# Inert Gas Shielded Arc Welding of Copper And Copper Alloys

By L R VAIDYANATH*

In spite of considerable work, welding of copper and its alloys pose a formidable problem due to their high thermal conductivity and relatively higher co-efficient of thermal expansion. The grades of copper available are tough pitch copper, phosphor deoxidised copper and the oxygen free high conductivity copper. The last of the coppers are broadly classified in the following groups—silicon bronzes, aluminium bronzes, tin bronzes (and gunmetals), brasses, cupro-nickels, nickel silvers and copper with small additions—Cu-Cd, Cu-Cr, Cu-Be etc.

**Copper**

When circumstances permit, it is convenient to weld copper with non-matching filler rods in the form of metal arc electrodes or as bare wires for oxy-acetylene or carbon arc welding. While the filler material requires the use of fluxes during welding operations, recent developments have made possible better weldments with the use of both argon or nitrogen shielded metal arc welding. With the advent and constant improvements in both the arc welding processes, it has been possible now to tackle welding of tough pitch copper ; still however, the migration of oxygen and associated brittle layer formation at the heat affected zone poses, if not a difficult, a major problem.

The high thermal conductivity of copper and its welding problem has been a subject of study by various workers, which has been reviewed by Taylor in a recent survey[1]. Even at the lowest value, the thermal conductivity is three or four times that of a low carbon steel. The difficulty of keeping a molten weldpool therefore increases with increased thickness of the welding member. Preheating is essential for a thickness above 3/16″ and 1/2″ and a temperature of at least 500—700°C is necessary to obtain fusion at the joint —a condition very difficult to obtain in practice. It is customary to specify a very high temperature of preheat so that at least the minimum is obtained. Recent approaches to such welding eliminate the preheat cycle viz., inert gas welding methods like MIG and TIG and manual arc welding electrodes with special formulated coatings[2] such as the ECUGT electrode recently developed in Poland. With this electrode, arc energies are considerably higher than those possible with the MIG arc and deep penetration is also possible, so that copper in thicknesses at least up to 3/4″ can be satisfactorily welded without preheating. Reduction of welding time and cost by as much as 90% is possible.

The ECUGT electrode, consists of a copper core with thick pressed covering which contains components for arc stabilization, de-oxidation of the weld, protection against oxygen other than necessary to combine with hydrogen and to increase the heat input by exothermic reaction. The voltage employed depending on the electrode diameter, will vary between 40—55 volts. The current is D.C. and the workpiece is connected to the negative polarity. Table I details some of the typical figures.

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**TABLE I**

| | | | | |
|---|---|---|---|---|
| Plate thickness in mm | 3 — 5 | 5 — 10 | 10 — 18 | 15 — 25 |
| Electrode diameter in mm | 3 | 5 | 5 | 6 |
| Welding current — Amps. | 200-300 | 300-400 | 400-500 | 500-600 |

Experience has shown that even with inert gas arc process with argon shielding, preheating is essential. The preheating temperatures for various shields are given in Fig. 1. To enable the preheat to be maintained at requisite level, helium instead of argon is preferred as shielding gas in TIG and MIG welding copper in the U.S.A. In some countries, the use of this gas may not be economic and the experience of some welders is that helium arc with MIG welding gives very much greater spatter.

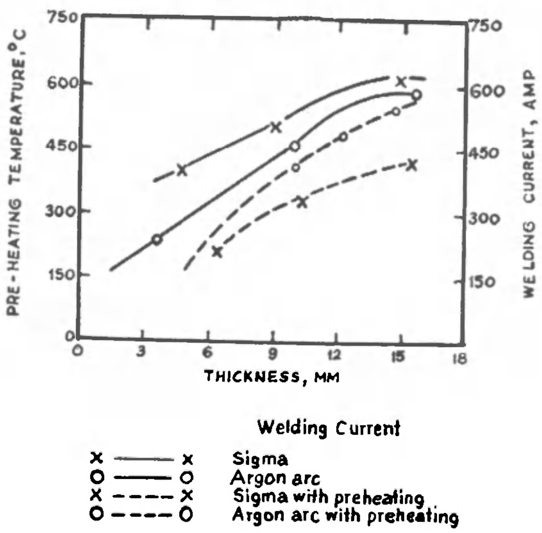


*Fig-1. Preheating temperature and welding currents for inert gas Arc Welding of Copper.*

Some relaxation for preheating can be obtained by substitution of nitrogen for argon but this is also not without problems. As with helium, arc voltages in nitrogen are higher than in argon and hence for comparable welding currents, greater welding power is available. Higher heat inputs can thus be obtained. For example, ½″ copper plates can be welded with current setting similar to those required for argon arc ¼″ material. An important economic consideration is

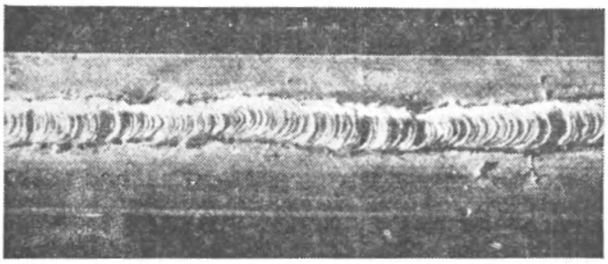

*Fig-2. Weld made with droplet mode of metal transfer*

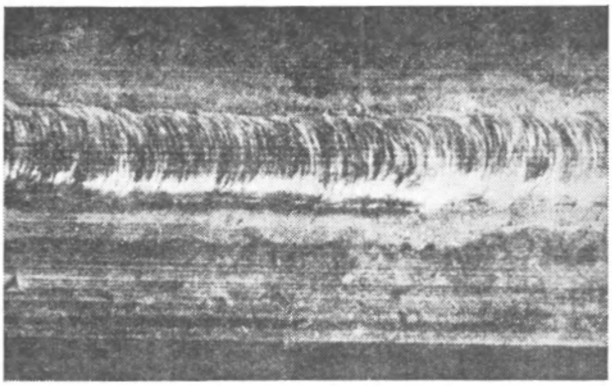

*Fig-3. Weld made with spray mode of metal transfer.*

that nitrogen is considerably cheaper than either argon or helium. The nitrogen used should be free from oxygen particularly when D.C. is used, and a thoriated tungsten electrode is connected to the negative pole of the power supply. This shielding gas is however not suitable for inert gas metal arc welding according to Moore & Taylor[3] because it is not possible to obtain spray transfer of metal—see Figures 2 & 3. According to recent work, the high rate of energy consumption in the arc column with dissociable gases (with $N_2$ this is 4—5 times that of argon) deters the arc from the configuration required for plasma jet and thus globular transfer predominates. Better metal transfer has been reported with MIG process using argon nitrogen mixture containing 5—33% nitrogen. Although it is not possible to avoid preheat even under this condition, to some extent a twin consumable electrode offers some promise—see Fig. 4. Fig 5

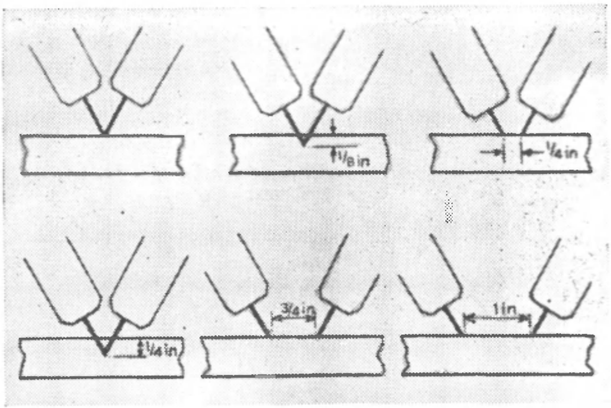

*Fig-4. Experimental arrangements of welding guns for the twin wire MIG process.*

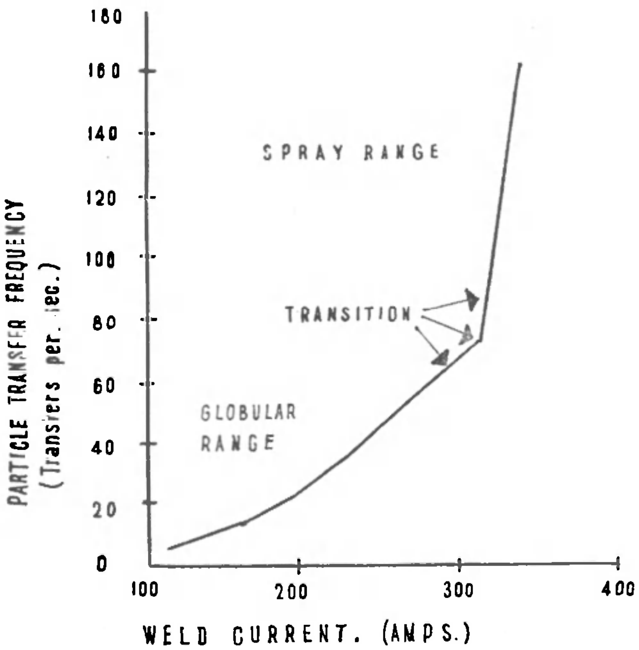


*Fig-5. Metal transfer characteristics of Copper Filler wire (1 16 in dia.) in Argon shielding.*

shows what happens in case of a copper filler wire in argon shielding as the welding current is increased, the transition is a range rather than discrete transition from globular to spray transfer. It is however agreed that in tungsten arc welding of copper with either helium or argon, direct current with electrode negative gives the best results. From the experiments successfully carried out so far it can be said that the twin electrode process can be used to weld ½″ thick unpreheated copper in the down-hand position. Because of the large weldpool, positional welding is ruled out.

In case of light gauge copper, use has been made of a spool mounted on the gun for welding both tough pitch and phosphor deoxidised coppers. Materials as thin as 0.032″ can be welded by using 0.03—0.04″ diameter filler wire, employing a current in the neighbourhood of 120—150 amps. In such cases, detachable heat sinks have to be employed to obtain reasonable welding speeds.

**Weld Porosity**

The problem of porosity with conventional filler rod (copper, 1% Ag, 0.05% P.) gave rise to considerable porosity and this led to the development of special filler rods of the same base composition but with addition of small amounts of powerful deoxidants such as silicon, manganese, aluminium, titanium and boron either singly or in combination. Some of the British Standard filler rod compositions along with respective coppers used are given in Table II.

A favoured filler rod in the U.S.A. is copper, 0.25% Si, 0.25% Mn and 0.75% Sn (A.S.T.M. B.225-571, 1957). Excellent soundness of the joint can be obtained if the joints are handled by experts.

**Pulsed-Arc Welding**

It is a recent development from basic MIG technique, with offers a means of controlling heat input in relation to metal deposition rate and gives exceptionally smooth spatter free welds. Most suited to welding thinner gauge material, the technique is, however, not definitely limited to light gauge work—in fact 1/16″ diameter filler wire can be used to weld a range of material thickness from ½″ or more down to 0.040″. The weldpool size is small and is suitable for positional welding.

The mode of metal transfer under pulsed current condition is an improvement of the MIG process in that, welding arc can be operated at relatively low average currents and burn off rates of the filler wire while still maintaining spray transfer of the high current rates. This is accomplished by super-imposing high current pulses on much lower back-ground current which provides for premelting of electrode tip. The high current pulses detach and transfer the molten metal as small droplets typical of spray transfer.

**Plasma Arc Welding**

This process—capable of yielding high rates of heat input—is a refinement of TIG welding to give an

## TABLE II

**Filler Metals for Inert-Gas Shielded Arc Welding of Copper**

| *Grade of Copper+* | *Inert-Gas Tungsten-Arc (B.S.2901 : Part 1)** | | *Inert-Gas Metal-Arc (B.S. 2901 : Part 2)** | |
|---|---|---|---|---|
| | *Argon* | *Nitrogen* | *Argon* | *Nitrogen* |
| C.106 Phosphorus-deox. non-arsenical (B.S. 1172) | C7, C9, C21 | C8, C9, C21 | C7, C9, C21 | C8, C21 |
| C.107 Phosphorus-deox. arsenical (B.S. 1174) | C7, C9, C21 | C8, C9, C21 | C7, C9, C21 | C8, C21 |
| C.101 Electrolytic tough pitch high conductivity (B.S. 1036) | C7, C8, C21 | — | C7, C8, C21 | — |
| C.102 Fire-refined tough-pitch high conductivity (B.S. 1037) | C7, C8, C21 | — | C7, C8, C21 | — |
| C.103 Oxygen-free high-conductivity (B.S. 1861) | C7, C21 | — | C7, C21 | — |

+ Symbols as defined in schedules for wrought copper and copper alloys B.S. 2870-2875.
* %Compositions of filler metals :
C7 : 0.05-0.35 Mn/0.2-0.35 Si/up to 1.0 Sn, 0.3 Fe/balance Cu
C8 : 0.1-0.3 Al/0.1-0.3 Ti/balance Cu
C9 : 1.0 Mn/3.0 Si/balance Cu
C21 : 0.02-0.1 B/balance Cu

arc of higher directional stability. Under controlled welding conditions, the plasma arc penetrates the metal in the form of a 'keyhole'. This effect characteristic of this process, causes metal to flow in behind the hole, due to surface tension forces as the torch moves over the work-piece to form the weld bead. Excess plasma energy escapes through the hole, making a non-turbulent weldpool condition. Fig. 6 shows a plasma weld in 1/8" copper made at BWRA. The uniformity of the weld top and bottom is clearly shown. Usually copper at this thickness requires a preheat of about 400°C. The limit of weldable thickness is imposed mainly by the requirement of 'keyhole' effect. A simplified diagram of plasma arc welding is shown in Figures 7 & 8.

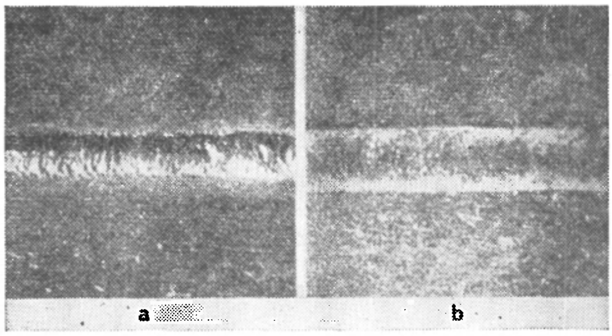


*Fig-6. Plasma-arc welded copper sheet a : Top weld bead, b : Under-bead.*

### Copper Alloys

Compared with pure copper, the thermal conductivities of copper alloys are significantly lower. Heat requirements for preheating, etc. are much lower ; in fact for metallurgical reasons preheating may have to be avoided. Because the heat requirements are low, the thickness weldable by conventional arc techniques are virtually unlimited. Shielded tungsten arc welding of these alloys which form refractory oxide is invariably carried out using A.C. The oxide films are disrupted by D.C. reverse polarity (electrode positive) working but the welding process is then inefficient and the electrode erosion rate high. A.C. working effects

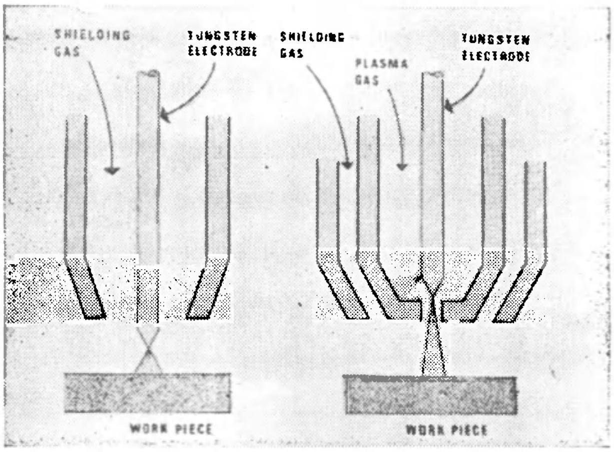


*Fig-7. Schematic comparison of TIG (left) and plasma welding torches.*

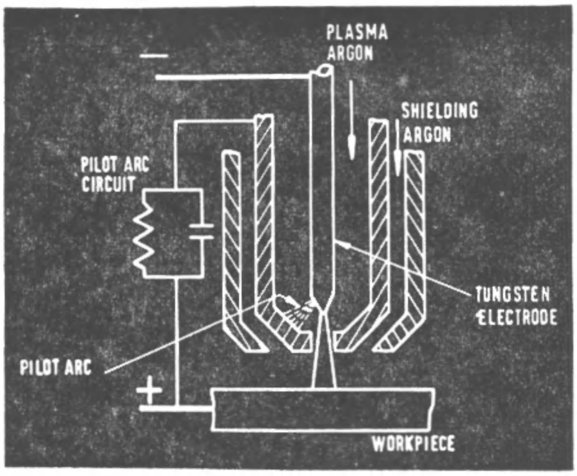


*Fig-8. Simplified diagram of the plasma-arc welding torch.*

a compromise ensuring good oxide disruption over each half cycle.

By virtue of good mechanical properties and excellent corrosion resistance to many media, aluminium bronzes are chosen for many applications. The alloys mainly are single phase alloys containing below 8% aluminium and duplex alloys containing 8—11% aluminium. In both cases, properties can be varied by the addition of Fe, Ni & Mn. The most important consideration is the removal of tenacious surface oxide film which is achieved by A.C. tungsten arc welding or metal arc welding by using D.C. with electrode positive.

Inert gas arc welding can be carried out in autogenous material without hot cracking in both the alloys. Some of the alloys studied are $\alpha$ alloys containing 7% aluminium and an iron bearing alloy containing aluminium + 1.5%—3.5% iron (ASTM B171 type D) and using a variety of filler rods. In the manufacture of condenser shells 3/8″ thick with or without filler, the welds were found to be hot short and there was a risk of embrittlement in multirun deposits—as revealed by room temperature tests. The latter defect was ascribed to the promotion of $\gamma_2$. However, later work suggests that the defect is rather due to presence of impurities than due to the formation of the brittle $\gamma_2$ film at grain boundaries.

The metallurgical factors affecting weldability of aluminium bronze have been well described in literature.

The best technique to get a satisfactory and uniform weld is to use inert gas shielded arc welding technique. Although metal arc welding with flux covered electrode is practised, the flux cover may not prove to be adequate and hence the weld may be unsatisfactory. It is important to keep the joint clean. Both with TIG and MIG, welding is fairly easy even for heavy sections ; weld cracking can occur due to weld metal restraint which can be overcome with the use of non-matching filler alloy of the aluminium-silicon bronze type. This helps in prevention of corrosion failure also.

Table III shows some of the filler metals for inert-gas shielded arc welding of aluminium bronze and some of the other copper alloys.

**Tin Bronzes**

The tin bronzes are generally either single phase wrought alloys containing up to 8% Sn and up to 0.4% P or duplex cast alloys containing more than 10% Sn with similar P content as wrought alloys. These are used for bearing application.

The weldability of tin bronzes is similar to that of Phosphorus Deoxidised Copper. Fusion welding leads to hot shortness in lead rich alloys and autogenous welding leads to porosity. Both TIG & MIG processes are satisfactory. Filler metals are given in Table III above. The gunmetals, another group of tin bronzes, are rarely fusion welded because of Zn fume hazards. Lead containing alloys are welded by inert gas shielded technique.

Both TIG & MIG techniques are suitable for non-leaded gunmetals using C 10 or C 11 filler metals. There is, however, much to be said for using an aluminium bronze filler rod to reduce Zn fume hazard. A.C. TIG is recommended for the purpose.

**TABLE III**

**Filler Metals for Inert-Gas Shielded Arc Welding of Copper Alloys.**

| *Alloy Description* | *Filler Metal Composition %* | *B.S. 2901* Designation* |
|---|---|---|
| Silicon Bronze | 3 Si/1 Mn/Bal. Cu | C9 |
| Phosphor Bronze | 4.5-6.0 Sn/0.4 P(max) Bal. Cu | C10 |
| | 6.0-7.5 Sn/0.4 P(max) Bal. Cu | C11 |
| Aluminium Bronze | 6-7.5 Al/Bal. Cu | C12 |
| | 9-11 Al/Bal. Cu | C13 |
| | 8-10 Al/1.5-3.5 Fe/4-7 Ni/Bal. Cu (A.S.T.M. B171 Alloy E) | C20 |
| Admiralty Brass | 70-73 Cu/1.0-1.5 Sn/0.02-0.06 As/Bal. Zn | C14 |
| Aluminium Brass | 76-78 Cu/1.8-2.3 Al/0.02-0.06 As/Bal. Zn | C15 |
| Cupro-Nickels | 10.0-21.0 Ni/0.2-0.5 Ti/0.2-1.0 Mn/Bal. Cu | C17 |
| | 29.0-31.0 Ni/0.2-0.5 Ti/0.2-1.0 Mn/Bal. Cu | C18 |
| | 5.0-6.0 Ni/1.05-1.35 Fe/0.2-0.5 Ti/0.3-0.8 Mn/Bal. Cu | C19 |

* Part 1 Gas Shielded Tungsten-Arc Welding.
Part 2 Wires for Gas Shielded Metal-Arc Welding.

**Brasses :**

Out of the large number of brasses available, the most used from welding standpoint is aluminium brass (76% Cu, 22% Zn, 2% Al), admiralty brass (70% Cu, 29% Zn, 1% Sn) and Naval Brass (62% Cu, 36.7% Zn, 1.25% Sn)—commonly used as tubes and tube plates for condenser and heat exchanger application.

*Weldability :*—The evolution of Zn fumes makes such welds which are likely to be porous. A non-matching filler (Al bronze or Si bronze) makes the problem a bit easier as autogenous welding will create the above problem. However, the use of non-matching filler may create heat affected zone cracking problem.

The amount of zinc fume given off by an alloy having zinc below 3% is not objectionable and inert gas shielded processes particularly with helium or argon shielding can give pore free and very satisfactory welds. In case of TIG and MIG welding A.C. must be used. Filler rods to B.S. 2901-C14 & C15 can be used. Post welding stress relieving treatments normally at 250—300°C are advisable to obviate the risk of stress corrosion cracking.

**Cupro-nickels :**

Alloys considered under this heading contain nickel from 5—30% with addition of iron and manganese in some alloys to prevent corrosion and cavitation resistance to certain environments.

*Weldability :*—Cupro-nickel alloys are solid solution single phase alloys and small additions of alloying elements do not alter this status. The wide solidification range and unavailability of equilibrium cooling conditions during welding produces a cored structure. Hot cracking can occur in the presence of such impurities as P, Pb and Si and hence their presence is not congenial to good welds. Fig. 9 shows the effect clearly.

Both TIG & MIG welding techniques are used with filler metals containing suitable deoxidants as can be seen from Table IV.

Welding speeds should be controlled to avoid breakdown of the gas shielding. The cupro-nickels are prone to oxygen and hydrogen pick up causing porosity. High quality work may require the use of argon to

## TABLE IV

**Typical welding conditions to obtain spray transfer for some copper alloys. (Argon shielding : 1/16 in. dia. filler wire)**

| *Filler Wire Composition* | *Welding Current (A)* | *Arc Voltage (V)* | *Wire Feed Rate (in./min.)* | *Current Density ($A/in.^2$)* |
|---|---|---|---|---|
| Phosph. Deox. Copper | 310 | 26 | 155 | 100977 |
| Silicon Bronze | 270 | 27-28 | 190 | 87948 |
| 93/7 A1 Bronze | 280 | 26 | 185 | 91205 |
| 70/30 Cupro-Nickel | 280 | 26 | 175 | 91205 |
| 80/20 Cupro-Nickel | 265 | 25 | 150 | 83060 |
| 94/5/1 Copper-Nickel-Iron | 265 | 24-25 | 150 | 86320 |
| 92/8 Phosphor Bronze | 270 | 27 | 165 | 87948 |

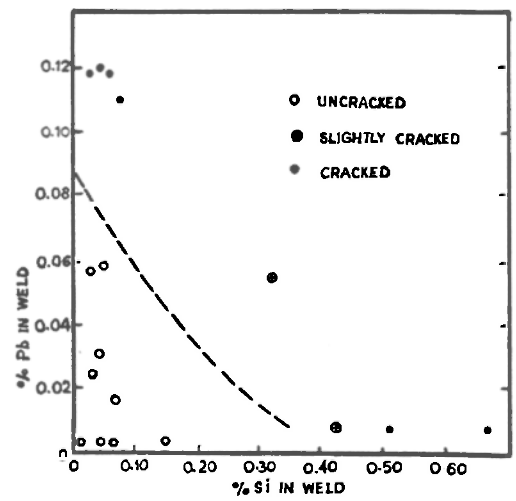


*Fig-9. Effect of Simultaneous Presence of Lead and Silicon on the risk of Hot-Cracking in cupro-nickel welds.*

protect the under-bead from atmospheric contamination.

Nitrogen shielded tungsten arc is suitable for the low alloyed 95% Cu, 5% Ni alloy using titanium deoxidised filler. Greater arc stability and faster welding speeds are achieved than in argon.

In general, sound welds can be produced by the TIG technique using either A.C. or D.C. (electrode negative). Thickness up to 3/8″ can be welded by TIG processes while with MIG it may be unlimited.

### References


(1) Taylor, E.A., Inert Gas Welding of non-ferrous metals, Part 2, Materials & Met. Rev. No. 116, Inst. of Met., London, 1967.

(2) WEGRZYN, J., Welding of Copper with deep penetration electrodes, British Welding Journal, Vol. 14, No. 5, May 1967.

(3) Moore, D.C. & Taylor, E.A., British Welding Journal, 1955, (2), 427.