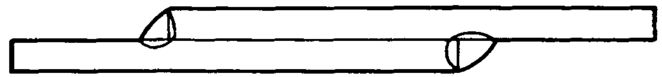

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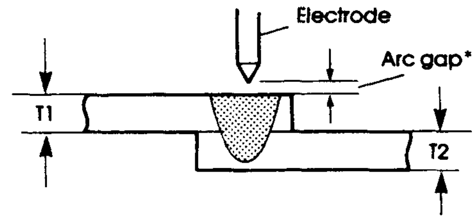
Plate and joint				Welding conditions							Consumables		
Leg length mm	swg	Sketch	No. of passes	Nozzle bore, mm	Wire dia, mm	Electrode dia, mm	Argon flow l/min	ft^3/hr	Current, A	Speed m/hr	Wire con'n kg/m	Argon con'n l/m	Arc time min/m
0.56	24	i or ii	1	6.4	1.2	1.2	2	4.3	15–20	15	0.018	8	4
0.9	20	i or ii	1	6.4	1.2	1.2	2	4.3	25–30	14	0.024	8.6	4.3
1.2	18	i or ii	1	9.5	1.6	1.6	3	6.3	35–40	14	0.046	12.9	4.3
1.6	16	i or ii	1	9.5	1.6	1.6	3	6.3	50–60	11	0.06	15.4	5.5
2.0	14	i or ii	1	9.5	1.6	1.6	3	6.3	65–75	11	0.074	15.4	5.5
2.6	12	i or ii	1	9.5	2.4	1.6	4	8.5	85–90	9	0.116	26.6	6.7
3.3	10	i or ii	1	9.5	3.2	2.4	4	8.5	110–130	8	0.141	30	7.5
4.8	3/16	i or ii	1	12.7	3.2	2.4	5	10	130–170	8	0.15	37.5	7.5
6.4	1/4	i or ii	1	12.7	3.2	2.4	5	10	170–200	8	0.22	37.5	7.5

Table 6.3 Spot welding conditions for various metals, DCEN



					Welding conditions						
T1		Nozzle bore,	Electrode	Thickness	swg	24	22	20	18	16	1/8	1/4
swg	mm	mm	dia, mm	T2	mm	0.56	0.71	0.91	1.21	1.62	3.2	6.4
Mild and stainless steel											
24	0.56	9.5	1.6	A (sec)†	50–55 (0.8)	55 (0.8)	55 (0.8)	55–60 (0.8)	60 (0.8)	60–65 (0.8)	65 (1.0)
22	0.71	9.5	2.4	A (sec)		75 (0.8)	75–80 (0.8)	80–85 (0.8)	85–90 (0.8)	90 (1.0)	95 (1.0)
20	0.91	12.7	2.4	A (sec)			85–90 (1.0)	85–90 (1.0)	85–90 (1.0)	95–100 (1.0)	100–105 (1.0)
18	1.21	12.7	2.4	A (sec)				140–150 (1.0)	160 (1.0)	160 (1.5)	160 (2)
16	1.62	12.7	2.4	A (sec)					175 (1.5)	180–190 (2)	200–220 (2)
Titanium and its alloys											
20	0.91	9.5	2.4	A (sec)			90 (0.5)				
18	1.21	9.5	2.4	A (sec)				140 (1.5)			
16	1.62	12.7	2.4	A (sec)					180 (2.5)		

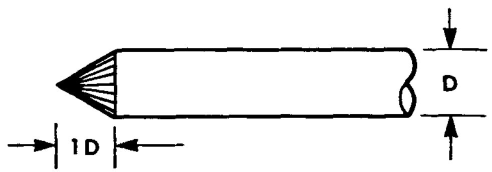
Aluminium and its alloys

20	0.91	9.5	3.2	A(sec)	135 (.7)		170 (.75)	300 (2.0)
18	1.21	9.5	3.2	A(sec)		160 (1.0)		
16	1.62	12.7	3.2	A(sec)			225 (1.3)	350 (2.5)

When using downslope

T1	swg	24	22	20	18	16
	mm	0.56	0.71	0.91	1.21	1.62
Crater time, sec		0.7	1	1.3	1.3	1.3

† These should be added to full 'arc on' times.
** Arc gap should be 0.6 mm (0.024 in) for 0.9 mm (20 swg) increasing to 0.9 mm (0.036 in) for 1.6 mm (16 swg).*
Argon flow rates should vary between 2 l/min and 6 l/min depending upon the bore of the nozzle.
The electrode should be ground to a taper of approx 1D



Filler wire and rods

Consumable wires or rods for TIG welding are obtainable compatible with most metals, and manufacturers will, on request, produce small batches of special materials. Table 6.4 lists a few popular proprietary filler rods sold by the main suppliers to the trade. The standards referred to are British and American, other countries have equivalents.

A list of all filler materials in wire form would more than fill this book. Specialist suppliers will advise the correct wire for any weld.

The last two joints in Table 6.5 show what to look for in a strong viable weld, the others are examples of poor welds and their causes.

Suggestions are made regarding torch and filler rod positions for four different types of joint.

BUTT JOINT

After the arc is established the torch can be raised to 70° from the work, Fig. 6.4. Establish a pool of the desired size and begin feeding filler rod into the leading edge of the pool. Hold the filler rod at about 20° as shown. Holding the arc length at about one electrode diameter, travel at a speed to produce a bead about 2 - 3 electrode diameters wide. When making a butt joint be sure to centre the weld pool on the adjoining edges. When finishing a butt weld the torch angle may be decreased to aid in filling the crater. Add enough filler metal to avoid an unfilled crater.

Cracks often begin in a crater and continue through the bead. A foot operated current control aids the finishing of a bead as current can be lowered to decrease pool size as filler metal is added.

LAP JOINT

Having established an arc, the pool is formed so that the edge of the overlapping piece and the flat surface of the second piece flow together, Fig. 6.5. Since the edge becomes molten before the flat surface, torch angle is important. The edge will also tend to burn back or undercut. This can be controlled by dipping the filler rod next to the edge as it melts away. Enough filler metal must be added to fill the joint. Finish the end of the weld the same as before. Fill the crater.

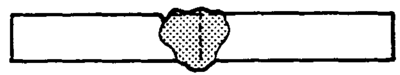
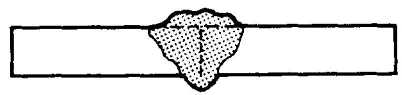
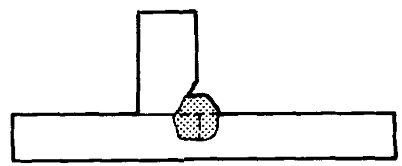
T JOINT

A similar situation exists with the T joint, Fig. 6.6, as with the lap joint. An edge and a flat surface are to be joined together. The edge again will heat up and melt sooner. The torch angle shown directs more heat on to the flat surface. The electrode may need to be extended further beyond the cup than in the previous butt and lap welds to hold a short arc. The filler rod should be dipped so it is deposited where the edge is melting away. Correct torch angle and placement of filler should avoid undercutting. Again the crater should be filled.

Table 6.4 Filler rods for manual TIG welding

Material welded	Rod composition	British standard	Nearest AWS	Comment or application
Low carbon steel	Deoxidised steel rod	BS 2901 A17 Part 1 1983	A5.288 R.60	Mild and low alloy steels
Medium carbon steel	High strength rod	BS 2901 A16	A5.2.88 R65	Also low alloy steels
Super steels	Mild steel plus some aluminium, zirconium and titanium, also silicon and manganese	BS 2901 A15	A5.18.79 ER 70S.2	Excellent for high quality root runs
Creep prone steels	Steel alloy plus 1% chromium and 0.5% molybdenum	BS 2901 A32	A5.28.79 ER 80S B.2	Boiler and superheater tubes
Creep prone steels	2% chromium, 1% molybdenum	BS 2901 A33	A5.28.79 ER 90S B.3	Consult supplier Automotive and aircraft frame tubes
Cast iron	Plus silicon	BS 1453B2		Cast iron cladding and resurfacing
Stainless steels	Rods and wires containing nickel, chromium, molybdenum and other metals in various amounts as suitable	BS 2901 part 2 347 S96 316 S92 308 S92 308 S94	A5.9.81 ER 347 ER 316L ER 308L ER 309	Consult supplier Many variations, particularly for austenitic steels
Aluminium bronze	Zinc free aluminium bronze	BS 2901 Part 3 C13	A5.777 ER–Cu A1–A2	Marine fittings
Aluminium	(a) Pure aluminium (b) + 5% silicon (c) + 10% silicon (d) + 5% magnesium (e) also with larger proportions of silicon and magnesium	BS 1453 BS 2901 Part 4 1050A 4043A 4047A 5356 5556A	A5.10.88 ER 1100 ER 4043 ER 4047 ER 5356	Use Food and aerospace Repairs General purpose Domestic and automotive AlZnMg alloys Other general purpose rods are available

Table 6.5 Weld quality inspection

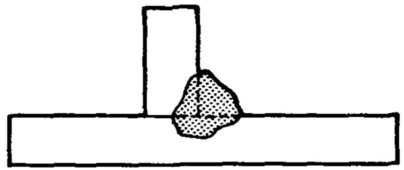
	Problem • Excessive build-up • Poor penetration • Poor fusion at edges	Cause Welding current too low
	Problem • Bead too wide and flat • Undercut at edges • Excessive burn through	Cause Welding current too high
	Problem • Bead too small • Insufficient penetration • Ripples widely spaced	Cause Travel speed too high
	Problem • Bead too wide • Excessive build-up • Excessive penetration	Cause Travel speed too low
	Problem • Undercut • Insufficient weld deposit • Uneven penetration	Cause Welding current too high and/or wrong placement of filler rod
	Problem • Poor penetration • Poor fusion	Cause Faulty joint preparation and too low welding current

Result

- Proper build-up
- Good appearance
- Good penetration
- Bead edges fused in

Cause

Correct technique and current setting

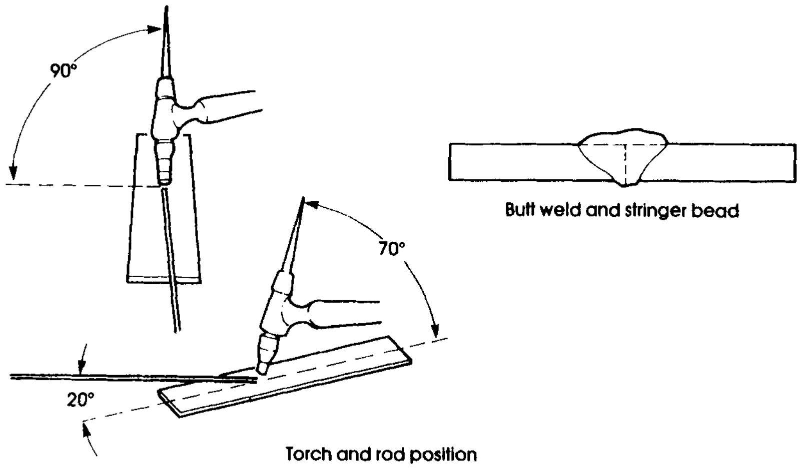


Result

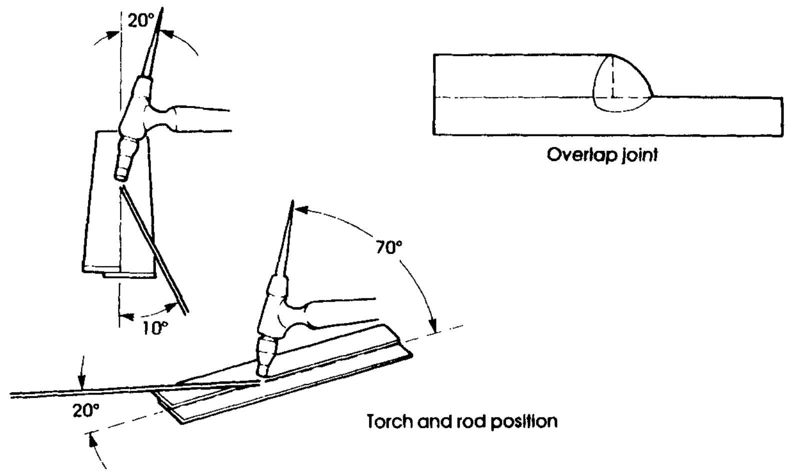
- No undercut
- Legs of fillet weld equal to metal thickness
- Slightly convex bead face

Cause

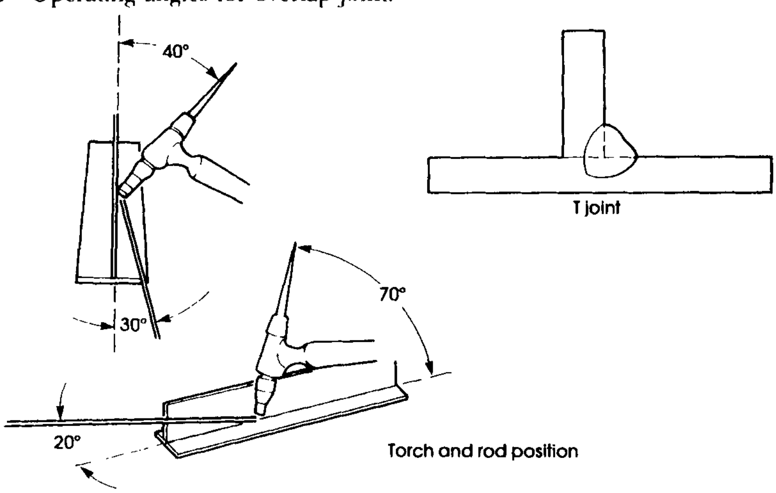
Correct technique and current setting



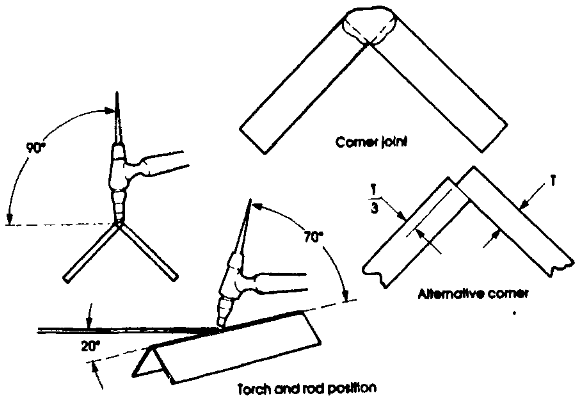
6.4 Recommended torch and filler rod angles for a butt weld and stringer bead.



6.5 Operating angles for overlap joint.



6.6 Operating angles for T joint.



6.7 Operating angles for corner joints.

CORNER JOINTS

Correct torch and filler rod positions are shown for a corner joint, Fig. 6.7. Both edges of the adjoining pieces should be melted and the pool kept on the joint centreline. When adding filler metal, deposit sufficient to create a convex bead. A flat bead or concave deposit results in a throat thickness less than the metal thickness. On thin materials this joint design lends itself to fusion welding without filler if the fit-up is very good. An alternative corner configuration is shown for autogenous welding.

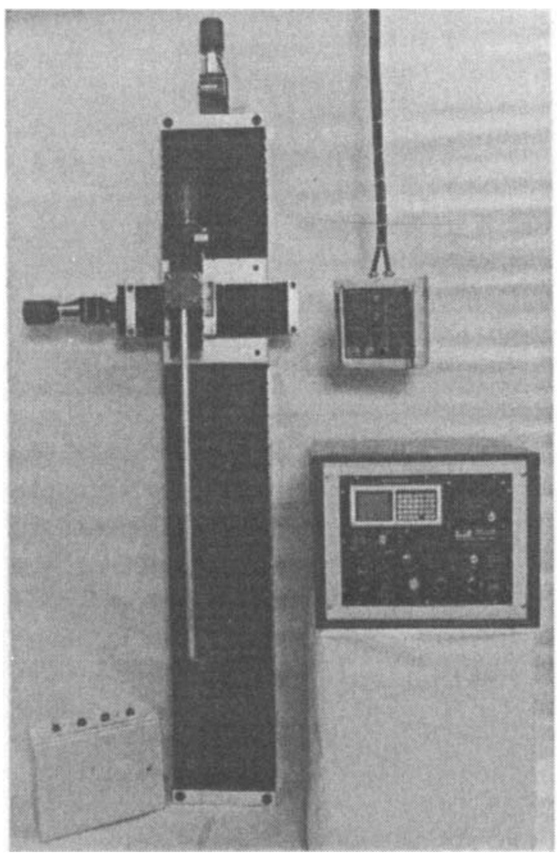
In Tables 6.6 and 6.7 suggested welding parameters, electrode sizes, filler rod sizes, gas flow rates and welding currents are given for these four types of joint in mild and stainless steels.

Table 6.6 TIG welding conditions for various joints in mild steel, DCEN

Nominal metal thickness, mm (in)	Joint type	Nominal tungsten electrode diameter, mm (in)	Filler rod diameter if required, mm (in)	Welding current, A	Argon flow, l/min (ft^3/hr)
1.5 (1/16)	Butt	1.5 (1/16)	1.5 (1/16)	60-70	7 (15)
	Lap			70-90	
	Corner			60-70	
	Fillet			70-90	
3.0 (1/8)	Butt	1.5-2.3 (1/16-3/32)	2.3 (3/32)	80/100	7 (15)
	Lap			90-115	
	Corner			80-100	
	Fillet			90-115	
4.5 (3/16)	Butt	2.3 (3/32)	3.0 (1/8)	115-135	10 (20)
	Lap			140-165	
	Corner			115-135	
	Fillet			140-170	
6.0 (¼)	Butt	3.0 (⅛)	3.8 (5/32)	160-175	10 (20)
	Lap			170-200	
	Corner			160-175	
	Fillet			175-210	

Table 6.7 TIG welding conditions for various joints in stainless steel, DCEN

Nominal metal thickness, mm (in)	Joint type	Nominal tungsten electrode diameter, mm (in)	Filler rod diameter if required, mm (in)	Welding current, A	Argon flow, l/min (ft³/hr)
	Butt			40-60	
1.5 (1/16)	Lap	1.5 (1/16)	1.5 (1/16)	50-70	7 (15)
	Corner			40-60	
	Fillet			50-70	
	Butt			65/85	
3.0 (1/8)	Lap	2.3 (3/32)	2.3 (3/32)	90-110	7 (15)
	Corner			65-85	
	Fillet			90-110	
	Butt			100-125	
4.5 (3/16)	Lap	2.3 (3/32)	3.0 (1/8)	125-150	10 (20)
	Corner			100-125	
	Fillet			125-150	
	Butt			135-160	
6.0 (¼)	Lap	3.0 (⅛)	3.8 (5/32)	160-180	10 (20)
	Corner			135-160	
	Fillet			160-180	



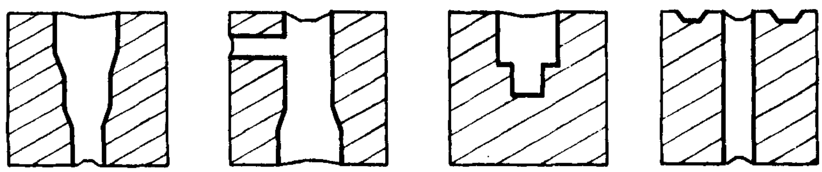
6.8 Mechanised internal TIG cladding torch and X, Y, Z axis positional controller.

TIG cladding and hardsurfacing

Coating the surface of one metal with a thin layer of another to provide wear or corrosion resistance has been carried out by TIG welding for many years. Expensive parts can often be rebuilt as required and then machined back to size. Tanks for corrosive liquids can be surfaced internally and valves in oil and chemical pipelines rebuilt. The reclamation of worn components is very cost effective.

Coating processes are mostly carried out by hand but much development is taking place in mechanical and automatic methods, Fig. 6.8.

Four types of internal cladding that can be carried out by programmed TIG are shown in Fig. 6.9 and turnkey equipment can be purchased for this purpose.



6.9 Various types of internally clad surfaces.

COMPONENT GEOMETRIES FOR INTERNAL CLADDING

- Plain, stepped and tapered bores;
- Bores with intersecting cross bores;
- Conical and spherical surfaces, internal and external, *e.g.* pressure vessel nozzles, control valve bores, seal faces and ball valves;
- Well head bonnets, gate valves;
- Components with pockets or blind bores;
- Valve ring grooves;
- Flat plates (gates) with/without intersecting holes.

The size of bores that can be clad varies from 25 mm upwards in diameter and up to 2000 mm length. The size and geometry of the bore dictate the welding process used. For plain, parallel bores up to 80 mm diameter the cold wire TIG process is used to weld the first pass, with hot wire TIG for subsequent passes. This combination provides good fusion/dilution properties and high deposition rates. Larger diameters are welded using hot wire TIG (or synergic MIG). The ultimate choice of process is based on economics and the weld properties required.

POINTS TO REMEMBER

- Ensure that metal surfaces are clean and correctly prepared;
- Use the correct wire or rod, many types are available;
- Keep the layer as consistent and as thin as practicable. Too thick a layer can be worse than one that is too thin;
- Preheat the component before commencing work if possible;
- Keep heat input as consistent as possible for a homogeneous layer.

For some stainless base materials the cladding process can give rise to severe hydrogen cracking problems, particularly in the bead overlap areas. Alloys with more than 0.3% carbon are troublesome but use of Inconel alloys can assist. Consult a specialist supplier dealing in surfacing wire and rod. TIG is a rather slow process for cladding, but has advantages such as arc concentration and heat control. Pulsed TIG helps in reducing porosity but slows the process even further although improving quality.

CHAPTER 6

Hot wire TIG welding

Welding techniques

The hot wire TIG variant was developed as a means of achieving very high deposition rates without reducing the high weld quality normally associated with TIG welding.

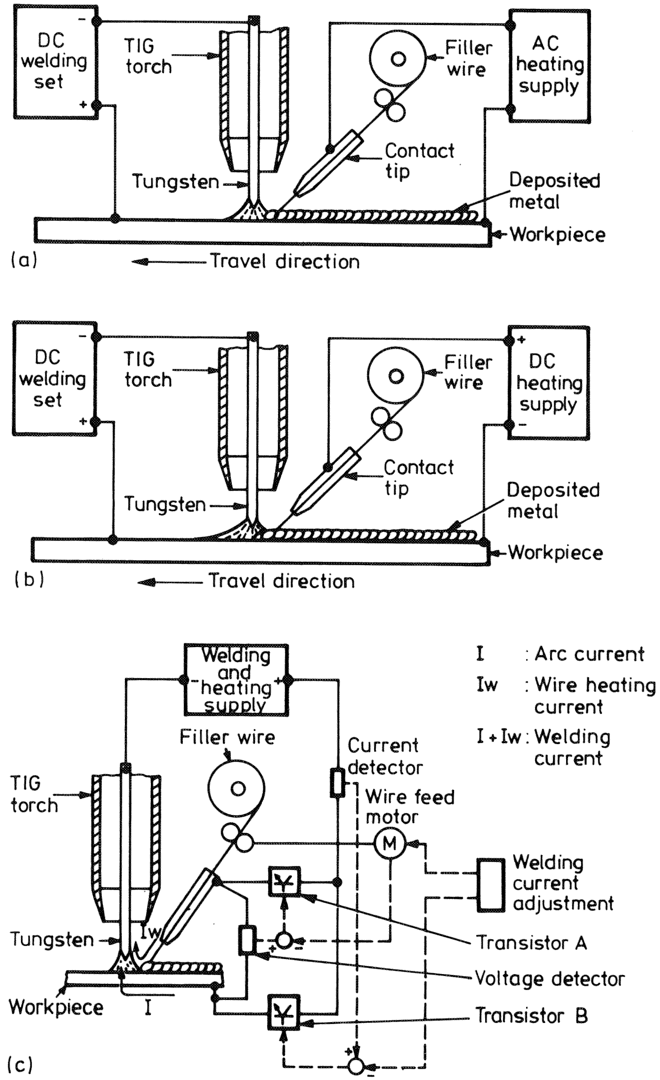
The essential feature is that filler wire is fed directly into the back of the weld pool and resistance heated using a separate power source which may be AC or DC as shown in Fig.31. An AC power source minimises any interference with the welding arc through the magnetic field generated by the current flowing in the wire and is normally chosen for mechanised systems. However, a single power source is also available commercially for supplying the arc and wire heating currents by a switching arrangement (Fig. 31c). Thus, in operation, the arc melts the base metal to form the weld pool. The filler wire, heated to its melting point source, enters the weld pool behind the arc to form the weld bead, Fig. 32. Smooth feeding of the wire, control of angle of entry into the weld pool, and a stable power source are all essential for stable operation, otherwise random arcing from the filler wire occurs with the resulting pool disturbances causing porosity.

Equipment

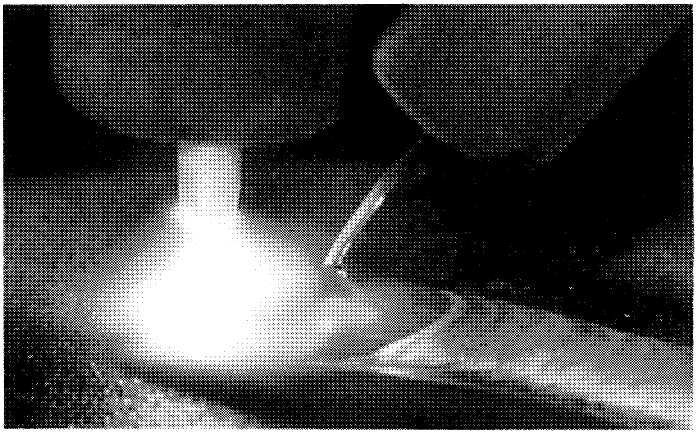
Examples of systems commercially available for manual welding and mechanised welding are shown in Fig. 33. In the manual system, a single power source is used (Fig. 33a) and the wire guide tube is attached to the side of the gas nozzle (Fig. 33b). The mechanised system has separate power sources and controllers for the arc and the wire (Fig. 33c) and the gas nozzle for preventing oxidation of the wire is separated from the TIG torch (Fig. 33d).

Applications

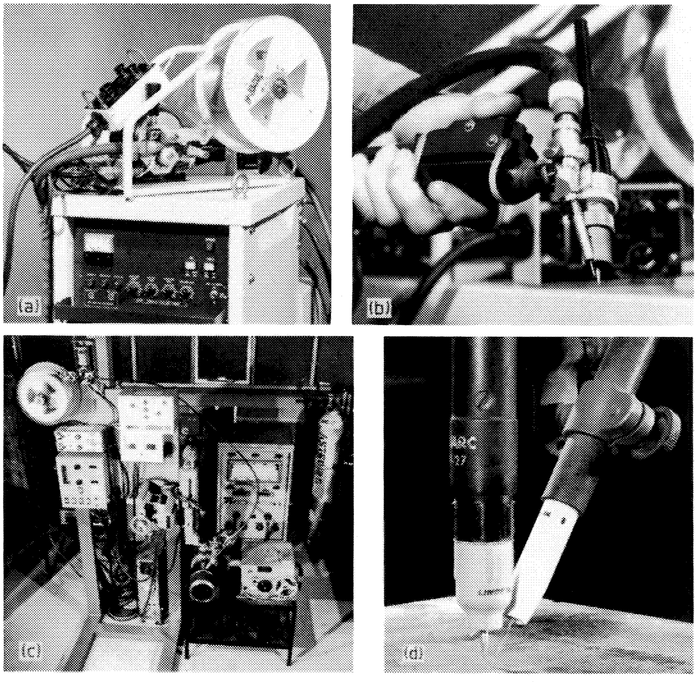
The main advantage of the process is that deposition rates can be achieved similar to those obtainable with MIG welding; typical rates are shown in



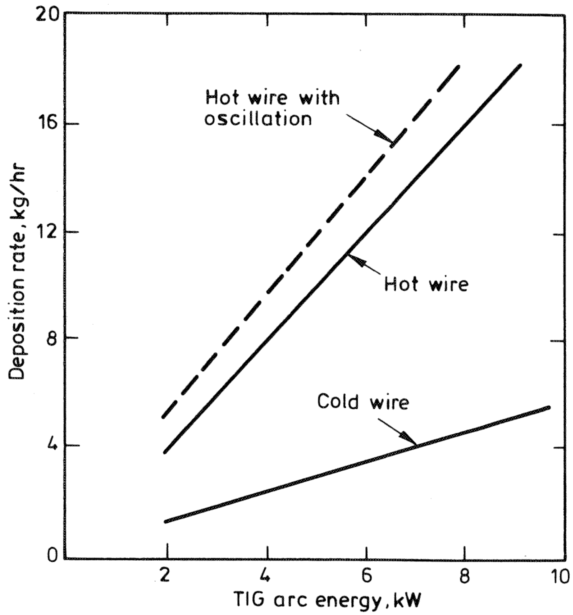
31 *Electrical system and torch arrangement for the hot wire TIG process: a) Separate hot wire AC power source; b) Separate DC power supply; c) Single power source for arc and wire currents.*



32 *Torch – filler wire arrangement showing angle of entry of the wire into the back of the weld pool.*



33 *Commercially available hot wire TIG equipment: a) Manual system with single power source and integral wire feed; b) Manual torch; c) Mechanised system with separate power sources for arc and wire; d) Mechanised head with separate torch and wire feed nozzle.*



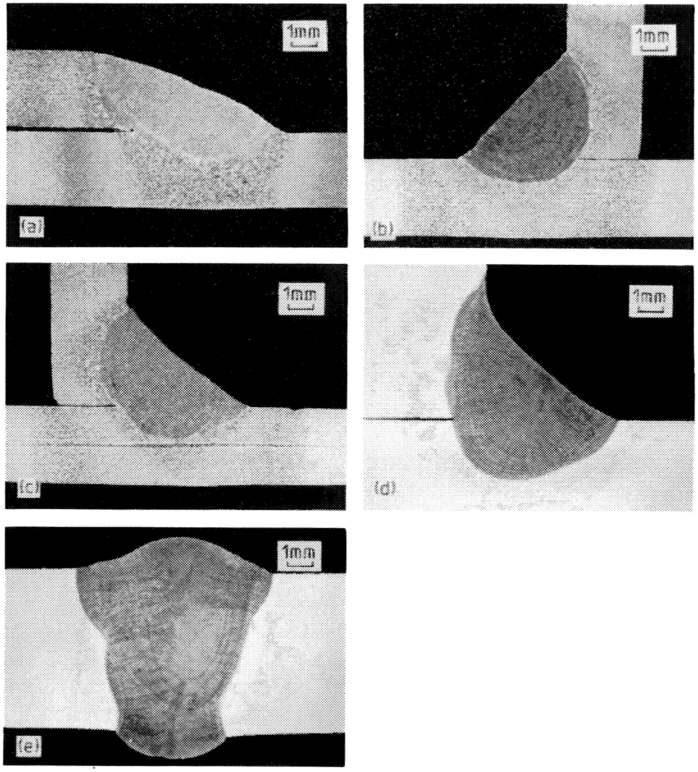
34 *Deposition rates that can be achieved with the hot wire TIG process compared with the conventional TIG cold wire process.*

Fig. 34. As shown in Fig. 35, the process can be used for a range of thicknesses to increase the welding speed whilst retaining good weld penetration and profile characteristics. The process has benefits over MIG for welding stainless steel which normally demands low defect levels and for 9% nickel steels which can suffer from magnetic arc blow.

The process has been used to reduce substantially the number of passes; a typical example is welding cast reformer nickel based alloy tubes, Fig. 36. A typical joint preparation for a weld in 8mm wall thickness, which was welded in three passes, is shown in Fig. 36b. In comparison, welding tube of the same wall thickness with the conventional cold wire TIG technique would have required at least five passes.

In large fabrications, the process has also been used for welding in the vertical-up position using DC current through the wire and mounting the welding head on to a portable carriage and track, Fig. 37. The advantageous features compared with the alternative of TIG-cold wire, are:

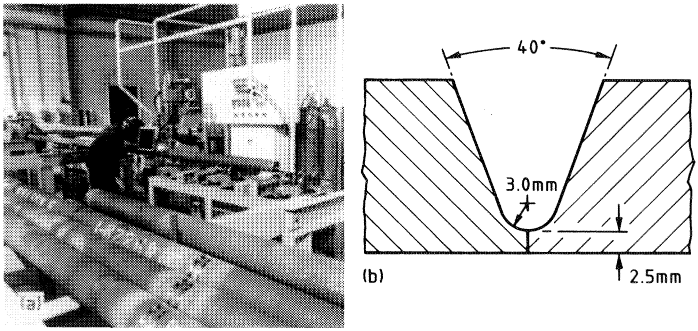
1 Deposition rate is increased by a factor of 2.



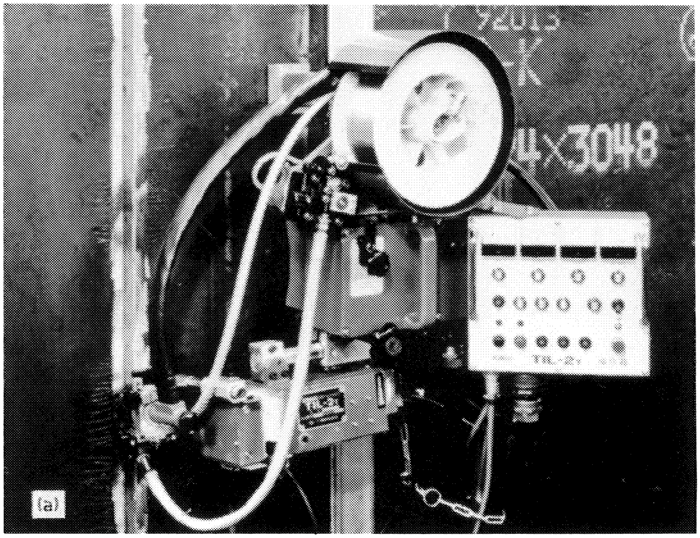
Weld	Method	Joint type	Material	Thickness, mm	Welding position	Welding current, A	Traverse speed, mm/min
a	Manual	Lap	Mild steel	3.0	Flat	200	180
b	Manual	Fillet	Mild steel	3.0	Flat	200	145
c	Manual	Fillet	Mild steel	3.0	Horizontal-vertical	200	175
d	Mechanised	Fillet	Austenitic stainless steel	6.0	Horizontal-vertical	210	130
e	Mechanised	Butt*	Austenitic stainless steel	6.0	Flat	Pass 1 210	180
						Pass 2 210	130

*60° V preparation, 1.0 mm root face, 1.5 mm root gap

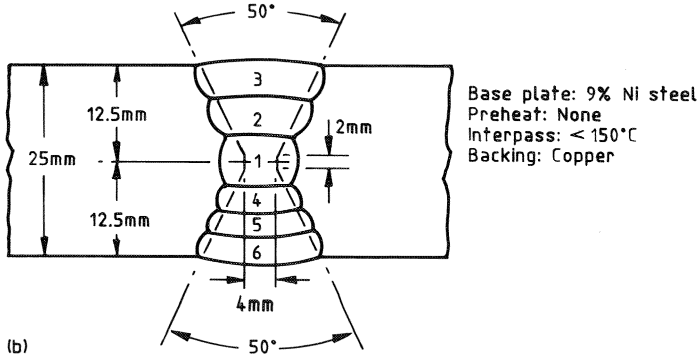
35 *Sheet material welded with manual and mechanised hot wire TIG.*



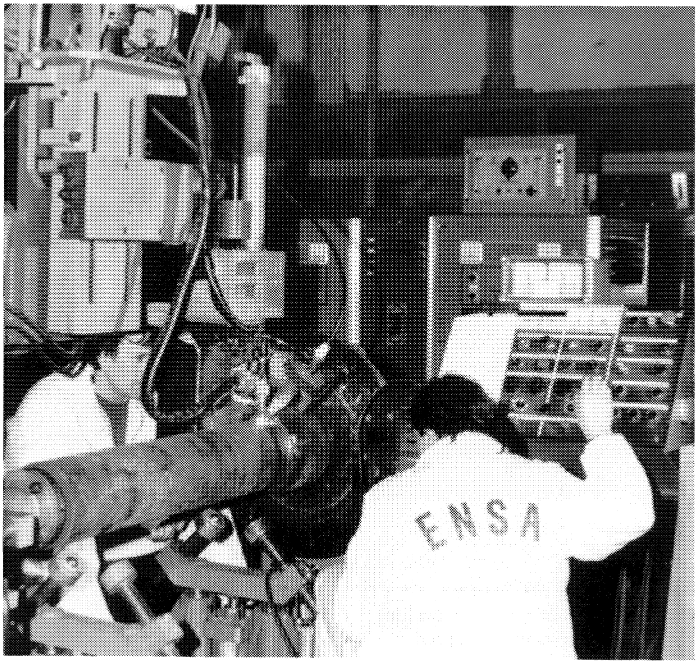
36 *Hot wire TIG welding of cast reformer catalyst tubes: a) General view of welding equipment; b) Joint preparation (courtesy of APV Paramount Ltd).*



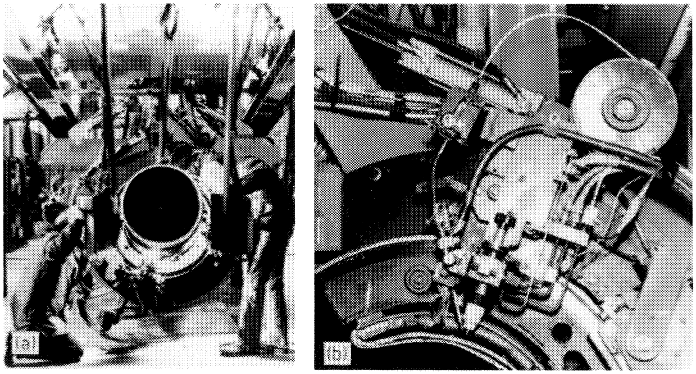
Welding conditions					
Arc current, A	Arc voltage, V	Travelling speed, cm/min	Filler wire current, A	Deposition rate, g/min	Heat input, kJ/cm
280–320	10–11	8–13	120	30–37	22.6–23.7



37 *Hot wire TIG welding of 9% nickel steel plate in the vertical position: a) Welding equipment; b) Joint preparation and welding conditions (courtesy of Kobe Steel Company).*



38 *Mechanised welding of a 180mm OD x 54mm wall C-pipe, internally clad with 2.4mm of austenitic stainless steel, to a stainless steel flange. Runs 1 and 2 – austenitic stainless steel filler wire, remainder – Inconel filler wire (courtesy of Equipos Nucleares SA).*



39 *Four head welding machine for linepipe girth welding: a) General arrangement; b) Welding head (courtesy of Saipem SpA).*

2 The DC current deflects the arc forward which facilitates an increase in welding speed and good sidewall fusion.

The technique has been used for welding plate up to 25mm (1in) in thickness in the fabrication of LNG storage tanks, for example, 9%Ni steels, where good mechanical properties are required; the joint preparation and welding parameters are also given in Fig. 37.

Hot wire (TIG) has also been used for welding thicker section material for example internally clad stainless steel pipe, 180mm (7in) OD x 54mm (2in) wall thickness, to a flange using a combination of austenitic stainless steel and Inconel filler, Fig. 38. The process has also been used in specialised systems for pipeline girth welds using a multi-head (four heads) to weld each quadrant of the pipe vertically downwards, Fig. 39.

Further reading

1 Mann A F: 'Hot wire welding and surfacing techniques'. *Weld Res Bull* 1977 223.

2 Harris I D: 'TIG hot wire offers high quality high deposition'. *Metal Construction* 1986 18 8.

3 Ogata Y and Aida I: 'A study on the improvement of TIG arc welding efficiency in out of position welding'. Kobe Steel Engineering Report No. 39 (April), 1980.

CHAPTER 7

Narrow gap TIG welding

Welding techniques

The narrow gap, or parallel sided, joint configuration offers a potentially more economic joining technique, because:

1 The amount of weld metal to be deposited is reduced;

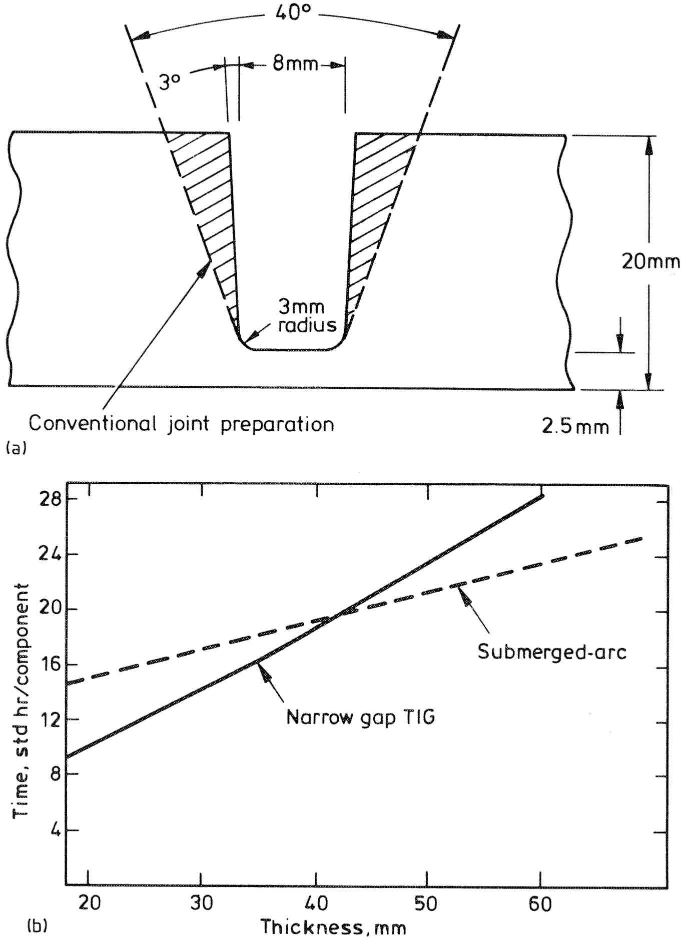
2 Fewer passes are required to fill the joint.

Additional advantages are derived from the narrow weld and heat affected zone which, compared with the alternative V joint, produce lower residual stresses and distortion, and often superior mechanical properties. The reduction in the amount of weld metal required to fill the joint, compared with the normal V joint, is shown in Fig. 40a. Thus, in production, using the (narrow gap) technique a joint can be completed in a shorter welding time than with the conventional submerged-arc process, which has a vastly superior deposition rate, Fig. 40b. In the example of welding thick walled tubular components (illustrated in Fig. 40b), despite a deposition rate of 2 kg/hr (4.41 lb/hr) (arc time) compared with 6 kg/hr (13.2 lb/hr) for submerged-arc welding, the time to complete the joint by TIG was significantly less, at least for section thicknesses up to approximately 50mm.

In considering the use of the narrow gap technique, greater attention should be paid to machining so as to achieve closer fit-up tolerances. In addition, there is a greater need for tracking the electrode along the centre of the joint, as slight deviation from the centreline can result in lack of fusion defects because the arc and weld pool are attracted to the sidewall.

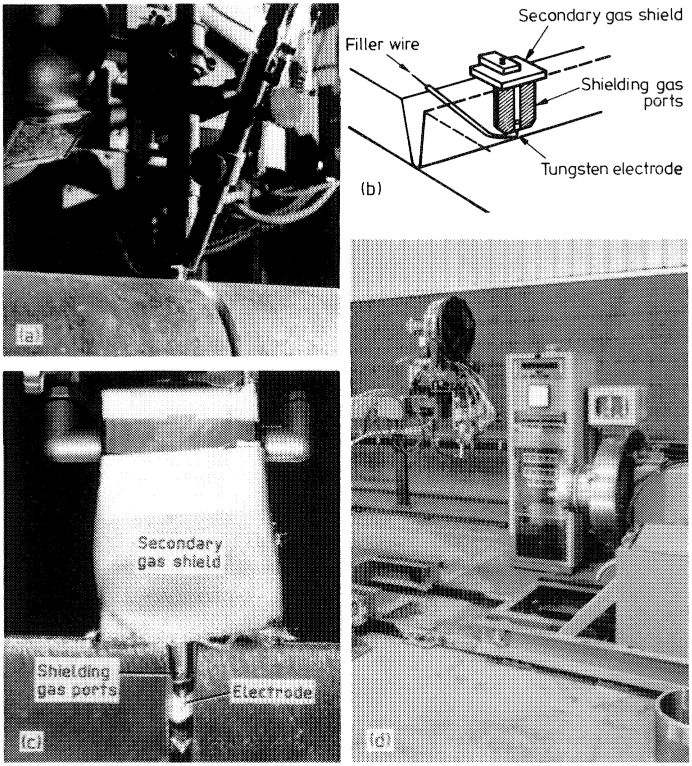
Equipment

For material thicknesses up to 25mm (1in), a parallel sided or slightly tapered joint preparation can be used with a joint gap of typically 6–8mm (1/4 to 5/16in). A conventional torch is used but with an extended electrode stickout. Process techniques such as current pulsing, use of argon-hydrogen



40 *Process features of the TIG-narrow gap techniques: a) Typical edge preparation used in the TIG narrow gap technique showing the reduced amount of filler metal required to fill the joint compared with a conventional V preparation; b) Time to weld tubular components of various wall thicknesses using the TIG narrow gap and submerged-arc welding processes.*

or helium shielding gas and arc oscillation have been employed to ensure a satisfactory weld bead profile. For arc oscillation, as the narrow joint generally precludes the use of torch weaving equipment, the arc itself is normally oscillated by an electromagnetic probe. However, as the depth to which the magnetic field can influence the arc is limited, this technique is normally applied only in wall thicknesses of less than 25mm (1in).



41 *Narrow gap welding equipment: a) Welding in a narrow gap joint using conventional (TIG-hot wire) equipment; b) Schematic diagram of welding operation using special purpose welding head; c) Welding head operating within a narrow gap; d) Production welding station (courtesy of Babcock Energy Ltd).*

The hot wire TIG process has also been applied as a means of increasing the deposition rate as illustrated in Fig. 41a.

The narrow gap welding operation is almost exclusively mechanised because of the need for precise positioning of the electrode in the centre of the joint. In the absence of suitable control devices, joint tracking is under the control of the operator. However, automatic arc length systems are almost always used.

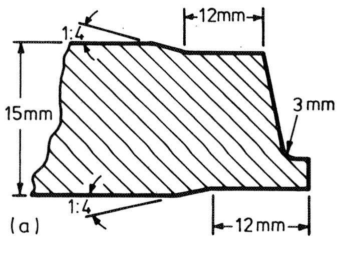
At greater material thicknesses, typically up to 40mm (but thicknesses up to 72mm (3in) have been reported), the joint preparation is normally slightly tapered, to accommodate the closing of the joint during welding. In addition, because of the greater joint depth, specially designed torches must be used. Particular features of a narrow gap torch include dual gas shielding at the front and rear of the electrode, secondary gas shield from the top of the joint and water cooling down to the electrode tip to minimise electrode wear: the operation of the system is shown in Fig. 41b, a production torch operating in a narrow gap, Fig. 41c, and a production welding station in Fig. 41d.

Video monitoring equipment can greatly facilitate control of the position of the arc and the wire feed relative to the weld pool. An arc length control unit is also considered to be essential.

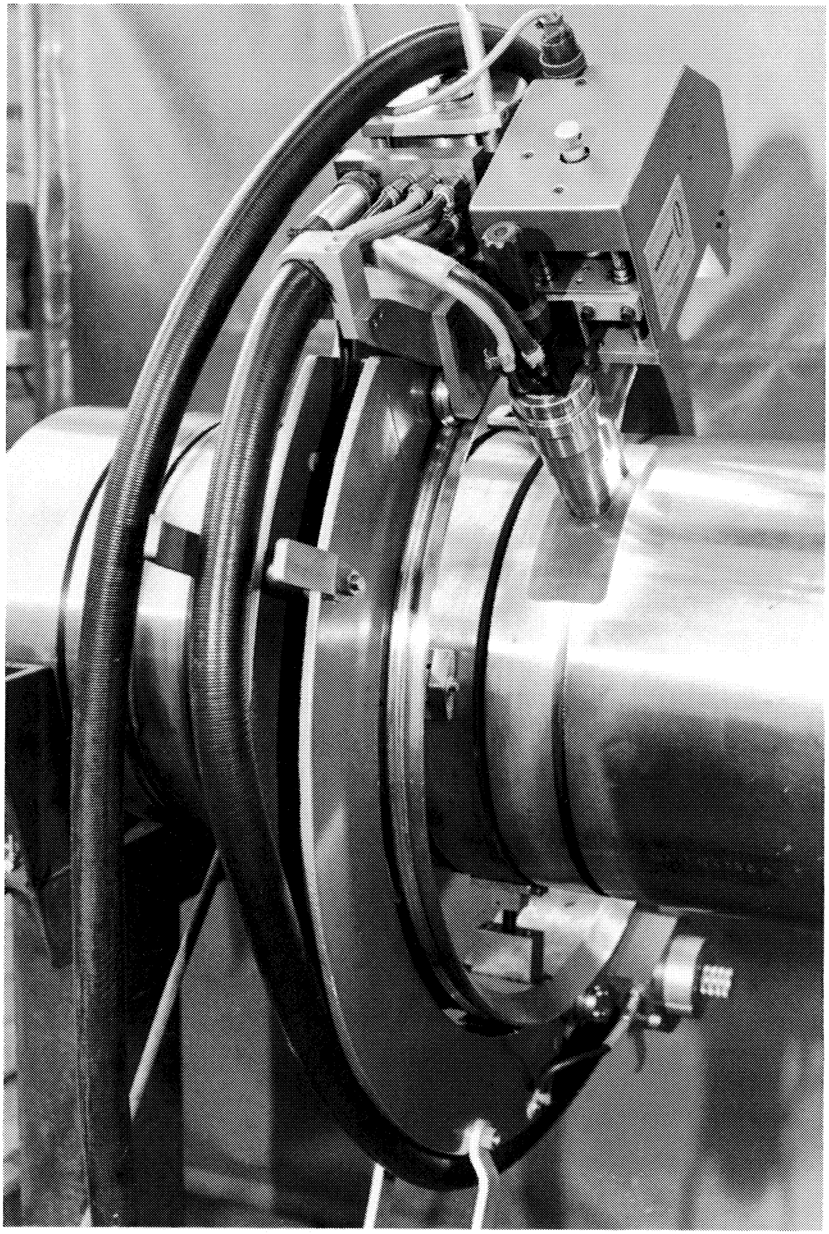
Applications

The technique has been used to advantage in the chemical industry, for welding 17.5mm (0.75in) wall thickness, 25%Cr, 20%Ni, 0.4%C (HK 40) tube. The joint was completed in only ten passes, as shown in Fig. 42. If the conventional V preparation had been used, approximately 20 passes would have been required.

The technique has also been applied in the power generation industry for welding pipes up to 700mm (12in) diameter and wall thicknesses up to 75mm (3in) in both ferritic and stainless steels, including transition joints. Although most reported applications are in the 1G position, specialised equipment has been produced for orbital welding of thick wall, low alloy steel piping, Fig. 43.

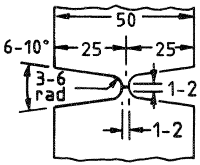
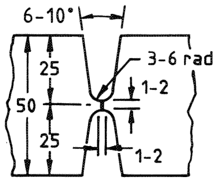


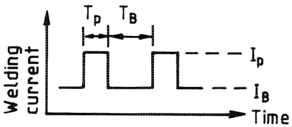
42 *Narrow gap weld in 15mm (0.6in) wall thickness cast HK40 pipe using TIG-cold wire: a) Joint preparation; b) Section through weld (courtesy of APV Paramount Ltd).*



43 *Narrow gap TIG welding head for orbital (5G) welding thick wall low alloy steam piping.*

Table 11 Examples of narrow gap/TIG-hot wire welding procedures for 50 mm thickness stainless steel (courtesy of Urantani et al)

Welding position	Joint preparation dimensions in mm	Number of passes	Welding parameters (3) Welding current (1) I_P A	I_B A	Pulse condition T_P sec	T_B sec	Welding voltage, V	Welding speed, mm/min	Wire heating condition, AxV(2)	Wire feed rate, mm/min
Horizontal		1	160	120	0.3	0.5	10	90	–	500
		2	280	200	0.5	0.7	12	130		900
		Remainder	220	160	0.4	0.4	10	110	90–120A	800
			380	330	0.6	0.6	12	150	(2–4V)	1800
Vertical		1	200	70	0.3	0.3	11	60	–	500
		2	280	100	0.5	0.6	12	100		900
		Remainder	220	160	0.4	0.4	11	80	90–120V	800
			380	230	0.6	0.6	12	130	(2–4V)	1800

Note(1) 

(2) Heating length: 40–60 mm
(3) Argon-helium shielding gas

The narrow gap joint configuration in combination with the TIG-hot wire process, can be used to increase further the joint completion rate. The standard commercially available equipment is suitable for wall thicknesses up to 25mm (1in) as shown in welding heavy walled pipe work, Fig. 41a, but as described above, at greater thicknesses special welding heads are normally required. The hot wire technique has been used in fabrication of 50mm thick stainless steel pressure vessels in the horizontal and vertical positions and in this case, the joint gap was 9mm wide; the joint configuration is given in Table 11 together with welding parameters.

Further reading

1 Hutt G A, Ward A, Cox B, Gough P C and Render G: 'Narrow gap welding'. *Metal Construction* 1984 16 6.

2 Render G S: 'Welding advances in power plant construction (Pt3)'. *Metal Construction* 1984 16 11.

3 Lockhead J C: 'Narrow gap welding'. South African Institution of Mechanical Engineers, 1 Paper 5, 1983.

4 Dawson D W O, Fivash R J and Ward A R: 'Automatic TIG welding'. *Metal Construction* 1976 18 3.

5 Hill R and Graham M R: 'Narrow gap orbital welding'. Welding Institute Conference, 'Advances in welding processes', Harrogate, May, 1978.

6 Harris L: 'Fabricating core barrels for nuclear reactors'. *Weld Des and Fab* 1980 6.

7 Urantani Y et al: 'Application of narrow gap GTA welding process to the welding of large type stainless steel pressure vessels'. IIW Doc XII-13- 83, IIW Doc XII-E-42-83.

8 Kripstrom K E and Pekkri B: 'TIG narrow gap orbital welding'. *Svetsaren* 1988 2.

9 Matsuda F et al (ed): 'Narrow gap welding (NGW), the state-of-the-art in Japan'. Tokyo 101, Japanese Welding Society, Japan, 1986.

Chapter 7

Machine TIG welding

Autogenous mode

Of all the welding processes TIG, by reason of its cleanness and controllability, is probably the most suitable for machine and automatic use. Some most ingenious and economical solutions have been found for producing consistent automatic welds of full strength and good cosmetic appearance. For reasons of clarity we now subdivide the various mechanical categories A, B and C as follows:

A Semi-automatic;
B Fully automatic, sometimes with computer programming;
C Automatic loading and unloading of the component added to A.

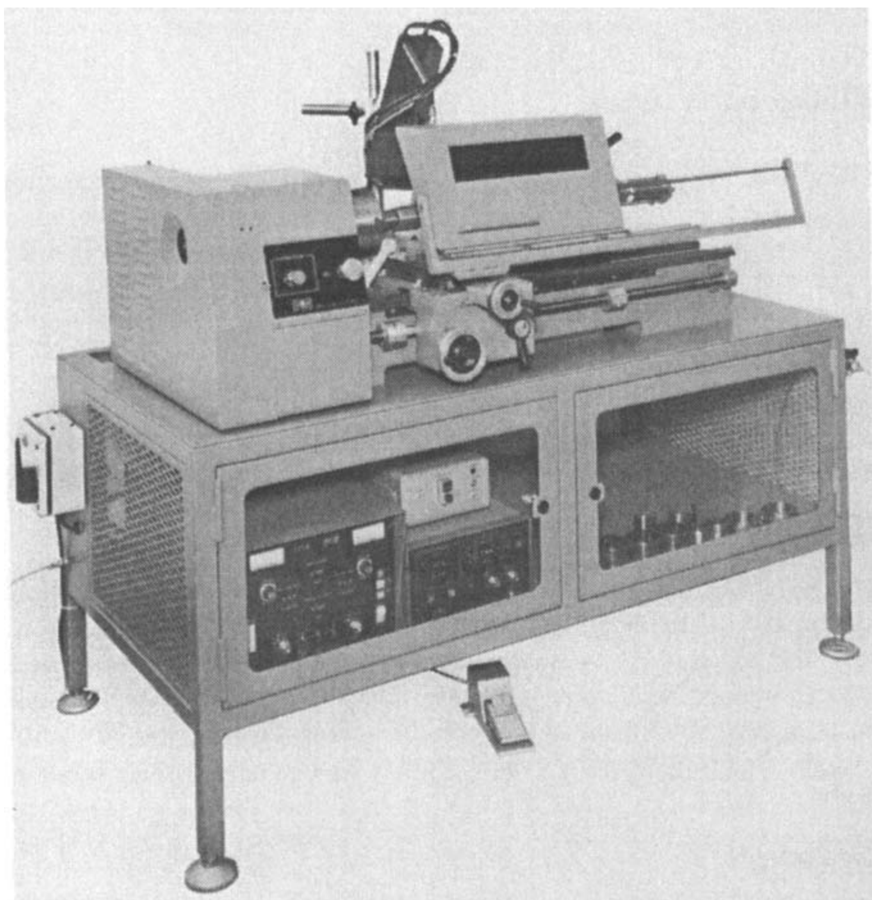
CATEGORY A

These are machines where loading is by hand and the linear or orbital motion and the welding process are brought on stream by the operator in sequence as required. A typical sequence would be load, clamp, start motion, weld on, weld off, stop motion, unclamp, unload, where each step in the sequence is manually initiated. This allows the operator to control each item individually in the sequence and is ideal for a budget type low production system.

CATEGORY B

A logical first step from category A. In these systems loading and unloading are still carried out by hand, after which one button can be pressed and the clamp, start motion, weld on, weld off, stop motion, unclamp items are automatically switched in as a continuous sequence. Many modern TIG power sources (category A, chapter 4) have remote sockets fitted to facilitate sequenced weld switching. A typical one button sequence would then be possible, *e.g.* clamp, start motion, pre-purge on, arc strike, current upslope, full weld on, full weld off, current downslope, arc out, stop motion, post-purge, gas off, unclamp, with loading and unloading still by hand. This is adequate for medium production and is often preferred for high precision welding as each finished weldment can be inspected by the operator before repeating the process.

Clamping is usually pneumatic and other items such as wire feeders, arc length control systems, safety screens and additional gas purge systems can be added to the system as and when required. Figure 7.1 shows a typical system with many of the functions of this category controlled by a single button.



7.1 Manually loaded automatic TIG welding lathe with single button sequence control.

CATEGORY C

As a further and equally logical step, these machines can be fitted with bowl or linear feeders and can often attain quite high production rates. It is usual on such machines to incorporate fail safe warning devices such as no gas, or component not in position, to reduce rejects. At the time of writing such machines are not common but are becoming increasingly so as techniques progress.

Automatic and semi-automatic welding machines are often built to machine tool accuracy. For welding thin sections the arc tip must be very accurately positioned and a constant arc gap maintained. Rotational and linear motion must be variable and, once started, capable of being maintained to an accuracy of ± 1% of set speed with instant stop and start functions. It is nearly always best to move the component rather than the arc and piece parts should be made to a high standard of finish and accuracy. For circumferential welds in particular, ensure good concentricity. Cleanness of the components is, of course, mandatory. Some advice on heat sinks for automatic welding will be given later along with suitable joint designs.

Welding parameters for automatic machines

Category A (chapter 4) power sources usually have all the necessary meters and dials to achieve a staggering number of different and very accurate combinations of arc time, pulse rate and current levels, none of which is any use if the business end, *i.e.* the torch and electrode, is not up to the job. For example, a greater accuracy of electrode tip is needed if fine welds are to be achieved and this is where a tip grinder really becomes an asset. There now follows some general advice on several very important points to consider when designing or using a machine welding system:

- Use the correct size and material for electrode. Keep point clean and sharp and keep stickout to a minimum, say 1.5 mm (1/16 in) beyond the tip of the ceramic shroud if accessibility to the weld allows. Otherwise, as short as possible;
- Ensure a warm, dry supply of the correct inert gas at a suitable flow rate. Do not confuse velocity with volume particularly when using small diameter gas cups. What *is* important is the spread of gas, and gas lenses fitted inside the shroud help with this by diffusing the gas flow. Too much gas can be as bad as too little; always back-purge the underside of the weld seam whenever possible.
- Try first a 2:1 primary to background current ratio and a 1:4 high to low pulse ratio;

- By experimentation select correct weld speed in automatic applications and adjust these ratios if necessary;
- Set the smallest practicable arc gap ± 0.05 mm (0.002 in) and maintain;
- Ensure a good fit-up and heat balance at the weld point (advice on this is given in a following chapter);
- Keep the weld area clean and uncontaminated. Aluminium for example oxidises very quickly: weld within ten minutes of cleaning;
- Provide current return (or earthing) sufficient to carry the *full* welding current. This is most important and often overlooked. Never use plain carbon brushes with automatic fixtures. Copper and brass are more suitable and copper-carbon is suitable below 50 A average current. A spring-loaded shoe should be in contact with a moving part of the jig as near as possible to the weldment. As a guide, using copper brushes, there should be *at least* 600 mm^2 (1 in^2) of brush surface in contact per 50 A of welding current (or pro rata). It is also useful to coat the rubbing surfaces lightly with fine graphite powder when running in a shoe.
- Try for a 5 - 10 per cent overrun of a circumferential or linear weld seam allowing upslope and downslope to occur whilst the component is still being moved under the arc.

WELDING CURRENT SELECTION AND TRAVEL SPEED

DCEN welding - for thin section autogenous welds only
The correct setting of welding current values can only be determined by experiment and production of samples, but the following is a guide for a safe starting point. Note that everything depends on smooth consistent travel either of the arc along the seam or vice versa. The values are given per 0.025 mm (0.001 in) of metal thickness and for a square butt joint.

- Carbon, mild and stainless steels - 0.50 A
- Aluminium and alloys - 1.5 A
- Copper and alloys - 2-3 A

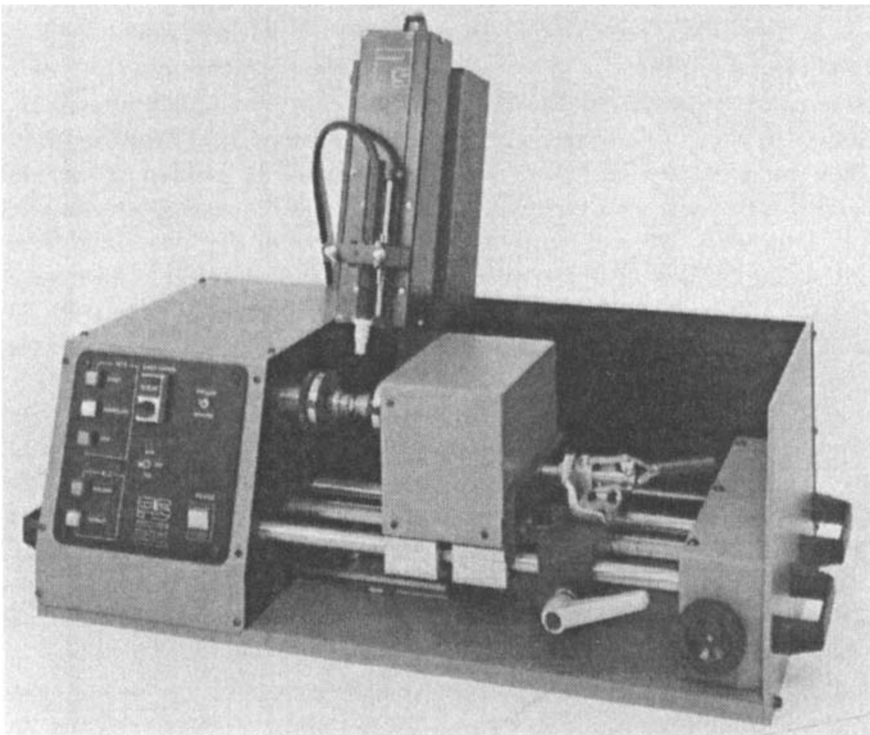
These are *average* welding currents and are purposely given low to avoid ruining too many expensive samples.

Regarding travel speeds these will usually range from 2 - 6 mm/sec dependent on material and thickness, although in production much higher speeds have been attained.

Circumferential welds

A welder's lathe is a great asset for coping with a wide range of cylindrical welded components. Heat sinks, sometimes watercooled, can be fixed to the headstock and tailstock with pneumatic positioning and clamping units fixed to and adjustable along the lathe baseplate, Fig. 7.2.

Much can also be accomplished using a fairly simple welder's turntable in the horizontal position with a rigid adjustable device for positioning the torch. It is essential that any rotating equipment is mounted on a firm heavy table or base, sometimes placing the power source within the frame to provide instant access to the controls plus additional stability.



7.2 Precision mini-lathe used in aerospace component welding. Manual loading, automatic weld sequencing.

Orbital welding

This is defined as the condition in which the arc travels around the external periphery of a fixed pipe or tube weld seam. Much ingenuity has been applied, particularly in the USA, to designing and producing orbital welding heads and several American manufacturers offer extensive standard ranges of such equipment. The USA seems to be the home of automated orbital tube welding. In addition this is one area to which computer programmed power sources have been extensively applied where a large number of programmes can be stored and called up as required. It is possible to purchase a compact and portable package system, Fig. 7.3, which operates over a large range of pipe and tube outer diameters, with many varying welding parameters to give choice of welding position.

For tubes up to 200 mm (8 in) outer diameter most precision orbital heads are the totally enclosed type where autogenous welding takes place within the body of the head in a fully gas purged atmosphere. These heads can be operated in conditions of limited access as they are comparatively small in size.

For large pipes a full function in position (FFIP) mechanised welding head can be a solution. These units, whilst very expensive, can work on a large range of pipe sizes often from 50 mm (2 in) up to 2000 mm (80 in). They also allow for several passes and filler runs for heavy wall sections. These units usually have all or some of the following facilities: arc length control, wire feed, cross seam arc oscillation (weaving) and various pulsing functions. They normally run on a split geared ring clamped around the pipe being welded. The fact that one ring - one pipe size is the norm accounts for much of the high cost but in nuclear construction one weld can be critical, in which case the advantages far outweigh the high cost of the ring, Fig. 7.4.

FFIP weld heads can be programmed to work over a wide range of weld parameters and, very importantly, with the electrode in a wide range of positions, from 12 o'clock to 6 o'clock and all positions in between. This facility is essential for fixed pipes whereas rotating pipes are usually welded in the 12 o'clock position.

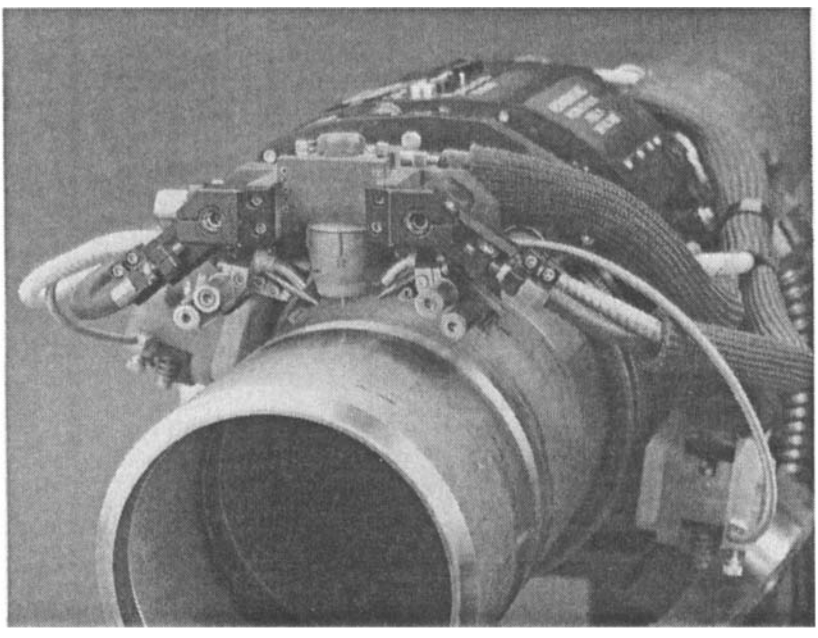
Table 7.1 lists the available schedule pipe sizes in their nominal diameters and is included here to show what sizes can be autogenously welded using enclosed orbital welding heads. However, such information is often difficult to find when required unless you are working in the pipe fitting and oil industries so its inclusion here is justified if only for the purpose of convenience.

Internal bore welding

This is a mechanised process where the electrode is rotated around the weld seam within the tube bore. This method requires very accurate arc positioning, smooth rotation, low, accurate gas flow and suitable positional weld programming. As it is not possible to guarantee the smoothness of the weld bead surface or porosity content it is not often used for food processing pipes, being mainly confined to boiler tubes and heat exchangers where it has been successfully applied to welds more than 1800 mm (6 ft) down from the tube end. Most welding systems are custom built to suit a particular weld, Fig. 7.5 and 7.6.

Internal bore welding, because of its application within a confined space, is almost always carried out using pulsed TIG in the DCEN mode and a square butt preparation.

7.3 A DCEN (DCSP) portable, programmable tube welding system.

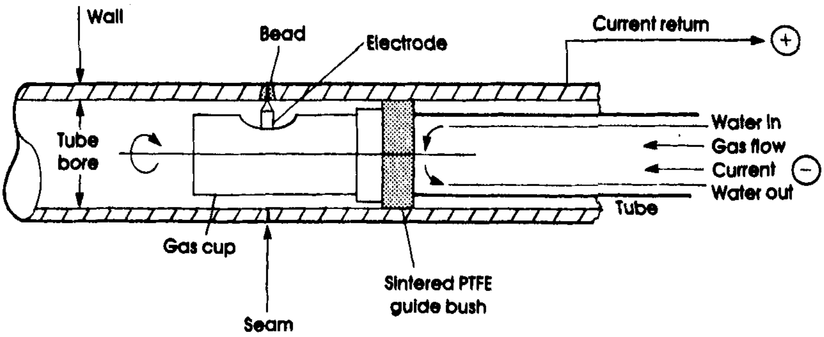


7.4 Full function orbital pipe welding head equipped with leading and trailing edge video viewing for hazardous location welding.

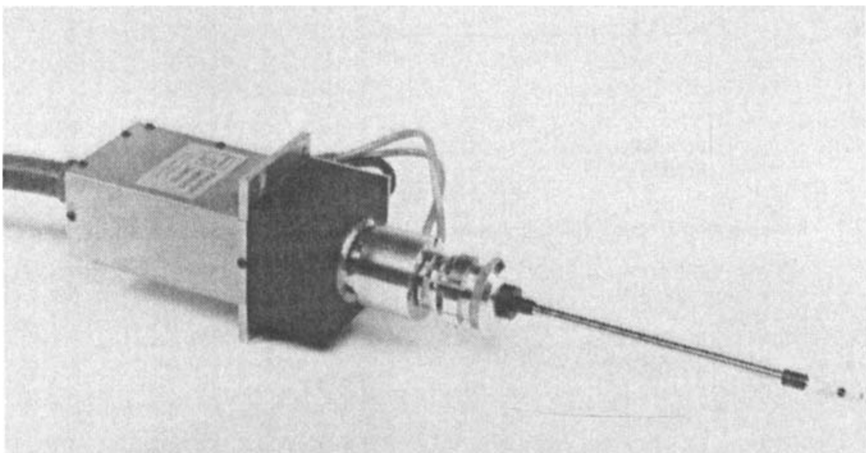
Table 7.1 Schedule pipe sizes to ANSI B 36.10 specification

Nom pipe size,	Outside diameter,		Schedule 5		Schedule 10		Schedule 20		Schedule 30		Standard, STD		Schedule 40		Schedule 60		Extra strong XS		Schedule 80		Schedule 100		Schedule 120		Schedule 140		Schedule 160		Extra strong XXS	
in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in
⅛	10.3	0.405	—	—	1.23	0.049	—	—	—	—	1.73	0.068	identical		—	—	2.41	0.095	identical		—	—	—	—	—	—	—	—	—	—
¼	13.7	0.540	—	—	1.65	0.065	—	—	—	—	2.24	0.088	to		—	—	3.02	0.119	to		—	—	—	—	—	—	—	—	—	—
⅜	17.1	0.675	—	—	1.65	0.065	—	—	—	—	2.31	0.091	standard		—	—	3.20	0.126	extra		—	—	—	—	—	—	—	—	—	—
½	21.3	0.840	1.65	0.065	2.11	0.083	—	—	—	—	2.77	0.109			—	—	3.73	0.147	strong		—	—	—	—	—	—	4.78	0.188	7.47	0.294
¾	26.7	1.050	1.65	0.065	2.11	0.083	—	—	—	—	2.87	0.113			—	—	3.91	0.154			—	—	—	—	—	—	5.56	0.219	7.82	0.308
1	33.4	1.315	1.65	0.065	2.77	0.109	—	—	—	—	3.38	0.133			—	—	4.55	0.179			—	—	—	—	—	—	6.35	0.250	9.09	0.358
1¼	42.2	1.660	1.65	0.065	2.77	0.109	—	—	—	—	3.56	0.140			—	—	4.85	0.191			—	—	—	—	—	—	6.35	0.250	9.70	0.382
1½	48.3	1.900	1.65	0.065	2.77	0.109	—	—	—	—	3.68	0.145			—	—	5.08	0.200			—	—	—	—	—	—	7.14	0.281	10.16	0.400
2	60.3	2.375	1.65	0.065	2.77	0.109	—	—	—	—	3.91	0.154			—	—	5.54	0.218			—	—	—	—	—	—	8.74	0.344	11.07	0.436
2½	73.0	2.875	2.11	0.083	3.05	0.120	—	—	—	—	5.16	0.203			—	—	7.01	0.276			—	—	—	—	—	—	9.53	0.375	14.02	0.552
3	88.9	3.500	2.11	0.083	3.05	0.120	—	—	—	—	5.49	0.216			—	—	7.62	0.300			—	—	—	—	—	—	11.13	0.438	15.24	0.600
3½	101.6	4.000	2.11	0.083	3.05	0.120	—	—	—	—	5.74	0.226			—	—	8.08	0.318			—	—	—	—	—	—	—	—	16.15	0.636
4	114.3	4.500	2.11	0.083	3.05	0.120	—	—	—	—	6.02	0.237			—	—	8.56	0.337			—	—	11.13	0.438	—	—	13.49	0.531	17.12	0.674
5	141.3	5.563	2.77	0.109	3.40	0.134	—	—	—	—	6.55	0.258			—	—	9.53	0.375			—	—	12.70	0.500	—	—	15.88	0.625	19.05	0.750
6	168.3	6.625	2.77	0.109	3.40	0.134	—	—	—	—	7.11	0.280			—	—	10.97	0.432			—	—	14.27	0.562	—	—	18.26	0.719	21.95	0.864
8	219.1	8.625	2.77	0.109	3.76	0.148	6.35	0.250	7.04	0.277	8.18	0.322			10.31	0.406	12.70	0.500			15.09	0.594	18.26	0.719	20.62	0.812	23.01	0.906	22.23	0.875
10	273.1	10.750	3.40	0.134	4.19	0.165	6.35	0.250	7.80	0.307	9.27	0.365			12.70	0.500	12.70	0.500	15.09	0.594	18.26	0.719	21.44	0.844	25.40	1.000	28.58	1.125	25.40	1.000
12	323.9	12.750	4.19	0.165	4.57	0.180	6.35	0.250	8.38	0.330	9.53	0.375	10.31	0.406	14.27	0.562	12.70	0.500	17.48	0.688	21.44	0.844	25.40	1.000	28.58	1.125	33.32	1.312	25.40	1.000
14	355.6	14.000	—	—	6.35	0.250	7.92	0.312	9.53	0.375	9.53	0.375	11.13	0.438	15.09	0.594	12.70	0.500	19.05	0.750	23.83	0.938	27.79	1.094	31.75	1.250	35.71	1.406	—	—
16	406.4	16.000	—	—	6.35	0.250	7.92	0.312	9.53	0.375	9.53	0.375	12.70	0.500	16.66	0.656	12.70	0.500	21.44	0.844	26.19	1.031	30.96	1.219	36.53	1.438	40.49	1.594	—	—
18	457.2	18.000	—	—	6.35	0.250	7.92	0.312	11.13	0.438	9.53	0.375	14.27	0.562	19.05	0.750	12.70	0.500	23.83	0.938	29.36	1.156	34.93	1.375	39.67	1.562	45.24	1.781	—	—
20	508.0	20.000	—	—	6.35	0.250	9.53	0.375	12.70	0.500	9.53	0.375	15.09	0.594	20.62	0.812	12.70	0.500	26.19	1.031	32.54	1.281	38.10	1.500	44.45	1.750	50.01	1.969	—	—
22	558.8	22.000	—	—	6.35	0.250	9.53	0.375	12.70	0.500	9.53	0.375	—	—	22.23	0.875	12.70	0.500	28.58	1.125	34.93	1.375	41.28	1.625	47.63	1.875	53.98	2.125	—	—
24	609.6	24.000	—	—	9.53	0.250	9.53	0.375	14.27	0.562	9.53	0.375	17.48	0.688	24.61	0.969	12.70	0.500	30.96	1.219	38.89	1.531	46.02	1.812	52.37	2.062	59.54	2.344	—	—
26	660.4	26.000	—	—	7.92	0.312	12.70	0.500	—	—	9.53	0.375	—	—	—	—	12.70	0.500	—	—	—	—	—	—	—	—	—	—	—	—
28	711.2	28.000	—	—	7.92	0.312	12.70	0.500	15.88	0.625	9.53	0.375	—	—	—	—	12.70	0.500	—	—	—	—	—	—	—	—	—	—	—	—
30	762.0	30.000	—	—	7.92	0.312	12.70	0.500	15.88	0.625	9.53	0.375	—	—	—	—	12.70	0.500	—	—	—	—	—	—	—	—	—	—	—	—
32	812.8	32.000	—	—	7.92	0.312	12.70	0.500	15.88	0.625	9.53	0.375	17.48	0.688	—	—	12.70	0.500	—	—	—	—	—	—	—	—	—	—	—	—
34	863.6	34.000	—	—	7.92	0.312	12.70	0.500	15.88	0.625	9.53	0.375	17.48	0.688	—	—	12.70	0.500	—	—	—	—	—	—	—	—	—	—	—	—
36	914.4	36.000	—	—	7.92	0.312	12.70	0.500	15.88	0.625	9.53	0.375	19.05	0.750	—	—	12.70	0.500	—	—	—	—	—	—	—	—	—	—	—	—

* *Sizes above the solid line are weldable with an enclosed automatic orbital welding head.*



7.5 Details of custom built internal bore welding torch.



7.6 Special long reach head for internally welding 16mm bore heat exchanger tubes.

Summary

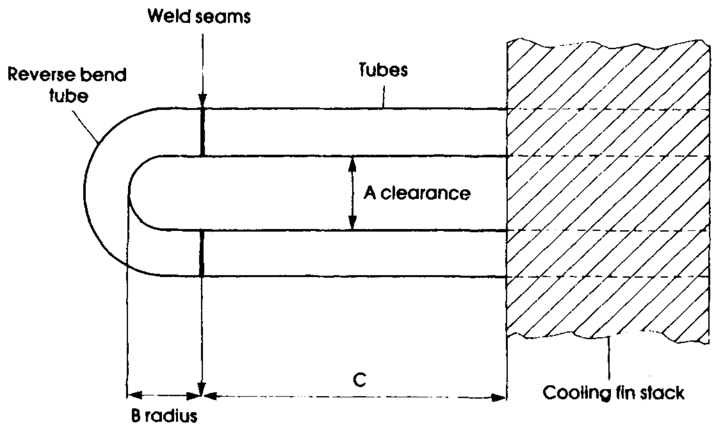
Weld mechanisation has many advantages, one of which is removal of the human element. However, in most cases cost is usually the greatest consideration when deciding to mechanise or not.

One ingenious type of orbital welding head is for production of reverse bends in boiler and heat exchanger tubing, Fig. 7.7.

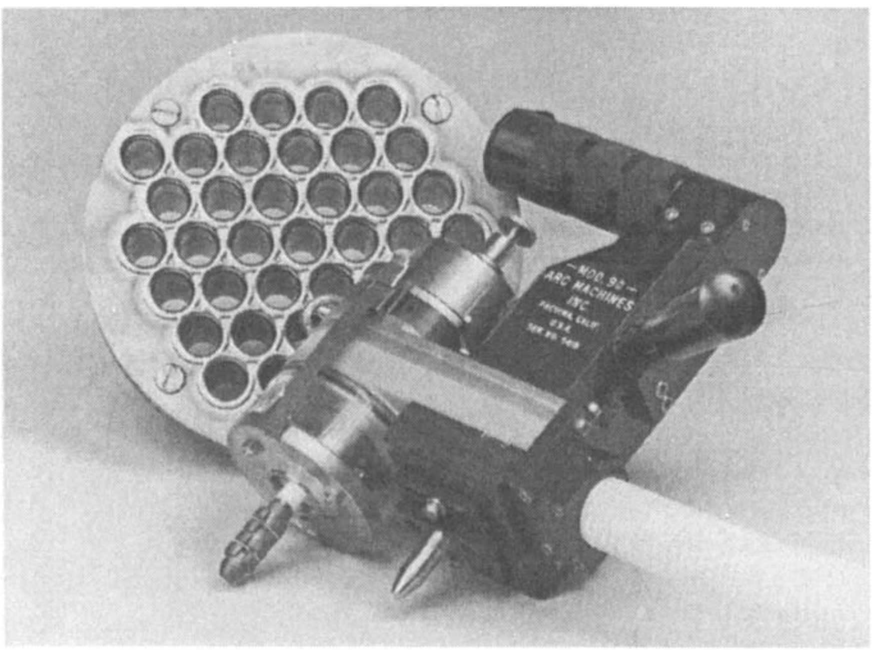
Heads must be of minimum size to fit in the available gap and at the same time be heat resistant enough to withstand a large number of welds without excessive heat build-up. Welds of this type are traditionally done by hand, and as yet not all reverse bends can be mechanically welded because of lack of clearance for the welding head.

Another welding head carries out welds of tubes to tube plates (or tube sheets) in boilermaking, Fig. 7.8. These heads are often located in one tube end whilst welding another and some possible joint designs and weld configurations are shown later.

These heads are usually coupled to a sophisticated power source and are a prime choice for computer programming as a large number of similar welds are often made during a shift.



7.7 Reverse bend heat exchanger tubes with limited access at A, B and C.



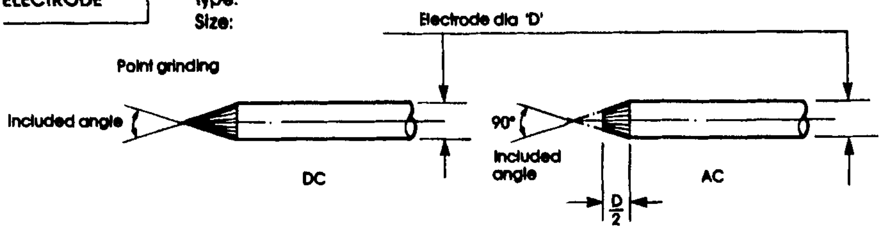
7.8 Tube to tube sheet fusion-only welding head.

Table 7.2 Welding conditions and procedure record sheet

Company:	Compiled by:	Date:
Component:	Material details:	
Power source used:		

Arc length control used: Yes/No		Arc gap:
If yes enter:	ALC delay period	Voltage setting
Other ALC control settings		

ELECTRODE	Type: Size:



WELDING CURRENT	Pulsed/unpulsed AC/DC	Arc strike current level	A
Upslope period	sec	Downslope period	sec
Peak current	A	Background current	A
Peak pulse time	msec	Background current time	msec
Pulses per sec		% pulse time	

Time on full weld current sec	Total weld time sec	Electrode stick-out distance mm

SHIELDING GASES	Type to electrode	Type to back purge
Gas cup type	Flow rate l/min	Flow rate l/min

Gas cup orifice	Gas lens used Yes/No	Pre-purge time sec	Post-purge time sec

FIXTURE	Rotation speed, rpm	Traverse speed mm/sec	Weld seam overlap mm

Other data and comments

WELD PROCEDURE RECORDS

As welding becomes more and more technical and parameters more complex, it becomes necessary to keep accurate records so that processes can be exactly repeated later. Even if the procedures have been fed on to tape or into computer memory these can sometimes become destroyed or corrupted, so that when a weld sequence is in preparation it is prudent to make out a written parameter sheet. A suggested design for such a sheet is shown in Table 7.2. The author has used this type of record sheet for many years with great success. The sheet is designed for mechanical or automatic welding; a similar but less complicated record should be kept for hand welding.

Chapter 8

Computer and microprocessor control of TIG welding

Among welding processes TIG is probably the most suitable for remote programming. The previous chapter has given some details of mechanical automation, this chapter very briefly covers the subject of use of computers and microprocessors for control of individual items in systems using an IBM PC or other similar equipment. This control involves ensuring that the power source is in the correct mode, welding current and arc voltage are displayed by instrumentation, weld finished commands given, *etc.*

Microprocessors are extensively used:

- In the power source;
- For transmitting data to external peripheral equipment;
- To interface with dedicated peripheral equipment;
- For programming constraints.

The advantage of microprocessor control is that accurate and repeatable arcing performance with minimal user involvement is made possible. The range encompassed can be from ordinary mechanisation to fully automatic operation of the welding station, control of turntables, traverses, and wire feed units.

Power source

The microprocessor controlled power source controls the following functions:

- Pre-purge gas flow volume and time;
- Initiate and establish welding current commands;
- Upslope, pulsing and downslope;
- Peak and base level welding current;
- Post-purge gas flow volume and time;
- Welding commands to external equipment.

Standard microprocessors are of the 8-bit variety, *e.g.* Z80, M6800, *etc*, but 16-bit and 4-bit types may also be used. The type reflects the complexity of the functions and resolution required in time and level.

The nomenclature of 4, 8 and 16-bit is that used in the computer industry to signify the binary number that represents a decimal number, *e.g.* 4-bit = $2^4 = 16$, 8-bit = $2^8 = 256$ and $2^{16} = 65536$. Naturally, the greater the bit capacity the greater the complexity of functions that the microprocessor can provide and speed of reaction.

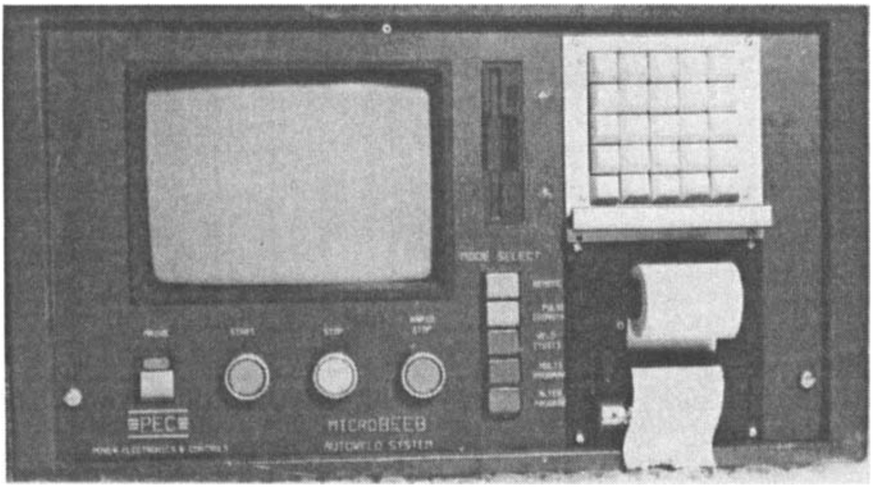
To provide the programme functions listed above a microprocessor should possess certain features:

- ROM (read only memory) which stores the programme;
- D-A (digital to analogue) convertor which converts digital numbers to analogue levels;
- I-O (input-output) interface which reads input switches and drives output solenoids, *etc*;
- RS232 (serial data line) which accepts and sends serial data from external computers;
- Timers to provide pulsing and timing facilities.

If the power source is a DC one with power transistors under feedback control from a current sensor (usually a current shunt or Hall effect device) then the microprocessor under programme control will generate the required waveform as selected by the user from thumbwheel or keyboard front panel switches, Fig. 8.1, or from external data from the RS232 serial line. On accepting a command to start welding, the microprocessor provides the waveform via the D-A convertor to the feedback controlled transistors. Further, the necessary gas flow signals and any relay commands for external peripherals can be given.

One detrimental effect may occur when HF is used to initiate the arc, because microprocessors and computers in general dislike random pulses and transient spikes as they tend to cause loss of control; also sensitive electronic components are prone to catastrophic failure in the presence of high voltages.

To avoid erratic programme control during HF initiation the circuits must be constructed with critical layout and protection methods. This usually warrants both filtering and spike protection of the relevant circuits. The programme must also possess fail safe software so that if a random spike does enter the microprocessor it does not behave erratically and cause full current output to occur, or turn on any connected peripherals.



8.1 Add on microprocessor control unit for TIG welding power source with keyboard programming and hardcopy printout.

External devices

Except in the simplest of systems, automated TIG welding requires certain peripherals such as turntables, lathes, AVC, *etc*. As TIG power sources come as stand alone devices a method of interfacing all the peripherals to act in concert during welding must be realised.

A complete welding station must be able to react to various commands, *e.g.* arc established, arc delay, upslope, downslope in progress, weld completed, and others. Other commands may be added, *e.g.* gas on, pulsing operative, arc out of limits.

The easiest way to execute these commands to all the required peripherals is to sense the output commands from the power supply unit and/or the serial line to tell the individual peripheral what to do.

Should no external computer be available to read and implement the proper commands, the power supply unit must provide all the features. Hence motor controls *etc*, must be incorporated in the peripherals. This implies that the power supply unit must be rather extensive in programme capability, which is not always the case. A more common approach is to provide an external controller driven from a remote computer or, if things are simple, a programmable logic controller (PLC) which is nothing more than a rather sophisticated microprocessor with various relay, optoelectronic, voltage and current outputs.

A complex TIG welding station could probably use a PLC but to have a printed record and limit settings as well as establishing that every function is operable, an IBM PC would be the easiest to implement. It should be noted that PCs come in a variety of formats and can be just a control card, not necessarily the desktop variety. Personal computers for industrial use generally have various features such as noise suppression which all help in TIG welding.

Programming

It is no use connecting a multi-unit welding station together and expecting the system to function without proper software. Production of software or programming is a time consuming process and involves many constraints. The initial problem is the language. There are many languages currently used, the main ones are BASIC, PASCAL, C, FORTH, and ASSEMBLY.

The easiest to use is BASIC and there are various implementations. The choice depends on familiarity with programming languages bearing in mind that speed of response is of the essence.

For programming to be effective, a clear outline must exist of what the programme is to do and this is easiest to achieve by first making a list of requirements of the system under control. A typical example is:

1 Check that all units are ready;
2 Turn on gas pre-purge;
3 Initiate upslope and arc;
4 Arc established;
5 Wait for arc delay;
6 Turn on traverse, turntable, *etc*;
7 Await end of weld time;
8 Initiate downslope;
9 Await end of welding current;
10 Turn off peripherals;
11 End post-purge gas flow;
12 Ensure all units return to datum for start of new weld.

The above list is by no means comprehensive and for a practical programme to be implemented many more features would have to be incorporated, with decisions made regarding loops awaiting commands from switches, *etc*. The programme could be written from a flow diagram which consists of a format outlining all the individual requirements of the system.

Part II PLASMA WELDING

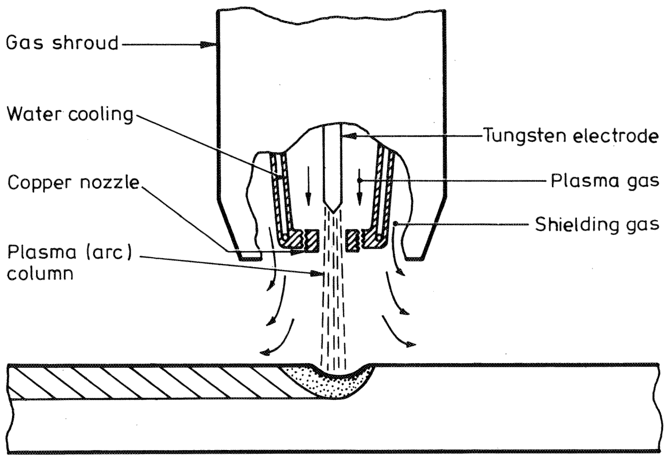
CHAPTER 8
Process fundamentals

DC plasma welding

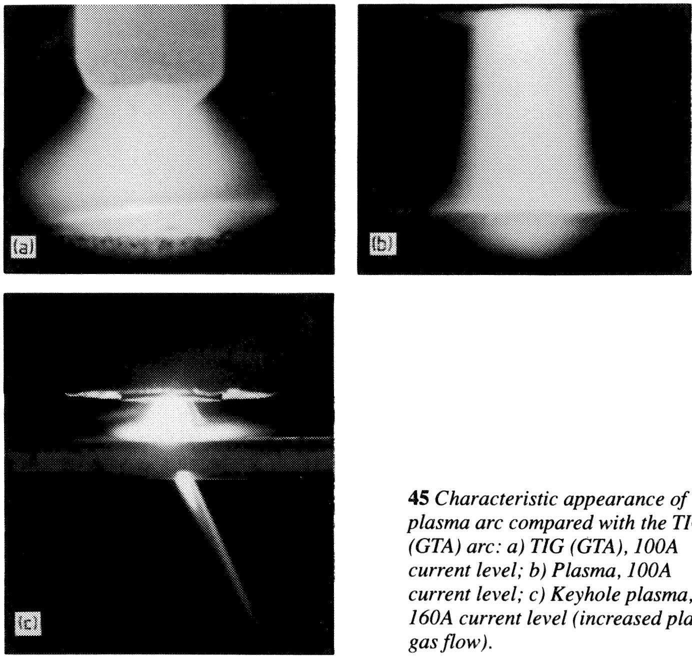
The similarities between TIG and plasma welding are readily apparent in that the arc is formed between a tungsten electrode and the workpiece but the torch arrangement generates the unique operating characteristics of the plasma arc torch. The electrode is positioned within the body of the torch, and the plasma forming gas is separated from the shielding gas envelope (Fig. 44). Thus, the emanating plasma is constricted by a fine bore copper nozzle. The most significant effect of plasma constriction is that the arc becomes very directional with deep penetration characteristics.

As shown in Fig. 45b the plasma arc assumes a columnar form compared with the conical TIG arc (Fig. 45a) at the same current.

The penetration capacity of the arc is determined by the degree of constriction of the plasma (diameter and length of the bore of the nozzle)



44 *Torch configuration for plasma welding. Note, electrode position and the addition of a separate plasma gas compared with the TIG torch (Fig. 1).*



45 *Characteristic appearance of the plasma arc compared with the TIG (GTA) arc: a) TIG (GTA), 100A current level; b) Plasma, 100A current level; c) Keyhole plasma, 160A current level (increased plasma gas flow).*

and the plasma gas flow rate. The electrode angle has no effect on penetration and is usually maintained at 30°. However, as in TIG welding, the gas composition has a secondary influence on penetration. In this instance hydrogen, which increases the temperature of the arc by increasing the ionisation potential, as shown by the increase in arc voltage, is particularly effective. Helium is also used to increase the temperature of the plasma but, because of its lower mass, penetration can actually decrease in certain operating modes.

A particular feature of the plasma system is the pilot arc. Whilst the arc is again initiated by HF, it is first formed between the electrode and the plasma nozzle. Thus the pilot arc is retained within the body of the torch. When required for welding the pilot arc is transferred to the workpiece by completing the electrical circuit. Hence, the pilot arc system ensures reliable weld starting even under adverse conditions (such as long welding cables, well used electrodes and 'dirty' components).

Protection of the arc, weld pool and weld bead during solidification requires the use of a shielding gas as in TIG; the plasma gas alone is too turbulent because of the small nozzle to give adequate shielding.

The properties of the constricted plasma with variable arc force, which results from varying the plasma gas flow rate, have led to three distinct welding process variants:

- Micro-plasma welding: 0.1-15A;
- Medium current plasma welding: 15-100A;
- 'Keyhole' plasma welding: >100A.

Micro-plasma

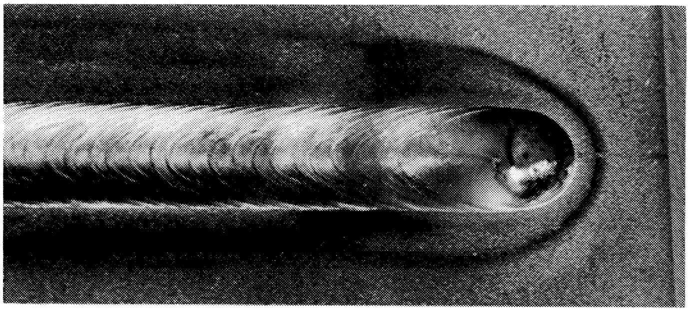
Micro-plasma welding has been so termed because a very stable arc can be maintained , even at welding currents as low as 0.1A. It is possible to vary the arc length over a comparatively wide range, up to 20mm (0.75in) without adversely affecting stability and, because of the columnar nature of the plasma, without causing excessive spreading of the arc. With TIG welding, whilst the newer transistor controlled power sources can maintain an arc at currents as low as 1A (see Chapter 5). The arc is more sensitive to variation in torch distance, both with regard to stability and to spreading of the arc, because of its conical shape.

Medium current

At higher currents, that is up to 100A, the plasma arc is similar to the TIG arc, although it is slightly 'stiffer' and more tolerant to variation in arc length. The plasma gas flow rate can also be increased to give a slightly deeper penetrating weld pool, but with high flow rates there is a risk of shielding gas and air entrainment in the weld pool through excessive turbulence in the gas shield and agitation of the weld pool.

Keyhole

The most significant difference between TIG and plasma welding arcs lies in the keyhole technique. A combination of high welding currents and plasma gas flow rates forces the plasma jet to penetrate the material, forming a hole as in electron beam welding (Fig. 45c). During welding, this hole progressively cuts through the metal with the molten metal flowing behind to form the weld bead under surface tension forces, as shown in Fig. 46. The deeply penetrating plasma is capable of welding in a single pass,



46 *Appearance of keyhole and solidified weld pool in welding 4mm thick, type 304 stainless steel.*

relatively thick sections within the range 3–6mm (0.1–0.25in). However, despite the tolerance of the plasma process to variation in torch to workpiece distance, this technique is more suitable to mechanised welding, as the welding parameters i.e. welding current, plasma gas flow rate and traverse rate, must be carefully balanced to maintain the stability of the keyhole and the weld pool. Instabilities can easily result in the loss of the keyhole giving only partial penetration of the weld bead and increasing the risk of porosity.

AC plasma welding

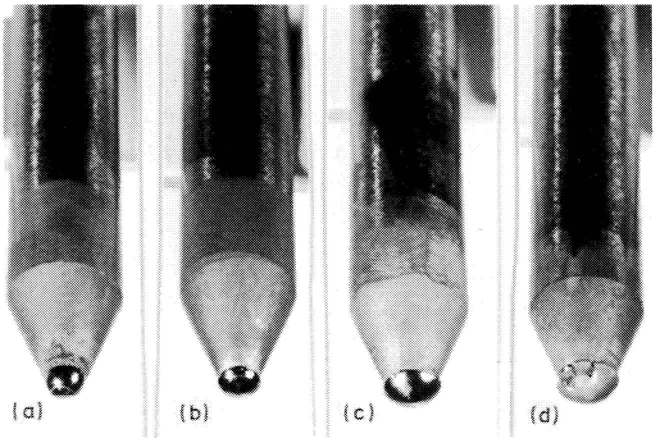
Sine wave

The AC plasma arc is not readily stabilised with sine wave AC for two reasons: arc re-ignition is difficult when operating with a constricted plasma and a long arc length; and the progressive balling of the electrode tip severely disturbs arc root stability. Thus, plasma welding of aluminium is not widely practised, although successful welding has been reported using DC (negative polarity) and helium shielding gas.

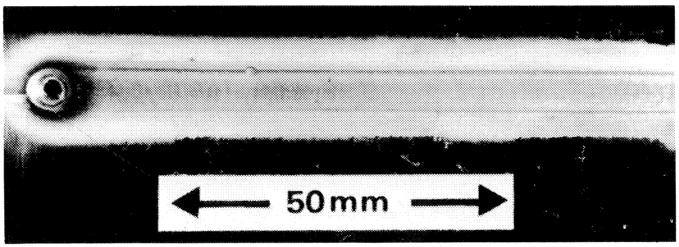
Square wave

The recent advent of the square wave power supplies described in Chapter 1 has made it possible to stabilise the AC plasma arc without the need for continuously applied HF for arc re-ignition. In addition, by operating with only 30% electrode positive the electrode is kept so cool that a pointed electrode tip and hence arc stability can be sustained. It is particularly important however, that to limit electrode/nozzle erosion the maximum current is reduced to less than that which can be operated with a DC (plasma) arc. For example, using 30% electrode positive, the current rating of a 4.8mm (3/16in) diameter tungsten electrode with a 40° tip angle would be reduced from 175A (DC) to approximately 100A (AC); the appearance of the electrode tip for 100, 120, 150 and 165A operation is shown in Fig. 47. Further, an increase in the proportion of electrode positive polarity, so as to improve arc cleaning, would significantly reduce the maximum operating current.

Despite the reduction in the maximum current at which the various electrode sizes can operate, stabilisation of the AC arc represents a significant advance in plasma welding. Until comparatively recently, when welding aluminium, no advantage could be taken of the deep penetration capability of the plasma arc because of the need to use a blunt electrode; the alternative AC TIG process produces shallow penetration. It is now possible to weld aluminium up to 6mm (0.25in) thickness in a single pass using the



47 *Appearance of electrode tip for various current levels. Electrode diameter, 4.8mm, initial tip angle 40°, 30% electrode positive polarity: a) 100A; b) 120A; c) 150A; d) 165A.*



48 *4mm aluminium plate welded by the AC keyhole plasma process.*

keyhole mode. A butt weld is shown in Fig. 48. Because the arc scours the joint interface on passing through the material, very low weld metal porosity can be obtained.

Pulsed current (keyhole) welding

Similar benefits can be derived from pulsing the welding current in microplasma and medium current welding as described for TIG welding, but there are special advantages when operating with the keyhole mode.

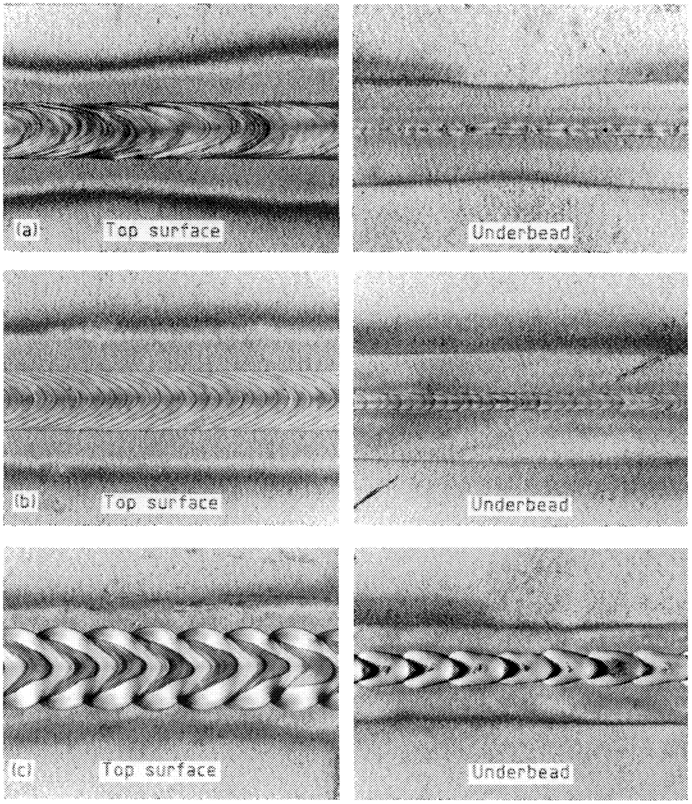
The same principle applies, in that a high current pulse causes rapid penetration of the material and establishes a stable keyhole and weld pool. If this high current were maintained, the keyhole would continue to grow, causing excessive penetration and, ultimately, cutting would occur. Therefore, the pulse is terminated after a preset time and the weld pool allowed to solidify under a low background or pilot arc. It is equally important that the plasma gas flow be maintained during this period so that the keyhole does not close and, on re-applying the pulse current, the plasma can quickly penetrate the plate, re-establishing a stable keyhole and weld pool. Thus, welding progresses in a series of discrete steps with the pulse frequency balanced to the traverse rate to produce overlapping weld spots, as shown in Fig. 49.

Parameter selection

In pulsing the important variables are:

Welding current	Plasma gas
Pulse time	Pulse level
Pulse level	Background level
Background time	
Background level	

Selection of welding parameters can be simplified, first with the knowledge that the pulse time is determined more by the physical requirements of forming the keyhole and weld pool at a given traverse rate, than by the plate thickness or material composition. For most material within a plate thickness of 3–6mm (0.1–0.25in) a minimum pulse time of 0.1sec is required to re-establish the keyhole and weld pool. At greater pulse times, the excess energy is largely dissipated in the efflux plasma. The background time is usually set equal to the pulse time, which is sufficient for



49 *Appearance of pulsed keyhole welds in 4.4mm austenitic stainless steel at different pulse frequencies. The background time is set equal to the pulse time: a) 8Hz; b) 2Hz; c) 0.5Hz.*

solidification between pulses. Thus, the pulse frequency is determined by the traverse rate and the need for at least 60% overlap of the pulses to provide a continuous seam. For instance, when welding 4.4mm (0.17in) stainless steel at 0.15 m/min (60 in/min) a suitable frequency is 2Hz. A pulse frequency of 8Hz gives insufficient time to re-form the keyhole weld pool, as shown by the intermittent penetration of the weld bead, whilst at a frequency of 0.5Hz, the weld spots become separated, giving pronounced undercutting on the top surface of the weld bead (Fig. 49(c)).

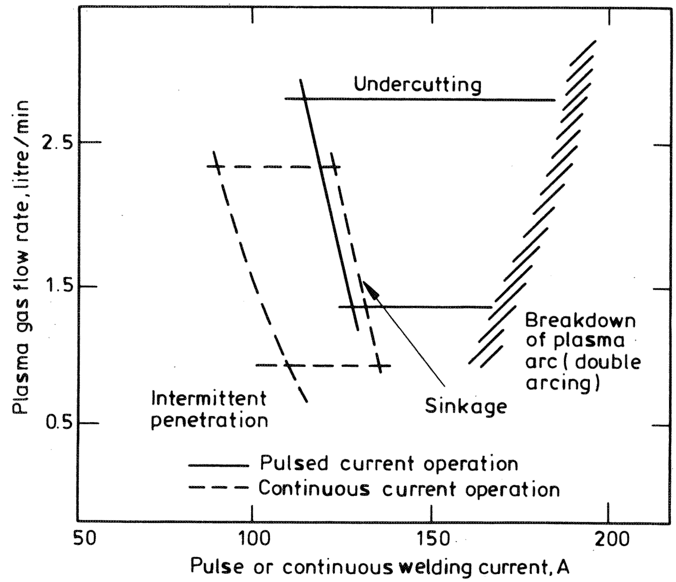
It follows that the pulsed current level and plasma gas flow rate are the major welding parameters which must be set to give an over-penetrating plasma for a particular material composition and plate thickness

Table 12 Welding parameters for keyhole plasma welding of austenitic stainless steel

Operating mode	Plate thickness mm	Plasma Bore, mm	Plasma Gas flow*, litre/min	Pulse frequency, Hz	Continuous current, A	Pulse current, A	Background current, A	Traverse rate, m/min
1 Continuous current	3.4	2.36	1.4	–	87	–	–	0.22
	4.4	2.36	1.75	–	120	–	–	0.22
	5.0	3.2	1.9	–	160	–	–	0.22
2 Pulsed current	3.4	2.36	1.4	2	–	115	20	0.15
	4.4	2.36	1.9	2	–	140	20	0.15
	5.0	3.2	2.3	2	–	190	20	0.15

*Plasma gas – argon, shielding gas – argon/5% hydrogen combination. The background current is held low to give rapid cooling between pulses while the plasma flow rate is held constant to maintain the keyhole. For instance, when welding 4.4mm (0.17in) austenitic stainless steel, the pulsed current and plasma gas flow rate are typically 140A and 2 l/min (4 cfh) respectively. However, when welding the same steel in 5.0mm (0.2in) thickness, the pulsed current and plasma gas flow rate are increased to 190A and 2.3 l/min (4.9 cfh) and all other parameters are held constant. Typical welding parameters for stainless steel (at the sample pulse frequency and traverse rate) are given in Table 12.

The data in Table 12 are, of course, only a guide for the initial selection of welding parameters and must be used with caution, particularly when welding outside the 3–5mm (0.12–0.2in) thickness range. For example, in thinner plates pulse time must be reduced to avoid undercutting, whilst above this thickness range the pulse time is increased to avoid using excessively high currents. This might require a large nozzle bore and lead to correspondingly wide weld beads.



50 *Tolerance to variation in welding current and plasma gas flow rate in pulsed and continuous current keyhole welding. The boundaries show the welding parameter combinations at which specific defects are likely to occur.*

Pulsing the welding current overcomes one of the major difficulties encountered in keyhole operation, namely tolerance to variation in welding parameters. Using the simple acceptance criteria of full penetration, no undercutting and no bead sinkage, it can be shown that pulsing greatly increases the range of usable welding parameters.

As shown in the tolerance boxes for keyhole welding of 4.4mm (0.17in) thick stainless steel plate in Fig. 50, the range of acceptable pulse current is approximately twice that for continuous current operation. Consequently, the technique of alternate periods of melting and solidification produces a greater operating range or conversely, variations in the major welding parameters in pulsed operations are less likely to upset the process and result in defects such as lack of penetration, undercutting or weld bead sinkage.

Further reading

1 O'Brien R L: 'Arc plasma for joining, cutting and surfacing'. Welding Research Council Bulletin No. 131, July, 1968.

2 Omar A A and Lundin C D: 'Pulsed plasma – pulsed GTA – a study of the process variables'. *Weld J* 1979 58 4.

3 Bashenko V V and Sosnin N A: 'Optimisation of the plasma arc welding process'. *Weld J* 1988 67 10.

CHAPTER 9

Applying the plasma process

Practical considerations

The operation of the plasma process is essentially similar to TIG welding in that the arc is used as a heat source to fuse the joint and, when required, filler material is added separately in rod or wire form. In contrast to TIG welding, because the electrode is held within the torch body behind a small copper nozzle (Fig. 44), plasma welding has several singular operating characteristics:

1 A pilot (non-transferred) arc can be formed between the electrode and the copper nozzle; since a non-transferred arc is relatively inefficient as a heat source, an arc must be transferred from the nozzle to the workpiece for welding to enable heat to be generated in forming the arc roots.

2 The nozzle constricts the plasma to form a columnar shaped arc which, compared with the TIG arc, is more directional and less sensitive to variation in arc length; in TIG welding, because of its conical shape, the arc is more sensitive to arc length variation, both with regard to arc stability and the spread of the arc.

3 By increasing the plasma gas flow the penetration depth of the weld pool can be increased. In the keyhole mode the deeply penetrating arc plasma has sufficient power to cut completely through the material with the molten metal flowing behind to form the weld pool.

4 As the electrode is held within the torch body, i.e. behind the constricting nozzle, there is little risk of contamination from touching the weld pool or filler rod.

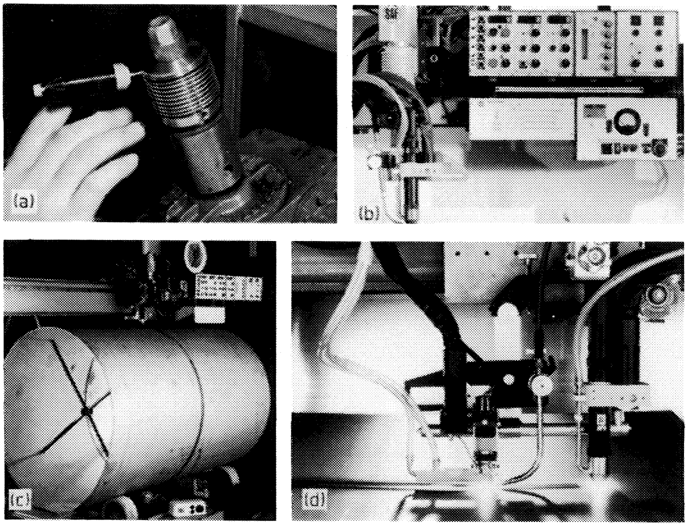
The practical operation of the plasma process is best considered in terms of the three distinct process variants noted before, which can be differentiated in terms of their operating current ranges.

- Micro-plasma welding, 0.1–15A
- Medium current plasma welding, 15–100A
- Keyhole plasma welding, >100A

The micro-plasma variant is applied in low current operations where the prime requirement is for a stable low current arc. The micro and medium current variants are normally employed manually, so that advantage can be gained from the tolerance to arc length variations, or in mechanised applications where the automatic arc starting and reduced electrode contamination features can be exploited. Because of the need for precise control of the welding conditions to maintain the keyhole, this high current variant can be applied only in mechanised operations.

Equipment

For micro-plasma operation the equipment is normally self-contained i.e. comprising a power source and control console. The torch is small and compact as shown in Fig. 51a.



51 *Plasma welding equipment: a) Micro-plasma torch being used to weld stainless steel bellows (courtesy of BOC Ltd); b) Plasma arc welding head and control console; c) Industrial installation for large stainless steel vessels; d) Plasma-TIG (filler wire) torch equipment and TIG capping pass (b-d courtesy of SAF Welding Products Ltd).*

A typical plasma welding head and control system for medium and keyhole operation is shown in Fig. 51b. The plasma console is interfaced with a conventional TIG power source to control the pilot arc and the torch gas and water supplies. Special features of the system include welding current sequence and plasma gas slope-out controls. The latter feature is essential for closing the keyhole, for example when welding tubes.

An industrial installation for welding large diameter stainless steel vessels is shown in Fig. 51c.

The plasma arc can also be combined with a TIG arc to form (leading) plasma-TIG system as shown in Fig. 51d; welding speeds can be increased by up to 50% compared to a single torch system.

Electrode and nozzles

The electrode in the plasma system is normally tungsten-2% thoria. Typical electrode diameters, vertex angles and plasma nozzle bore diameter for the various current ranges are given in Table 13. At low and medium currents the electrode is sharpened to a point, whilst at high currents it is blunted to approximately 1mm diameter tip.

The plasma nozzle bore diameter, in particular, must be selected carefully, and it is prudent to use a nozzle whose current rating is well in excess of the operating current level. The plasma gas flow rate can also have a pronounced effect on the nozzle life with too low a flow rate possibly leading to excessive erosion. Multi-port nozzles, which contain two additional small orifices on each side of the main orifice, can be used at high current to improve control of arc shape. Use of an oval or elongated plasma arc has been found to be beneficial in high current welding, particularly when operating in the keyhole mode.

Plasma and shielding gas

Typical plasma and shielding gas compositions for the normal range of engineering materials are given in Table 14. The most common combination of gases currently employed in industry is argon for the plasma and argon or argon plus 2-5% H_2 for shielding. However, there are several other possible gases available which offer specific advantages.

Argon is the preferred plasma gas as it gives the lowest rate of electrode and nozzle erosion. Helium can be used for medium and high current operations to increase the temperature of the plasma which, in the melt (non-keyhole) mode, often promotes higher welding speeds. However, use of helium as the

Table 13 Maximum current for plasma welding for selected electrode diameter, vertex angle and nozzle base diameter (Levels are for guidance only, it is important to refer to manufacturer's recommended operating conditions for specific torch and plasma nozzle designs.)

Maximum current, A						Plasma*		Shielding†	
Torch rating, A				Electrode diameter, mm	Vertex angle, degrees	Nozzle bore dia, mm	Flow rate, litre/min	Shroud diameter, mm	Flow rate, litre/min
20	100	200	400						
Micro-plasma									
5				1.0	15	0.8	0.2	8	4–7
10						0.8	0.3		
20						1.0	0.5		
Medium current									
	30			2.4	30	0.79	0.47	12	4–7
	50					1.17	0.71		
	75					1.57	0.94		
	100					2.06	1.18		
		50		4.8	30	1.17	0.71	17	4–12
		100				1.57	0.94		
		160				2.36	1.42		
		200				3.20	1.65		
			180	3.2	60**	2.82	2.4	18	20–35
			200			2.82‡	2.5		
High current									
			250	4.8	60**	3.45‡	3.0		20–35
			300			3.45‡	3.5		
			350			3.96‡	4.1		

*Argon plasma gas † Argon and argon-5% H_2 shielding gas ** Electrode tip blunted to 1mm diameter ‡ Multi-port nozzle

Table 14 Plasma and shielding gas compositions for plasma arc welding

Material	Plasma gas	Shielding gas
Mild steel	Argon	Argon Argon – 2–5%H_2*
Low alloy steels	Argon	Argon
Austenitic stainless steel	Argon	Argon – 2–5%H_2 Helium*
Nickel and nickel alloy	Argon	Argon Argon – 2–5%H_2*
Titanium	Argon	Argon 75% Helium – 25% Argon*
Copper and copper alloys	Argon	Argon 75% Helium – 25% Argon*

*Also used

plasma gas can reduce the current carrying capacity of the nozzle. Furthermore, because of its lower mass, weld pool penetration is reduced which, in certain materials, makes the formation of a keyhole difficult. For this reason, helium is seldom used for the plasma gas when operating with the keyhole mode.

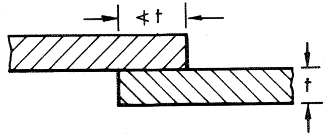
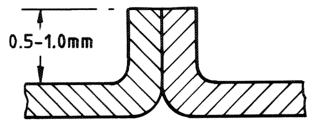
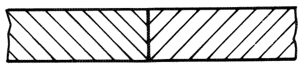
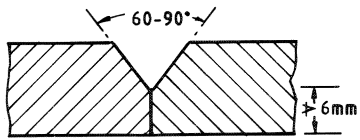
Hydrogen is often added to the shielding gas, up to a maximum of 15%, to produce a hotter arc and a slightly reducing atmosphere. Hydrogen also constricts the arc which can increase the depth of weld pool penetration and promote higher welding speeds.

Helium, or a helium-argon mixture, typically 75% helium-25% argon, can also be used as the shielding gas. Whilst a hotter arc is generated it is less constricted, which can result in a wider weld bead compared with argon or argon-hydrogen shielding.

Joint preparation

As the selection of suitable joint preparations is largely determined by the type of component and the material thickness, specific joint designs are discussed in the appropriate sections on applications, but some general points are noted here.

Table 15 Joint configurations for plasma welding sheet and tubular components; for medium current plasma operating mode see also Fig. 7 (sheet) and Fig. 14 (tube).)

Thickness range, mm	Joint type	Joint configuration	Process variant	No. of runs	Comments
0.5–1.0	Micro lap		Micro plasma	1	Edges fully fused to produce additional weld metal – good clamping essential
0.5–1.5	Flanged edge		Micro plasma	1	Edges fully fused to produce additional weld metal
3.0–6.0	Square butt		Keyhole plasma	1	Grooved backing bar required to prevent disturbance of the efflux plasma. Additional (cosmetic) run using melt mode may be employed
6.0–15	Single V butt		Keyhole plasma	2 or more	Keyhole technique used for root run only. Joint completed with the melt mode plus filler wire

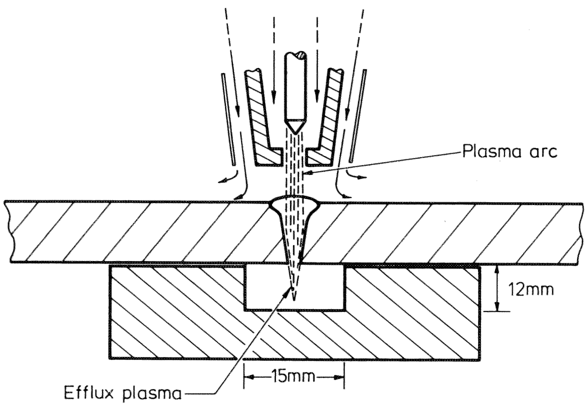
In welding thin sheet material using the micro plasma operating mode, those designs incorporating integral filler material, see Fig. 28 and Table 15, provide some tolerance to joint fit-up and reduce the risk of burn-through. Use of a copper backing bar and finger clamps is strongly recommended when welding butt joints; to ensure a uniform heat sink.

As medium current plasma is employed as an alternative to TIG, the joint designs described in Chapter 2 can be used when the technique is applied to welding butt, T, edge and corner joints; typical sheet and tube edge preparations are shown in Fig. 7 and 14 respectively.

As the keyhole process variant has a deeply penetrating arc and weld pool, a greater sheet thickness, compared with TIG or the medium current plasma process, can be welded before an edge preparation needs to be employed (Table 15). It is current practice to limit the square edge closed butt joint preparation to 6mm (0.25in). Above this thickness, the normal V edge preparation is adopted, typically 60° included angle, with a root face of no more than 6mm.

Backing systems

The normal range of backing bar designs or shielding gas techniques, as previously described for TIG, is used when welding sheet by the micro and medium current techniques.



52 *Backing bar used in plasma (keyhole) welding.*

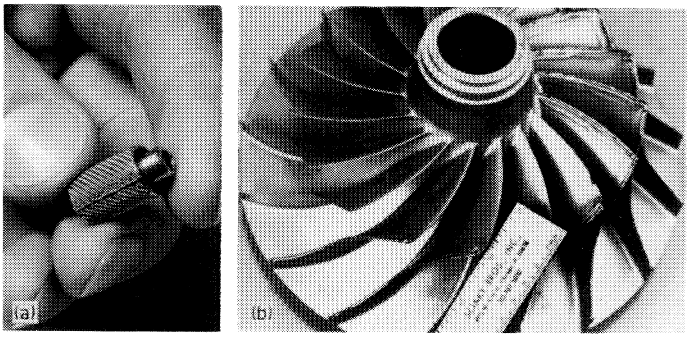
When applying the keyhole mode a grooved backing bar, with or without gas shielding, or total gas shielding of the underside of the joint must be used. Because the efflux plasma normally extends around 10mm (0.5in) below the back face of the joint, the groove must have sufficient depth to avoid any disturbance of the arc jet. Inadequate clearance gives the risk of turbulence in the efflux plasma arc, which disturbs the weld pool, causing porosity; a typical backing bar for plasma (keyhole) welding is shown in Fig. 52.

Industrial applications

Applications of plasma welding are considered in terms of the three process variants – micro-plasma, medium current and keyhole – and when describing specific applications, comparison has been drawn with the operating features of TIG welding to show why plasma was selected in preference to TIG.

Micro-plasma

The micro-plasma technique is particularly suited to welding sheet down to 0.1mm (0.004in) thickness, and wire and mesh sections. The narrow 'needle-like' stiff arc at welding currents within the range 0.1-15A prevents arc wander and minimises distortion; the equivalent TIG arc at this current suffers from instabilities because of arc wander, and is much more diffuse. Plasma can also be readily used manually as the torch is compact and there is high tolerance to torch-to-workpiece variation.



53 *Micro-plasma welding applications: a) Filter assembly (courtesy of BOC Ltd); b) APU impeller welded with pulsed wire micro-plasma process (courtesy of Huntingdon Fusion Techniques Ltd/Sciaky Bros Inc).*

Examples of the application of micro-plasma include thin section bellows (Fig. 51a), filter assemblies for the aerospace industry (Fig. 53a), and on-site welding of 0.3 and 0.5mm sheet for insulating elements in the advanced gas-cooled reactor (AGR) vessel. In the first two applications emphasis was placed on the need for careful consideration of component jigging, preparation of the joint edges and when possible, the use of a joint design which incorporates an integral filler to minimise the risk of burn-through. In the installation of the AGR insulating elements in areas of difficult access, the advantageous operating features of arc stability at low current levels, lighting of the joint area with the pilot arc before welding and tolerance to arc length variations were particularly important.

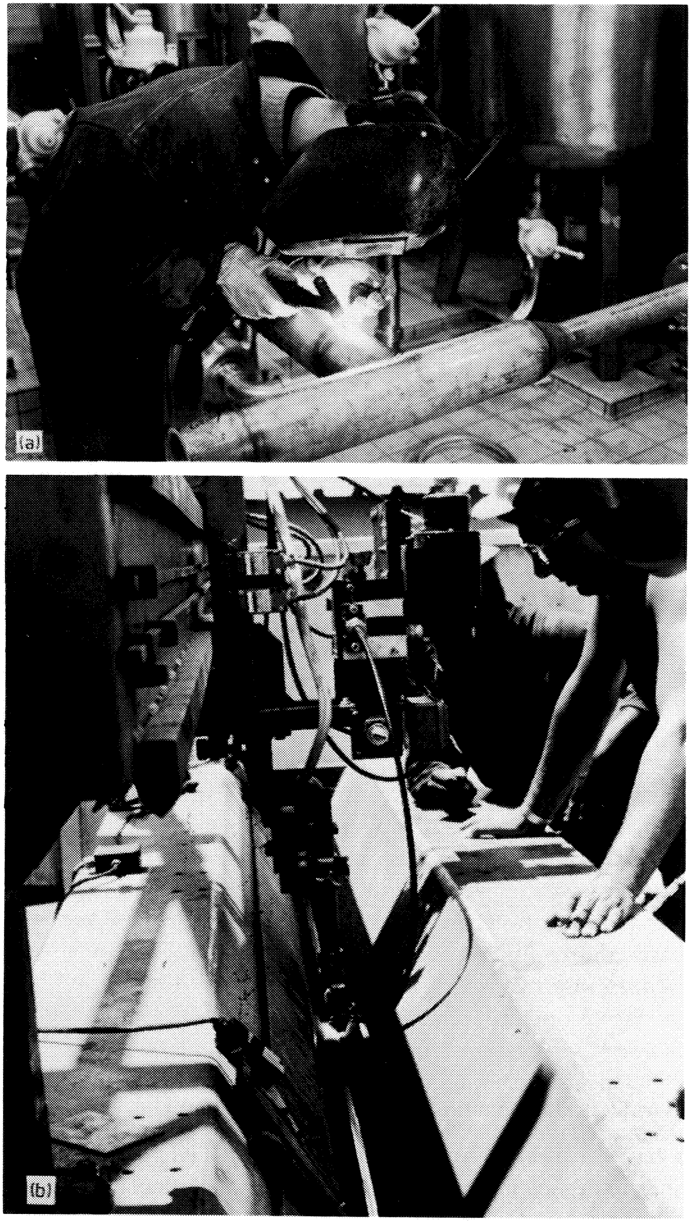
Micro-plasma with pulsed wire feed can also be used for building up the edges of worn impeller blades as shown in Fig. 53b. The impeller was manufactured in titanium 64 and edges were built up by 0.75mm (0.030in) in three passes using 0.875mm (0.035in) diameter filler wire.

Medium current

Plasma welding in the intermediate 15-100A range, and with the melt or keyhole operating mode, is more directly in competition with TIG. Successful applications have exploited the capacity to improve the depth-to-width ratio of the weld bead by use of higher plasma gas flow, and the position of the electrode within the body of the torch which can significantly reduce electrode contamination, which is particularly important in welding oily sheet material. These advantages, however, must be balanced against the increased bulkiness of the torch, which to some extent negates the advantages of the tolerance to variation in torch-to-workpiece distance in manual welding.

Examples of the manual use of plasma are found in the auto and chemical industries. In the fabrication of car bodies in approximately 1mm (0.04in) thick mild steel, plasma (braze) is applied to fill the joints between the panels to give a smooth surface after mechanical dressing; of other welding processes, MIG produces an unacceptable surface finish, whilst TIG suffers from difficulties in arc starting, the need to hold a short arc length and excessive electrode contamination from the surface oil.

Plasma has also been selected in preference to TIG for welding stainless steel pipes in fabricating brewery plant, which is particularly noteworthy as welding was carried out both in the factory and on site (Fig. 54a). The advantages claimed are better control of the weld bead penetration profile, which was particularly demanding in view of the stringent requirements of



54 *Medium current applications of plasma: a) Manual welding of stainless steel pipes; b) Mechanised seam welding machine for fabricating large panels in 0.9mm thick stainless steel sheets (courtesy of William Press Ltd).*

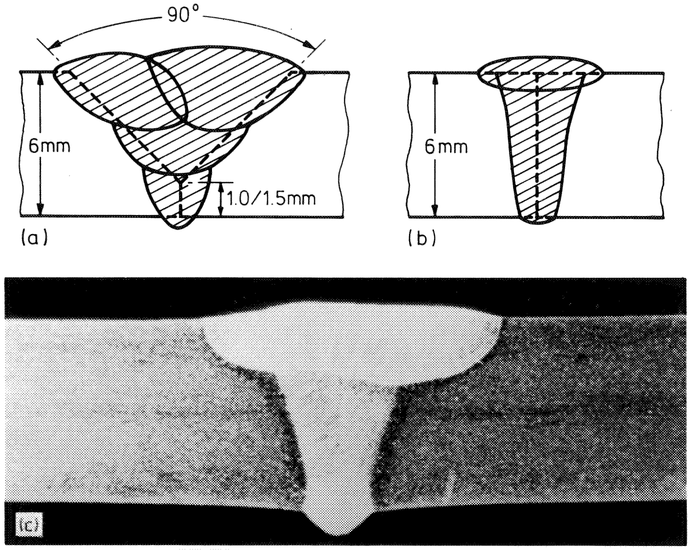
crevice-free welds and maximum allowable pipe misalignment of ±0.13mm (0.005in) and the capacity to vary weld penetration by means of the plasma gas flow in preference to changing the welding current. The latter was found to aid positional welding and to facilitate control of the width of the weld pool.

Medium current plasma is also applied in mechanised operations and here the advantages of automatic arc starting and reduced electrode wear are particularly important. However, there is a need for close control of the welding parameters, particularly the plasma gas flow rate, and for regular equipment maintenance, to achieve consistent weld quality; a variation of 0.2 l/min (0.4 cfh) in the plasma gas flow rate significantly influences weld pool penetration. A unique application of mechanised techniques was welding 0.9mm (0.036in) thick stainless steel linings (1.6km (1 mile) in total) for a solvent copper extraction plant, which was installed in Zambia. The special plasma welding equipment adapted for welding 0.9mm (0.036in) sheet on site is shown in Fig 54b.

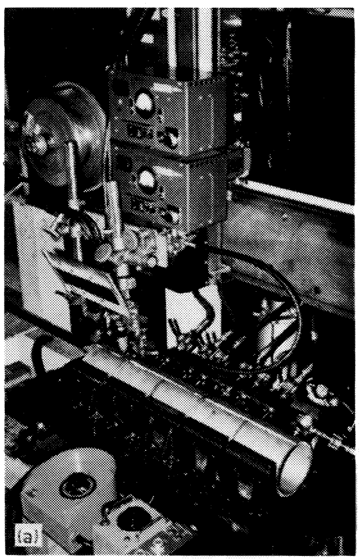
Keyhole plasma

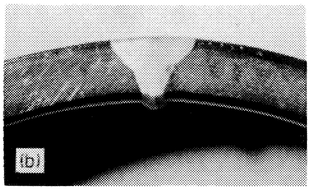
As the keyhole operating mode has several special advantages (deep penetration, high welding speed) it is not normally in direct competition with TIG. The deep penetration capability, in particular, enables plate material up to 6mm to be welded in a single run or up to 12mm (0.5in) in two runs; the advantage over TIG welding is shown diagrammatically in Fig. 55 where 6mm (0.25in) wall thickness stainless steel tube which required four runs using TIG was welded in two runs using plasma. The most common technique is to carry out the first run using the keyhole mode and the second run using the melt mode if necessary with a filler wire addition; the practical arrangement for the plasma and TIG plus filler wire torches was shown in Fig. 51d. The limitations of the keyhole mode lie in the need for close control of welding parameters to maintain the keyhole and the difficulty of feeding filler wire into the keyhole without disturbing its stability. However, in sensitive materials, such as cupro-nickel alloys, the addition of filler wire during the keyhole run is essential to prevent porosity.

For these reasons the process is best applied to welding long linear seams in plate or circumferential joints in tube, in materials which are not susceptible to cracking or porosity in the autogenous welded condition. Orbital welding of tubular components is not usually practised because of the need to modify the plasma parameters to circumvent heat build-up to accommodate the changes in welding position as welding progresses around the joint, and



55 *Welding sequence in TIG and plasma welding of tubes; whilst the TIG weld requires four runs, the plasma weld is completed in two: a) TIG weld; b) Plasma weld, the first run is completed with the keyhole mode and a cosmetic pass is used to ensure a smooth surface profile; c) Typical appearance of two pass (keyhole plasma plus TIG) weld.*





56 *Machine for plasma (keyhole) seam welding of pipe: a) Torch mounting and pipe clamping arrangement; b) Section through autogenous weld in 6mm thick stainless steel (courtesy of Devtec Ltd).*

to fill the keyhole on completion of the weld. Simultaneous sloping-out of the welding current and plasma gas can be employed to fill the keyhole but this requires specialised equipment and close control of the parameters to produce a satisfactory bead profile and to avoid porosity.

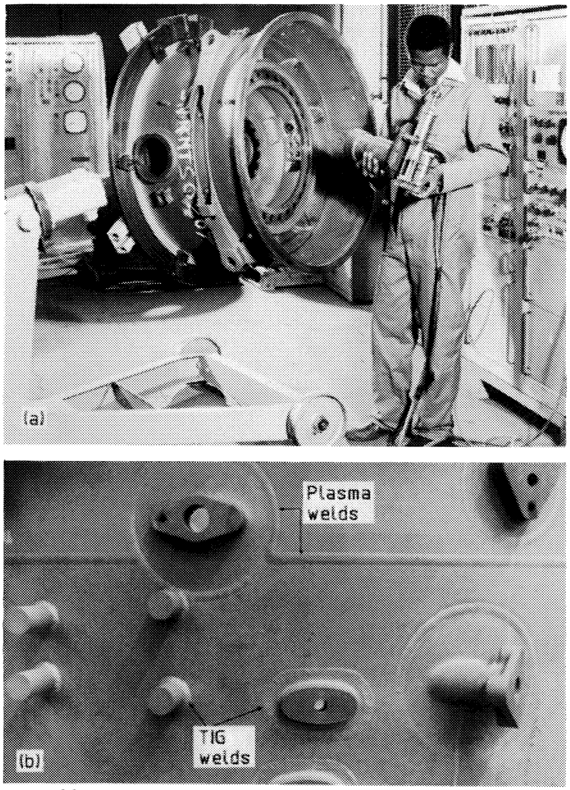
For the equipment shown in Fig. 51a, the manufacturer's suggested welding parameters for butt joints in stainless steel sheet are given in Table 16.

The keyhole technique has been applied successfully for several years in seam welding tube material in a range of thicknesses (6-12mm (0.25-0.5in)) and material compositions (stainless steel, Monel 400, and titanium). The welding equipment is shown in Fig. 56a and a section through the weld in Fig. 56b. Practical experience has shown that thicknesses up to 6mm can be

Table 16 Welding parameters for plasma (keyhole) welding of butt joints in stainless steel (courtesy of SAF)

			Filler metal		Gases used (flow rate, l/min)		
Thickness mm	Arc current amperage, A	Welding speed, cm/min	ϕ, mm	Wire feed speed, cm/min	Plasma producing gas argon	Nozzle argon 2/5%H_2	Additional argon
Stainless steel							
2	120	65	1	60	2–3	15	–
	Pulsed current						
3	130–140	45–50	1	50	3–4	20	–
4	150–160	35–38	1.2	60	4-5	20	–
5	150–160	28–32	1.2	60	4.5–6	20	–
6	160–180	26–32	1.2	60	8–9	25	–
8	250–280	18–20	1.2	90	8–10	25	–
Titanium							
6	220	26	–	–	7	30	30
	180	15	–	–	2	30	30
8	240	26	–	–	8	30	30
	180	15	–	–	2	30	30
10	940	20	–	–	10	30	30
	240	20	–	–	2	30	30
Zirconium							
5.8	140	98	–	–	3	30	40
7.2	150	97	–	–	4	95	40
	140	19	–	–	2	20	40

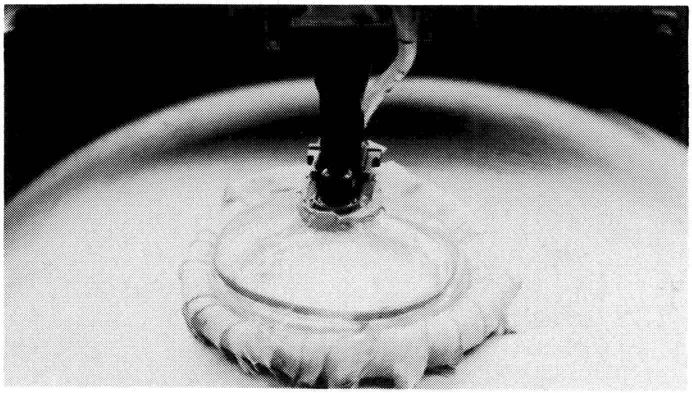
Shielding on underside of weld–argon or argon–H_2 (10–90 l/min)



***57** Plasma welding aero engine components: a) Intermediate compressor casing for the RB 211 jet engine (the complete casing held in the positioner); b) Circumferential and boss welds completed by plasma and TIG (courtesy of Rolls-Royce Plc). Typical welding parameters for plasma welding: plasma and shielding gas composition – argon, plasma nozzle orifice diameter – 2.35mm, plasma gas flow rate – 1.2 l/min, welding current – 55A welding speed – 0.15 m/min.*

welded in a single pass, but greater thicknesses require the use of joint preparations of 75° (included angle) and a 5mm (0.2in) root face. The weld is then completed in two passes – an autogenous plasma (keyhole) root run followed by a capping run of plasma (melt mode), or TIG plus filler wire.

An equally successful application has been in the fabrication of high integrity components for the aerospace industry. A notable example is that of the intermediate compressor casing for the Rolls-Royce RB211 jet engine, Fig. 57a. The appearance of the circumferential weld and the smaller boss insertions in the casing wall are shown in more detail in Fig. 57b; also shown are manual TIG welds which, because of their non-circular



58 *Plasma keyhole welding of titanium showing the use of a glass cap to give total shielding of the weld and surrounding area (courtesy of Rolls Royce Plc)*

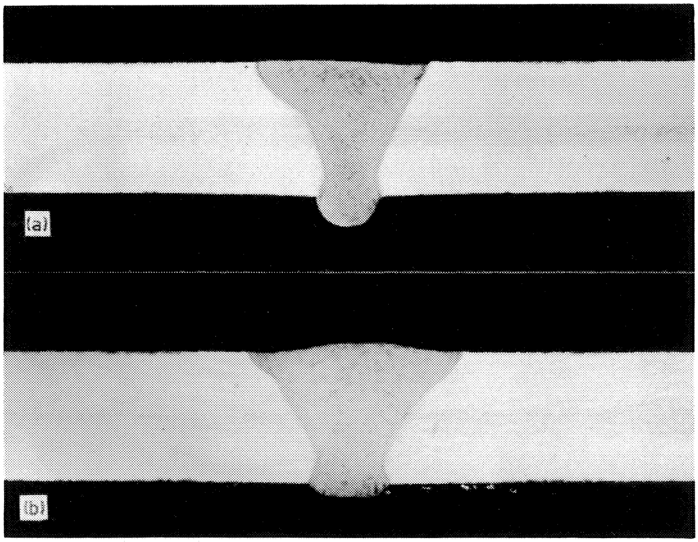
profile, would be difficult to weld using the keyhole process. As the material thickness in this instance is only 2.6mm (0.1in) preference for the plasma process is based solely on the integrity of the weld. The narrow weld and heat affected zone results in sound welds and low distortion in materials such as Jethete M152 and 12%Cr air hardening material.

Plasma (keyhole) welding also has particular advantages for welding titanium alloys, producing very low porosity without resort to special preparation of the joint edges. This is directly attributable to the scouring of the arc as the keyhole cuts through the material; an example of plasma welding of a 2mm thick titanium casing in the aeroengine fabrication is shown in Fig. 58. The effectiveness of the plasma process in making a narrow weld which cools quickly means that only simple shielding of the weld bead is necessary in production. A trailing gas shield is sufficient, compared with the more common use of glove boxes or vacuum chambers for TIG welding titanium, particularly where the section thickness is greater than 1.5mm (0.06in).

Pulsed (keyhole) welding

The comments on pulsed current TIG apply equally to plasma welding for the melt type operating mode, but special advantages are to be gained from its adoption in the keyhole operating mode.

Despite the successful application of keyhole plasma described above, the technique is not widely applied in industry. The major reasons are:



59 *Sections through plasma keyhole welds in 4.4mm austenitic stainless steel, showing the effect of pulsing the welding current on weld bead penetration profile: a) Continuous current; b) Pulsed current.*

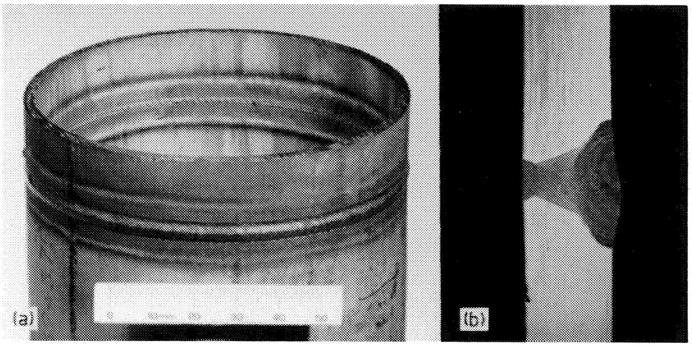
Typical welding parameters

	Continuous	*Pulsed*
Plasma gas composition	*Argon*	*Argon*
Plasma nozzle diameter, mm	*2.36*	*2.36*
Plasma gas flow rate, l/min	*1.75*	*1.9*
Plasma current, A	*120*	
Plasma current, pulsed, A		*140*
Pulsed frequency, Hz		*2*
Welding speed, m/min	*0.22*	*0.15*

1 Close control is required of the major welding parameters to maintain keyhole/weld pool stability.

2 The complex torch arrangement requires more than normal planned maintenance to ensure reproducible performance.

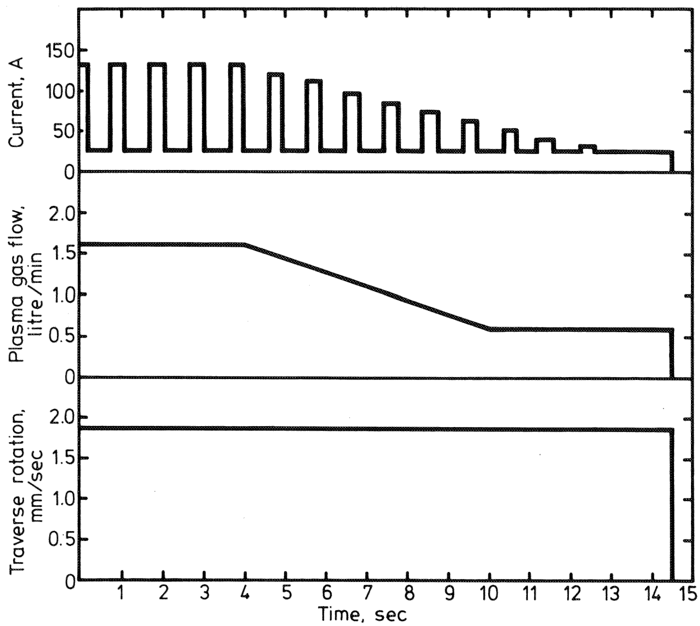
Defects which are frequently observed in practice include undercutting through too high a plasma force and 'humping' when welding at high traverse speeds. Catastrophic breakdown of keyhole/weld pool stability results either in partial penetration of the plate and excessive porosity in the weld bead, or in cutting without establishing the weld pool. Consequently precautions must be taken to avoid destroying the component and incurring expensive repairs.



60 *Pulsed keyhole plasma weld in 40mm OD, 4mm wall thickness stainless steel steel pipe, welded in the 2G (pipe rotated) position: a) Surface appearance; b) Section through weld. Typical welding parameters: plasma gas composition – argon, plasma nozzle diameter – 2.36mm, plasma gas flow rate – 1.9 l/min, plasma current – 125A, Pulsed frequency – 2Hz, welding speed – 0.15 m/min*

Pulsing the welding current overcomes the major limitation of poor tolerance to variation in welding parameters: as shown in Fig. 50, tolerance to variation in welding current and plasma gas flow is greatly increased through the intermittent solidification of the weld pool. Improvements have also been observed in the weld bead penetration profile, as shown in Fig. 59. The continuous current weld has the characteristic 'wine glass' penetration profile, which is particularly narrow in the centre of the plate. The underbead in materials such as stainless steel is invariably 'peaky' with a sharp angle of contact with the surface of the parent plate (Fig. 59a). In contrast, the penetration profile of the pulsed keyhole weld has a more uniform width through the thickness of the plate, and has a flatter underbead (Fig. 59b). Thus, the increased width of the weld bead through pulsing of the current is advantageous in reducing the demands on joint tracking.

In application of the technique to welding pipe it has been demonstrated that stainless steel pipes of 40mm (1.6in) 0D, 4mm (0.16in) wall thickness, can be welded in the torch horizontal and pipe vertical position (rotated pipe) without an edge preparation. The surface appearance of the horizontal weld is shown in Fig. 60a, and a section through the weld in Fig. 60b. The section should be compared with that of the typical pulsed TIG welded pipe of 5mm (0.2in) wall thickness shown in Fig. 22, where the weld required an expensive U type joint preparation (Table 7) and five runs to complete the weld. The specific problem in pipe welding, that of closing the keyhole on



61 *Sequence of operations required to fill the keyhole on completion of orbital weld. Note, simultaneous sloping-out of the welding current and plasma gas flow.*

completion of the operation, was overcome by simultaneously sloping-out the welding current and plasma gas flow, the sequence of operations is given in Fig. 61.

Although the pulsed plasma process has not been widely adopted in industry, applications have been reported in the US and more recently in the UK for the manufacture of aeroengine components. In the US, 25mm (1in) diameter, 3.1– 4.6mm (0.12–0.18in) wall pipes in $2^1/_4$Cr– 1Mo steel were fabricated for the steam generators of the high temperature gas-cooled reactor. The advantages of the plasma arc process compared with the alternative TIG were higher welding speeds, greater depth of penetration, simpler joint preparation for a weld quality matching that observed in TIG welding.

In the manufacture of aeroengine components, 50mm (2in) diameter bosses were welded into a titanium casing which had a wall thickness of only 2mm (0.08in). Pulsing was carried out purely to enable the keyhole mode to be applied in such a section thickness and to produce a satisfactory surface appearance, particularly in the slope-out region. The reason for employing the keyhole mode was to achieve low porosity (from the scouring action of the arc as it passed through the material section) and to minimise distortion.

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Chapter 9

Exotic and difficult-to-weld metals

Many unusual metals and alloys can be welded using TIG. Amongst these are Monel metal, nimonic and other nickel based alloys, titanium, zirconium, molybdenum, *etc*, all of which can be welded with care. In the case of reactive metals which rapidly oxidise after cutting and cleaning, *e.g.* titanium, zirconium and aluminium these must be welded within a few minutes of preparing the seam. If any delay occurs the joints should be abraded or solvent cleaned again before welding.

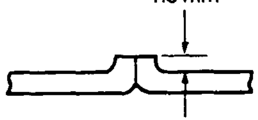
For scraping or abrading use either stainless steel wool or a suitable proprietary dry scouring medium such as Scotchbrite. *Never* use the latter on a hot weld as it will melt and leave impurities. After abrading, wipe the edges clean with a fluff free cloth damped with solvent and allow to dry.

Preparation of reactive metals for welding is very important. With care, even beryllium copper can be welded in thin sections such as are used sometimes in production of edge welded bellows. (Beware, beryllium is highly toxic.) One point though with such metals, reruns are seldom if ever possible, so everything must be right first time. On occasions, using autogenous DC TIG, aluminium can with care be overwelded.

Titanium welds well in the DC mode and flows easily but is very prone to surface oxidation and cracking whilst cooling. For this reason the amount of purge gas needs to be increased or, when machine welding, a trailing shield can be fitted to the torch. Table 9.1 gives details of three different edge preparations for titanium butt welding, also some suggested weld parameters in the DCEN mode, gas flow, consumables, *etc*.

For critical welds in titanium it is best to operate within a chamber purged and filled with shielding gas. These chambers are commercially

Table 9.1 TIG welding conditions for butt welds in titanium, DCEN



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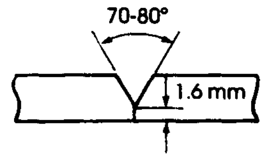

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Plate and joint				Welding conditions							Consumables		
Thickness, mm	swg	Sketch	No. of passes	Nozzle bore, mm	Wire dia, mm	Electrode dia, mm	Argon flow l/min	Argon flow ft^3/hr	Welding current, A	Speed m/hr	Wire con'n kg/m	Argon con'n l/m	Arc time min/m
0.35	28	1	1	*	–	0.8	7	15	10–15	21–24	–	18	2.5
0.45	26	1	1		–	0.8	7	15	15–20	21–24	–	18	2.5
0.56	24	1	1		–	1.2	9	19	20–25	18–21	–	25	2.8
0.7	22	1	1		–	1.2	9	19	25–30	18–21	–	25	2.8
0.9	20	1	1		–	1.2	9	19	25–30	15–18	–	30	3.3
1.2	18	2	1		1.6	1.6	9	19	30–40	15	0.014	36	4.0
1.6	16	2	1		1.6	1.6	9	19	50–75	15	0.014	36	4.0
3.3	1/8	2	1		2.4	2.4	12	25	100–140	12–15	0.029	48	4.0
6.4	1/4	3	**2		3.2	2.4	12	25	1st 60–80 2nd 120–180	15 9–12	0.046	108	90
9.5	3/8	3	**2		3.2	2.4	12	25	1st 60–80 2nd 180–240	15 9–12	0.046	108	90

* *Use a large nozzle for the torch and a trailing shield for extra gas coverage.*
** *Root run: no filler.*

available and are sometimes referred to as glove compartments.

This procedure is also useful for high quality welds in zirconium and its alloys, also for aluminium if cost permits. A purge chamber does not necessarily eliminate the need for gas flow to the torch. Use a gas lens with a large bore ceramic gas cup fitted. Access to a purge chamber is by a sealed glove compartment and considerable operator skill is often required to use such equipment. Many critical welds for the nuclear industry are carried out in this way.

Welding within a purged chamber is very effective in the automatic mode. Clamping and heat sinking are of extra importance with these metals.

Phosphor bronze

Welded by TIG, phosphor bronze flows well and has a good bead appearance. As it contains copper it needs considerable heat and can seldom be welded without use of a suitable filler wire as it is extremely prone to porosity. The use of current pulsing at a rate of about two pulses per second or lower is recommended. Oscillation across the weld seam is also advantageous as it assists with sidewall fusion. This should be fairly slow, perhaps one cycle per second, easy to achieve by mechanical means. Most copper-nickel alloys benefit from using this technique. Check carefully that the filler rod or wire is compatible with the base metal.

Free machining steels

Mention must be made here of these very difficult-to-weld metals. The addition of higher proportions of sulphur and graphite can give rise to extreme porosity and they should be avoided for welding whenever possible. If welds are essential, improvements can be made by careful use of heat sinks and arc pulsing as the pulses often bring inclusions to the bead surface. The real problems arise in autogenous welding but here the addition of suitable filler wire can, as with many other metals, reduce porosity considerably.

Stainless alloys

Stainless steels can have cast-to-cast variations in alloy content which, however slight, may produce unacceptable welds. For critical aerospace, nuclear and process welds obtain metals with a certificate guaranteeing the batch quality and alloy percentages. Most stainless steels such as types 308, 316 and 347 are considered very weldable for most purposes. For special alloys, experiment carefully first. Always consult a manufacturer of filler wires for compatible materials as a vast range of wires is available.

Brass

Some types of brass can be welded with DC TIG but the generally large zinc content makes these metals very difficult to join. The author's advice is not to bother. Other joining methods, *e.g.* brazing are much less trouble and more cost effective.

Chapter 10

Aluminium welding

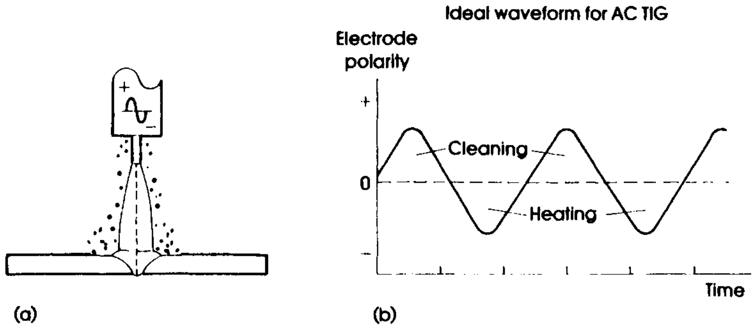
AC mode

It is generally considered in the welding industry that aluminium, magnesium and their alloys should always be welded by the AC TIG process. It is true to say that the AC mode is more successful because the alternating current has some cleaning effect on the weld bead, bringing unwanted oxides to the surface, Fig. 10.1.

This mode is particularly successful for thicker metals using filler wire and is almost mandatory where aluminium filler wire or rod are being used. One slight disadvantage is that AC TIG can sometimes produce considerable sparking and spatter but even this can be minimised with proper cleaning of the weld preparation. Aluminium should be welded immediately after cleaning the weld seam surfaces for best results. Keep the weld area free from any contaminants which might be a potential source of hydrogen porosity.

DC mode

Autogenous welding of some aluminium alloys can be carried out by DCEN but it is usually only possible with fairly thin sections and with pulsing of the arc. It should be noted that aluminium welding often involves considerable experimentation before good results are achieved, because two



10.1 AC TIG welding arc effect: a) Good cleaning action and weld preparation; b) Ideal current waveform.

batches of what is ostensibly the same alloy often differ considerably in weldability. Generally speaking the purer the metal the better it will weld by DC. The following have given successful results:

- Pure aluminium;
- N3, N4, N8, H30;
- 2219, 5083 (N8), 5454, 6082 (H30). Avoid *all* 2000 series alloys.

CONDITION

Fully annealed is best but half hard can be welded with care.

CLEANNESS

Lightly abrade, solvent clean and weld within ten minutes.

JOINTS

A tight, square, closed butt preparation is best. Back purge the underside of the seam if possible. Ensure an even heat balance either side of the seam and clamp faces firmly to avoid distortion.

ARC GAP

This is critical. Either make *very* accurate piece parts or use arc length control (ALC) to maintain a constant gap.

WELD RUN

Use *minimum* overlap at end of weld. A second run over a seam often spoils the weld. Too long a downslope time has the same effect as too much overlap.

METAL THICKNESS

For all practical purposes maximum thickness is 2 mm for an autogenous butt weld but conditions vary from alloy to alloy.

SHIELDING GASES

Argon gives good results on most occasions. Helium is more satisfactory but expensive. Satisfactory gas spread and arc strike are difficult to achieve in helium, which can also totally inhibit pulsing of the arc.

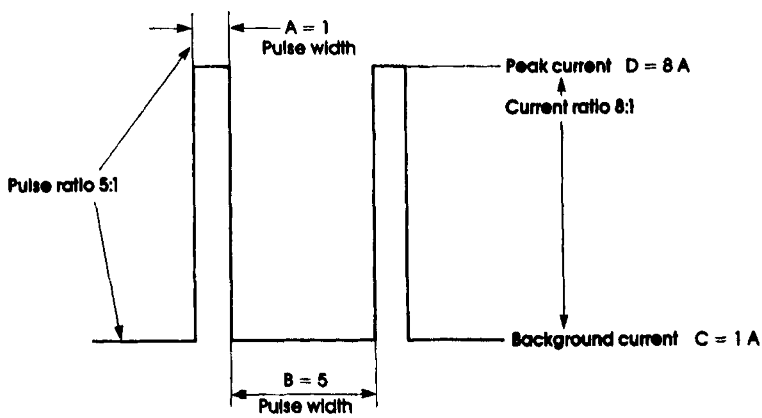
WELDING CURRENT - PULSED DC

High, short, primary pulses and low, long, background pulses give best results, Fig. 10.2.

Typical parameters

Primary current:	64 A	Background current:	8 A
Primary pulse:	30 msec	Background pulse:	150 msec
Upslope:	Nil	Downslope:	2 sec max

Keep higher or lower currents within the same average ratios.



10.2 Recommended waveform for pulsed DC TIG welding of aluminium and its alloys.

WELDING SPEED

Determined by experiment. Speeds up to 16 mm/sec (36 in/min) have been achieved with thin materials but some alloys need to be welded much more slowly. Avoid remelt runs.

CLAMPING

Must be firm. Any heat sinking and watercooling requirements must be determined by experiment.

HELIUM

This increases heat input into the weld and can give a better cosmetic finish. However, arc strike is difficult in helium and it may be necessary to establish an arc in argon and then switch over as quickly as possible to helium. In some circumstances, particularly when using helium in a pressurised chamber, pulsing the arc may not be possible. Try to use low (around 2 bar) gas pressure with good flow and spread. A gas lens collet assembly in the torch is advantageous too and will maximise localised gas coverage within the chamber.

ARC STRIKE

Set any strike current level control on the power source to *maximum* (usually around 20 A) when using helium.

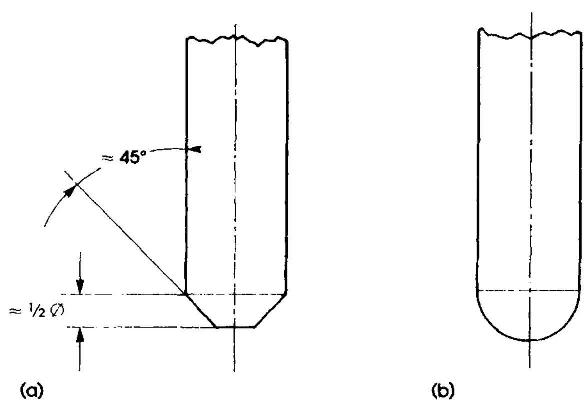
Aluminium has extremely good thermal conductivity and thus needs a higher current at all times than steels. Try to concentrate the arc as much as possible by keeping the arc length short and consistent.

ELECTRODES

When used for AC TIG welding electrodes have a comparatively short life compared to DC use and are generally made from pure or 0.8% zirconiated tungsten. Figure 10.3 shows a preferred method of tip grinding. During welding a smooth surfaced ball forms on the end and this gives the correct arc form. For DC TIG welding a sharp ground point can be used.

EDGE PREPARATION

Table 10.1 gives details of four different edge preparations for aluminium butt welding, together with some suggested welding parameters, gas flow, consumables, *etc.* Further parameters are given in Table 10.2 (with Table 10.2 refer to chapter 6 for reference to the listed joint types).



10.3 Electrode tip shape for AC TIG welding: a) As ground; b) During welding.

Table 10.1 Manual TIG welding conditions for butt welds in pure aluminium, AC, flat position

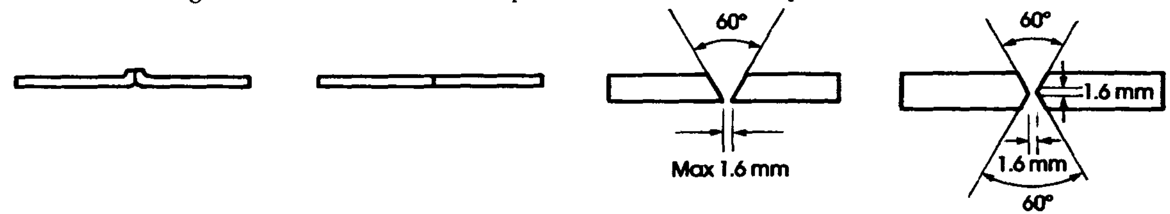


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Plate and joint				Welding conditions							Consumables		
Thickness, mm	swg	Sketch	No. of passes	Nozzle bore, mm	Wire dia, mm	Electrode dia, mm	Argon flow l/min	ft³/hr	Welding current, A	Speed m/hr	Wire con'n kg/m	Argon con'n l/m	Arc time min/m
0.9	20	1 or 2	1	9.5	1.6	1.6	5	10	45–60	21	0.007	14	2.8
1.2	18	2	1	9.5	2.4	2.4	5	10	60–70	18	0.018	17	3.3
1.6	16	2	1	9.5	2.4	3.2	5	10	75–90	18	0.024	17	3.3
2.0	14	2	1	12.7	2.4	3.2	5	10	90–110	18	0.028	17	3.3
2.6	12	2	1	12.7	3.2	3.2	6	13	110–120	18	0.034	20	3.3
3.3	10	2	1	12.7	3.2	3.2	6	13	130–150	17	0.047	21	3.5
4.8	3/16	3	1	12.7	3.2	4.8	7	15	150–200	15	0.09	28	4.0
6.4	1/4	3	1	16	4.8	4.8	7	15	200–250	15	0.13	28	4.0
9.5	3/8	3	2	16	4.8	6.4	8	17	270–320	10–12	0.22	87	10.9
12.7	1/2	4	2	16	6.4	8.0	9	19	320–380	9–10	0.28	108	12.0

Zirconiated electrodes are preferred

Table 10.2 Further welding conditions for AC welding of aluminium

Metal thickness, mm (in)	Joint type	Tungsten electrode diameter, mm (in)	Filler rod diameter mm (in)	Welding current, A	Argon flow, l/min (ft^3/hr)
	Butt			60-85	
1.5 (1/16)	Lap	1.5 (1/16)	1.5 (1/16)	70-90	7 (15)
	Corner			60-85	
	Fillet			75-100	
	Butt			125-150	
3.0 (1/8)	Lap	2.0- 3.0	2.0 (3/32)	130-160	7 (15)
	Corner	(3/32-1/8)		120-140	
	Fillet			130-160	
	Butt	3.0-3.8		180-225	
4.5 (3/16)	Lap	(1/8-5/32)	3.0 (1/8)	190-240	10 (20)
	Corner			180-225	
	Fillet			190-240	
	Butt	3.8-4.5		240-280	
6.0 (¼)	Lap	(5/32-3/16)	4.5 (3/16)	250-320	13 (25)
	Corner			240-280	
	Fillet			250-320	

CHAPTER 10

The future

The TIG and plasma processes are used where high quality welds must be achieved, and although they are often considered to be in competition, specific advantageous features can make a particular variant the preferred choice on purely economic or quality considerations. Secondary factors such as available workforce skills, ease of use or even initial cost of welding plant can have a determining influence. It is hoped that the detailed information given here will lead not only to a more uniform choice but also to the advancement of process technology.

With regard to progress in TIG and plasma in the 1990s, the potential of transistor power sources and microcomputers deserves particular mention. The accuracy and flexibility of commercial transistor power sources will enable the processes to be used more widely and in more demanding conditions. This will be particularly true in mechanised operations where the operator has little or no control over the behaviour of the weld pool. The capacity to set and to maintain the welding parameters will remove one possible production variable. Furthermore, as the power sources lend themselves readily to programming and to the use of feedback systems for keeping constant the welding parameters and the weld bead penetration profile, transistor systems will play an increasingly significant role in controlling welding.

Microprocessor based systems, exploiting the advantages of flexibility in design, memory and computation will also promote the increased use of mechanised and automatic welding systems. For example, in the automation of the TIG and plasma processes, microcomputers will be capable of storing optimised welding parameter values, and hence suitable parameters, even for the more complex welding operations such as pulsed TIG, should be readily produced from the input of information on the material, joint type, welding position, etc. The development of these 'intelligent' devices will greatly enhance the performance capabilities of the techniques described, leading to more economical welding methods and more consistent weld quality.

Chapter 11

Design of weld joints for TIG

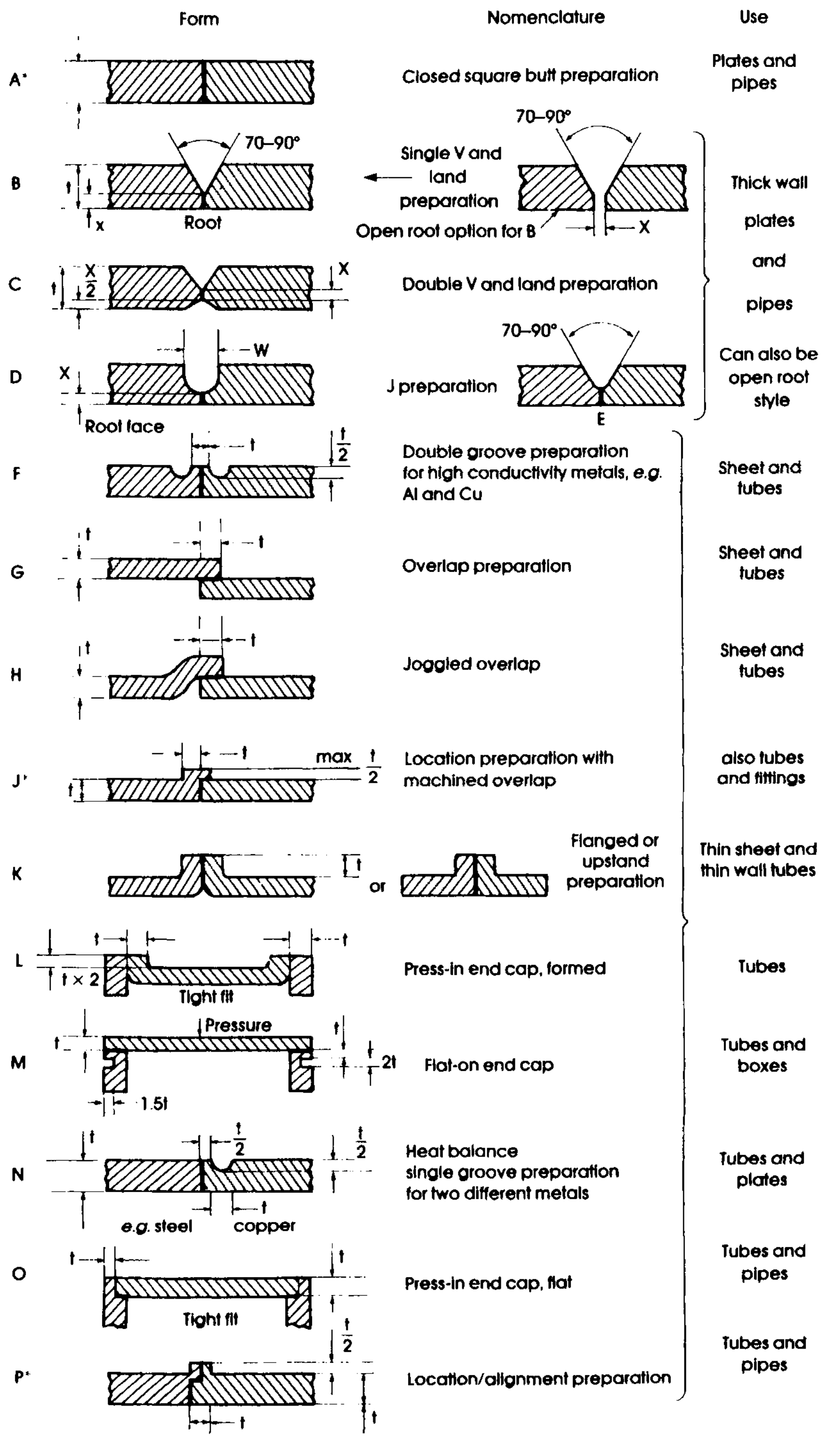
Figure 11.1 shows a fair selection of the more common seam and edge preparations for TIG welding. The author does not recommend that *any* edges which are to be TIG welded be laser cut. On stainless metals in particular, laser cutting often leaves a very slight burning or charring of the edge, not always visible to the naked eye but which can lead to inclusions and porosity in the weld. Guillotined or machined edges are always preferable and must be as clean and true as possible. Try to achieve a nil gap condition at all times. Some comments on the various forms in Fig. 11.1 now follow:

A CLOSED SQUARE BUTT PREPARATION - HAND OR MACHINE WELDING

This is the most common, particularly when joining thin sheets and thin wall tubes. It is generally agreed that 2.5 - 3.0 mm (0.100 - 0.120 in) is the maximum thickness which, dependent on material, can be autogenously welded using this preparation.

B, C, D AND E MACHINED PREPARATIONS FOR HEAVY PLATE OR PIPE WALL - HAND OR MACHINE WELDING

These preparations can also be used in the *open root* condition. The best preparation for a specific weld can be found from experience or experiment. Preparations D and E probably give better sidewall fusion but are most costly to machine. See also note 1 below.



**Also for internal bore welding, t max 2.5 mm.*
t = total metal thickness, X = face width at root, W = width of J preparation at top surface.
For preps B, C and D the value of X seldom needs to exceed $\frac{t}{4}$, using an autogenous weld run.

11.1 Selection of joint preparations for TIG welding.

F DOUBLE GROOVE PREPARATION – HAND OR MACHINE WELDING

This preparation is useful for copper and alloys with high thermal conductivity. It has a slight disadvantage in as much as it leaves a depression (undercut) in the top surface of the weld bead with subsequent reduction in strength.

G OVERLAP PREPARATION – HAND OR MACHINE WELDING

A good preparation for alignment of tubes but difficult to weld unless some really sophisticated heat sinking is applied. The material either side of the overlap could melt back if the electrode is not correctly positioned and incorrect welding parameters used. Best used with arc pulsing.

H JOGGLED OVERLAP PREPARATION – HAND OR MACHINE WELDING

Similar to G with the same problems. Should not be used for welds which require top quality mechanical strength.

J LOCATION PREPARATION WITH MACHINED OVERLAP – MACHINE WELDING

Excellent for alignment, this preparation puts a small amount of extra metal into the weld pool. Can be welded externally or internally for thick walls. Widely used for welding end fittings to small bore tubes in the process industries.

K FLANGED OR UPSTAND PREPARATION – HAND OR MACHINE WELDING

Ideal for thin aluminium sheet.

L INSERTED END CAP FOR TUBES AND CANISTERS – HAND OR MACHINE WELDING

The end cap should be a tight fit and held in by a heatsink to prevent tipping and distortion when welding. Very suitable for items such as aluminium battery cans.

M FLAT-ON END CAP FOR TUBES AND CANISTERS – MACHINE WELDING

This can be used for welding the sensor plate to a transducer body, a bursting disc to a liquid pressure overload device, pressure plates to load cells, *etc.* Align the disc carefully and hold in place with a suitable heat sink. Also suitable for some battery cans.

N HEAT BALANCE PREPARATION – HAND OR MACHINE WELDING

A single groove is cut into the metal which needs the most heat. The easier melting metal needs careful heat sinking close to the weld line. Not all metals are compatible so check first whether the two metals *will* mix and weld.

O PRESS-IN END CAP FOR TUBES AND CANISTERS - MACHINE WELDING

Similar to L. Both these preparations are useful for welding a thin disc to a thick walled tube.

P LOCATION PREPARATION, PIPES AND TUBES - MACHINE WELDING

This preparation adds some extra metal to the weld pool and can be used for either external or internal welds. Should be made with a tight fit. Similar to J.

NOTES

1 Root runs for preparations with open gaps such as B, C, D and E should be kept as small as possible consistent with strength. Distance x, *i.e.* the face width at the root, should be roughly proportional to the thickness t in about a 1:4 ratio but is seldom less than 1.5 mm in practice;
2 Any preparation where one side is located within the other such as J, L, O and P should always fit tightly and have clean faces;
3 Proportions given in Fig. 11.1 are by no means mandatory but given as a guide;
4 Preparations G and H need great care with arc positioning;
5 Try to machine preparations with a minimum of cutting oil or fluid, and clean off any surplus oil with a solvent before welding. Ground edges are not recommended because of possible grit inclusions.

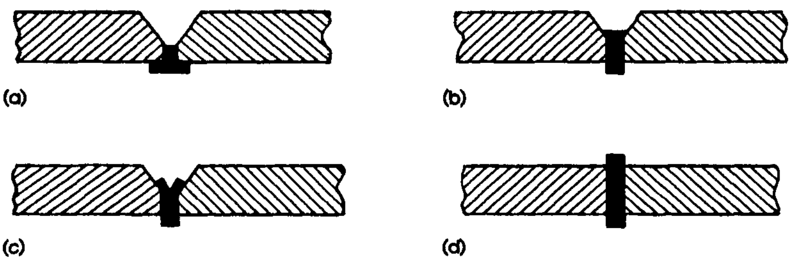
Open gap preparations for root runs

These preparations, all variations of types B, C, D and E in Fig. 11.1, are very useful for obtaining a full bead with good sidewall fusion.

Ensuring that the bead does not droop when carrying out an open gap run demands great skill on the part of the operator. This closing run is critical to weld viability and it is here that pulsing the arc can be of great help by allowing the bead to freeze between bursts of high current. This applies to both autogenous and filler wire runs. After the root run has been completed the object is to fill the gap with metal in the strongest and most economical manner, at the same time achieving maximum penetration into the sidewalls.

Consumable weld seam inserts

Mention of possible droopthrough when carrying out root runs in open gap welding leads naturally on to consumable inserts. These take the place of filler rod or wire and are available in the form of either straight extruded strips for longitudinal seams or, more commonly as rolled split rings to be inserted when welding tubes where they come in a wide variety of sizes, forms and materials. Shown are some of the most popular forms, Fig. 11.2, although some suppliers will produce specials in small quantities.



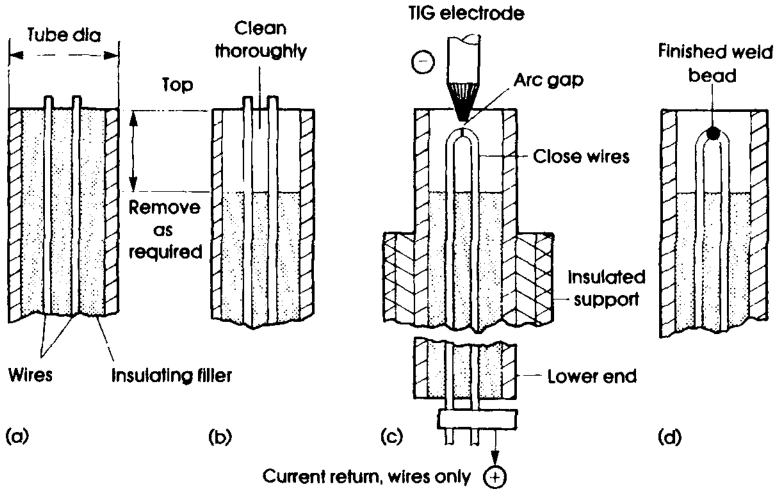
11.2 Common types of consumable insert: a) EB insert; b) Tacking not needed; c) Tacking not needed; d) Needs tacking.

Some shapes such as (b) and (c) stay in place without tacking but others need this. Always ensure that inserts are made from compatible metals and have sufficient but not too much metal bulk on melt down. They are useful for filling root runs in open gap V or J preparations, especially for mechanised orbital welding as they often obviate the need for a wire feeder. Attention must be paid to the following:

- Arrange for some slight lateral pressure to be put on the component parts either side of the joint when welding starts. This pressure is only to hold the gap, not to close it or the bead will be squeezed out;
- Track the torch accurately along the seam centreline;
- Use arc pulsing wherever possible to freeze the bead between pulses. This prevents droopthrough;
- Always back purge if convenient but keep internal build-up of gas pressure to a minimum. Sometimes nil or even negative pressure is an advantage to assist with full underbead formation.

Wire feed for open gap – for filler runs on V and J preparations

Use a feeder which gives pulsing of the wire in synchronisation with the level and time of background current. This facility is generally found only on the most expensive power sources and feeders.



11.3 Thermocouple junction welding: a) As cut; b) Ends prepared; c) Ready to weld; d) Weld completed.

Thermocouple tip welding

Figure 11.3 shows preparations for TIG welding the two internal wires at a thermocouple tip.

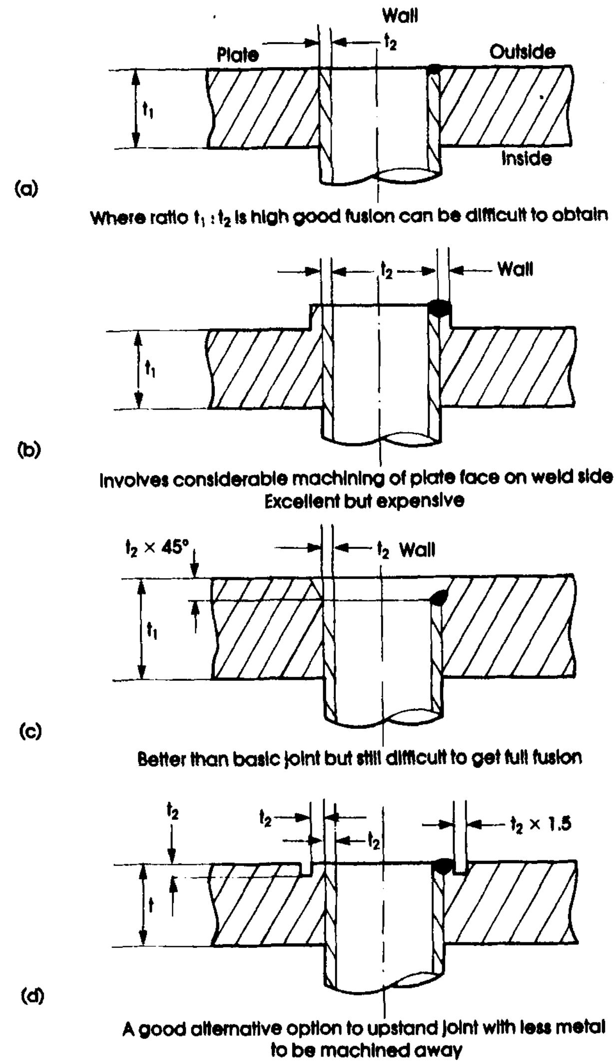
Points to remember here are:

- Total cleanness of the area where welding takes place is needed;
- Accurate electrode-to-work gap and tip positioning are essential;
- Suitable heat sinking must be provided;
- Very precise arc-on timing and consistent current values have to be maintained;
- Good shielding gas coverage must be present.

Thermocouple wire welding is a very exact technology and many ingenious solutions have been found.

Tube to tube plate (or tube sheet) weld preparations

Equipment to carry out this task can be very expensive and is briefly discussed in chapter 7. Some basic weld preparations for external welds are shown in Fig. 11.4. Try to design joints for autogenous welding as it is difficult and even more expensive to use equipment with built-in wire feed to the arc area. Ensure that preparations are machined to give the tube a good fit

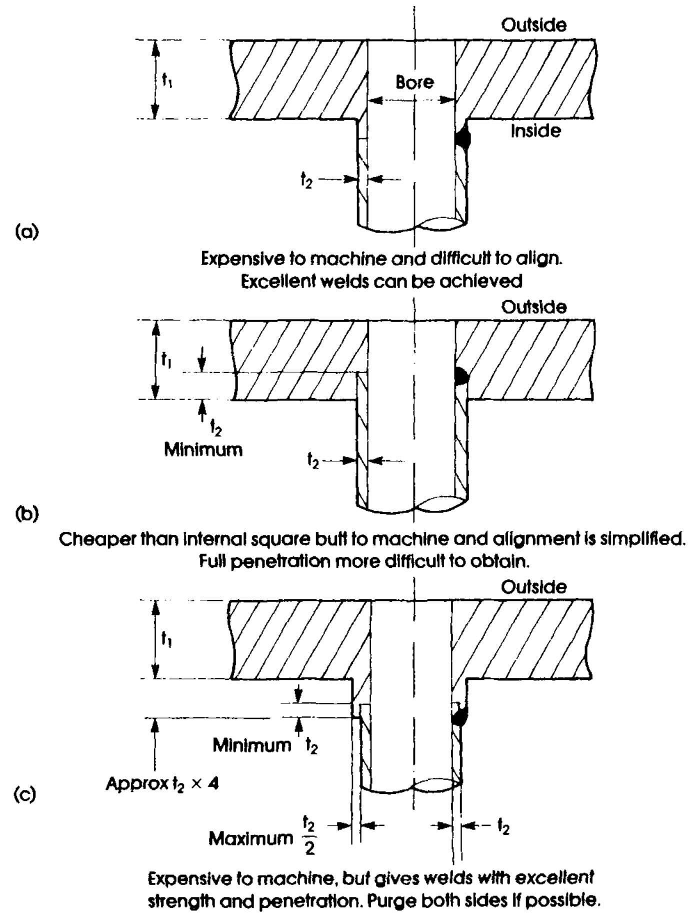


11.4 External tube to tube plate weld preparations: a) Basic joint; b) Upstand joint; c) Countersunk basic joint; d) Recessed upstand joint.

in the tube plate. Mechanical expanding machines both pneumatic and hydraulic are commercially available and of great assistance in achieving such fits.

Internal welds can be made to ensure that the outer face of the tube plate remains clean and free from weld spatter. Special internal orbital welding heads are needed for this process and it is especially advantageous to make all such welds autogenously as the tubes are of small bore on many occasions, Fig. 11.5.

Internal welds often need slight longitudinal pressure to be applied to the joint whilst welding takes place.

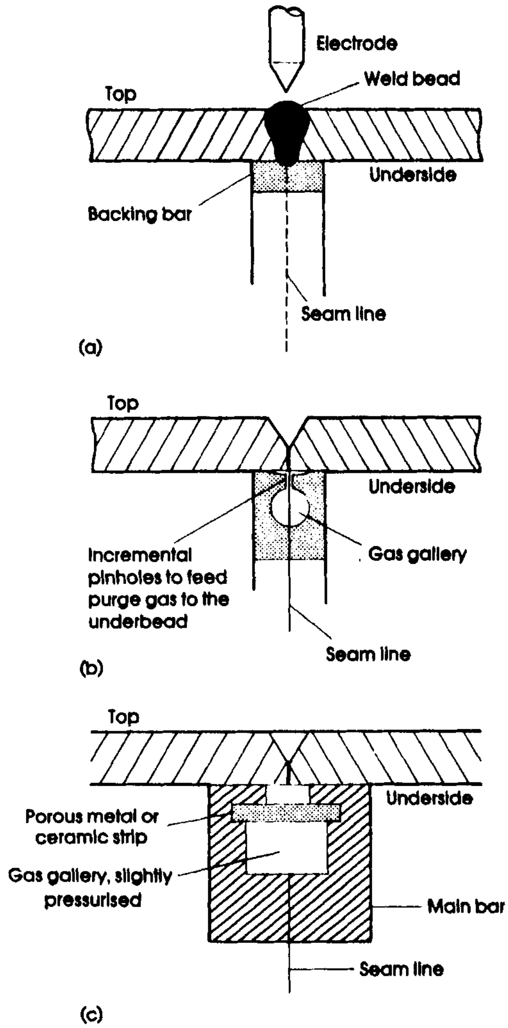


11.5 Internal tube to tube plate weld preparations: a) Square butt; b) Self-aligning; c) Spigot alignment.

Backing bars and rings

To ensure a good underbead when carrying out weld seam root and capping runs, particularly for an open gap root run, it sometimes becomes necessary to provide a removable backing bar or ring which supports the molten underbead, preventing droopthrough and also provides heat sinking either side of the weld seam. Figure 11.6 shows some configurations and chapter 12 lists suitable materials and their advantages and disadvantages.

Internal backing bars inside pipes and tubes should always be made split or segmented for easy removal when welding is completed. Figure 12.2 gives some groove proportions.



11.6 Backing to: a) Support weld underbead; b) Purge and support underbead; c) Provide back purge only.

Chapter 12

Jigs, fixtures and heatsinks for automated TIG welding

Most of the skill required to carry out machine welding successfully is in design of the fixtures that hold the components together whilst welding takes place. In fact the author considers that the mechanical items account for about 85% of problems. Power sources are very accurate and by using the correct electrodes and gases produce almost any type of arc required.

Welding engineers contemplating automation must develop a feel for a particular job and can soon attain the necessary know-how to design and produce suitable tooling, the aim being to transfer unwanted heat build-up away from the weld area, at the same time holding the joint faces together to produce viable welds with maximum penetration and strength. Chapter 7 has shown some of the machinery required: this chapter gives advice on tooling and clamping.

Heatsinks or chills

These can be made to provide clamping or merely laid in place alongside the seam. It is most economical if they can carry out both functions. The first problem is to find a suitable material, this must be chosen for its heat transfer properties, strength and life and, by its nature, have no effect on the parent metal when heated. Some metals outgas when heated which produces contamination, perhaps only slightly, in many critical joints. Materials may be as follows:

- *Copper*. This may require plating to ensure that no copper contamination takes place from rubbing. Excellent heat transfer properties;
- *Stainless steels*. These have a low melting temperature and are best used for fine, low current pulsed welds, *e.g.* edge welded bellows;
- *Mild and carbon steels*. Not recommended but satisfactory for non-critical welds. Easy to machine and cheap to replace. Prone to rust;
- *Brass*. Not recommended. Easily machined and cheaper than copper but a source of possible contamination. Could also be plated.
- *Ceramics*. Specially made for a particular job the use of these has not yet been fully investigated. Consult a ceramics expert first;
- *Aluminium*. Like copper, aluminium has good heat transfer properties but is soft and easily damaged. Use for smooth components which will not easily damage the heatsink.

The above materials have been suggested for manufacture of heatsinks and backing bars. Two typical precision heatsink types and the proportions involved are shown in Fig. 12.1.

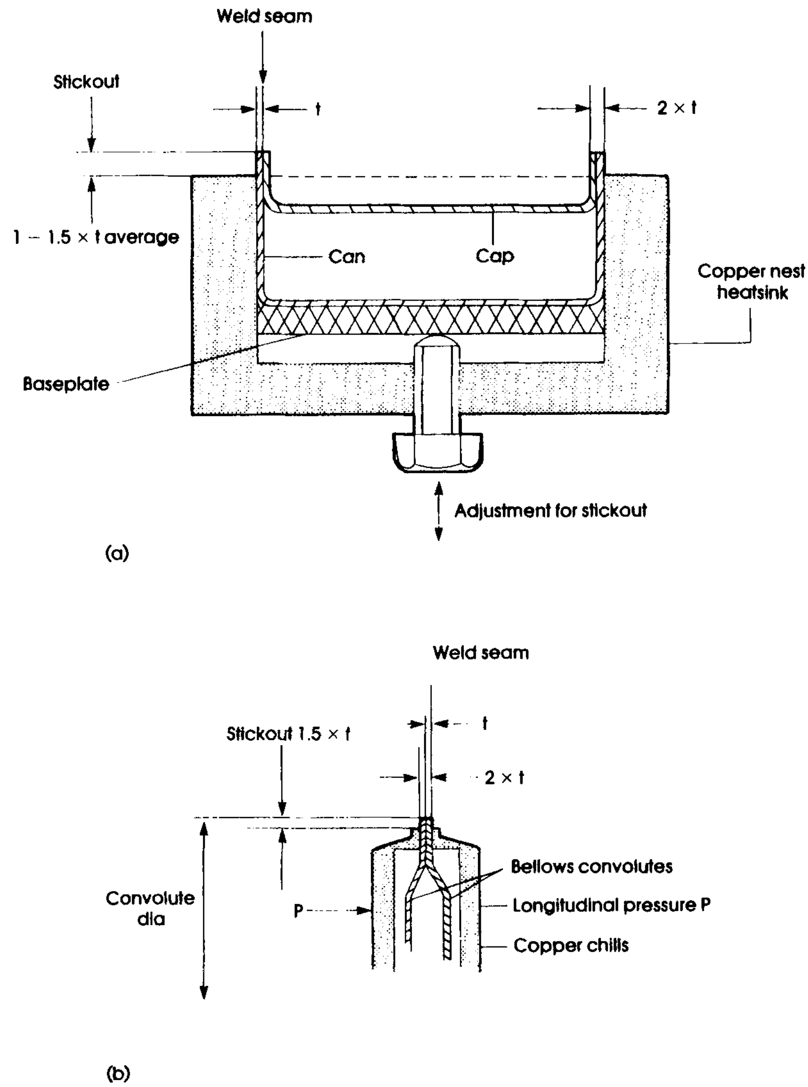
Precision welding

The word precision implies that finished components are accurate and clean with minimum distortion, another factor in heatsink design. They do not always need to be in tight contact with the component as this sometimes makes it difficult to remove a finished item after welding, a point often overlooked. It is good practice to include some form of ejection if possible, which can save burnt fingers. Remember that a heatsink stores heat, so give the fit some allowance for thermal expansion.

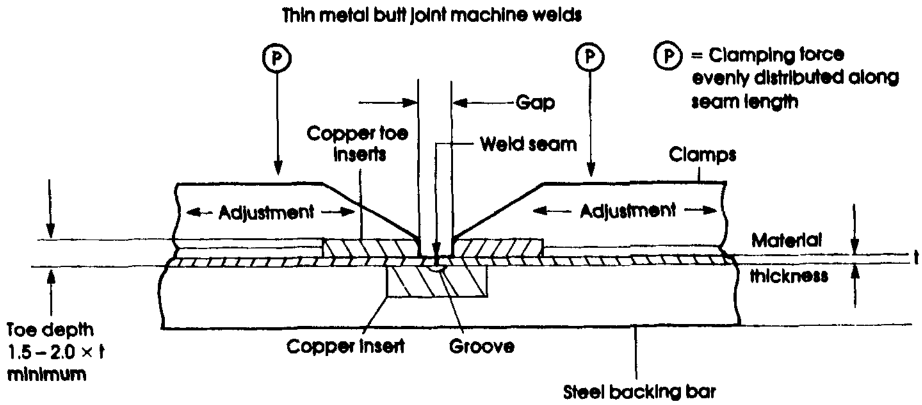
Clamping jigs for machine seam welding

The principles involved here are shown in Fig. 12.2 together with suggested proportions. The clamp toes are usually made from steel or copper, or steel tipped with copper to save replacement expense.

Segmented or finger clamps are useful to ensure even pressure along the seam length. The layout shown is that which would be used for thin sheet welding with a square closed butt edge preparation. Other suitable edge preparations are shown in chapter 11.



12.1 Special heatsinks: a) Nest type for battery canister seals; b) Copper chills for edge welding of bellows.



12.2 Clamping jig for mechanised longitudinal seam welding.

Notes on Fig. 12.2

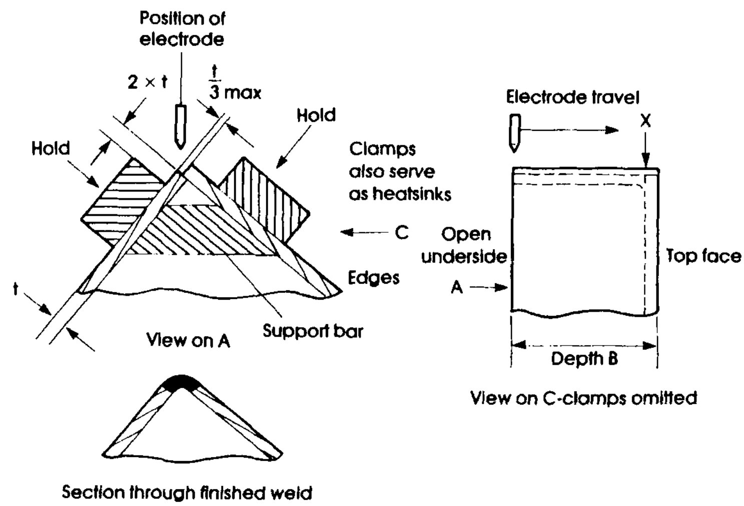
- Gap for metal thickness 0.08–0.5 mm (0.003–0.020 in) = 0.8–2.0 mm (0.030–0.080 in).
- Gap for metal thickness 0.5–2.0 mm (0.020–0.080 in) = 2.0–4.0 mm (0.080–0.160 in).
- Gap for metal thickness over 2.0mm (0.080 in) = 1.5–2.0 times t.
- Groove: width 2 × t; depth 1 × t or 0.25 mm (0.010 in), whichever is smaller.
  Metals less than 0.25 mm (0.010 in) thickness may need no groove in backing bar.
  The gap should be evenly astride the weld seam.
- Clamps should be independently adjustable.
- Clamps and backing bars should be either made completely from copper, or steel with copper toe inserts.
- For even clamping over the seam length use segmented fingers, particularly on long seams.
- Good values of P per unit length of weld are:
  - Metal up to 1.0 mm (0.040 in) thickness: 10 N/mm (50 lbf/in) per side;
  - Metal over 1.0 mm (0.040 in) and up to 3.0 mm (0.120 in) thickness: 20 N/mm (100 lbf/in) per side;
  - Over 3.0 mm (0.120 in) much higher forces may be needed.

Remember, firm accurate clamping is a must. Values given are for guidance only.

Hand welding clamps

Although use of clamps is most advantageous in machine welding, fairly simple devices can free the operator's hands as well as allowing him more room for error in heat input. Hand operated toggle clamps or similar can be used, being comparatively cheap and easily replaceable. Magnetic clamps are *not* recommended for use with manual TIG, as they have a tendency to deflect the arc if placed too near the seam.

Clamps reduce HAZ size and also make for a reduction in final cleaning and polishing of the finish welded joint, particularly in the case of machine welded metal cabinet top corners, Fig. 12.3. Tops welded thus require only degreasing before going for spray or powder painting.



12.3 Suitable joint configuration and clamping for machine welding sheet metal cabinet top corners.

Notes on Fig. 12.3

The proportions given are approximate only. Pulsed welding is preferable and the metal should be wiped before welding but not necessarily solvent cleaned as the TIG arc can cope with a very thin film of oil on the metal surfaces. The gap along the weld seam must be completely closed.

The weld sequence should be as follows:

1 Close clamps - purge gas on - arc strike;
2 Short upslope and electrode travel dwell;
3 At full welding current electrode travel starts;
4 Short downslope should commence at point X;
5 Extinguish arc when electrode is aligned with top face;
6 Purge gas off. Retract clamps, remove finished component.

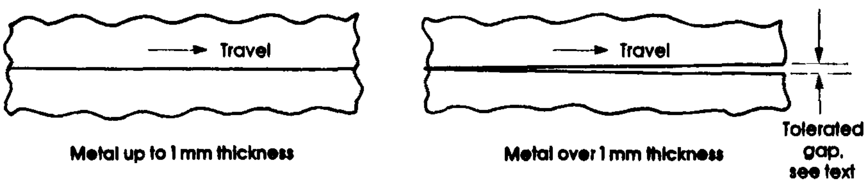
A cabinet top where dimension B = 30 mm can be welded in 7–10 seconds using this method. A fully specified power source is required.

Summary of tooling, fit-up, heat sinks and clamping

Attention to these points is every bit as important as care taken over the actual welding process. An automatic weld is only as good as its tooling. So check out the following:

- Heat balance when welding dissimilar materials, *i.e.* metals with differing thermal conductivity, is *critical*;
- Try also to achieve optimum heat balance when welding thick to thin materials;
- For high speed welding try for maximum heat isolation;
- Try to allow for extra component material to be available for a good melt down. This can be part of the original material when performing autogenous welds, filler wire or rings for thicker materials;
- Keep all joints clean and contamination free before welding and keep seam edges sharp. Use guillotined rather than laser cut edges;
- Heatsinks or chills improve heat balance and can in addition sometimes be used for clamping;
- Make all clamping and manipulation devices as accurate as possible, with smooth progressive motion;
- Ensure first class current return (earthing).

Some important alignment details are given in Fig. 12.4 and its accompanying notes.



12.4 Alignment of longitudinal weld seams.

Notes on Fig. 12.4

- All butted edges must be straight, clean and square cut with no burrs;
- Tolerated gap in (b) should always be less than 10% of the material thickness. This tolerated gap applies only to metal over 1 mm (0.040 in) thickness, where progress of the arc along the seam often pulls the edges together. Many companies making rolled seam welded tubes use this technique successfully;
- For very thin metal observe almost clinical cleanness and use a good non-inflammable solvent to remove excess oil and grease. Use a lint free cloth;
- Take off any slight burrs with a fine dry stone lightly applied to the edges, then wipe and solvent clean again.

Chapter 13

Ancillary equipment

This chapter is concerned with equipment and devices which add to the efficiency of the TIG process. No item of equipment will be described at great length or in detail, neither will any specific recommendations be made. Many specialist companies produce equipment as described. Obtain information from them and a demonstration wherever possible. Some equipment is tried and tested, some is new and still in the development stage.

Wire feeders

When compared with feeders used for MIG/MAG welding, TIG wire feeders need to be much more comprehensively equipped. In addition to a lower overall wire speed range it is usual to provide all or some of these features:

- Wire speed range down to 0.5 mm/sec and up to around 18 mm/sec;
- Instant stop/start of wire by remote control;
- A burnback facility at switch off to retract the wire from the weld pool and prevent it freezing in. Usually this switch off and retraction occurs just before commencement of downslope but this time should be variable to suit;
- Variable pulsing of the wire feed synchronised with arc pulsing;
- Accurate and consistent wire speed;
- Instant switch off if the electrode stubs in to the pool;

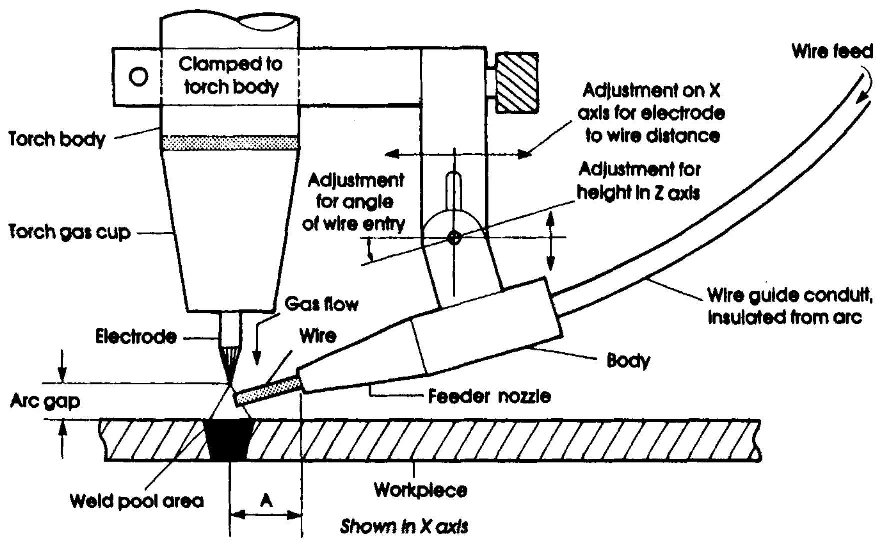
- Four roll wire drive mechanism for smooth operation and to give some wire straightening.

Manufacturers of TIG wire feeders offer a wide range of optional features. This makes them rather expensive but for critical welds in expensive components the cost is justified.

At the point where the arc occurs and the feeder nozzle is situated, several adjustment facilities are needed, Fig. 13.1.

Wire nozzles should be made from a good grade of hard copper and easily replaceable. Keep distance A as short as possible to avoid any tendency for the wire to curl. On automatic TIG set-ups the wire is often supplied tightly wound on to special 100 mm (4 in) diameter spools and needs straightening before it emerges from the nozzle tip. Four roll wire feed drive units solve this problem to a great extent.

A TIG wire drive unit should be able to accept wires from 0.4 mm diameter (not a standard size) up to around 1.6–2.0 mm diameter.



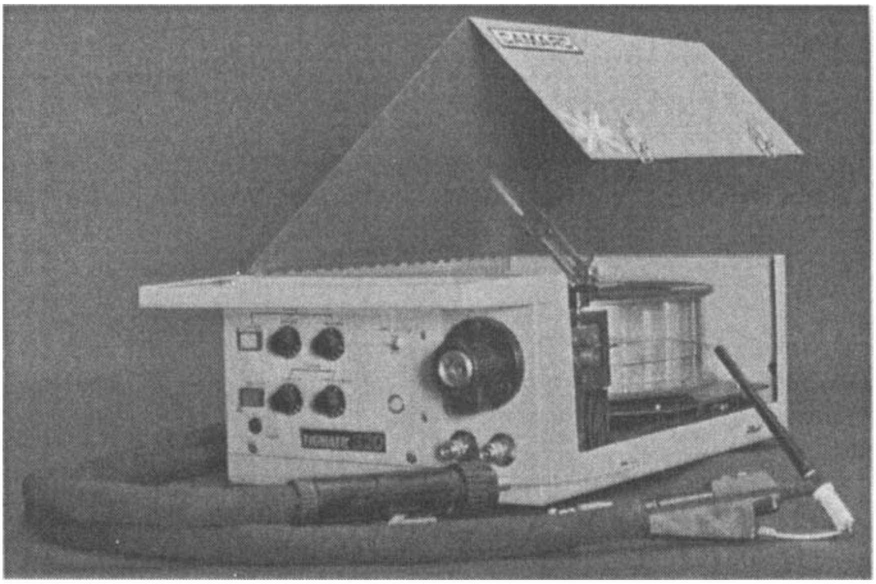
13.1 Details of wire feed for automatic TIG welding.

HAND WELDING WIRE FEED

An ingenious wire feed system is available with the wire fed directly to the torch, Fig. 13.2. This gives the operator a free hand and is most useful in confined spaces.

Arc oscillation – methods and equipment

As has already been mentioned in previous chapters it is advantageous when seam welding thick sections using a V or J preparation to oscillate or



13.2 Wire feed system with 'through-the-torch' placement nozzle.

weave the arc laterally across the seam. This assists in obtaining optimum edge melt in or sidewall fusion. Usually employed in automatic welding this oscillation can be carried out in two ways. One is by mechanically moving the torch nozzle with the electrode in its gas cup across the seam at a predetermined distance to travel rate ratio. The other is by magnetically bending the arc, using double or multiple magnet poles positioned either side of the arc and switching polarity to deflect the arc to one side or the other in sequence as required. Arc switching can in both cases be synchronised with arc pulsing. Both systems offer a good solution to the problem of successfully carrying out large TIG filler runs, in particular.

Seam followers - for mechanical systems only

With a straight seam and a large V or J preparation, there is little difficulty in following the seam by guiding the electrode down the centreline using a mechanical follower probe travelling a short distance ahead of the arc. This probe when moved laterally sends signals back to servo-motors which correct the arc position in relation to the seam deviation which it has sensed. This type of mechanism is rugged and can be used either with longitudinal seams for flat plates or circumferential seams in pipes and tubes. However, seams in the latter are usually machined true with a suitable preparation before welding takes place so a follower is needed only if seam accuracy is in doubt.

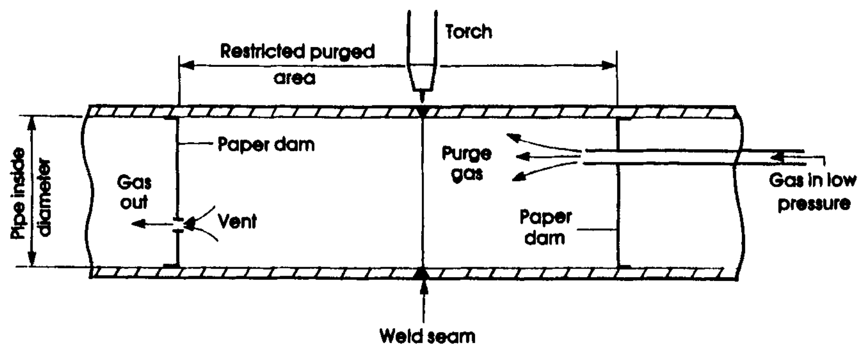
A probe needs faces or an edge for guidance so grooved seam preparations are ideal. However, for an almost invisible seam, *e.g.* a closed square butt, something more sophisticated is needed, perhaps an infrared beam, a magnetic sensor, a laser beam or an acoustic probe. These all have an advantage in that they are non-contacting devices. To summarise, check which system suits your needs and purchase equipment to suit from a reliable supplier. Many seam followers are very expensive and dedicated to one job only.

Internal gas purging systems

When working on welds in, say, large diameter pipes where gas back purging of the weld underbead is essential, it is unsatisfactory and uneconomical just to flood the inside of the pipes with shielding gas. There are several methods of achieving economy with efficiency in this area.

PURGE DAMS

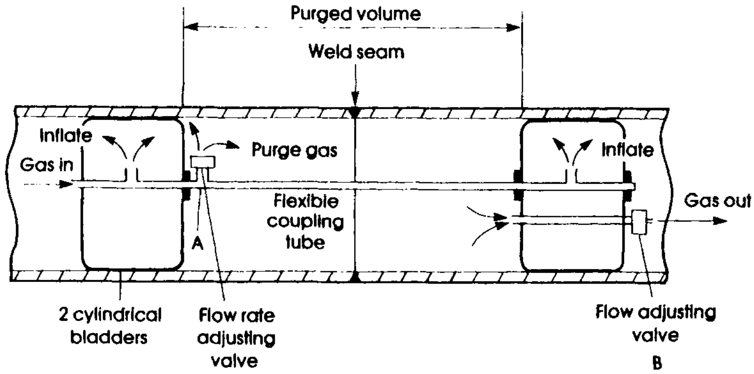
A paper or card dam can be arranged in the tube, Fig. 13.3. The disadvantage of this method in a closed or inaccessible system is removal of the dams after welding is completed. A proprietary range of semi-stiff soluble paper circles is available for making dams and these are dissolved and flushed away when no longer needed using large quantities of water.



13.3 Paper dams for back purging.

BLADDERS

A much superior and reusable method of back purging is by a system of inflatable dams, more usually known as bladders, Fig. 13.4. The bladders are inflated by air or, for small diameters, by the shielding gas itself. After use the gas is cut off, deflating the bladders and allowing the system to be pulled out of the pipe by a chain or cord. When using such a system *never* allow too much gas pressure to build up within the purging region as this will produce deformed underbeads or in extreme pressurised cases weld pool blowout.



13.4 Inflatable dams or bladders for back purging.

The purpose of back purging is to minimise the amount of free oxygen remaining in the shielding gas. Ensure that your gas flow rate is adequate and that the pre-purging period is of sufficient duration.

Free oxygen meters

These are readily available as proprietary items and should be used in the outgoing gas line from the purge system. Try to achieve an oxygen content of *less* than one per cent for best results.

Watercoolers

In heavy and continuous TIG welding the torch can become extremely hot and uncomfortable for the operator. Usually torches with a capacity of 125 A or less get adequate cooling from the flow of shielding gas passing through the torch to the arc area, and these seldom need any extra cooling. Torches with a capacity of 125 A upwards need some extra assistance by use of a watercooler which circulates water around the internal torch body, usually entering through a single tube and returning to the cooler via a sealed tube which has the incoming power cable concentric with the tube, with a space between the cable and the tube wall. See also under cables, chapter 3.

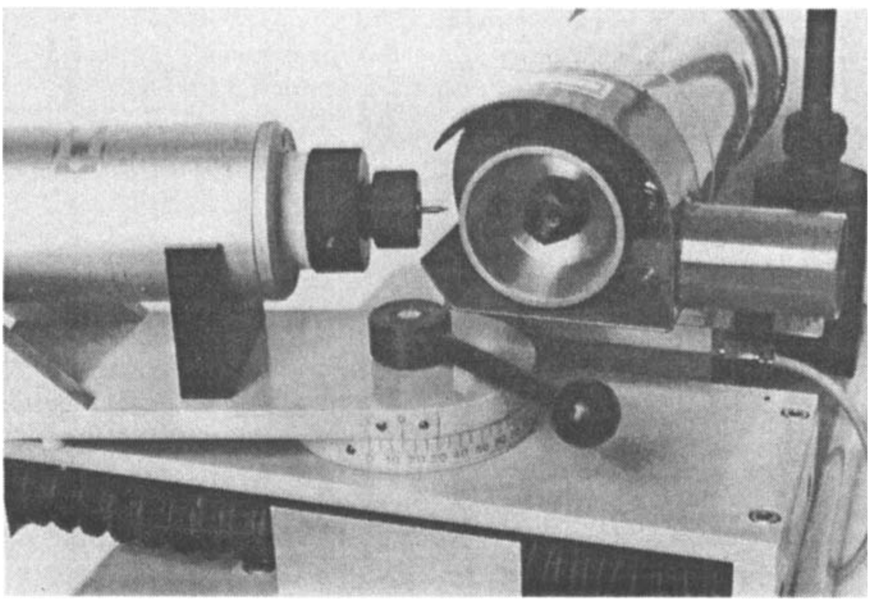
Watercoolers are generally small, light and compact as they only need to provide a flow of water of about 7 l (1.5 gallons) per minute. They are usually of the recirculating type with an anti-rust header tank containing about 14 l (3 gallons). It is good practice to add a small quantity of anti-freeze/rust inhibitor to the top-up tank when in continuous use in extreme temperature conditions. It is useful to note that a system employing small orbital or bore weld heads needs deionised water in the cooling system. This not only protects the system but in certain cases can also help with arc strike.

Tungsten electrode grinders

Electrodes for hand welding can be sharpened manually quite successfully, using a bench grinder fitted with suitable grinding wheels as already mentioned in chapter 3. Also in chapter 3 the optimum point geometry for machine welding was discussed and illustrated.

For fine and fully specified machine welding to be successfully executed on a consistent basis, all parameters including the tungsten tip shape must be exactly repeated each time a weld is made. To achieve repeatable points at each sharpening a dedicated mechanical grinder is a must. There are many on the world market with an enormous price differential so the choice is up to you and will probably be determined by economics, *i.e.* how many resharpenings will be required and to what accuracy.

If budget allows, the author recommends any well made machine which rotates the tungsten slowly whilst the tip is being ground at high speed, Fig. 13.5.



13.5 Precision bench mounted tungsten electrode grinder.

These are, however, rather expensive, so failing this if you cannot afford one of this type ensure that the grinder you choose leaves the tips finished as in chapter 3. Many extra accessories are available for all machines.

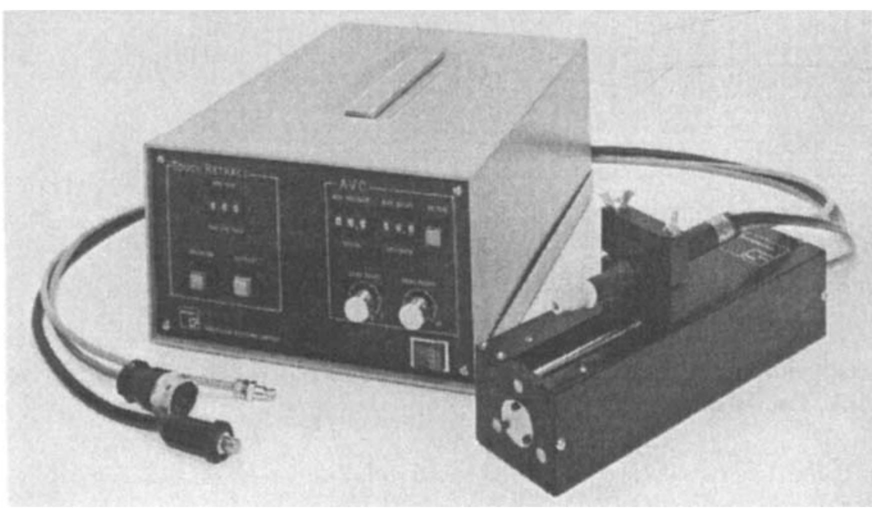
For very fine long points diamond wheels are a great advantage, but again expensive, so use them with care.

In passing it should be noted that electrode point sharpening *liquids* are available. The method here is to heat up the tungsten tip to a cherry red by shorting it out against the ground (earth) clamp and the tip is then immersed in the liquid, repeating this until the desired point is formed. This operation is claimed to take about one minute. However, the author has no experience with these liquids but feels that they could not produce accurate, consistent points.

Arc length control systems

Sometimes it is not possible for a weld seam in a circular component to be fully concentric or for a longitudinal seam face to be level. It then becomes necessary to try and keep the arc gap consistent to equalise heat input and thus ensure the quality and appearance of the finished weld. Whilst lateral traverse or rotational speed can be kept to fine limits using tachogenerator feedback (TGF) on the motor drive control system which moves the torch or component, the most usual method of arc length control (ALC) is based on the fact that arc voltage is proportional to arc gap. The TIG welding process is most suitable for this type of equipment.

In these systems arc length is maintained by constantly measuring arc voltage. When a variation occurs against a set datum voltage for a particular gap, an electronic signal is referred to a stepper motor driven slide on which the torch is mounted to adjust the electrode to work gap accordingly and keep the gap constant, Fig. 13.6.



13.6 Touch-retract arc length controller with torch adjusting slide.

Several other methods using lasers or acoustics *i.e.* listening to the sound of the arc, have been used but voltage measurement remains the most successful and most economical method of arc length control.

Voltage measurement ALC systems often incorporate a touch-retract gap setting system. This can be an advantage in an automatic TIG system to give a sequence as follows:

1 An initiate button is pressed with electrode in the datum position;
2 Electrode advances towards the component to be welded and touches it;
3 A low voltage circuit is completed and the electrode instantly retracts;
4 When a preset gap is reached using, say, a stepper motor or encoder to count exactly the revolutions of a leadscrew, the retraction ceases;
5 A signal is then sent to the power source to initiate the weld sequence;
6 Sequence goes through pre-purge to arc strike;
7 After upslope (if any) and a preset delay period, arc length control if selected will commence. Fixture movement starts;
8 Welding continues for the required arc on time, with the ALC circuit sensing the changing arc gap and adjusting it accordingly;
9 Weld time finishes and arc is extinguished. ALC off;
10 After downslope, fixture motion ceases. Post-purge continues;
11 After post-purge the electrode returns to datum;
12 Sequence over – a new component is positioned and sequence repeated from 1.

If components are accurate and level or concentric the ALC function may not be needed. In such cases a touch-retract only system will suffice, simply to set the arc gap accurately for each sequence regardless of wear at the electrode tip.

The touch down period is negligibly short before retraction takes place so even very fine electrode points are not damaged.

Top quality ALC systems have the ability to react to changes in the arc to work gap of about 3 mm in 1 second, positional resolution of around 0.01 mm (0.0004 in) and voltage setting to 0.1 V, plus sensitivity and ALC on/off delay adjustments.

Gas cylinder regulators

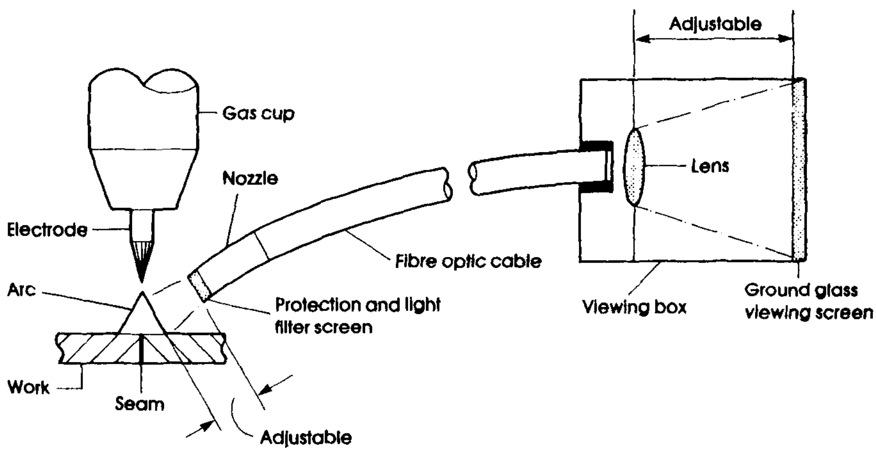
Special regulators are available specifically for argon and should always be used with that gas. Check with your dealer to see that you have the correct type. Two basic models are available: one has both pressure and flow rate regulation and meters, to be used when gas is piped directly to the torch; the other has pressure regulation only. The latter can be used when the power source is fitted with a gas flow regulator and should be set to around 2.4 - 3.4 bar (35 - 50 PSI) for best results.

The gas output tube connection for argon usually has a right hand (RH) thread. To avoid accidents, regulators for argon/hydrogen mixes had a left hand (LH) thread on the gas line connector. For safety, ensure that a shut off key is attached to the cylinder by chain or cord and readily accessible so that gas flow can be quickly terminated in the event of emergency.

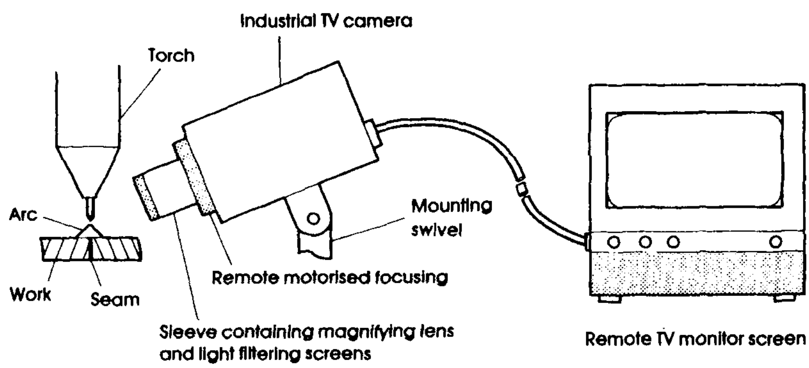
Arc viewing

Equipment to perform this function falls mainly into two categories:

1 Fibre optics and a viewing/magnifying screen, Fig. 13.7.
2 Closed circuit television (CCTV) systems, Fig. 13.8.



13.7 Fibre optic arc viewing system.



13.8 Closed circuit television arc viewing system.

Item 1 has two drawbacks, one that the operator's viewing screen cannot be very far away from the arc because of light attenuation in the fibre optics bundle and degradation of the pick-up tip at the point nearest the arc. Nevertheless these systems are efficient if regular cleaning of the probe tip takes place, and they are not too expensive.

Item 2 is rapidly improving, mainly through continuing miniaturisation of TV cameras. The operator can watch the arc from a considerable distance and adjust the focus to suit. The camera lens assembly can also be situated well back from the arc and protected from its effects.

Arc starting devices

The early method of starting an arc when TIG was still used exclusively for hand welding was to scratch the electrode on the work then rapidly withdraw it to make an arc before the electrode fused to the work. Operatives obtained a high degree of skill in doing this but as TIG progressed to be used on expensive metals and critical joints, it became obvious that an open arc start must be performed to avoid problems with tungsten inclusions in the weld. One method still used today is to use capacitor banks or a coil to produce a high frequency spark which rapidly ionises the gas in the arc gap and allows the welding current to use this as a bridge for arc initiation. HF, as it is called, is messy and interferes with ancillary equipment such as DC motors either through mains borne spikes or RF radiation. Use of computers in close proximity also made it imperative to replace this as much as possible, so modern power sources use electronically produced impulse strike methods, each with its own advantages and disadvantages. Check on this before buying a power source. Some old scratch start equipment is still in use, a tribute to its strong construction.

Hot wire feeders

The extra heat needed to melt a wire infill slows metal deposition, so methods of preheating the wire as it enters the weld pool have been devised. Some units can be added to existing systems and are commercially available from specialist suppliers who, in some cases, claim that they have deposition rates as good as in MIG welding (see chapter 7).

Cladding benefits from this technique where it reduces the amount of preheating of the base metal. The process is also particularly suitable for heavy plate welding for filler and capping runs. Most suitable for mechanical TIG welding systems, check carefully as to the economics before purchase.

Penetration control

Systems are available which view the weld underbead using fibre optics and/or a CCTV camera. Light emerging from the underbead is measured and corresponding feedback referred to a computerised control unit. This in its turn adjusts the welding current parameters at the power source, ensuring a consistent underbead size and width and thus the required weld penetration. These units are expensive but, if the amount of penetration is critical, can be invaluable.

Chapter 14

Safety

TIG welding properly carried out is not particularly hazardous. However, as in all engineering processes, care should be taken. This chapter briefly covers the main areas where attention to safety is vital, and is based mainly on UK standard practice. Other countries will have equivalents.

Eye protection

TIG welding does not usually produce much spatter except with AC where it is more pronounced, and commercial eyeshields and screens take care of any that may arise. Spatter is often the result of unclean or damp work-pieces but some alloys and coated materials also cause problems in this respect.

What *is* essential, however, is that all eye screens should be of sufficient optical density as the TIG arc is extremely intense. Screens are graded for density and it is the author's opinion that the screen to use should be of the maximum possible opacity consistent with adequate arc and work viewing.

Grading of density in the UK is often done by marking screens, particularly replacement screens for helmets, with an EW (electric welding) rating from 1 - 15, grade 15 being the most opaque. Nothing below EW8 should be used for TIG welding, a good grade being EW10 which is quite dense. This can make it difficult to see before the arc lights up the weld area. Peripheral viewing of arcs by other personnel can be prevented by hanging suitable semi-opaque curtains around the work areas. There are on the market certain visor screens and goggles which are clear until the arc is struck, similar to light reacting sunglasses but with a much more rapid response time. At the time of writing these screens do not appear to have met with any significant success but their makers claim that they are perfectly safe. Certainly it is a great advantage to be able to see the exact location for starting a weld before striking an arc but it is suggested that extensive trials of such reactive screens take place before comprehensive use is made of them.

In the end the choice of helmet or goggles, conventional or reactive screens will be made by the welder himself and will be of the type considered the most comfortable and convenient.

A flash, or arceye as it is called, can be very inconvenient and uncomfortable. This occurs after an arc is accidentally viewed without a safety screen. Usually a day or two of rest and wearing dark glasses produce a cure. Eyedrops can help but these should *only* be used on professional medical advice. Never ignore a flash, take some action.

Cleaning solvents

Solvents containing trichlorethene (formerly trichlorethylene), perchlorethene (perchlorethylene) *etc* must only be used in a well ventilated area and allowed to dry off before welding. These substances can produce phosgene, a very toxic gas, in the heat of the arc. Trichloroethane is a safer solvent.

Safe handling, storage and use of compressed gas cylinders

The following practices are recommended for safe handling, storage and use of high pressure gaseous and liquefied compressed gases. Additional precautions may be necessary depending upon the category to which the gas belongs (corrosive, toxic, flammable, pyrophoric, oxidant, radioactive or inert), the individual properties of the gas and the process in which it is used.

GENERAL

- Only experienced and properly instructed persons should handle compressed gases.
- Observe all regulations and local requirements regarding the carriage and storage of cylinders.
- Do not remove or deface labels provided for identification of cylinder contents.
- Ascertain the identity of the gas before using or transporting it.

- Know and understand the properties and hazards associated with each gas before using it.
- Before using or transporting compressed gases, establish plans to cover any emergency that might arise.
- When doubt exists as to the correct handling procedure for a particular gas, contact your supplier.
- If you own your cylinders you must be aware of and discharge your statutory obligations with regard to maintenance and testing. These regulations are constantly under extensive review.

HANDLING AND USE

- Wear stout gloves.
- Never lift a cylinder by the cap or guard, unless the supplier states it is designed for that purpose.
- Use a cylinder trolley or other suitable trolley for transporting cylinders even for a short distance.
- Leave valve protection caps in place until the cylinder has been secured against either a wall or bench, or placed in a cylinder stand or trolley and is ready for use.
- Check for gas leaks using approved leak detection solution.
- Ascertain that an adequate supply of water is available for first aid fire fighting in the event of leakage.
- Use suitable pressure regulating devices on all cylinders when the gas is being delivered to systems with a lower pressure rating than that of the cylinder.
- Before connecting the cylinder for use ensure that backfeed from the system into the cylinder is prevented.
- Before connecting a cylinder check the complete gas system for suitability, particularly for pressure rating and materials.
- Never permit liquefied gas to become trapped in parts of the system as this may result in hydraulic rupture.
- Ascertain that all electrical systems in the area are suitable for service with each gas.
- Never use direct flame or electrical heating devices to raise the pressure of a cylinder. Cylinders should not be subjected to temperatures above 45 C.
- Never recompress a gas or a gas mixture from a cylinder without consulting the supplier.
- Never attempt to transfer gases from one cylinder to another.
- Do not attempt to increase liquid drawoff rate by pressurising the cylinder without first checking with the supplier.
- Do not use cylinders as rollers or supports or for any other purpose than to contain the gas as supplied.
- Never permit oil, grease or other readily combustible substances to

come into contact with valves of cylinders containing oxygen.

- Keep cylinder valve outlets clean and free from contaminants, particularly oil and water.
- Do not subject cylinders to abnormal mechanical shocks which may cause damage to their valves or safety devices.
- Never attempt to repair or modify cylinder valves or safety relief devices. Damaged valves should be reported immediately to the supplier.
- Close the cylinder valve whenever gas is not required even if the cylinder is still connected to equipment.

STORAGE

- Cylinders should preferably be stored in a purpose built compound which should be well ventilated, preferably in the open air.
- Store cylinders in a location free from fire risk and away from sources of heat and ignition.
- The cylinder storage compound should be kept clear, access should be clearly marked as a cylinder store and appropriate hazard warning signs displayed, *e.g.* flammable, oxidant, compressed gas, *etc.*
- Smoking and the use of naked flames either inside or in the vicinity of the cylinder storage area should be prohibited.
- Cylinders should be stored in the vertical position and properly secured to prevent toppling. The cylinder valves should be tightly closed and, where appropriate, valve outlets capped or plugged. Cylinder valve guards or caps should be in place and properly secured.
- Protect cylinders stored in the open against rusting and extremes of weather. It is advisable to stand cylinders on open galvanized steel gridwork to reduce corrosion of the cylinder base.
- Store full and empty cylinders separately and arrange full cylinders so that the oldest stock is used first.
- Gas cylinders should be segregated in the storage area according to the various categories, *i.e.* toxic, flammable, *etc.*
- Cylinders containing oxygen and oxidants should be separated from flammable gases by a minimum distance of 6 m (20 ft) or, alternatively, a fire resistant partition.
- Do not mix cylinders in the full cylinder store. Store full cylinders of different gases separately, each in a well marked place.
- The amounts of flammable or toxic gases in storage should be kept to a minimum.
- Cylinders containing flammable gases should be stored away from other combustible materials.
- Cylinders held in storage should be periodically checked for general condition and leakage.

CARRIAGE

- Make sure that the driver who carries cylinders in a vehicle, particularly flammable and toxic gas cylinders, has been properly instructed in the method of handling and loading cylinders, in dealing with any emergency and carries the required information.
- Carry cylinders in open vehicles if possible. A closed vehicle may be used to carry small quantities of cylinders if well ventilated.
- Ensure cylinders are properly secured on the vehicle and that propane cylinders are always kept upright during carriage.

Further reading

Handbook of compressed gases, Compressed Gas Association Inc, Reinhold, 1981.

Patty, F A editor, 'Industrial hygiene and toxicology', 2nd edition vol 2, John Wiley & Sons, 1962.

Gas Data Book, Matheson Gas Products, 1971.

British Compressed Gas Association, CP9-Code of Practice 'The safe filling, handling, storage and distribution of gases in transportable containers', 1982.

'Safe under pressure', BOC Ltd.

Gas encyclopaedia, L'Air Liquide, Elsevier, 1976.

The Road Traffic (carriage of dangerous substances in packages, *etc.*) Regulations 1986, SI.1986, No. 1951 and supporting code of practice.

Notes on argon hazards and basic safety precautions

FIRE AND EXPLOSION HAZARDS

Neither gaseous nor liquid argon is flammable and do not in themselves constitute a fire or explosion risk. However, they are normally stored under pressure and the storage vessels, whether gas cylinders or liquid tanks, should not be located in areas where there is a high risk of fire or where they may normally be exposed to excessive heat. Containers of compressed gaseous argon may rupture violently if overheated as a result of exposure to fire.

Oil lubricated compressors operating continually on argon service for a prolonged period should not be switched to air service without thorough cleaning, otherwise there is a danger that unoxidised pyrophoric deposits which may have formed in the machine will explode violently on contact with compressed air.

HEALTH HAZARDS

Asphyxia

Argon, although non-toxic can constitute an asphyxiation hazard through displacement of oxygen in the atmosphere. The potential for this type of hazard is significant because of the widespread use of argon in industry. Neither argon nor oxygen depletion is detectable by the normal human senses. Unless adequate precautions are taken persons can be exposed to oxygen deficient atmospheres if they enter equipment or areas which have contained argon or in which argon has been used.

Symptoms of oxygen deprivation, *e.g.* increased pulse and rate of breathing, fatigue and abnormal perceptions or responses, may be apparent at an oxygen concentration of 16%. *Breathing a pure argon atmosphere will produce immediate loss of consciousness and almost immediate death.*

PRECAUTIONS

Operation and maintenance

It is essential that operations involving use of gaseous or liquid argon, particularly in large quantities, are conducted in well ventilated areas to prevent formation of oxygen deficient atmospheres.

Ideally, argon should be vented into the open air well away from areas frequented by personnel. Argon should *never* be released or vented into enclosed areas or buildings where the ventilation is inadequate. Both cold argon vapour and gaseous argon at ambient temperature are denser than air and can accumulate in low lying areas such as pits and trenches.

EMERGENCIES

In the event of accident or emergency the instructions below should be implemented without delay.

Asphyxiation

Persons showing symptoms of oxygen deprivation should be moved immediately to a normal atmosphere. Persons who are unconscious or not breathing must receive immediate first aid. Medical assistance should be summoned without delay. First aid measures include inspection of the victim's airway for obstruction, artificial respiration and simultaneous administration of oxygen. The victim should be kept warm and resting.

Further reading

Cryogenics Safety Manual 'A guide to good practice' published by The British Cryogenics Council, London SW1.

Prevention of accidents arising from enrichment or deficiency of oxygen in the atmosphere 'Document 8/76E Industrial Gases Committee of CPI Paris 1976'.

Fume extraction

For most TIG welding all that is needed is good ventilation to avoid gas build-up. Argon is denser than air and tends to concentrate in low lying areas and is very seldom a problem. Just an open door in the welding area is usually all that is needed, ensuring of course that no draughts can disturb the gas shield around the arc.

TIG welding produces very little smoke but does form ozone, particularly when welding aluminium and stainless steels, which has a characteristic smell associated with TIG welding. Ozone should *not* be extensively inhaled although exposure to the smell usually causes no harm.

HEALTH RISKS OF WELDING FUME

(from HSE (Health and Safety Executive) Guidance Notes EH54 and EH55 - UK only.)

Welding fume is a mixture of airborne gases and fine particles which if inhaled or swallowed may be a health risk. The degree of risk depends on:

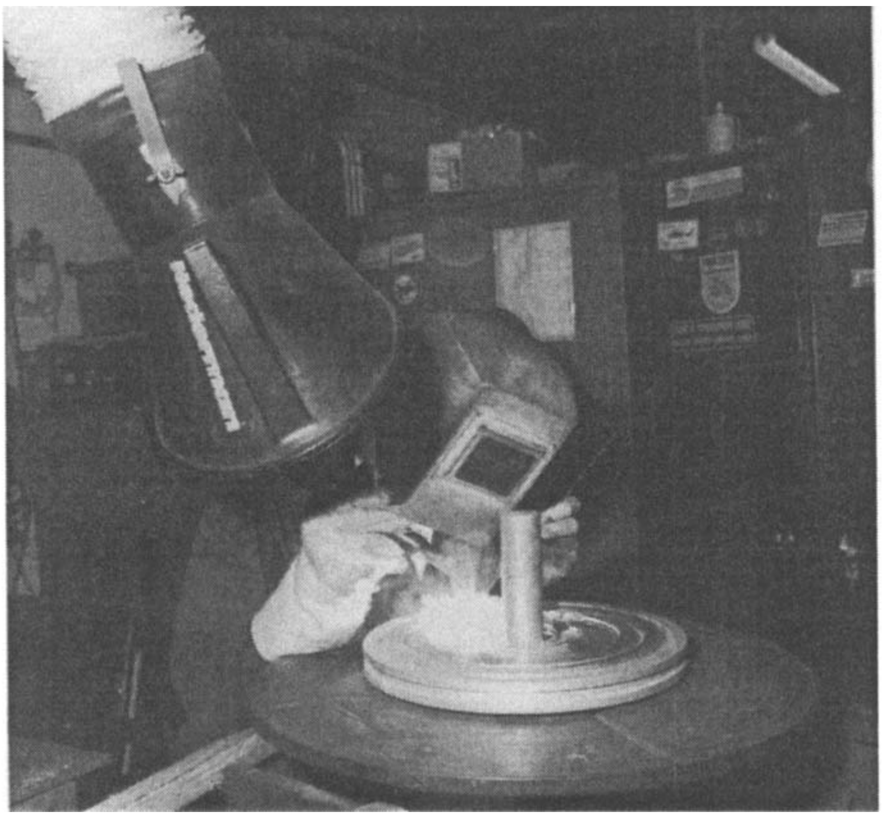
- The composition of the fume;
- The concentration of the fume;
- The duration of exposure.

The main health effects are:

- Irritation of the respiratory tract. Gases or fine particles of fume can cause dryness of the throat, tickling, coughing, tightness of the chest and difficulty in breathing.
- Metal fume fever. Inhaling many freshly formed metallic oxides, such as those of zinc, cadmium, copper, *etc* may lead to acute influenza-like illness termed metal fume fever. With the exception of exposure to cadmium fume serious complications are rare. The commonest cause of metal fume fever is welding galvanized steel.
- Systemic poisoning. Systemic poisoning can result from inhaling or swallowing substances contained in welding fume such as fluorides, hexavalent chromium, lead, barium and cadmium. The presence of these substances in the fume depends upon the welding process being used and the material being welded.
- Long term or chronic effects. Inhaling welding fumes can lead to siderosis or pneumonoconiosis. A subject of current concern is whether welders have an increased risk of developing respiratory cancer, as certain constituents of some welding fumes, *e.g.* hexavalent chromium and nickel, may be carcinogenic.

Document EH 54 or a related publication of other countries' safety councils should be obtained and studied carefully. All such councils have set limits to exposure times and levels, along with recommended limits of particle inhalation. As TIG introduces filler metal into an already molten weld pool there is no transfer of metal particles directly through the arc, so escape of metal particles is minimal. Study the documents carefully and equip your welding area accordingly.

Operators should not, if possible, position their heads directly over the arc unless wearing an extractor mask. For normal purposes the helmet deflects fume and for extra safety a simple cloth mouth and nose face mask will suffice. Very low current precision TIG welding needs no mask at all, but ensure good ventilation at all times. For further details, and a list of relevant regulations, consult COSHH (Control of Substances Hazardous to Health) and any applicable British and European Standards, *etc.* (Also in the UK consult BS6691.) In other countries obtain the relevant literature from the official authority. Further data can usually be obtained from manufacturers of welding consumables.



14.1 Fume extractor for manual TIG welding.

METHODS OF FUME EXTRACTION

Figure 14.1 shows an extractor duct for MIG welding, the requirements for TIG are similar but not as demanding. The main point is that suction should not be too fierce or the inert gas shield will be reduced, and do not forget, gases cost money.

Collection of dust and metal particles from the fume is useful but does not present too much of a problem for TIG welding. However, fit the best extraction you can afford consistent with the work being done.

Chapter 15

Future developments for TIG welding

Over the whole history of TIG welding the working end, *i.e.* the torch, electrode and gas, have remained much the same since its inception. Torches have become more versatile and lighter, reasonable quality electrodes are offered in a large range of sizes and material content and gases are available in an even greater variety of purity and mixes. So, not much improvement left to make? Well, human ingenuity is always devoted to producing cheaper and better technical items, so maybe we will have to wait and see what improvements, if any, are to be made in those areas.

Where improvements *will* be made is undoubtedly in equipment, *i.e.* power sources, control systems, monitoring, arc viewing and data recording, *etc.* Systems already exist for remote control of arc and electrode position, along with closed circuit TV viewing in inaccessible areas. Mechanical handling and arc positioning are already used in 'hot' nuclear areas with great success and the author has seen many ingenious installations of this type.

Electronics will be improved to a very high standard to provide smaller, lighter and more efficient power sources. TIG, of all the welding processes, is extremely well suited to computer control and most future equipment will be upgraded to allow for computers to be fitted on an add-on basis.

In the author's opinion there are some areas where further attention could be paid to improving equipment and lowering the cost. Arc length control, seam following and arc viewing equipment are capable of further development and would be more widely used if they were not as costly as at present. A considerable amount of electronic components are used and these are getting cheaper and easier to obtain. Many power source control and regulation circuits are now solid state and more will become so.

Regarding control of automated mechanical systems, this is already widely carried out by pneumatic logic so further detailed development to allow these circuits to be integrated with the power source and manipulation systems is necessary.

Arc starting devices must be developed always to be computer friendly leading, the author hopes, to the eventual abandonment of the use of primitive HF with all its problems.

Some research must be done by manufacturers to produce better and more consistent electrodes. TIG alone poses the problem where extremely expensive welding systems depend on an item costing a few tens of pence. The complaint here is not about cost but quality. Perhaps there is an element other than thorium, zirconium, cerium or lanthanum that will have all their virtues and none of their drawbacks.

Any developments must be seen to be advantageous and progressive, not as is often the case, change for change's sake. As the current saying goes 'We have the technology', let us use it for real improvement. If we do this, TIG welding will have a bright and commercially viable future.

Finally the author would be pleased to hear readers' comments on the material in this book. Nobody knows it all and argument, disagreement, discussion and constructive criticism should bring progress for the good of industry in general.

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