CHAPTER II

NATURE OF THE WELDING PROCESSES

It is desirable to describe the main welding processes—gas, arc and resistance welding—as clearly as possible in order to avoid misunderstanding. They are all fusion welding processes. Fusion welding may be defined as the joining of two pieces of metal by melting adjacent portions, so that there is definite fusion between them to an appreciable depth. In gas and arc welding, a further supply of the same metal, usually containing small amounts of other elements (for the purpose of deoxidising, improving fluidity, etc.), may be added in the molten state. The term "autogenous" weld refers to a welded joint, the material of which is identical in composition with that of the parent material.

A. OXY-ACETYLENE WELDING

General

The oxy-acetylene blowpipe and the technique of using it are well known, and are described in detail in so many handbooks that only a brief description is considered necessary here. Acetylene mixed with oxygen issues from the nozzle of a welding blowpipe and, when ignited, produces a high-temperature flame. Independent control of both acetylene and oxygen makes it possible to vary the size of the flame and its character, which may be reducing, neutral or oxidising in the region beyond the tip of the bright central cone. The character of the flame may be distinguished as follows:

Neutral—Central cone sharply defined, almost white; envelope reddish purple.

Oxidising (slightly)—Cone shorter and more pointed than that of the neutral flame.

Reducing or *carburizing* (slightly)—Cone white and luminous, less sharp and surrounded by ragged white feather; envelope reddish purple.

The hottest part of a neutral flame has a temperature of between 3100° C. and 3500° C., and lies about $\frac{1}{8}$ in. beyond the tip of the cone; when welding copper and copper alloys, the tip of the cone is held $\frac{1}{8}$ in. to $\frac{1}{4}$ in.

away from the surface of the metal. The size, and hence the heating capacity, of the flame may further be varied widely by changing the size of the blowpipe tip or nozzle.

Oxygen is usually obtained in high-pressure cylinders. Acetylene may be generated at low pressure from calcium carbide, or obtained dissolved in acetone in cylinders. Where many welders are at work, it may be economical to have a single source of acetylene and another of oxygen, and convey them by independent piping systems to each welder.

TABLE II

CALORIFIC VALUES AND FLAME TEMPERATURES OF FUEL GASES

Fuel gas	Approx. Cal. Value B.T.U./cu. ft.	Flame Temperature, °C	
		With oxygen	With air
Coal Gas	450–650	2000–2200	1500–1800
Hydrogen	280–340	2300–2700	2000
Acetylene	1450–1550	3100–3500	2200–2400
Propane	2400	2600	1800–1900
Butane	3400	3000	1900

Table II demonstrates the superiority in heating power and flame temperature of acetylene with respect to coal gas and hydrogen. For the gas welding of copper and its alloys, the oxy-acetylene flame is more widely used than any other. Gases such as propane and butane have, however, been used instead. The hydrogen fluorine flame reaches temperatures exceeding 3300° C. and has been applied experimentally in the U.S.A. However, the cost of fluorine and its containers has so far been prohibitive.

Preparation of Joints

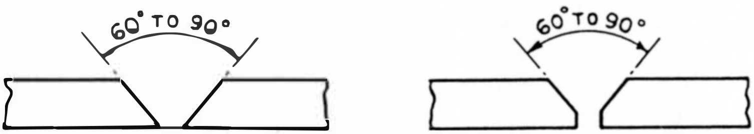
Fig. 11 shows several types of joint and indicates the thicknesses for which they are suitable. An essential preliminary to successful welding is the careful preparation of the metal edges. Upturned or flanged edges must be uniform in height, since a varying welding speed, heavy beads

Flange

No gap. No filler rod. Maximum thickness 16 S.W.G.

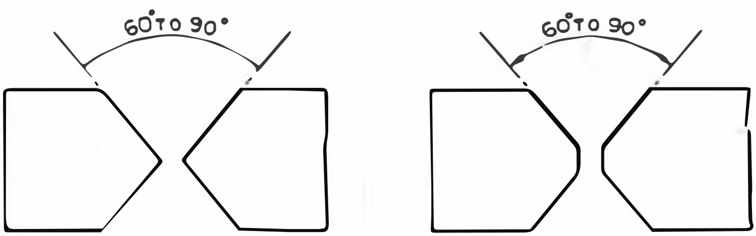
Square edge butt

Gap 0 in. to $\frac{1}{16}$ in. Thickness 18 to 10 S.W.G.



Single V

Suitable for one welder or, on thicknesses above $\frac{1}{4}$ in., one welder and one preheater.
Gap. $\frac{1}{16}$ in. to $\frac{1}{4}$ in. Thickness $\frac{1}{8}$ in. and over.



Double V

Suitable for two-operator vertical welding
Gap $\frac{1}{16}$ in. to $\frac{1}{4}$ in. Thickness $\frac{1}{4}$ in. to 1 in.
Seam must be accessible from both sides.

Fig. 11.—Edge preparation for the gas welding of copper sheet and plate.

and adhesion (instead of fusion) must be avoided. Bevelled edges must be uniform in depth and angle throughout the length of the seam, otherwise the quantity of weld metal and, therefore, the heat input and shrinkage, will vary. Buckling and distortion will also be excessive and the penetration will be irregular. The edges may be prepared by machining or by pneumatic chisel. Grinding must be followed by filing so as to remove all particles of grit. In cases where high strength is required, the thickness of metal at the joint may be increased by hammering and shaping the sheet edges pneumatically.

As regards the angle of the V, this should be as small as possible in order to save metal, heat and time, and to reduce shrinkage. The angle must be large enough, however, to achieve full fusion and penetration throughout the thickness of the base metal. The V-joint is used for joining plates exceeding $\frac{1}{8}$ in. in thickness and the included angle of the V should be 60°–90° for most copper-base materials.

Apart from correct edge preparation, alignment and spacing of the edges are very important if full penetration is to be achieved. Taper spacing is necessary for long seams, the gap gradually closing up as welding proceeds; but long seams should not be tack welded. (See pages 27, 28.) The rule for copper is to allow a $\frac{3}{16}$-in. gap per foot run.

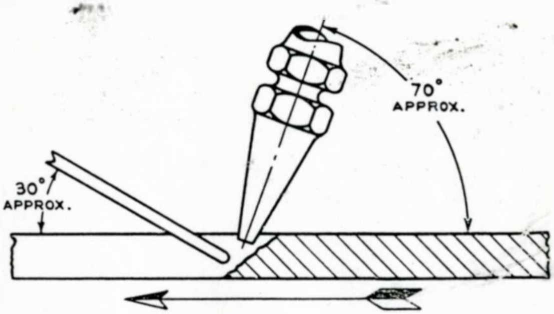
A method which has been found successful when welding longitudinal seams is to commence welding at a distance of about one-third of the total length from the end, the gap being maintained by means of a wedge or clamp. Welding should then be carried out throughout two-thirds of the length of the seam. Returning to the previous starting-point, the last third of the weld is then completed in the opposite direction.

The width of the gap at the point of welding should be just sufficient to permit full fusion of the edges of the joint. Any wedges or clamps will, therefore, have to be adjusted from time to time as the welder progresses along the seam, in order to allow for contraction.

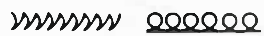
Copper or steel strips are suitable for backing plates. They may be provided with a groove under the seam of thick plates to ensure penetration. The undersides of backing plates are often covered with asbestos strip.

Gas Welding Techniques

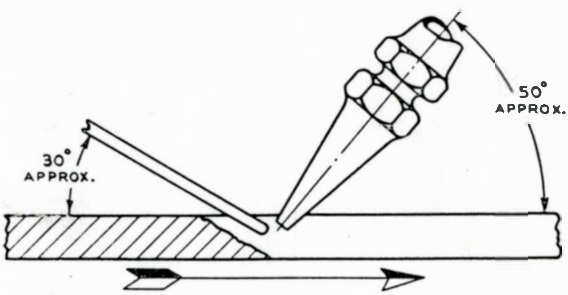
If possible, the down-hand position should be used, i.e. the work should be arranged so that the joint makes about 10° with the horizontal. The operator works above the joint and upwards along the slope. There is then little tendency for the molten metal to run over the unfused edges and through the gap. The operator may work from right to left (leftward welding), or from left to right (rightward welding). This terminology applies to a right-handed operator who would normally hold the blowpipe in his right hand. (A left-handed man would use the rightward method when welding from right to left, and vice versa.)



"Leftward" welding
Rod moves in straight line.



Motion of blowpipe often combined with slight up-and-down movement.



"Rightward" welding
Blowpipe moves in straight line.
(*Not usually applied to copper or copper alloys.*)

Fig. 12.—Leftward and rightward methods of welding.

Leftward Welding (see Fig. 12)

The welding rod, held in the left hand and moving in a straight line, precedes the blowpipe, which is given a rotary or semicircular progressive movement so as to obtain even fusion on both sides of the weld. Some operators prefer an up-and-down progressive movement of the blowpipe, allowing the ripples at the back of the pool to solidify while the front of the pool is kept fluid. The nozzle of the blowpipe should remain in line with the seam to ensure even heat distribution. This is the method usually employed for the gas welding of copper and its alloys.

Rightward Welding (see Fig. 12)

With the blowpipe in the right hand, but at a smaller angle with the work and moving in a straight line, the filler rod now follows behind and is given a weaving circular motion. This method is generally used for steel welding, on plates thicker than $\frac{3}{16}$ in. It is not very often applied to non-ferrous metals (which have a lower melting-point), in view of the heat concentration at the point of welding and the difficulty of maintaining control over the very fluid weld pool.

The chief difference between leftward and rightward welding lies in the control of the molten metal. Whereas leftward welding tends to force the molten metal forward on to the unfused edges, by the rightward method the weld metal is largely controlled by the uplifting force of the flame gases and by the movement of the filler rod. Since there is no lateral blowpipe movement, the heat is concentrated within the V-faces. The welding wire is melted more rapidly in front of the flame against a background of deposited weld metal and thus a higher welding speed can be achieved.

Vertical Welding

The welding of a vertical surface, preferably by the two-operator method (one operator on each side of the plate) generally proceeds from the bottom upwards, the rod preceding the blowpipe, as in leftward welding (see also pages 53, 54).

Overhead Welding

Whatever the parent metal, it is never easy to secure adequate penetration. Overhead welding of copper is difficult also because of its high fluidity and the necessarily large heat input. Therefore, if the work can be turned over, this should be done.

B. ARC WELDING*

The main processes are:—

(1) Metal Arc Welding, with flux-coated electrode.
(2) Carbon Arc Welding, with carbon electrode and uncoated filler rod.

Metal Arc Welding

This process also is so widely known as to require little description. A low-voltage high-current arc is struck between the work-piece and the tip of an electrode, which consists of a length of wire surrounded by a coating of flux. The wire may be of the same composition as the work-piece, or it may be alloyed with other elements to deoxidise the weld, promote fluidity, etc. The flux coating consists mainly of a mixture of chemicals, mineral and metal powders, chosen to suit the metal being welded, with a binding agent. The heat developed in the arc melts a small volume of each of the work-pieces, and also the tip of the electrode wire,

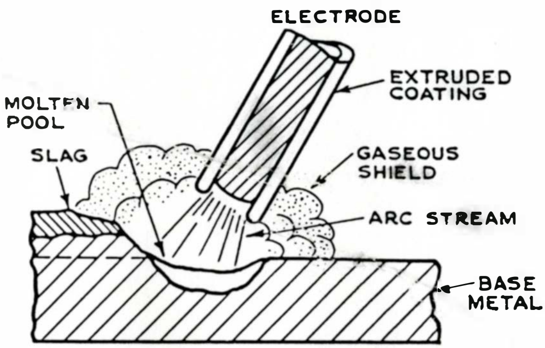


Fig. 13.—Diagram showing the metal arc welding process.

which is transferred to the molten pool between the work-pieces and helps to fill up the groove or angle between them. The flux coating is also melted and transferred to the molten pool, where it floats on the surface and protects the metal from contact with the air, and also reduces any oxides that may have formed in the arc.

For copper and copper alloys direct current is generally used, with the electrode positive. Two-thirds of the heat is developed near the positive pole, the temperature of the arc near this point exceeding 3500° C.,

* Several other arc welding processes are referred to in Chapter VIII.

On inspection, a limited amount of porosity may be expected, but root penetration must be complete and there must be no cracks or large inclusions. Radiographic inspection may be specified for high-grade work.

*Joints in Tubes**

Owing to the high conductivity of copper, the portions of pipe in the neighbourhood of the joint must first be thoroughly preheated. The joint is then "tack-welded" in two or three spots to hold the pipes in alignment while the rest of the weld is made. Starting from a "tack," welding proceeds round the pipe by the local fusion of both pipe ends and filler rod or by the melting down of the flanges. At the end of the operation, it may be necessary to fill the small cavity which sometimes occurs at the starting- and finishing-points of the weld. Joints made on the bench can, of course, be rotated so that welding takes place on the top only. Welding *in situ* is more difficult, especially at the underside and back of a horizontal pipe which is near a wall. In such cases there will be less risk of burning holes if the joint is prepared with a spigot and socket, and welded with a filler rod. Finished joints, if properly executed, have a surface of regular waves, as indicated in Fig. 28, due to the repeated application and removal of the rod as the weld proceeds. The width of joints in light gauge tube need not be more than about $\frac{1}{4}$ in. to $\frac{1}{2}$ in., depending on tube diameter and wall thickness.

Welding of Locomotive Fireboxes

In some workshops of British Railways, the following practice is adopted when repairing copper fireboxes. The worn half side-plates are cut out and new plates are welded in, without removing from the steel shell the remainder of the single sheet, which originally formed the firebox crown and sides.

When fitting a complete new copper firebox to a boiler under repair, it is not possible, in some cases, to introduce the complete box into the steel shell owing to their relative shapes and because of the small space between the copper and steel plates. The copper wrapper, consisting of the crown and sides is, therefore, made in two pieces which, after having been placed in position inside the steel shell, are joined by welding along the central seam in the crown.

The edges of the plates, which may be $\frac{1}{2}$ in. to $\frac{3}{4}$ in. thick, are machined to form a single bevel joint with an included angle of about 90°. A special type of copper backing bar, of section as shown in Fig. 29, A, which permits

* *See also* C.D.A. Publication No. 25, *Copper Pipe-Line Services in Building.*

full root penetration, is placed underneath the joint, supported in turn by a layer of asbestos and a steel plate. The copper backing bar remains welded to the plates and enhances the strength of the joint. Copper end pieces, provided with a special cavity, as shown in Fig. 29, B, are placed across the ends of the seam, their purpose being to prevent the molten metal from running out of the joint. These plates are cut off afterwards.

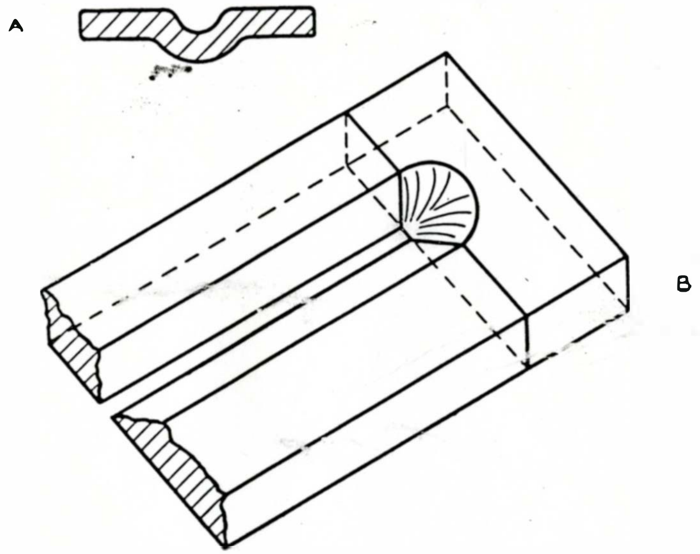


FIG. 29, A.—Section of copper backing bar; B.—Copper end piece.

With the seam horizontal, the plates are clamped in such a way that a tapering gap allows for expansion. As the gap closes up during welding, the clamps are adjusted.

The welders take up their position in the firebox, one in line with the seam and the other alongside it. After heating up the parent metal for a short period, the first operator begins to melt the metal near the root of the joint and proceeds to deposit metal from his filler rod. He is followed by the other welder, who melts the sides of the V-joint higher up and completes the filling-up process with his own rod. The distance between the two blowpipes may only be 1 in. to 1½ in. and before long they

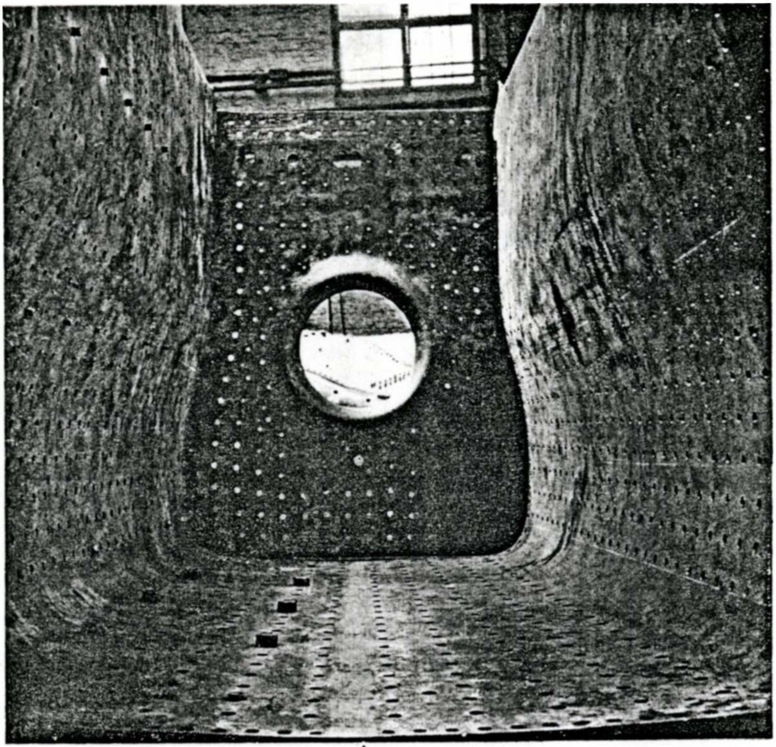


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FIG. 30.—Locomotive firebox. A completed and dressed weld in the crown of a replacement copper box. (*By courtesy of the Railway Executive.*)

are moving ahead of a pool of molten metal about 3 in. long. Sand is thrown by a labourer on the seam as it solidifies, in order to protect the joint from the atmosphere. After having welded about 3 ft. of the seam, the operators are relieved by two others who continue the work immediately without allowing the pool to solidify.

The work is allowed to cool down, after which the joint is dressed by means of a pneumatic hammer and chisel. It is finally hammered and is brushed with a wire brush until the surface is level and smooth.

In another British Railways workshop the design of copper fireboxes is such that new fireboxes can be built separately and fitted to the boiler without the need for welding. With the high scrap value of copper, complete replacement of plates is often more economical than heavy repairs.

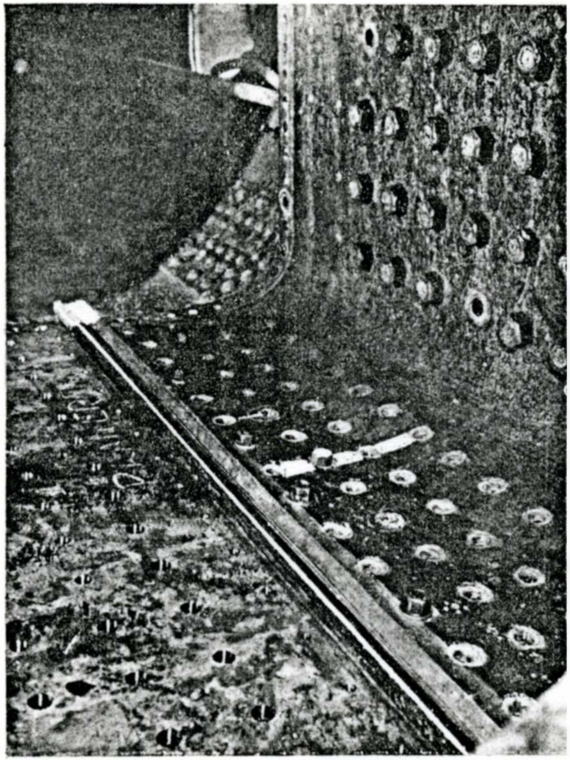

FIG. 31.—Locomotive firebox. New copper half side-plate in position for welding.
(*By courtesy of the Railway Executive.*)

FIG. 32.—Locomotive firebox. Welding in progress on the joint between half side-plate and crown shown in the previous photograph.
(*By courtesy of the Railway Executive.*)

Extensive use is made of copper welding, however, for such repairs as replacing worn three-quarter wrapper side-plates, building up wasted fire-door and tube plate flanges, cutting away and welding flange radius cracks and welding tube plate bridge cracks. When a three-quarter side weld is made with the fire-door plate or tube plate in position, access to the ends of the seam is provided by cutting out a half-moon piece from the fire-door or tube plate flange, a new piece of plate being subsequently welded into the flange.

When welding the longitudinal seam of three-quarter sides, a steel backing bar with a machined groove of semicircular section is used, permitting root penetration. With the seam horizontal, the plate is clamped in such a way that a tapering gap allows for expansion. The work is carried out by the rightward welding method. No flux is used. The welder is preceded by a preheater. After about 6 in. of the seam has been filled up, the blowpipes are extinguished and the hot metal is immediately given blows from the round heads of light hand hammers. At dull red heat, a pneumatic hammer is applied until the appearance of the metal is black. Welding is then resumed in stages as before, the technique being an adaptation of welding intermittently by the two-operator vertical method. The surface of the finished weld may be wire brushed, after which very little chipping and grinding should be necessary. End plates, as previously described, are placed across the beginning and the end of the seam. They are cut off after welding.

The strength of the welds produced in British Railways workshops is nearly the same as that of annealed copper. The working pressures on the outside of copper fireboxes may be up to 280 lb./sq. in., and test pressures considerably exceed this figure. When, after years of reliable service under arduous conditions, copper fireboxes are in need of repair, it is in large measure due to welding that they can be given a new lease of life.

Arc Welding Deoxidised Copper

In this country, autogenous welding of copper is at present carried out almost entirely by the oxy-acetylene process. The most promising of the arc welding methods seems to be the inert-gas shielded arc process, which has reached an advanced stage of development (see Chapter VIII).

Some difficulties are encountered when welding autogenously with the metal or the carbon arc. Good results can, however, be obtained when alloy electrodes and filler rods are used. In contradistinction to "bronze

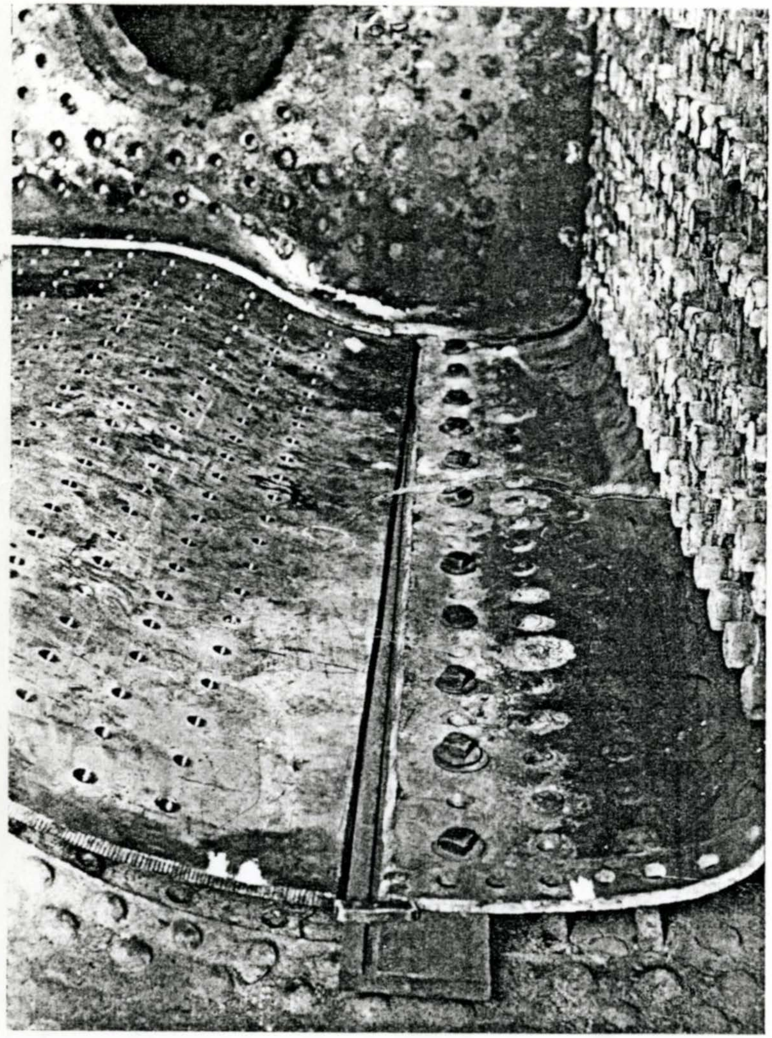

FIG. 33.—Locomotive firebox. View, from barrel, of the three-quarter wrapper side-plate set up for welding. Note the half-moon piece cut from the flange of the copper firedoor plate to permit access to the far end of the weld. The copper tube plate has been removed. (*By courtesy of the Railway Executive.*)

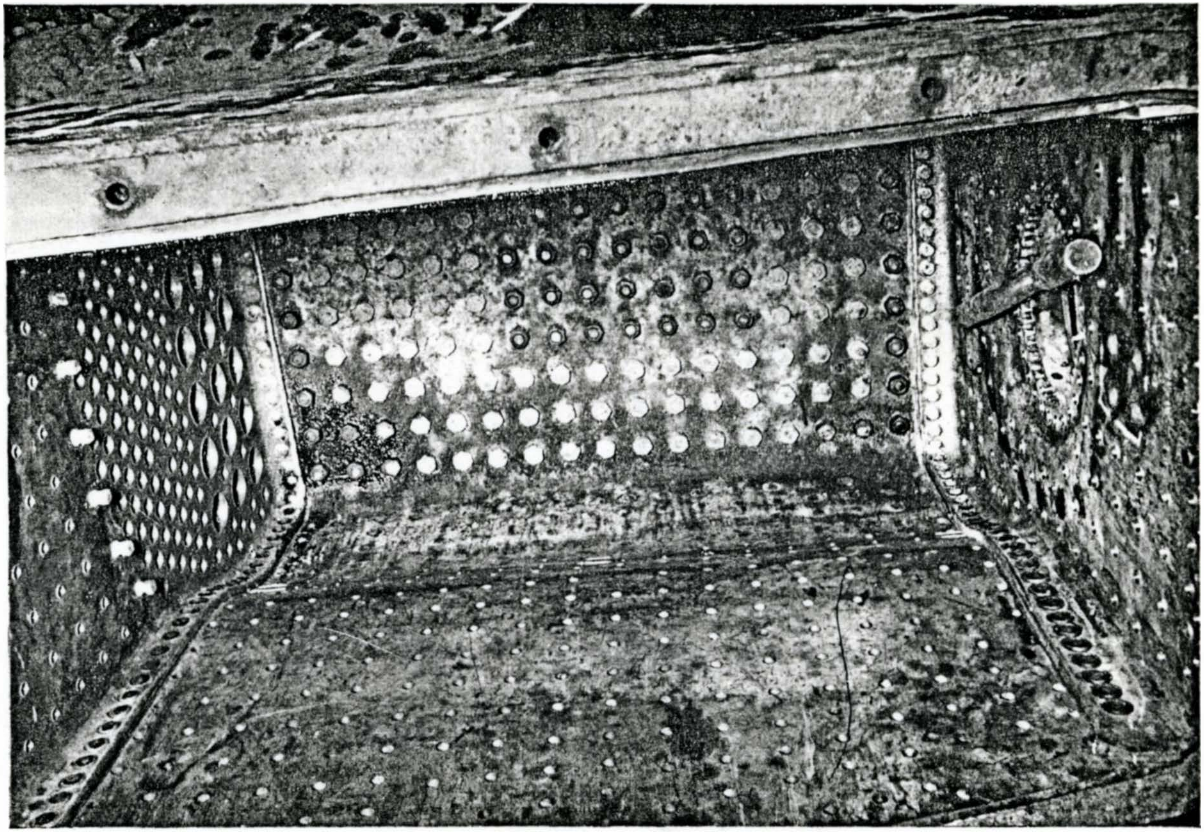

FIG. 34.—Locomotive firebox. New three-quarter wrapper side-plates having been welded into position, the repair is completed by fitting a new tube plate and a new door plate. (*By courtesy of the Railway Executive.*)

welding" by gas, fusion of the parent metal is generally essential in arc welding and bronzes are used for the rods, not brasses.

A material of low conductivity, such as steel, can be arc welded satisfactorily at a comparatively high speed and usually less skill is required than for gas welding. Owing to the high thermal conductivity of copper, however, a larger heat input is required which necessitates some preheating and higher currents. An additional disadvantage is the ease with which gases are absorbed by the metal at the high temperature of the arc, resulting in porous welds.

Progress continues to be made with the arc methods of welding copper. There is scope for an arc welding process which will produce a weld deposit of strength, conductivity and corrosion resistance equal to that of the parent metal. A pure copper deposit would probably be best, but so far it does not seem to have been possible to produce one, by arc welding, free from porosity and of adequate strength. The nearest approach appears to be a silicon deoxidised copper, essentially pure but containing a little more silicon than is required for deoxidising. In the U.S.A., welds made with electrodes of this type have been found to have tensile strengths (unhammered) of up to 11½ tons/sq. in., as compared with upwards of 14 tons/sq. in. for annealed copper. The conductivity of silicon-copper is 80 per cent I.A.C.S. for 0·05 per cent silicon content and 64 per cent I.A.C.S. for 0·1 per cent content. If high conductivity is important, it is clear that the weld may contain no more than traces of silicon. Of course, some silicon is lost during welding by oxidation, but it might be possible to design an electrode and, with suitable technique, to produce a weld containing 0·05 per cent silicon or less, with properties closely approaching those of pure copper.

Tests show that sound welds made by carbon arc welding with alloy filler rods have a tensile strength equal to that of annealed copper, and this may be raised slightly by cold-hammering.

In view of the dearth of authentic information on the subjects of metal and carbon arc welding of copper, the recommendations given must necessarily be of a tentative nature. Deoxidised copper to British Standards 1172 and 1174 can be arc welded satisfactorily. As regards joint preparation, some notes will be found in Chapter II, pages 36, 37.

Metal Arc Welding

Electrodes.—The use of coated electrodes offers definite advantages. The coatings usually consist of patented chemical mixtures and their functions