Weldability and Welding of Copper and Some Applications in Electrical Industry

By V. R. SUBRAMANIAN*

Introduction

In copper, we have a material which has the most attractive electrical and other properties needed for electrical, electronic and chemical industries. Various joining processes have also been developed which can reliably ensure either the strength or the electrical continuity or both, as required. These two features make the position of copper in electrical, electronic and chemical industries unique.

The paper is an attempt to review in a very general way the present status of the processes of welding of copper and high conductivity copper alloys. The processes have been briefly described and the metallurgical aspects of the processes have been outlined to help proper understanding for the efficient application of the processes. Some applications of the processes in electrical industry are discussed which highlight both the technological and metallurgical problems.

Weldability of Copper—Metallurgical Consideration

The thermal conductivity of copper in commercial use which ranges from 0.95 cgs units for the oxygen-free high conductivity copper to about 0.52 cgs units for the phosphorus deoxidised copper places the welding of copper in a class of its own. Even at the lowest thermal conductivity value, it is 3-4 times that of mild steel. It is, therefore, extremely difficult to maintain a molten weld-pool in copper. Difficulties in welding increase significantly with the increase in thickness and for thicknesses above 5 mm and upto 12 mm, preheating becomes essential. The preheat may range from about 400-700°C. While preheat of this order may not be difficult to apply in simple plate or pipe butt joints it poses problems in the more complex shaped com ponents in heavy electrical industries and in chemical industries which form largest number of applications where thick sections of copper have to be welded. Preheating of these components cannot be local since conductivity is such that the temperature soon becomes uniform throughout. Thus, considerable heat is required to give adequate preheat at the welds. This is obviously a costly operation and also makes conditions extremely uncomfortable for the operators. As can be appreciated, the use of high preheat temperature required is really an obstacle in welding, particularly, heavy sections of copper. Preheating can to some extent be reduced or eliminated in some of the recent methods available described later in the paper.

Copper has also a high coefficient of expansion. At high preheat temperature, considerable distortion or even buckling may occur, and therefore, careful control over joint configuration and jigging is imperative.

The standard material used for most welded construction is phosphorus deoxidised copper having a residual phosphorus content. The amount of phosphorus in the parent material is inadequate to ensure complete deoxidation during autogenous welding and for this reason, a series of filler metals have been developed which contain powerful deoxidisers, which help in obtaining sound, ductile welds, free from porosities and cracks.

Oxygen bearing tough pitch copper is a cheaper source of high conductivity material for bus-bars, induction coils and other electrical applications, but there are metallurgical problems to be overcome during welding. Oxide migration in the heat affected zone giving rise to embrittlement and weld metal porosity

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is the most important problem. The nature of the heat affected zone and porosity is dependant on the amount and distribution of oxide in the parent metal. Welding conditions must be controlled to give a good metallurgical structure but, scope for adjustment must be limited by the need to obtain freedom from other weld defects and good weld profile.

Effect of Thermal Conductivity

The main difficulties encountered in welds in copper are lack of fusion and penetration, porosity and cracking. The difficulties encountered due to high thermal conductivity of copper such as formation of peaked weld bead and lack of fusion, undercutting and overlapping may be obviated by adopting one or a number of means described below :—

(i) Preheating can be used to establish a favourable heat distribution during welding. The extent of preheating required unfortunately makes the working conditions very uncomfortable.

(ii) In case of TIG welding, substitution of argon by helium increases the heat transfer to the work piece. For a given arc length, the arc voltage is higher, therefore for a specific current, the total energy input is higher in helium than in argon. This helps reducing the level of preheat required.

(iii) During welding of phosphorus deoxidised copper, nitrogen can be used as shielding gas along with copper-titanium-aluminium filler metal. The gas which dissociates in the arc, recombines at the surface of the work piece, releasing heat. Additionally, there is an arc voltage increase over that when argon is used as shielding gas and this reduces the level of preheat required.

(iv) In MIG welding, metal is transferred as large droplets when helium or nitrogen is used as shielding gas. Though the heat input to the work piece is increased by using helium or nitrogen in place of argon, spatter is very high. Spray transfer occurs when argon is used as the shielding gas and additions of 25 per cent of helium or nitrogen decreases the size of droplets and increases their rate of detachment. Thus with a gas mixture, there is not only an improvement in the metal transfer, but also an increased heat transfer to the work piece.

(v) The weld zone can be protected with flux to reduce heat losses.

(vi) Recently as a result of investigation carried out at the Polish Welding Institute, a deep penetration manual metal arc welding electrode offering many advantages has been introduced for welding of copper. These electrodes have specially formulated flux covering aimed at enhancing the arc voltage and therefore, the arc energy. The flux covering also includes exothermic compounds to give additional heat. Compared to the MIG process, the rate of deposition, is however lower and the time interval between detachment of droplets is long. Consequently, the heating effect of the arc is more. The deposited metal has however been found to contain porosity and slag inclusions very often.

(vii) Linear heat sources i.e. linear through the plate thickness may be used. Example of such heat sources are plasma arc and electron beam.

Porosity

Autogenous welds in copper are usually porous. The number and size of porosities depend upon the rate of cooling of the deposited metal and the nature of the gas evolved forming the pores. Even when no additional hydrogen and oxygen are supplied from the exterior of the metal, as is the case in electron beam welding, porosity can still occur due to the diffusion of hydrogen and oxygen up the thermal gradient from the colder regions of the parent metal towards the weld metal. In materials containing little oxygen, the tolerance for hydrogen increases markedly with temperature rise. Consequently, the molten weld-metal in autogenous welds in low oxygen coppers may contain a high concentration of hydrogen. When a slow welding process is used in which there is adequate time for appreciable diffusion of hydrogen, much of the hydrogen can be trapped in solution if the weld-metal is then rapidly cooled. In tough pitch copper, which contains oxygen in the form of cuprous oxide, the tolerance for hydrogen only slightly increases with temperature rise. In the latter case, diffused hydrogen reacts with copper oxide or oxygen in the weld pool to form steam pores and slow cooling rates favour their exit.

When suitable deoxidised filler wires are used, porosity in weld-metal is absent unless the deoxidants are consumed by the oxide formed during preheat or the arc atmosphere. The problem of scale may be effectively combated by smearing the prepared edges and adjacent regions of the parent metal with a slurry of brazing or welding flux. The flux coating does not interfere with the use of inert gas shielded arc processes.

Although suitable deoxidants may be present in adequate quantity in the weld metal, porosity will be found in the heat affected zone in tough pitch copper. The pores usually are formed at sites occupied by Cu-Cu_2O eutectic or at isolated Cu_2O particles. The size and distribution of the oxide particles which are determined by the manufacturing processes, control the size and distribution of pores (Figure 1).

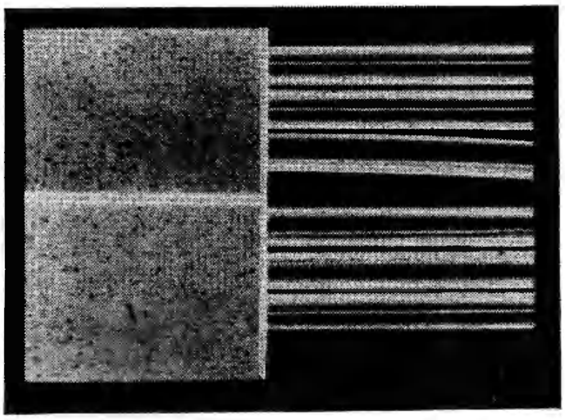

Fig. 1.

With rapid heat input process, for example the electron beam process, the size of the pores is governed mainly by the rate of heat input (Figure 2a, 2b).

Cracking

Cracking in welds in copper is almost invariably confined to the weld-metal. In autogenous welds in tough pitch, phosphorus deoxidised and oxygen free high conductivity coppers, centre line cracking occurs in fusion welds with shallow penetration. Successful welds can usually be made in crack sensitive materials by electron beam welding, a process capable of giving deep and narrow welds.

Cracking is rarely noticed when copper—titanium—aluminium or copper—silicon—manganese filler wires are used because these alloys contain 0.5 per cent deoxidants, which may not be sufficient to prevent cracking if excessive oxidation occurs during preheat or during inter-run heating or when a defective part is repaired by repeated cutting out.

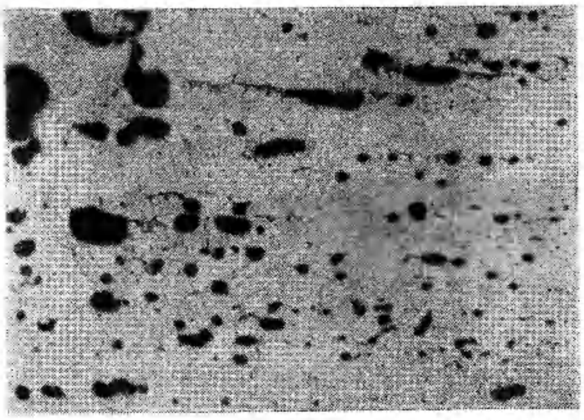

Fig. 2a.

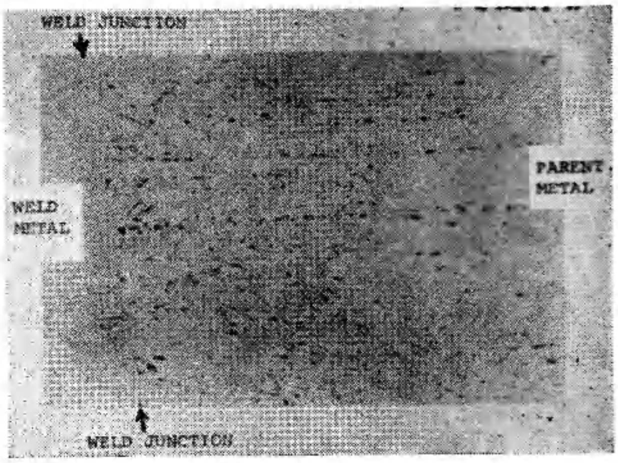

Fig. 2b

Boron deoxidised copper filler wires give a fluid weld pool unaffected by deoxidation products and because of this, is liked by welders. Boron content (0.02-0.08 per cent) may not be sufficient, if it is at the lower limit of the range for welding tough pitch copper having high oxygen content. As the speed of welding determines to an extent the length of time available for the consumption of the deoxidant, fast welding processes such as MIG, produce successful welds. With slow welding processes such as TIG, care should be exercised to deposit sufficient filler metal in the weld pool to maintain adequate supply of deoxidant. Use of filler wire of increased diameter in such instances may result in production of sound welds which otherwise might tend to crack.

The Welding Process

(*i*) *Gas Welding*

There has been a decline in the use of oxy-acetylene welding for copper in the electrical industries.

(*ii*) *Manual Metal Arc Welding*

Manual metal arc welding with coated electrodes has been attempted many times, but not with great success. However, the recent claims of development of manual metal arc welding coated electrodes by the Polish Welding Institute deserve consideration because of the extremely simple and inexpensive equipment needed for the manual metal arc welding.

(*iii*) *Submerged Arc Welding*

Submerged arc welding is reported to be in wide use in the U.S.S.R. The process employs a continuous bare wire feeding to a mould of flux, arranged along joint line as is common for welding of ferritic steels. The secret in obtaining sound welds in thick sections is probably dependent on the flux used.

(*iv*) *Electro-slag Welding*

Electro-slag welding is a vertical welding process whereby the pool of molten slag is established between the square edges of the parts to be joined and is contained in the gap between the parts by water cooled retaining shoes. Filler wire is fed into the slag bath and is melted by conduction, forming a molten pool beneath the slag. The entire apparatus is then mechanically moved up the joint as the filler wire is fed in. Preliminary experiments on copper have been in progress and the indications are that it may be possible to produce sound weld-metal. The problems centre around obtaining fusion with the parent metal and obviously preheat is indicated. At the present stage of development, experiments are inadequate to claim categorically any success for the process.

(*v*) *Electron Beam Welding*

Electron beam welding may now be taken as an established process even though it is today an exotic and an expensive process. It has excited great interest recently as the process having important characteristics which make it attractive as a fabricating technique. The arrangement consists of a device for producing a focussed beam of electrons, mounted on or in an evacuated chamber which contains a device for holding and moving the work piece. Fig. 3 illustrates the basic system of electron beam welding. The heating current passing through the filament causes it to emit electrons. These are accelerated from the filament to the anode by establishing a high voltage "V_a" between them. A control electrode is situated near the filament and is held at a negative potential, "V_b" with respect to it. By this means, the emission of electrons can be controlled and the beam shaped to pass through the hole of the anode. The beam then passes through the centre of a magnetic focusing coil whose current can be varied so that the beam is focused on the work piece. Below the focusing coil are the pairs of deflection coils, which act horizontally at 90° to each other. Electrical signals applied to these enable the beam to be manipulated in various ways. The optical microscope is essential for precise operation. Through it the beam can be aligned and focused accurately on the work piece and its behaviour examined during welding. After welding, the microscope acts as a very useful inspection tool. The three main attributes of electron beam welding are purity, concentration of heat and control. The most important feature of electron beam welding from the point of view of applications is the deep narrow penetration which is possible. Welding is carried out in a vacuum which makes the process useful for sealing components which must contain no atmosphere.

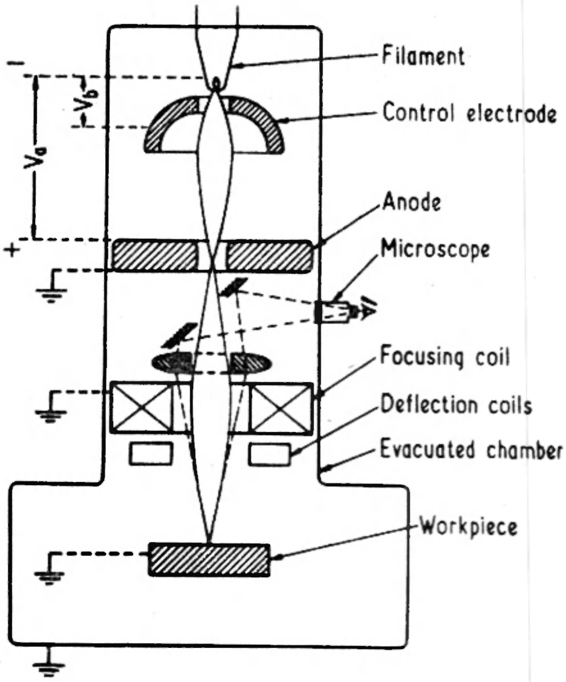

Fig. 3.

There are three recent developments in electron beam welding. The first incorporates a bend in the

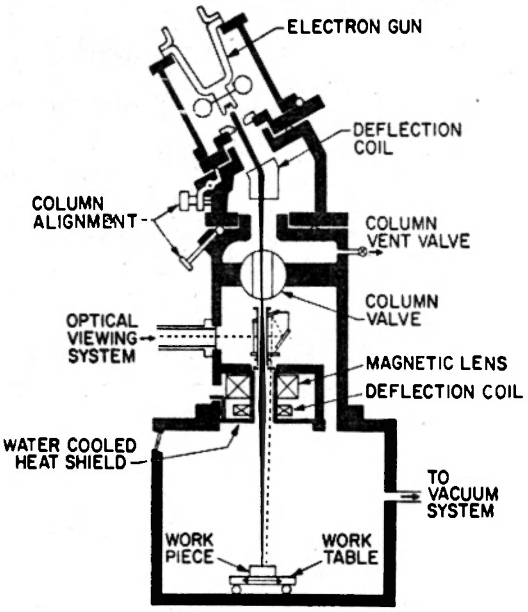

Fig. 4.

electron optical system to prevent metal vapour from reaching the electron gun (Fig. 4). The second is the electron beam welding with 25 KW at 150 KV. The third development is the non-vacuum electron beam welding equipment which has been developed to the extent that it can now be considered as a fabricating technique for production welding applications.

(*vt*) *Inter Gas Shielded Arc Process*

The conventional gas shielded processes are TIG and MIG processes. Though the conventional inert gas shielded arc welding processes were developed for tackling joining problems in aluminium alloys, magnesium, magnesium alloys and stainless steels, these processes have now been applied to copper and its alloys and other less common metals.

(a) TIG Process

The electrode material is usually zirconiated or thoriated tungsten having a much greater erosion resistance than pure tungsten. Direct current straight polarity (electrode negative) is always used when welding copper mainly to gain maximum heat input at the work piece and also to minimise electrode wear. Nitrogen, argon and helium are used as shielding gases depending upon their availability in different countries. Helium enhances the arc cleaning effect and gives a hotter arc.

Copper upto 6 mm in thickness may be satisfactorily welded by argon gas shielding. No preheat is necessary upto 3 mm thickness, above which preheating becomes important. Thickness upto 12 mm can be TIG welded using nitrogen as a shielding gas with adequate preheat (700°C). The substitution of argon by nitrogen has important technical as well as economic advantages in that, greater heat input is obtained because arc voltages are higher for a given setting and also a degree of chemical heating is obtained by recombination of the dissociated nitrogen molecules in the arc at the work piece.

The appearance of the weld is however rough when nitrogen gas is used and also gives rise to more troubles with porosity. This is particularly applicable for thinner materials and the present tendency is to revert to the use of argon as shielding gas for materials above 6 mm in thickness. A special filler metal has been developed for use with nitrogen which, although more difficult to manipulate requiring greater skill, is capable of giving satisfactory results. There is certainly an advantage in using nitrogen shielding and the special filler metal for material thickness less than 8 mm. Higher welding speeds can be maintained with reduction in necessary preheat temperatures.

(b) MIG Process

The familiar inert gas metal arc process is by far the best for welding copper in thickness above 6 mm. Rapid deposition of large amounts of weld-metal is achieved and, the thickness of material weldable in one pass with preheating is about 8 mm with nitrogen shielding and 5 mm with argon shielding. This compares favourably with 5 mm with nitrogen shielding and 3 mm with argon shielding for TIG process.

Recently, sophisticated wire feed mechanisms have been developed to such an extent that it is now possible to feed filler wires down to about 1.10 mm in diameter. This enables sheet material to be welded at thickness in the region of 0.8 mm. The MIG process is therefore becoming an extremely flexible tool for the welding of a wide range of material sizes. The fine wire process is particularly suited to the welding of condenser tube to plate joints. The procedure can be made automatic and high degree of uniformity is achieved. In the standard MIG process, either argon or nitrogen may be used as the shielding gas. The greater heat input obtainable with nitrogen means that the preheat temperatures may be somewhat lower or welding speeds higher than with argon shielding. It is a characteristic of nitrogen arc that at all currents, the metal transferred is coarse and leads to excessive spatter and the resulting weld may be porous. In argon, at sufficiently high currents, the metal transferred is in the form of spray, resulting in a smoother weld deposit. It is, however, possible to obtain sound welds in nitrogen shielding in the downhand position. The use of argon-nitrogen gas mixture with an optimum composition of 20-23 per cent nitrogen is capable of giving a combined advantage of greater arc heating with nitrogen and superior arc characteristics of the arc with argon.

Welding of Thick Copper

The amount of preheat applied is probably the most important single factor determining the successful welding of materials with thick section. MIG welding of 12 mm plate with the necessary 700°C preheat often makes the working conditions extremely uncomfortable and a lack of attention to the correct preheat has been responsible for a large number of weld failures in thick copper.

Work directed towards determining suitable conditions for obtaining reliable welds with reduced preheat or complete elimination of the preheat have been in two directions i.e. use of nitrogen-argon mixture with special filler wire (boron deoxidised copper filler wire) and applying twin consumable electrodes to control the weld pool shape. The first approach did not prove to be successful as the observations on the nature and the extent of weld porosity, reinforcements and depth of penetration, etc., showed clearly that though some benefit could be obtained by the gas mixture, a high level of preheat would still be required for satisfactory welding. The second approach of using twin consumable electrodes (Fig. 5) gives successful welding of 12 mm thick unpreheated copper in down hand position.

A single V-butt weld with an angle of 70° gave the best result, the optimum electrode separation being 10 mm. Because of the large size of the weld pool, positional welding is not possible. In the experiments to determine the above parameter, argon had been used as shielding gas; perhaps twin electrode with nitrogen-argon mixture for shielding gas may prove even better.

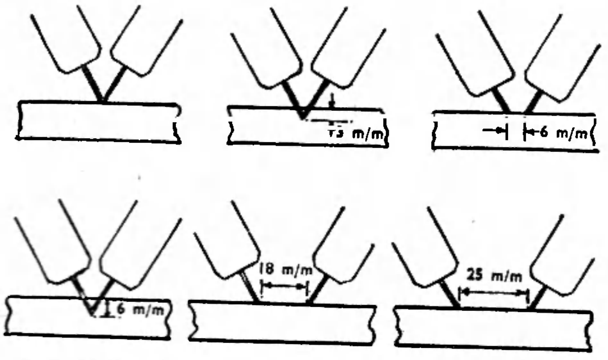

Fig. 5—EXPERIMENTAL ARRANGEMENTS OF WELDING GUNS FOR THE TWIN WIRE MIG PROCESS.

Welding of Light Gauge Copper

With the recent development of fine wire welding gun having a spool of filler wire attached to the gun, copper sheets of about 0.8 mm thickness have been successfully welded using filler wires 0.8 to 1.0 mm diameter. For manual butt welding of sheets, maximum permissible currents to avoid overheating range from 150 amps for lightest gauge to 400 amps for 3 mm sheets. Detachable backing bars which act as heat sinks and enable reasonable welding speed to be obtained, are to be used. Uniform high strength can be obtained in phosphorus deoxidised copper with a joint efficiency of 80-100 per cent. In thinner materials of tough pitch copper, the strength is lower, suggesting the greater effect of oxygen migration in thinner gauges. The process is quite versatile for light gauge copper work.

The MIG welding process lends itself to mechanisation. Two methods are commonly employed : the first relies upon the self-adjustment of the arc when the wire speed is pre-set to a known value and the gun is used with constant voltage power source. The second method relies on the control of arc length, with the wire speed variable and control by arc voltage which is maintained at a constant value. The former method is widely used.

Pulsed Arc Welding

Pulsed arc is a recent development from the basic MIG process. It offers a means of controlling heat input in relation to metal deposition rate and gives spatterless welds with exceptional smooth finish. Pulsed arc welding finds particular application in welding of thin gauge materials, where the welding current required for optimum transfer characteristics is often too high for satisfactory control in the conventional MIG process. The pulsed arc technique is however not limited to light gauge work only. It has in fact been used with 1.5 mm dia filler wire to weld material with thickness from 1-12 mm. Weld pool size is small because of low average operating current and is attractive for positional welding. In the normal MIG process, there is a threshold current for a given filler wire size, below which, the material is transferred across the arc in the form of coarse droplets and above which the transfer is in the form of spray. The distinct feature of the pulsed arc technique is that the welding arc can be operated at relatively low average currents and burn off rates, while still maintaining the spray transfer. This is accomplished by superimposing high current pulses on a much lower background current which provides for pre-melting of the electrode tip. The high current pulses detach and transfer the molten metal as small droplets, typical of spray transfer. When the operating conditions are correctly controlled, the average current, the mean of the high pulse and low background value, is just adequate to burn off the filler wires at a particular preset wire feed rate. By selecting the pulse frequency and suitable adjustment of the pulsed and background current, condition can be obtained so as to transfer one droplet per each current pulse. The background current maintains the arc and provides energy not only for electrode heating but also for weld pool heating. The weld pool shape and the arc length can be controlled by alteration of the arc voltage. The mean current is controlled in the normal way by adjustments of wire feed speed. The process is applicable to all metals which are capable of being welded by argon shielded metal arc. The initial application of this technique for welding copper has been found to be quite promising.

Plasma Arc Welding

The development of the plasma arc as a welding tool is less than a decade old and is applicable to a wide range of materials including copper and its alloys. Plasma arc welding is basically a modification of the conventional TIG process (Fig. 6) the main difference being that the nozzle is made to constrict the arc.

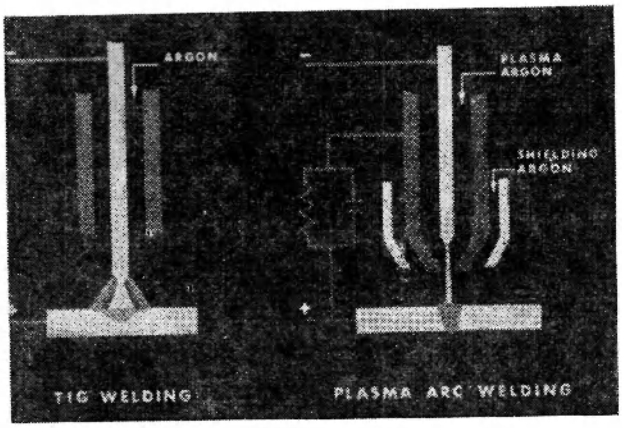

Fig. 6.

The effect of this constriction is to raise the arc temperature considerably and impart greater directtional stability to the arc. Argon or mixture of argon and hydrogen or argon and helium can be used as plasma gas and shielding gas depending on the material to be welded. The tungsten electrode has a centering device and the copper nozzle is water-cooled to avoid rapid deterioration.

A low gas flow is necessary to maintain the plasma arc at a workable level so that additional shielding gas must be supplied to ensure adequate protection of the weld pool. The supplementary gas is normally supplied through an outer nozzle with a diffusing arrangement to provide a smooth uniform shrouding. Gas flows are normally in the range of 3-10 cu. ft. per hour for plasma gas and above 20-35 cu. ft. per hour for the shrouding gas.

The basic power requirement is a constant direct current source capable of supplying upto about 400 amp. A fairly high open circuit voltage is desirable to facilitate main arc starting under the plasma conditions. High frequency is used to strike a pilot arc between the tungsten electrode and the copper nozzle. The ionised gas is then blown through the nozzle, thus transferring the arc to the work piece (Fig. 7). For copper, straight polarity is always employed.

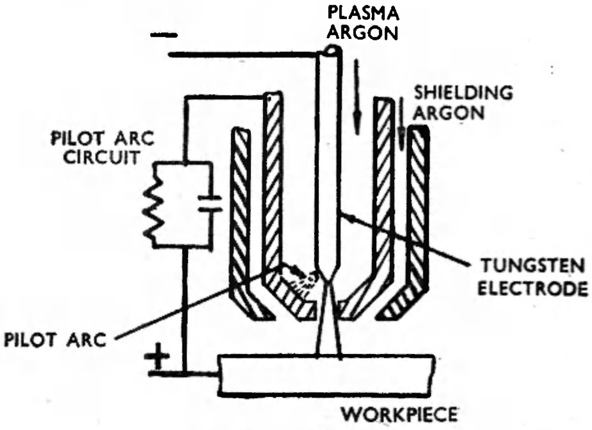

Fig. 7—SIMPLIFIED DIAGRAM OF THE PLASMA-ARC WELDING TORCH.

The outstanding characteristic of the plasma arc process is its ability to produce fully penetrated "keyhole" type welds. The "keyhole" condition is achieved through proper selection of currents, travel speed and orifice diameter to produce a plasma jet forceful enough to penetrate through the work piece completely, but not high enough to expel the molten metal as in the plasma cutting. As the plasma column is moved along the work piece, the base metal, melted ahead of it, flows behind the keyhole due to surface tension forces, to form a weld bead. Excess plasma energy escapes through the hole, making for non-turbulent weld pool conditions.

The columnar nature of the constricted arc makes this process less sensitive to variations in arc length than TIG welding. Since the unconstricted TIG arc has a conical shape, the area of the heat input varies as the square of length of the arc. A small change therefore, causes relatively a large change in the unit area heat transfer rate. With the columnar plasma jet, when the arc length is varied within the normal limits, the area of heat input and intensity are virtually constant. The arc shaping can be accomplished by providing the orifice of the arc constricting nozzle with a pair of auxiliary ports. The multi-port nozzle design with a single port nozzle is illustrated in Fig. 8.

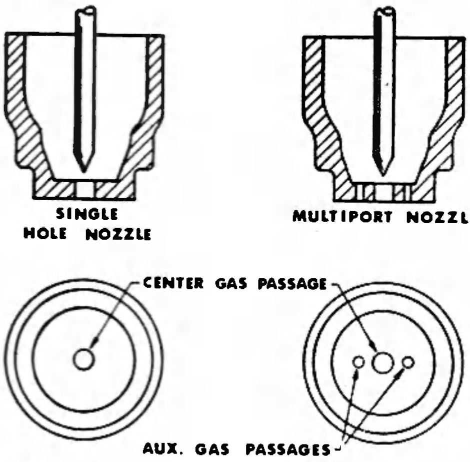

Fig. 8—Single port and multiport nozzles

The effect of the relatively cold gas flow from the auxiliary ports is to squeeze the normal circular pattern of the plasma jet into an oval or elongated shape on the work piece. This is illustrated in Fig. 9.

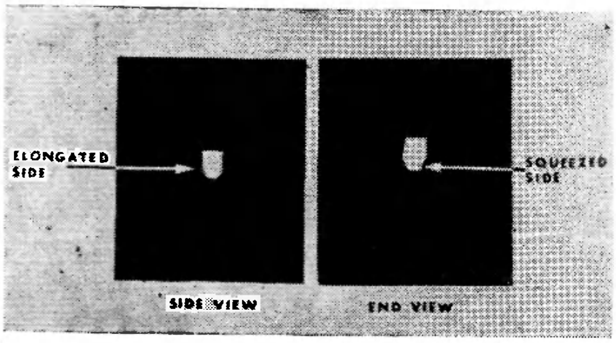

Fig. 9.

When the multi-port nozzle is aligned with the centre line of the joint, the arc is elongated in line with the joint, and helps attaining greater welding speeds and welds with narrower heat affected zone. The improved heat distribution from the multi-port nozzle has increased welding speeds from 50-100 per cent over those obtained with single port nozzle.

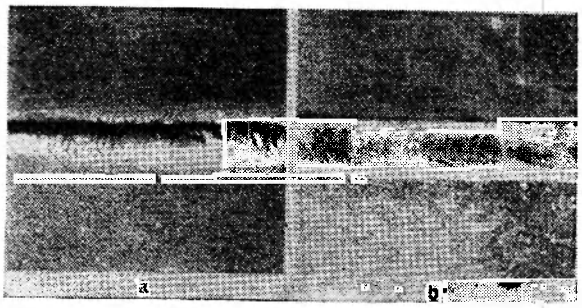

Fig 10.

Fig. 10 shows a weld in 3 mm thick copper. The uniformity of both top weld and under bead is clearly depicted. Even at this thickness, copper requires preheating, in this case to 400°C, but with adequate preheat, thickness upto 6 mm could be satisfactorily welded. The limit on the weldable thickness is imposed mainly by the requirement of producing a "keyhole" effect essential for the control of the process.

The main advantage offered by the plasma technique over TIG and MIG are high welding speed, reduced joint preparation and greater tolerance to joint mismatching. Little or no filler metal is normally required and there is a greater tolerance to variation in arc length, since the arc is more uniform in its cross-section. The process is still in relatively early stages of development but it will undoubtedly find a number of important applications.

These processes offer many advantages over conventional gas welding such as greater rates of weld-metal deposition, higher welding speeds, multi-run and positional welding. The recent refinements on these basic processes, namely, pulsed arc technique and plasma arc are very relevant to welding of copper and its alloys.

Bus-bar : For the joining of bus-bars, a number of processes can be employed; thin bars or thin-walled hollow sections (3-5 mm) can be joined by the TIG, MIG or Pulsed arc processes. With the TIG process using argon as shielding gas, it is usually necessary to preheat the material to 100-200°C, if the thickness is 5 mm. If, however, MIG or MIG pulsed arc process is used, no preheat is required. But MIG processes are good for long lengths of weld. Pulsed arc MIG process is applicable to positional welding particularly in overhead position. With thicker material, the welding current required is dependent on the preheat as indicated in Table 1.

While welding materials with higher thickness (12 mm) by MIG process, high currents are required even when a high level of preheat is used. Under these conditions, the arc force is high and often elongated cavities form in the weld metal. If however, the width to depth ratio is increased, for example, using two MIG

Table 1—Typical currents for TIG & MIG Welding in Argon

Process	*Preheat temperature °C*	*Thickness 3 mm*	*Thickness 6 mm*	*Thickness 12 mm*
TIG	None	230 amp.	360 amp.	550 amp.
	300	150 ,,	275 ,,	500 ,,
	600	Not applicable	180 ,,	375 ,,
MIG (1.5 mm dia filler wire)	None	350 amp.	450 ,,	600 ,,
	300	*250 ,,	350 ,,	†450 ,,
	600	Not applicable	*250 ,,	360 ,,

* This current is the threshold current for spray transfer. The dip transfer MIG process or the MIG pulsed arc welding process should be used

† The use of such high currents may result in the production of elongated cavities in the weld-metal.

guns side by side, satisfactory welds can be made. Helium shielded TIG is becoming more popular where helium is available at cheap rates. Fig. 11 illustrates the technique used for making root run in unpreheated 10 mm wall tubular conductor by TIG process using helium gas. In this case the filler rod is of copper-boron. The substantial root run can be observed in the figure. The completed weld after the second and final runs had been deposited is shown in Fig. 12.

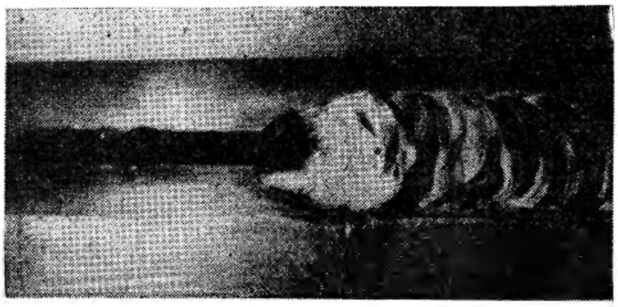

Fig. 11.

Fig. 11.

Commutators

The working conditions of many D.C. machines are arduous e.g. those in diesel electric locomotives. The conventional methods used for joining armature conductors to commutator risers have been found to be inadequate. Soft solders do not have satisfactory properties at the working temperatures of certain machines. Silver solder is also not entirely satisfactory as the deposition temperature is high (680°C). The time required for the copper surface to reach silver soldering temperature is long which results in appreciable softening of commutator surface.

TIG welding with helium as shielding gas is recommended for such applications with high conductivity copper-boron as the filler metal. The welding speed is high and the welding time is too short for any significant softening of commutator segment. If copper-zirconium commutator bars can be used, they may be welded without filler wire. The commutator material provides sufficient deoxidiser under suitable welding conditions to deoxidise the melted armature conductor even if it is made from oxygen bearing copper.

Fig. 13.

Fig. 13 shows a method of joining stator windings. In this particular instance, a U shaped clip was slipped over the four terminations and a MIG weld deposited in each open side of the clip. A mixture of argon and helium was used as shielding gas with copper-boron alloy filler wire. The gas mixture (75 : 25 : : A : He) increased both the heat transfer to the work piece and the transfer frequency of metal droplets detached from filler-wire, as compared to argon shielding. Since no preheat was required, there was no damage to the insulation.

Cable Sheathing

The TIG process has been used for some time in the U.K. and the U.S.A. for autogeneously welding the logitudinal joints in strip formed of oxygen-free high conductivity or tough pitch copper tube for use in cable.

Squirrel Cage Rotors

Joints between bars and end-rings may be made with the recently introduced deep penetration coated manual metal arc welding electrodes. In this application, the principal requirement is electrical continuity. The bars are partially inserted into holes drilled into end-rings and the cavity filled with a plug of weld-metal, no preheat being required. The deposit which often contains pores and slag inclusions are of adequate strength.

Table II—Filler Metals for Inert Gas Shielded Arc Welding of Copper

Grade of Copper	*ISS Designation (draft) Inert Gas*	
	Argon/ Helium	*Nitrogen*
Phosphorus-deox. non-arsenical	S—Cu 1 S—Cu Si 1	S—Cu 2 S—Cu Si 1
Phosphorus-deox-arsenical	S—Cu 1 S—Cu Si 1	S—Cu 2 S—Cu Si 1
Electrolytic tough pitch conductivity	S—Cu 1 S—Cu Si 1	— —
Fire refined tough pitch high conductivity	S—Cu 1 S—Cu Si 1	— —
Oxygen free high conductivity	S—Cu 1	

End rings of large induction motors present formidable difficulties in butt welding. Some success has been claimed in Russia for submerged arc welding in this application.

Filler Metals

The filler metals for inert gas arc welding of copper and its alloys are fully described in the draft Indian Standard Specification for filler rods and wires for inert gas arc welding of copper and copper alloys presently under wide circulation. Table II summarizes the filler materials covered. Normally, the boron-deoxidised filler is used only where joints of high electrical conductivity are required.

Conclusion

Copper and high conductivity copper alloys enjoy a unique position in the electrical, electronic and chemical industries, because of their superior properties. Certain inherent physicals properties of copper have been standing in the way of joining coppers by fusion welding process. Recent developments in the fusion welding processes hold promise of making fusion welding of copper in thin as well as thick sections easy and reliable. High heat intensity processes such as electron beam welding and plasma welding are expected to find useful applications in the electrical industries for fusion welding of coppers.

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