# OXY-ACETYLENE WELDING

With a Chapter on Oxy-Acetylene Cutting

BY

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WITH 43 ILLUSTRATIONS IN THE TEXT

CASSELL AND COMPANY, LTD
London, Toronto, Melbourne and Sydney

First published *October* 1918.
*Reprinted* *March* 1919.
" *January* 1920.
" *January* 1921.
" *June* 1924.
*May* 1927.

*Printed in Great Britain*

# EDITOR'S PREFACE

THIS Handbook is offered as a workshop guide to the arts of welding and cutting metal with the oxy-acetylene blowpipe. Its authors are Mr. T. Newton, an engineer, and Mr. A. Eyles, a workshop foreman, the latter being responsible for the three chapters relating to the jointing of aluminium and aluminium alloys.

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# OXY-ACETYLENE WELDING

## CHAPTER I

### Introduction—The Oxy-acetylene Flame

**Introduction.**—The term " welding " is now commonly employed to denote the modern process of uniting metals by fusion. In former days it had a limited signification, and rarely meant more than the uniting of two pieces of wrought-iron or steel after heating them to the temperature at which they became plastic. Nowadays, by means of the heat of the oxy-acetylene flame, the electric arc, etc., in addition to iron and steel such commercial metals as cast-iron, copper, aluminium, lead, and many alloys, can be successfully welded. The new welding is often differentiated as " fusion " welding, " autogenous " soldering or welding, or " burning," but as this book is limited to the chief method of effecting fusion welding, its title is limited to the name of the most important of the modern welding processes—the oxy-acetylene, which is executed by means of a blowpipe in which acetylene and oxygen are burnt together under pressure.

The term " fusion " is self-explanatory: the two pieces of metal are fused together. The term " autogenous," on the other hand, may not be so easily understood. Its dictionary meaning is "self-produced." But the word may also mean "of the same kind," and was applied to this form of welding by the Swiss engineer Schoop, because only metal of the same kind as the articles to be joined was employed for making the joint.

The term "soldering" in this connection may be misleading, as the surfaces to be united are actually fused or melted, thereby causing them to flow together; thus the process is more akin to welding than to soldering proper. As is well known, soldering, strictly speaking, is suitable for only small or light work that is not exposed to high temperatures, as the melting point of soft solders is rarely much more than 400° F.

In the case of jointing lead, iron and steel, the term "autogenous welding" may be considered strictly appropriate; but in the case of aluminium, brass, copper, and cast-iron, the employment of a flux is absolutely necessary; hence the term may not be regarded as quite an accurate one. Probably there is no term that conveys all the ideas involved.

Oxy-acetylene welding has made such phenomenal progress during recent years, and has proved so highly successful in almost every conceivable set of circumstances and conditions (both as regards new work and repair work) that it is universally recognised as an important branch of modern engineering. The claims made on behalf of the system are many and varied, but they are all capable of demonstration; and many welding operations are being constantly performed to-day that were simply undreamt of a few years ago. Some idea of the usefulness and adaptability of the system may be gathered when it is stated that by means of the oxy-acetylene blowpipe it is now possible to weld together steel plates 1¾ in. thick, or to repair a fractured cast-iron flywheel, a cracked motor cylinder, or the fractured water-jacket of a gas-engine cylinder; to weld together a spray of sheet-iron leaves to form part of some artistic ironwork; or to add metal to take the place of that worn away by excessive wear and tear, or by friction.

In large establishments the oxy-acetylene system of welding has been advantageously employed in the manufacture of steel safes, boilers, tanks, metallic car wheels, cylindrical tubes, tee-pieces, breeches pieces, branch connections, parts of locomotives and automobiles, etc. etc. In the manufacture of iron hollow-ware, artistic ironwork, and as a substitute for riveting and brazing, the oxy-acetylene blowpipe can be most effectively and profitably employed.

In small repair shops an oxy-acetylene apparatus will be found invaluable for repairing fractures in wrought-iron, steel, cast-iron, copper, brass, bronze, or aluminium articles, which, in the light of our knowledge of this system of welding, are more likely to be repaired in future than scrapped to make room for new ones.

**The Oxy-acetylene Flame.**—The oxy-acetylene system of welding is a method of fusing metal in a given place by means of the combustion of acetylene in oxygen by means of a specially designed blowpipe. The temperature of the flame is intense, registering as high as about 6,000° F. or 3,315° C. at the tip of the luminous inner cone—the part of the flame that is employed for the actual welding process—and this temperature is second only to that of the electric arc.

It is possible to adapt the flame for melting the contents of a crucible. This should have a cover and should be enclosed in a muffle. Then the oxy-acetylene flame may be used as a source of heat to raise the temperature of the muffle. In the event of a muffle not being available, build a quantity of small pieces of firebrick round the crucible, in order to conserve the heat.

The modern art of welding with the oxy-acetylene blowpipe flame is now extensively used, possibly on account of the simplicity of the apparatus and the small amount of experience demanded from the operator. The worker is cautioned, however, not to consider himself a welder as soon as he has finished reading this book. In order to attain proficiency and certainty, he should go through a period of actually trying out his newly acquired knowledge on work of little or no value.

Acetylene ($C_2H_2$) is what is known as an endothermic gas, that is, it is a compound gas that evolves heat when it is decomposed, and this accounts to a great extent for its high flame temperature. When the combustion of acetylene takes place in oxygen, the resultant products are carbon dioxide and water vapour. But the heat generated, including the heat liberated due to the endothermic nature of acetylene, is so intense as to preclude the formation of water vapour round the luminous inner cone of the flame, hence one of the constituents of water (hydrogen) is free to burn round this luminous inner cone (which it does), thus protecting it from the cooling effect of the atmosphere. Incidentally, this envelope of hydrogen round the inner cone of the flame is a distinct advantage in connection with all welding operations, since the flame is thereby rendered a reducing, rather than an oxidising flame. In other words, the nature of the flame is such that, generally speaking, the formation of oxide, scale, etc., is prevented.

The oxy-acetylene flame is superior to the oxy-hydrogen flame (used for "lead burning," limelight, etc.), inasmuch as when the gaseous carbon constituent ($C_2$) of acetylene ($C_2H_2$) is burnt in oxygen, it produces more heat than when hydrogen is similarly burnt; and, in addition, there is also heat liberated when the acetylene is decomposed into carbon and hydrogen.

The combustion of *hydrogen* in oxygen yields about 345 B.T.U.'s (British Thermal Units) per cubic foot, but only half of this heat (approximately) is available for welding purposes; whereas the combustion of *acetylene* in oxygen yields 1,500 B.T.U.'s per cubic foot, and a comparison with the foregoing may be made when it is stated that the calorific value of coal-gas is about 500 B.T.U.'s per cubic foot.

The physical characteristics of the oxy-acetylene blowpipe flame, namely, the structure, size, shape, and colour, form a somewhat rough and ready though reliable index as to the relative amount of acetylene and oxygen which is present in the flame itself. Thus, what is known as a *neutral* flame (that is, a correctly adjusted flame in which neither gas is in excess of actual chemical requirements for complete combustion, so producing perfect chemical combination) is indicated by the distinct definition of a white inner cone against the remainder of the flame, varying in length according to the size of the blowpipe. This flame is rather pale owing to the absence of free carbon, and it is of a slightly reducing character owing to the absence of free oxygen. And the general structure of the flame, medium as regards length, pale as regards colour, with a sharply defined vividly white inner cone, is evidence of an almost perfect chemical combination of both gases which is essential for all ordinary welding operations.

The informative tables on pp. 7 and 8 have been prepared by the Acetylene Illuminating Company, Limited, showing the relationship between the consumption of acetylene per hour and the length of the white inner cone of the flame shown by Fig. 1. The pressures and consumptions of both gases are also given, together with the approximate speeds of welding various thicknesses of metal; and the blowpipe tip number corresponds to the consumption of acetylene in litres per hour. This, it will be observed, refers to the high-pressure oxy-acetylene process (both of the gases from cylinders), which will be dealt with in a later chapter.

HIGH-PRESSURE OXY-ACETYLENE PROCESS. DISSOLVED ACETYLENE (D.A.) SYSTEM.

| Consumption of acetylene per hour in litres. | Approximate length of cone. | Consumption of acetylene per hour in litres. | Approximate length of cone. |
|---|---|---|---|
| 50 | 6 m/m | 500 | 10 m/m |
| 75 | 6·5 m/m | 750 | 11 m/m |
| 100 | 7 m/m | 1000 | 12 m/m |
| 150 | 7·5 m/m | 1500 | 13 m/m |
| 225 | 8 m/m | 2000 | 14 m/m |
| 350 | 9 m/m | 2500 | 15 m/m |

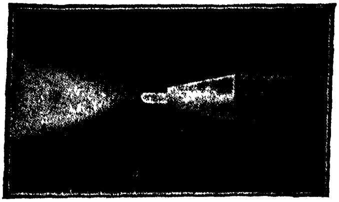


**Fig. 1.—Correct Condition of Oxy-acetylene Flame; the white inner cone is evidence of a neutral flame**

An excess of acetylene in the oxy-acetylene blowpipe flame causes the inner cone to lose its distinct outline, and this results in a long, brilliant flame of reduced temperature. Moreover, the presence of free carbon in the flame not only discolours the work in hand, but it also tends to carbonise, and thus harden, the welding seam—an altogether undesirable result. A flame having an excess of acetylene is therefore known as a "*carbonising* flame."

An excess of oxygen in the flame produces oppo-

APPROXIMATE CONSUMPTION OF GASES AND WORKING PRESSURES REQUIRED FOR THE VARIOUS TIPS.

| Blowpipe tip No. | | 50 | 75 | 100 | 150 | 225 | 350 | 500 | 750 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|
| Acetylene | Cubic feet per hour. | 1·75 | 2·66 | 3·5 | 5·25 | 7·75 | 12·25 | 17·28 | 26·25 | 36 |
| | Pressure in lb. per sq. in. ........ | 2 | 2 | 2 | 2 | 2½ | 3 | 4 | 4 | 7½ |
| Oxygen | Cubic feet per hour. | 2·33 | 3·25 | 4·25 | 7 | 11·375 | 16·125 | 24 | 36 | 46 |
| | Pressure in lb. per sq. in. ........ | 4 | 4 | 4 | 4 | 4½ | 5 | 7½ | 7½ | 15 |
| Approximate thickness for most economical results.... | | 1/32 in. | 1/24 in. | 1/16 in. | 1/12 in. | 1/8 in. | 3/16 in. | 1/4–5/16 in. | 5/16–1/2 in. | 9/16–1 in. |
| Approximate speed of welding—Linear feet per hour...... | | 30 to 35 | 30 to 35 | 20 to 30 | 12 to 20 | 8 to 12 | 6 to 8 | 4 to 6 | 3 to 4 | 1 to 3 |

site effects. Instead of being long and brilliant the flame becomes short and pale. The bright inner cone loses its intense whiteness and assumes a violet colour. When the flame is applied to metal, sparks are generated (the metal burns) on account of the presence of free oxygen in the flame, and a general oxidising effect is produced which is injurious to the metal. Therefore a flame having an excess of oxygen is known as an "*oxidising* flame."

Goggles with coloured glasses should be worn by the operator when executing welds by the oxy-acetylene process, to protect the eyes not only from the intense light, but also from the fine slag-like substance that is formed during the welding operation. The operator may also need leather face protection.

# CHAPTER II

## The Oxy-acetylene Blowpipe Described

THERE are two kinds of oxy-acetylene blowpipes, one for use with acetylene under pressure, the other to take acetylene as it comes from an ordinary generator or gas-bell. In both cases the oxygen is under pressure as customary with all oxy-blowpipe work. For portability the flasks of dissolved acetylene (see p. 49) are usually the more convenient, and then the blowpipe must be suitable for acetylene under pressure; but when it is possible to use acetylene direct from a generator (as it is in general workshop practice and some outdoor jobs), then it is considered better to do so. The blowpipe, however, has then to be of a different kind from the other; it must be suitable for low-pressure acetylene with high-pressure oxygen. In this essential detail it resembles low-pressure coal-gas blowpipes, in the fact that it works on the principle of an injector, the gas at the higher pressure drawing or carrying in the gas at the lower pressure.

To secure the best results the blowpipe should be properly designed and correctly proportioned in all its several parts. The blowpipe should be provided with two taps—one to control the oxygen, and the other to control the acetylene. The first satisfactory welding "burner," "torch," or blowpipe, is due to a French engineer named Fouché; but since then, design and construction have progressed considerably, until to-day the appliance is all that can reasonably be desired.

In the early days the problem to be solved was how to design and construct a satisfactory oxy-acetylene blowpipe which would not back-fire. An ordinary blowpipe would not answer at all, chiefly because the ignition velocity of the explosive mixture of acetylene and oxygen is greater than the velocity

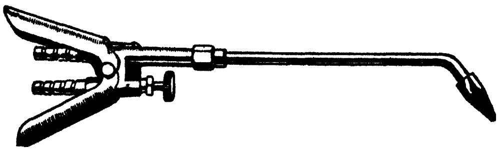


**Fig. 2.—"Kayron" Blowpipe, High Pressure or Low Pressure**

of these gases as they issue from the nozzle of an ordinary blowpipe; hence the explosive wave would travel back and result in back-firing the gas. Therefore it will be seen that the tendencies just alluded to must be completely reversed in any form of oxy-acetylene blowpipe before the latter can be deemed satisfactory. Obviously, no attempt should be made to use any blowpipe for autogenous welding except those specially made for the purpose. Many ingenious experiments have been made from time to time, and the results of successful experiments have been embodied in different types of blowpipes. Thus, one type of blowpipe has the mixing chamber located in the handle, whereas another has the mixing chamber in the burner head (in which the injector principle is very advantageously employed).

Fig. 2 represents the "Kayron" blowpipe made by the Acetylene Illuminating Company, Limited, and designed for use where repetition work of set thicknesses is undertaken, a different blowpipe being supplied for welding each thickness. The handle consists of two hollow pieces of nickel-steel forming a sheath, inside which the nozzles for the gas inlets are connected to the flexible tubes. The weight being held in the hand, a perfect balance is thus obtained. This blowpipe may be used with equal efficiency with either the low- or the high-pressure system. It is light and easy to handle, while the simplicity of its design makes it almost impossible to get out of order. After lighting the acetylene flame the oxygen is then

**THE "KAYRON" BLOWPIPE**

| No. | Capacity. | | Thickness to be Welded. | Pressure of Oxygen. | Weight (Copper). | |
|---|---|---|---|---|---|---|
| | Acetylene cub. ft. | Oxygen cub. ft. | in. | lb. per sq. in. | lb. | oz. |
| 0 | $1\frac{3}{4}$ | 2 | $\frac{1}{32}$ | 11·3 | 1 | 0 |
| 1 | $2\frac{1}{2}$ | 3 | $\frac{1}{32}$—$\frac{1}{16}$ | 14·2 | 1 | $0\frac{1}{2}$ |
| 2 | $5\frac{1}{4}$ | 6 | $\frac{3}{32}$ | 14·2 | 1 | 1 |
| 3 | 8 | $8\frac{3}{4}$ | $\frac{1}{8}$ | 14·2 | 1 | 1 |
| 4 | $10\frac{1}{2}$ | $12\frac{1}{4}$ | $\frac{3}{16}$ | 14·2 | 1 | 2 |
| 5 | $15\frac{3}{4}$ | $17\frac{3}{4}$ | $\frac{1}{4}$ | 17·7 | 1 | 5 |
| 6 | 21 | 23 | $\frac{5}{16}$—$\frac{7}{16}$ | 21·3 | 1 | 7 |
| 7 | 35 | 38 | $\frac{1}{2}$ | 22·6 | 1 | 8 |
| 8 | 52 | 59 | $\frac{3}{16}$—$\frac{5}{8}$ | 25·5 | 1 | 9 |
| 9 | 87 | 96 | $\frac{3}{4}$—1 | 28·4 | 1 | 12 |

turned on, and the flame is correctly adjusted by means of the milled screw until the white cone

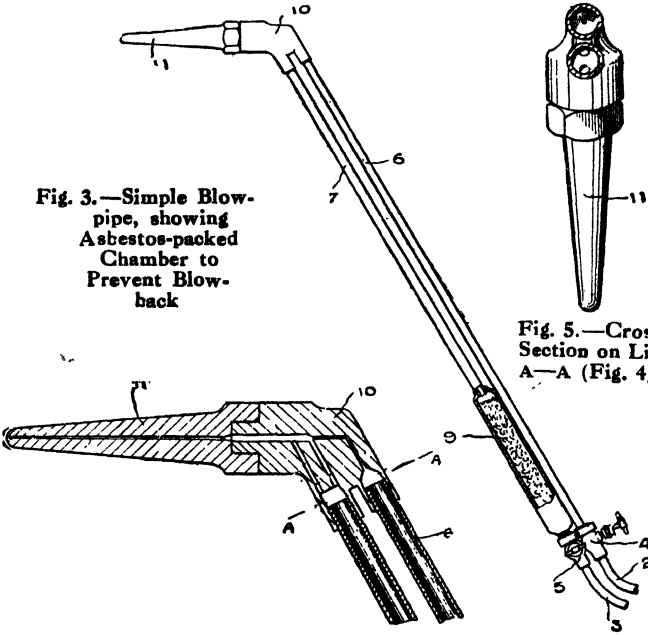



**Fig. 3.—Simple Blowpipe, showing Asbestos-packed Chamber to Prevent Blowback**

**Fig. 5.—Cross Section on Line A—A (Fig. 4)**

**Fig. 4.—Section through Head of Blowpipe**

appears. The particulars in the table on p. 12 (supplied by the company) are self-explanatory:

Many blowpipes are provided with special chambers to prevent blow-back, or back-fire. For example, Figs. 3 to 5 show a device invented by T. B. Montgomery and A. Lochok, two acetylene welders. It has extreme simplicity, the gases meeting in a one-piece combining head through which simple direct ducts communicate with a combining passage which delivers the gases to the tip. This tip is formed as a removable part to allow of the size of the flame being varied; 2 and 3 represent the nipples to which the flexible hose pipes of the oxygen and acetylene gas supply are connected; these nipples have ordinary needle valves 4 and 5 which are connected to the head 10 by lengths of tubes 6 and 7. The acetylene tube 7 has an enlarged chamber 9, close to the valve, charged with asbestos wool to check blow-back. Into the head of the blowpipe is screwed the nipple 11.

A blowpipe having interchangeable tips is the "Cyclops" (Acetylene Manufacturing Co., Ltd.). This blowpipe (see Fig. 6) has twelve interchangeable tips which are graded for welding metals varying in thickness from $\frac{1}{32}$ in. to $1\frac{1}{4}$ in. or more. It is made in three sizes, A, B, and C, and can be used with either the low- or high-pressure system. The construction of this blowpipe is of patented design, and it is claimed that the risk of back-firing is eliminated and the correct admixture of the gases ensured. The range of each tip is not strictly confined to the thicknesses given in the table on p. 15, but depends on the mass of metal being dealt with and the skill of the operator.

Reference has been made to the embodiment of the injector principle in blowpipe design, and Figs. 7 to 9 illustrates the "Universal" blowpipe—an appliance of this type—which is made by the British Oxygen Company, Limited. One positive and desir-

## TABLE I

CONSUMPTION OF GAS AND THICKNESSES OF METAL CORRESPONDING TO THE VARIOUS TIPS OF THE "CYCLOPS" BLOWPIPE.

| Number | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Approx. consumption per hour in cubic feet. | Acet. | $1\frac{3}{8}$ | $2\frac{1}{4}$ | $3\frac{1}{2}$ | $5\frac{1}{2}$ | 8 | $12\frac{1}{2}$ | 18 | 27 | 36 | 54 | 72 | 89 |
| | Oxy. | $1\frac{3}{4}$ | $3\frac{1}{2}$ | 5 | $7\frac{1}{4}$ | $10\frac{1}{4}$ | $16\frac{1}{4}$ | 24 | 36 | $46\frac{1}{2}$ | 72 | 95 | 118 |
| Thickness of Iron and Steel plate which can be welded by these tips. | S.W.G. | 25 | 19 | 18 | 14 | 10 | 10—5 | 5—2 | — | — | — | — | — |
| | In. | $\frac{1}{32}$ | $\frac{3}{64}$ | $\frac{1}{16}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{1}{8}$–$\frac{7}{32}$ | $\frac{7}{32}$–$\frac{9}{32}$ | $\frac{9}{32}$–$\frac{3}{8}$ | $\frac{3}{8}$–$\frac{9}{16}$ | $\frac{9}{16}$–$\frac{3}{4}$ | $\frac{3}{4}$–1 | 1–$1\frac{1}{4}$ |

Tips Nos. 1 to 5 can be used with Model "A" Blowpipe.
" 4 " 9 " " "B" "
" 10 " 12 " " "C" "

able result of the employment of the injector type of blowpipe for low-pressure acetylene in conjunction with oxygen at a higher pressure is the creation of a vacuum or "pull" on the acetylene in the holder, and this "pull," operating towards the direction of the flame, overcomes the velocity of ignition, thus obviating the danger and inconvenience of constant and persistent back-firing. A special feature of this blowpipe is the bent head and the metal-to-metal swivel joint with the injector elbow. This universal joint

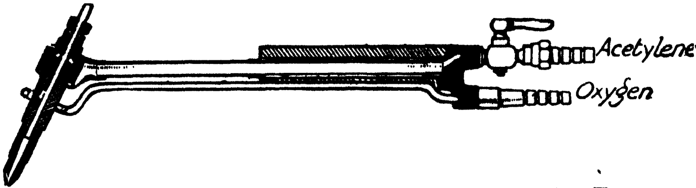



**Fig. 6.—"Cyclops" Blowpipe with Interchangeable Tips, for High or Low Pressures**

enables the nozzle of the blowpipe to be turned to any desired angle relative to the handle without even extinguishing the flame, in which position it may be fixed by simply tightening the mill nut A by hand. The advantages are obvious, and will appeal to those operators who have to execute difficult welding repairs in awkward and somewhat inaccessible parts of boilers and other structures. By screwing back altogether the milled nut A, the bent nozzle-head can be removed and all the essential parts of the blowpipe can be inspected and, if necessary, cleaned. The makers claim that the injector and other passages and profiles of this blowpipe have been carefully proportioned to give the best results; consequently the blowpipe is light and well balanced in all sizes, and can be used with equal facility and efficiency for either the low- or high-pressure welding systems. The table

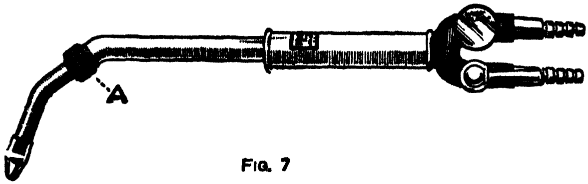



FIG. 7

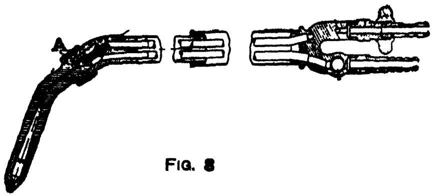



FIG. 8

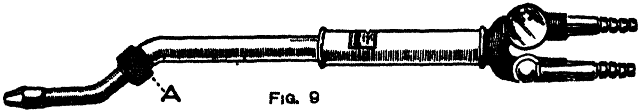



FIG. 9

**Figs. 7 to 9.—The "Universal" Blowpipe, working on the Injector principle, for use with Low-pressure Acetylene**

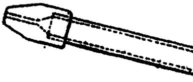
on p. 18, supplied by the company, gives average results obtained when working on cold steel plates, and, of course, in the thicker section, a considerable saving of gas can be effected by resorting to pre-heating in the vicinity of the joint.

Two other of the many proposed arrangements for producing an injector effect in the blowpipe will now be illustrated. Fig. 10 is a section through a blowpipe

TABLE II

APPROXIMATE CONSUMPTION OF GAS, PRESSURE OF OXYGEN, AND THE THICKNESS OF MILD STEEL PLATE, FOR THE WELDING OF WHICH EACH SIZE OF "UNIVERSAL" BLOWPIPE IS BEST ADAPTED.

| Size of Blowpipe. | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Approximate thickness of plate joint. | | $\frac{1}{32}$ in. | $\frac{3}{64}$ in. | $\frac{3}{32}$ in. | $\frac{1}{8}$ in. | $\frac{3}{16}$ in. | $\frac{9}{32}$ in. | $\frac{3}{8}$ in. | $\frac{1}{2}$ in. | $\frac{3}{4}$ in. | 1 in. |
| Approximate consumption of gas per hour in cubic feet. | Oxygen | c. ft. 1·75 | c. ft. 3·0 | c. ft. 6·5 | c. ft. 9·0 | c. ft. 16·0 | c. ft. 23·0 | c. ft. 34·0 | c. ft. 48·0 | c. ft. 75·0 | c. ft. 100·0 |
| | Acetylene | c. ft. 1·2 | c. ft. 2·0 | c. ft. 4·5 | c. ft. 6·3 | c. ft 11·2 | c. ft. 16·0 | c. ft. 24·0 | c. ft. 34·0 | c. ft. 52·0 | c. ft. 70·0 |
| Pressure of oxygen in lb. per sq. in. | | 8 | 10 | 11 | 12 | 14 | 16 | 19 | 21 | 25 | 30 |



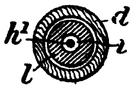



Fig. 11.—Section on Line 2—2 (Fig. 10)

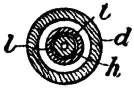



Fig. 12.—Section on Line 3—3 (Fig. 10)


Fig. 13.—Section on Line 4—4 (Fig. 10)

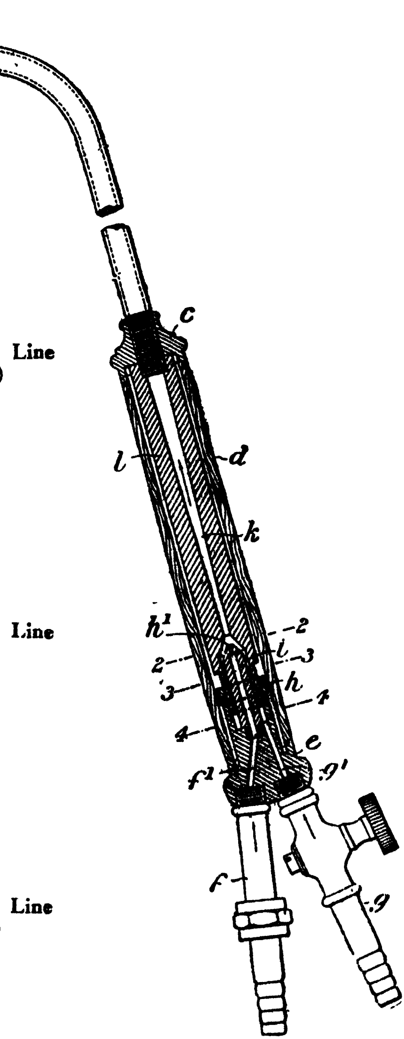



Fig. 10.—Thorp & Hoddle Low-pressure Blowpipe

introduced by the Thorn & Hoddle Acetylene Company, Limited. Figures 11, 12 and 13 are cross sections respectively on the lines 2-2, 3-3 and 4-4. There is the usual tube with nozzle at one end, and fitted at the other end with the cap *c* attached to the cylindrical wooden handle *d*; *e* is a plug fitted to the other end of the handle, and *f* and *g* are the external supply pipes or tubes for the oxygen and acetylene. Tube *f* leads into the passage $f^1$, and tube *g* into passage $g^1$. A hollow injector device *h* is screwed into a recess in the inner end of the plug *e*, and provided with the outlet orifice $h^1$. The fitting *l* is screwed into the recess in the plug *e*, and passes completely through the handle *d*. Oxygen is supplied under pressure to the pipe *f*, whence it passes through passage $f^1$ into the injector device *h*, through the orifice $h^1$ of which it issues, thereby drawing acetylene gas through pipe *g* and passage $g^1$ into the annular space *i*, the two gases there mixing and flowing in the direction of the arrow (Fig. 10) into the passage *k*, and finally to the blowpipe nozzle.

The Acetylene Dissous & Applications l'Acetylene, of Paris, are responsible for the next low-pressure blowpipe to be here shown (see Fig. 14). This blowpipe contains an injector A having a central orifice O for the supply of the oxygen under pressure, the orifice being varied by means of a conical needle B, adjusted by handwheel V. To protect this orifice from the effects of careless operation, needle B has an enlargement at C which abuts on the seat D only when the needle completely closes the orifice; acetylene at low pressure is supplied through E where it is drawn in by injector

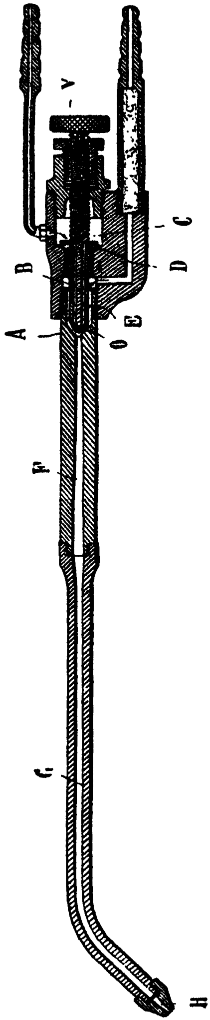



Fig. 14.—A French Low-pressure Blowpipe on the Injector Principle

action, mixed with the oxygen, and carried through the conical channel F, whence a tube G leads to the nozzle. To suit the requirements of any different sized nozzle that may be fitted, it is a simple matter to adjust the quantity of oxygen by means of a handwheel V. It is claimed that it is possible to adjust down to power corresponding to one-tenth of the maximum gas consumption for which the apparatus was designed, without altering the pressure of supply of the oxygen. It is also possible to obtain any desired number of intermediate steps by changing the nozzle. The length of the tube G is of importance. It is claimed that the design is such that the time taken by any explosion to travel through the tube from the nozzle to the point of injection is sufficiently long for the disturbing effect caused to the injector by the pressure of the explosion to have time to work so that an amount of non-explosive gas accumulates at the point of injection and extinguishes the flame on its arrival. By this means back travel of the flame is rendered harmless. In practice, a length of 20 cm. to 30 cm. (say 8 in. to 12 in.) for the tube G is found sufficient for blowpipes of average dimensions. The safety of the device may be still further increased by arranging a check chamber on the inlet pipe for the acetylene.

J. A. Lucas, in the " American Machinist," states that the guard (shown by Fig. 15) for protecting the hand from being burnt has proved indispensable in all overhead work, such as boilers and work in close surroundings. As a usual precaution an asbestos gauntlet is used, but this is no protection in places where there is danger of the molten metal falling, for the intense heat is reflected on the gauntlet, which burns through before the operator has time to remove it. At the end of the torch is a disc A, which has a

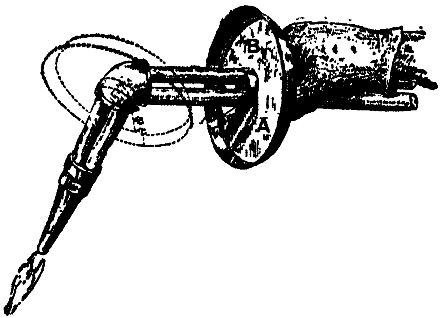



Fig. 15.—Blowpipe Hand Guard

vertical flange B running round the edge; this serves to catch falling molten metal. The disc has a cut, which is held together by the bolts, making the device readily attachable and detachable. The device can be held in any position on the torch as shown.

# CHAPTER III

## Acetylene Generation and Purification

**Acetylene Generation.**—Acetylene is generated by bringing carbide of calcium into contact with water, the reaction being expressed by the following equation:—

$$\underset{\text{(Calcium Carbide)}}{CaC_2} + \underset{\text{(Water)}}{H_2O} = \underset{\text{(Acetylene)}}{C_2H_2} + \underset{\text{(Quicklime)}}{CaO}$$

But in practice a further reaction takes place between the quicklime and water, which is expressed by the following equation:—

$$\underset{\text{(Quicklime)}}{CaO} + \underset{\text{(Water)}}{H_2O} = \underset{\text{(Calcium Hydroxide or Slaked Lime)}}{Ca(OH)_2}$$

Stated simply, wet calcium carbide separates into acetylene and quicklime, and the latter takes up more water and becomes slaked lime.

It is therefore necessary to bring more water into contact with the calcium carbide than is expressed by the first equation, inasmuch as some calcium hydroxide (slaked lime) is formed before the completion of the first reaction as regards the whole of the carbide present, otherwise the yield of acetylene would obviously be diminished. Moreover, the quantity of heat liberated when an excess of carbide is present is liable to produce an intense local temperature, which is altogether undesirable, and sometimes even dangerous.

Calcium carbide is a bad conductor of heat, and it is quite conceivable that a great amount of heat could be readily imprisoned in a quantity of the carbide under certain conditions. The effect of this excessive heat on acetylene causes it to change into other chemical compounds. What is known as "polymerisation" occurs, which results in the acetylene being converted into benzene ($C_6H_6$). At elevated temperatures the products of polymerisation are very unstable, and are liable to explode spontaneously, hence excessive temperatures in the generation of acetylene should be rigidly guarded against.

The temperature in any part of the generator when working for a prolonged period should not exceed 266° F. (130° C.); but since water boils at 212° F. (100° C.), and as water forms the seal of the gas bell, it is advisable to work at a temperature much below the boiling point of water. As the ill-effects due to polymerisation are not likely to occur even at treble the former temperature, an absolute margin of safety is thereby ensured.

To avoid misunderstanding, it should be observed that no danger is to be apprehended in the use of any of the recognised standard makers' generators. These are absolutely safe, and may be relied on. The foregoing precautionary sentences are intended particularly for those who may feel constrained to make their own generators.

The manufacture or selection of a suitable and adequate generator is supremely important, since unless the gas is constantly produced and automatically stored so as to be available whenever it may be required, much inconvenience and annoyance is sure to result as a direct consequence.

The size of the generator should be proportionate to the work contemplated, and it should be of ample dimensions to cope with the maximum demand likely to be imposed on it. Preferably, the gas should be generated at a uniform rate so as to allow the heat liberated during production to be constantly, uniformly, and effectively dissipated. The spasmodic generation of acetylene involving periods of rest after the violent liberation of comparatively large volumes of gas should be avoided. Acetylene produced in these circumstances will certainly contain a greater percentage of impurities than that produced otherwise. A constant, steady, and uniform production is more desirable; and every endeavour should be made to collect the gas under these conditions. Supposing the maximum demand to be, say, 30 cubic feet per hour, then this volume, plus a margin for contingencies, should determine the size of the generator required, and the rate of the production of the gas.

**Generator Construction.**—Acetylene generators should be substantially built of suitable metal to withstand the repeated action of water, heat, the chemical impurities in the crude gas, and the ravages of the atmosphere; but copper should be rigidly excluded. Acetylene in the presence of copper is apt to form highly dangerous and even explosive compounds under certain conditions—and prevention is always better than cure. Soft-soldered seams should also be excluded in favour of brazed, riveted, or autogenous-welded seams.

The water tank and the rising gas-bell or holder should be preferably constructed of steel plates not lighter than No. 20 B.W.G. strength. The apparatus should be so designed and constructed that the water seal (which prevents the gas escaping from the holder, where it is stored immediately after it is generated) should not exceed 20 in. That is to say, that when the holder has risen to its highest point, the distance between the bottom of the holder and the top of the water must not be greater than 20 in. But no such pressure as 20 in. of water is ever likely to be used in low-pressure welding; as a matter of fact, acetylene at a pressure varying from 7 in. to 10 in. of water is that most generally employed. Whatever pressure is decided upon, that pressure must be constant and uniform; and a given pressure within these limits may readily be obtained by simply weighting the holder accordingly.

Under no consideration should an acetylene generating apparatus be sealed hermetically, otherwise great pressures and high temperatures would inevitably be produced—with undesirable results.

There are quite a number of important considerations governing the construction of acetylene generators which are embodied in the recommendations issued by the British Acetylene Association. And as these recommendations are the cumulative result of scientific research coupled with practical experience, it is essential that they should always be rigidly adhered to.

There is no necessity to go astray in the selection of a suitable generator, since all the standard makers now make them to comply with these recommendations.

**Generators Described.**—There are two kinds of generators, automatic and non-automatic; and these are further subdivided into two types, water-to-carbide and carbide-to-water. When selecting a water-to-carbide automatic generator, it is better to choose one in which the charge of carbide is divided into two or more separate compartments or drawers. In some generators these compartments are arranged horizontally at the base of the apparatus. The water is automatically admitted in excess to the first compartment, and, after flooding this, in process of time it eventually attacks and then floods the carbide in the second compartment; and this process is repeated until all the compartments of carbide are flooded in turn, and the charge is spent. This type of generator minimises the phenomenon known as "after generation." The charge of carbide being subdivided, and the water being admitted in excess to only one subdivision at a time, excessive heat in the generation of the gas is thereby avoided, and the production of abnormally impure acetylene is thus obviated.

In contradistinction to this type, the carbide-to-water generator is also extensively used for oxy-acetylene welding. The gas is probably more violently generated in an automatic carbide-to-water generator; but as an excess of water is always present during the production of the gas, the resultant heat which is liberated is readily dissipated. "After generation" in this type of apparatus is due to the moisture in that portion of the carbide which is spent "creeping" to that portion which is unspent. This occurrence, therefore, emphasises the necessity of selecting ample holder capacity in connection with this type of generator.

As a general rule the decomposition of the carbide should proceed at the rate of 4 lb. per hour, unless water is present far in excess of that required to bring about the chemical action—otherwise excessive heat will be generated, and this is altogether undesirable, besides being detrimental to the quality of the gas.

It should be said that when the design of the generator admits of the carbide falling into an excess of water, the rate of decomposition can be materially accelerated.

Fig. 16 shows a water-to-carbide generator which is made by the Dargue Acetylene Gas Company, Limited. A is the water tank, B the gas bell or holder, C and D are the carbide containers, E and F are the water valves which regulate the supply of water to the carbide containers, G and H are a hook and ring on the valve chain of the valve E, $G^1$ and $H^2$

are a hook and ring on the valve chain of the valve F, I and I' are water supply pipes leading to the carbide containers, and P is an eyelet on the top of the gas-holder.

The two water valves E and F are automatic in action, E regulating the supply of water to the carbide container C, while F regulates the supply of water to the carbide container D. The valves are opened by the valve seats being raised. This is done automatically by the falling of the gas-holder B, a chain being attached to each valve seat, thence over the two pulleys, after which it is attached to the eyelet P on the top of the gas-holder. Thus when the latter sinks as a consequence of the gas being used, a valve seat is raised allowing water to flow to the particular carbide container of which it controls the water supply.

When the hook and ring of one of the valve chains are joined together, it reduces the length of that chain by about 2 in., and thus causes the valve to which it is attached to operate first.

The method of charging and working this generator is extremely simple, as may be gathered from the following: First take off the doors on the carbide containers C and D, by unscrewing the hand screws, draw out the trays, half fill them with carbide, then replace them and re-fix the doors securely by means of the hand screws.

Following this, the water tank should be filled with water; and incidentally it may be remarked that when a carbide container is re-charged, the quantity of water required to decompose the carbide should be added to the water tank. Now join together the hook and ring G and H and turn on tap K. The generator will at once begin to make gas from the carbide container C, and the gas passing into the gas-holder

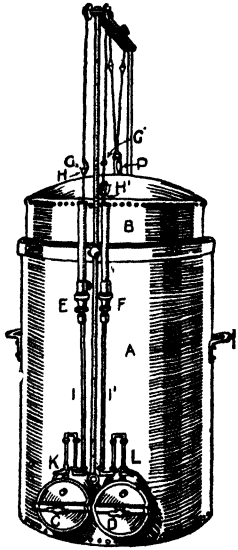



**Fig. 16.—The "Dargue" Acetylene Generator; Water-to-carbide Type**

B will cause it to rise until the valve is closed, thus cutting off the supply of water. When the gas-holder has risen about 6 in. turn on the tap L. The rising and falling of the gas-holder as gas is made and used will continue until the carbide in C is completely spent, when the gas-holder will fall about 2 in. and open the valve F, allowing water to flow into the carbide container D, thus automatically bringing it into operation.

To ascertain if the carbide in a given container is exhausted, turn on the indicator tap at the back of the container; if water flows it is exhausted, but if gas, then it is not yet spent. If by turning on the indicator tap it is found that the carbide container C is exhausted, turn off the tap K, disconnect the hook and ring G and H, and join together $G^1$ and $H^1$. The container C can then be emptied, the tray dried, re-charged, and replaced in the container. After it has been fixed in position and firmly screwed up, turn on the tap K, so that when the container D is exhausted, the gas-holder will again fall about 2 in., and opening the valve E it will automatically bring the container C into operation again.

The container D can then be similarly re-charged, after which it will in due course again take its part in the cycle of operations. A word of warning might profitably be added at this juncture. Do not examine or charge the generator with a light, or when smoking.

Figs. 17 and 18 are sectional illustrations of an automatic carbide-to-water apparatus termed "The Acetylite," which may be obtained from R. J. Moss and Sons.

In this, the downward movement, or the sinking of the gas bell, causes the weight to come in contact with an adjustable table, and this action raises an attached cone (shown in detail at A), which liberates a small quantity of carbide. The evolved gas, by immediately lifting the bell, allows the weight attached to the cone to pull the latter down on to its seating, thus preventing more carbide from falling until some of the gas is used, when the bell again

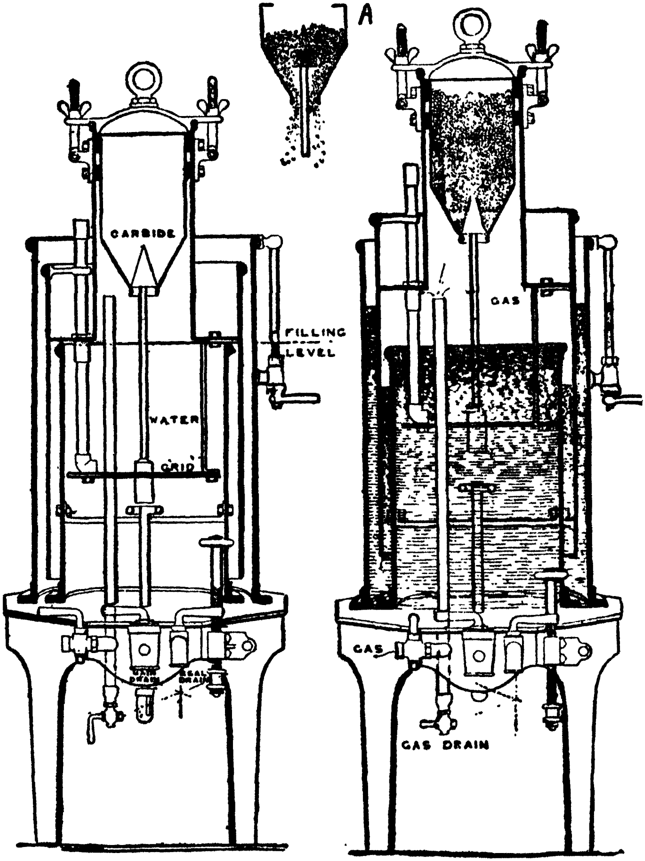



FIG 17 FIG. 18

**Figs. 17 and 18.—Elevation and Vertical Section of the "Acetylite" Generator: Carbide-to-water Type**

sinks. This cycle of operations is automatically repeated, and thus ensures a stock of gas being always available.

The action of the apparatus is obviously very simple, and it is practically impossible for the machine to get out of order. Large granulated carbide is used, and this may be shovelled into the hopper quickly and easily, the spent carbide being drawn off in the form of sludge by simply turning the main drain cock. It is claimed for this apparatus that there is no "after generation," which phenomenon is an undesirable feature in connection with any acetylene generator.

The water in the water tank should be occasionally replenished to compensate for that used in the decomposition of the carbide. On referring to the illustration, it will be noted that the gas produced by this generator gradually diminishes in pressure as the carbide container gradually becomes empty; but this apparatus can now be supplied with certain improvements designed to overcome this objection.

The undesirable phenomenon known as "after generation" is not likely to be encountered in either of the generators illustrated in this chapter. There is a very large number of generators of different designs representing both types now on the market, and "after generation" in a generator has been mentioned in order that it might be avoided. It will be seen by referring to Figs. 17 and 18 that the carbide container of this particular generator is situated well above the water, and the small granulated carbide is not likely to be "hung up" for that very reason.

The cone valve in Figs. 17 and 18 is proportioned to the size of the generator, and it will allow all the carbide to fall that can be dealt with, or, in other words, it will allow as much carbide to fall as the holder will accommodate.

**Care of Generator.**—In the management and care of acetylene generators certain precautions should be observed and insisted on, so as to facilitate smooth working and to obviate risk. Naked lights should not be allowed in the immediate vicinity, neither should smoking. The water in the water tank should be periodically changed for clean water, and all the various parts of the apparatus should be occasionally overhauled, cleaned, and kept in working order.

In the event of the water in an acetylene generator becoming frozen, care should be exercised in thawing it with hot water only, and on no account should heated metal or flames or lights be employed for this purpose.

When an automatic generator is used in very low temperatures, the heat liberated as a result of the chemical reaction between the carbide and the water should, if necessary, be conserved by lagging the apparatus with hair felt or other non-conducting material. Conversely, when in normal temperatures the heat liberated unduly raises the temperature of the water, colder water should be added as the warm water is drawn off, in order to disperse the heat. The decomposition of calcium carbide should not be forced at a greater rate than, say, 4 lb. per hour. This would yield about 18 cub. ft. of acetylene, and a gallon of water per pound of carbide should be allowed.

It is important that in all generators adequate provision should be made for the removal of the lime sludge or spent carbide, and for the introduction of fresh charges without the admission of air into the gas-holder.

**Purification of Acetylene.**—After acetylene has been produced, it must be purified before it is used in the blowpipe for welding. It has been demonstrated that lime is formed when acetylene is generated, and one of the impurities of the gas takes the form of minute particles of this lime held in suspension.

Lime may be termed a physical, as distinct from a chemical, impurity, and it may be removed mechanically by filtering the gas through some porous material, such as cotton-wool or felt. The importance of removing this impurity will be readily appreciated by considering what would be the effect of its going forward along with the gas to the blowpipe flame. A small but perceptible stream of lime would be constantly deposited precisely where its presence would be most objectionable, with the result that the weld would be contaminated and the welding process retarded.

The other impurities in the acetylene are chiefly chemical impurities—ammonia, phosphorus and sulphur compounds; and these must needs be otherwise removed.

Practically all the ammonia is automatically removed from the acetylene as the latter bubbles through the water on its way to the holder, ammonia being very soluble in water. (Incidentally, it may be remarked that the ammoniacal impurity which is present in crude coal-gas is similarly removed by water in the washing and scrubbing apparatus.) And this is an important consideration—although by no means the only one—in favour of the carbide-to-water type of generator as against the water-to-carbide type.

The other impurities referred to are removed by chemical means. One of the most satisfactory agents for the purification of acetylene is known as "Heratol," a compound expressly prepared for this purpose, 1 lb. of which is usually regarded as being sufficient to purify 100 cub. ft. of acetylene.

It might be erroneously supposed by some that the purification of acetylene for welding purposes is entirely unnecessary; but, as a matter of fact, it is absolutely essential. It is impossible to expect a clean, sound weld from the use of a foul gas laden with various chemical impurities, and this fact alone furnishes one very good reason for using only high-grade carbide. Crude acetylene contains quite a sufficient number of impurities without adding to the list by using cheap and dirty carbide. Assuming, however, that a good-quality carbide is used, the purification of the gas may be smoothly and automatically effected, and the results obtained will justify all reasonable expectations.

Dissolved acetylene—that is, acetylene in cylinders—needs no purifying, as it must needs be purified before it can be stored in cylinders. This is one of the many advantages of using cylinder acetylene (see p. 49).

# CHAPTER IV

## Valves, Gauges, and Regulators

**Oxygen Cylinders and their Fittings.** — The welder has less practical interest in the process by which oxygen is generated than in the case of acetylene, because although, as a matter of fact, oxygen can be quite easily made on the spot, it is much cheaper and more convenient to purchase it compressed in steel cylinders.

Oxygen for welding is usually obtained in steel cylinders which are filled to a pressure of 120 atmospheres. These cylinders should be made, annealed, tested, and filled strictly in accordance with the recommendations of the British Government Departmental Committee of 1896, since the British railway companies require these conditions to be complied with. It is essential that the oxygen be pure, therefore a guaranteed standard of purity of not less than 98·5 per cent. should be stipulated when ordering. The British Oxygen Company, Limited, supply oxygen in cylinders containing 100 cub. ft. or upwards of free gas, which may be obtained from their works at London, Birmingham, Wolverhampton, Cardiff, Manchester, Birkenhead, Sheffield, Newcastle, and Glasgow. Oxygen cylinders should never be exposed to high temperatures on account of the consequent increase in pressure which is due to the tendency of the confined gas to expand under the influence of heat.

In order to reduce the pressure of the compressed oxygen in the cylinder to a suitable working pressure, which may vary from 8 lb. to 30 lb. per square inch,

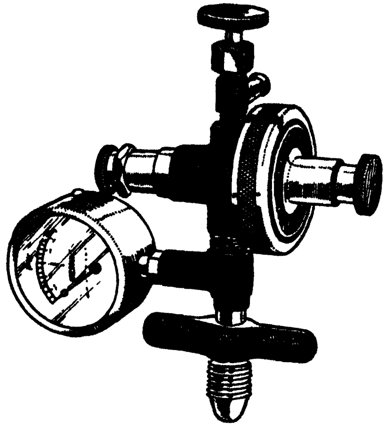


**Fig. 19.—" Endurance " Automatic Regulator for Oxygen Cylinder**

according to the size of the blowpipe employed, a governor or automatic regulator is necessary. Fig. 19 illustrates the British Oxygen Company's "Endurance" Automatic Regulator, which is specially designed and substantially constructed to accomplish this object. It is fitted with a gas-expansion device which obviates ignition risks at the valve seat, and it is capable of reducing the pressure of the oxygen to any given working pressure that may be required. The pressure gauge shown registers the pressure of the oxygen in the cylinder, and the working pressure is obtained by simply setting the adjustable screwed socket to give the requisite number of pounds pressure per square inch.

**The Hydraulic Back-pressure Valve.**—Fig. 20 represents what is known as the hydraulic back-

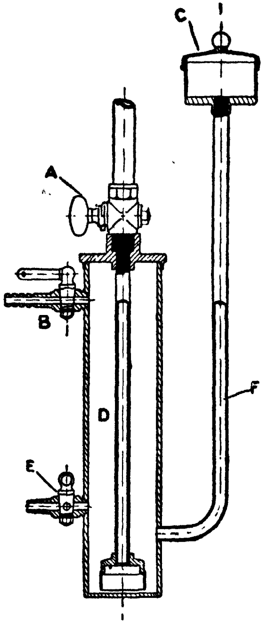



Fig. 20 (*above*).—Hydraulic Back-pressure Valve for use in Low-pressure Welding and Cutting

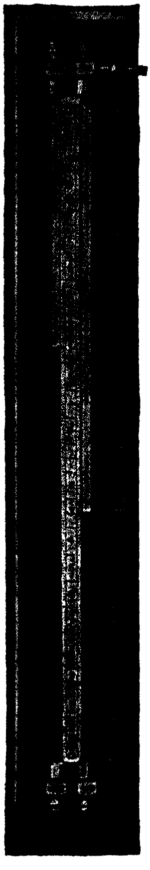


Fig. 21 (*on the right*).—Gas-pressure Gauge, Water-column Type pressure valve. This must be used in all low-pressure work—that is, when the acetylene is produced on the spot by means of a generator, or is taken from bell holders. The use of this valve is a necessary precaution, since in the event of the blowpipe nozzle becoming choked during the process of welding, the oxygen is effectively prevented from travelling along the acetylene pipe to the generator, and thus disorganising the working of that apparatus and creating a highly dangerous condition. Under working conditions the valve is attached to the acetylene supply pipe in a vertical position (on account of the seal), and it is situated as near to the blowpipe as may be practicable. When charging the valve to put it into working order, first turn off the tap A, which is connected to the acetylene supply from the gasholder, and then pour water into the vessel D, by means of the filling cap C, which is provided with a loose lid. When water runs through the tap E, the charge is sufficient, whereupon E should be closed, A should be opened, and the lid C should be replaced. The acetylene supply pipe to the blowpipe is connected to the tap B, and when the blowpipe is in use, both taps A and B should be open, the acetylene being controlled at the blowpipe only. It should be noted that the filling pipe F should contain a column of water about 1 ft. high, so as to withstand the pressure of the gas in the holder, which would be about 8 in. or 10 in. If the seal in the filling pipe were less than the pressure in the holder, the valve would be inoperative, and acetylene would escape at C before travelling to the blowpipe. The function of the hydraulic back-pressure valve is as follows: Supposing that from some reason or other the blowpipe nozzle became blocked, then the back pressure thus originated would first seal the acetylene pipe by forcing the water in the vessel D up the central tube, after which the pressure would destroy the seal in the pipe F, and thus blow the lid off the filling cap C, allowing both gases to escape until the taps A and B were closed.

This brief explanation of the function of the hydraulic back-pressure valve at once shows the necessity of placing it beyond the reach of any open-flame artificial light, and preferably in the open air; or, if that be impracticable, it should be situated in a well-ventilated building where due precautions can be observed.

The internal diameters of the tubing required between the acetylene generator and the hydraulic back-

| Distance (in feet) between the acetylene generator and the hydraulic back-pressure valve. | 50 | 100 | 200 | 500 | 1,000 |
|---|---|---|---|---|---|
| **Number of cubic feet of acetylene required per hour.** | **Internal diameters of tubing in inches** | | | | |
| 5 | $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 |
| 10 | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | 1 |
| 25 | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 | 1 | $1\frac{1}{4}$ |
| 50 | $\frac{3}{4}$ | 1 | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ |
| 75 | 1 | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ |
| 100 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ | 2 | 2 |

pressure valve to deliver at the normal working pressure the stated quantities of gas mentioned are given (approximately) in the table at the foot of p. 43.

**Pressure Gauges.**—It has already been stated that the range of variation of the acetylene pressure for welding should be between 7 in. and 10 in. of water, therefore provision should be made in the inlet supply pipe of the hydraulic back-pressure valve for the purpose of fixing a pressure gauge in order that the working pressure may be constantly noted. Either a dry or a water-gauge may be used, and the scale should be graduated in terms of inches and tenths of inches of water. Fig. 21 represents a water-gauge for registering pressures up to 12 in., which is made by Wm. Sugg, of Westminster; while Fig. 22 illustrates a dry gauge for registering pressures up to 60 in., which is made by the Cambridge Scientific Instrument Company, Limited. These gauges are also made in other ranges of pressure.

**Complete Low-pressure Outfit.**—Fig. 23 shows the British Oxygen Company's diagrammatic illustration of a complete oxy-acetylene blowpipe equipment, with the exception of the acetylene generator and holder, which apparatus may be placed in any suitable position (preferably outside) at any reasonable distance from the blowpipe. A is an ordinary gas-tap connecting the hydraulic back-pressure valve with the acetylene supply pipe from the acetylene holder. The acetylene supply pipe, by the way, should extend vertically not less than 2 ft. above the tap A. A canvas-covered rubber tube connects the outlet tap $A_1$ of the hydraulic back-pressure valve to the valve A, and thus forms the acetylene supply pipe to the blowpipe. Another canvas-covered rubber tube connects the outlet tap B of the oxygen pressure regulator with the valve *b* on the blowpipe, and thus

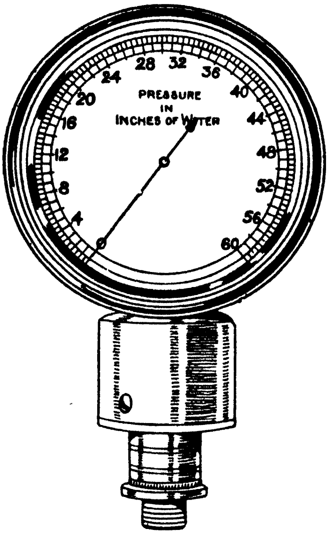



**Fig. 22.—Gas-pressure Gauge : Spring Type**

forms the oxygen supply pipe to the blowpipe. The latter supply pipe should be securely wired or clipped on to withstand the pressure of the oxygen, which varies from 5 lb. to 40 lb. per square inch. The hydraulic back-pressure valve must be charged with water (as previously explained), and the gas regulator must be securely attached to the oxygen cylinder, as indicated, after which the blowpipe apparatus is ready for use.

First open the cylinder valve slowly by means of the key supplied for that purpose, then by means of the thumb-screw P adjust the low pressure to the correct working pressure according to the size of the blowpipe used. (The correct working pressures for the different sizes of blowpipes are given in the table relating to the "Universal" blowpipe, on p. 18.) The taps A and $A_1$ are now opened, and, when acetylene is unmistakably smelt at the blowpipe nozzle, light it by means of a gas-jet or taper. The acetylene should afterwards be regulated and slowly throttled down by means of the tap *a*, until the white inner cone becomes well defined. The tap A must never be used to regulate the supply of acetylene. In fact, after the hydraulic back-pressure valve has been charged with water it is best to leave this tap always on. Should the flame fire back and go out owing to improper regulation, turn off the taps *a* and *b* at once, wait a few seconds, then relight and readjust the blowpipe. On stopping work the acetylene tap *a* should be closed first, and then the oxygen tap *b*; afterwards close down the oxygen supply at the cylinder. The oxygen cylinder valve should never be opened until the taps B and *b* are open, and then it should be opened slowly. Sudden impact of oxygen in the regulator is thus obviated.

The operator will need goggles and, frequently, both hand and face protection.

A bucket of water should always be available during welding operations for the purpose of cooling the blowpipe whenever this becomes overheated through being held in a confined space. During the

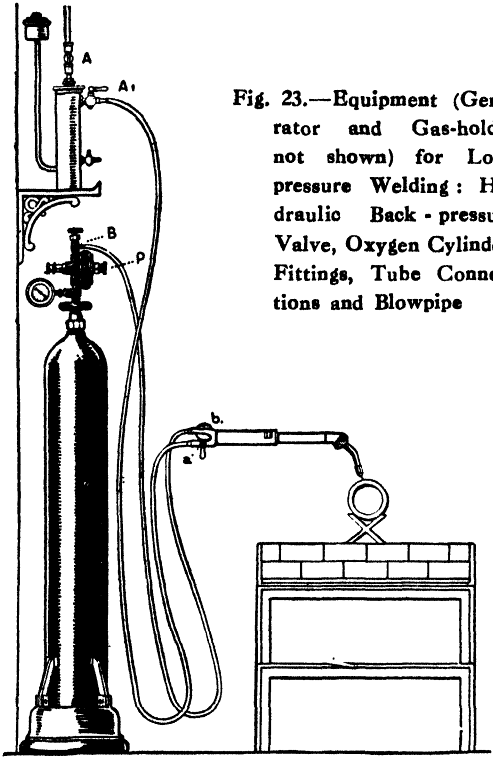



**Fig. 23.—Equipment (Generator and Gas-holder not shown) for Low-pressure Welding: Hydraulic Back-pressure Valve, Oxygen Cylinder, Fittings, Tube Connections and Blowpipe**

cooling process both gases should be turned off for the time being. Unless the blowpipe is kept sufficiently cool the acetylene is liable to undergo a chemical change which is detrimental to the entire process of welding, and which, if unchecked, would cause particles of carbon to accumulate within the blowpipe. Should the nozzle of the blowpipe become choked or obstructed through splashes of molten metal a wire brush should be used to remove the obstruction, and, if necessary, a piece of copper wire should be employed in addition; but on no consideration should it be reamered out, nor should any sharp steel instrument be inserted in the nozzle.

An automatic cooling arrangement has been advantageously employed in connection with pipe-welding machines, whereby the blowpipe is surrounded with a water-jacket fitted with two pipe connections. A supply of cold water is continuously delivered into the water-jacket by means of the inlet pipe, and, after due circulation, the water is conducted away through the outlet pipe. The tip of the blowpipe is thus kept cool, and fluctuating flame temperatures are thereby obviated.

## CHAPTER V

### High-pressure System of Oxy-acetylene Welding

**Dissolved Acetylene.** — In the early days of oxy-acetylene welding, the purification of the gas did not concern the welder, because what is known as the high-pressure system of welding was in vogue, and the acetylene was delivered to the welder in cylinders, just as oxygen is delivered to-day. Special precautions, however, had to be taken by the makers or producers of acetylene to render the gas chemically pure before introducing it into the cylinders, since the compression of acetylene in its impure state is attended with considerable risk under certain conditions. Nowadays, acetylene in cylinders is dissolved in acetone, a liquid hydrocarbon of high solvent power, which is capable of absorbing 300 times its original volume of the gas under a pressure of twelve atmospheres.

The cylinders usually supplied for trade purposes contain a porous material, such as fossil meal, which is treated with acetone, which in turn is proportioned to retain 100 volumes of acetylene at ten atmospheres pressure per cylinder. In process of time the low-pressure system superseded the high-pressure system, and thus made it possible for the welder to be independent of "cylinder" acetylene. Notwithstanding this evolution, it must be remembered that acetylene in cylinders is invaluable for portability, and is especially useful, for example, on board ship. Although under considerable pressure in the cylinders—a pressure far exceeding that at which it is required for use in connection with the oxy-acetylene blowpipe—it is, nevertheless, possible so to regulate or govern the pressure down by means of a regulator and pressure gauge, that any required pressure may be readily obtained. Thus high-pressure acetylene may be used for low-pressure welding. And this much must be stated in favour of high-pressure acetylene in cylinders, that its purity is unquestionable.

The full pressure in a D.A. (dissolved acetylene) cylinder is approximately 150 lb. per square inch, and the pressure is governed down as required by means of an acetylene regulator. The approximate contents of D.A. cylinders Nos. 1, 2, and 3 are 60, 100, and 200 cub. ft. respectively, and the gas consumed on any given piece of work may be approximately estimated by the proportionate decrease in pressure, although a much more accurate method would be to weigh the cylinder and contents before and after use, and then reckon 1 cub. ft. for every 1·10 oz. loss in weight.

The advantages of dissolved acetylene are at once apparent when it is considered that the purity of the gas must necessarily be of a high standard and that the cylinders are extremely portable. A cylinder may be taken with ease and safety on a scaffold, in a trench, under roofs and floors, in a stokehold, or main thoroughfare, on a railway or tramway system, as well as indoors. And it should also be remembered that a greater range of pressure is obtainable from cylinder acetylene than is possible from a generator.

Fig. 24 illustrates the method of connecting the gas cylinders to the blowpipe, in connection with which

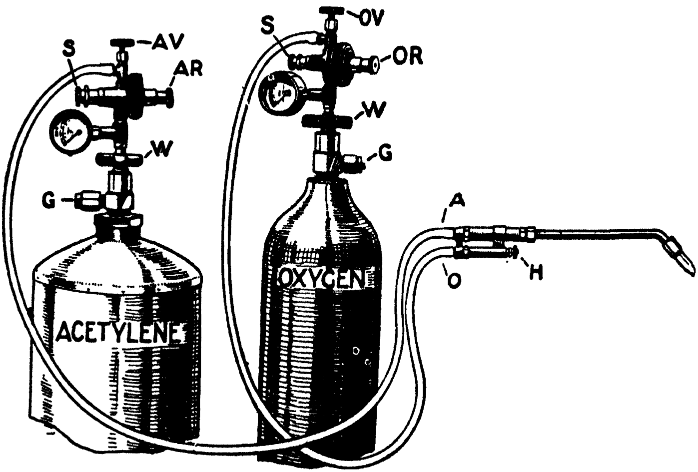



**Fig. 24.—Dissolved Acetylene and Oxygen Cylinders, Fittings, Connections and Blowpipe for High-pressure Welding**

the following instructions should be carefully observed: See that the cone seats in the sockets of the cylinder valves are perfectly free from grit and grease. Open the cylinder valves momentarily in order to discharge any foreign substance in the gas passages. Screw the acetylene regulator (painted red and fitted with a left-hand thread) into the D.A. cylinder-valve socket. Screw the oxygen regulator (painted black and fitted with a right-hand thread) into the oxygen cylinder-valve socket. The wing-nuts W should be tightened with the key provided, but excessive force should not be used. Connect the tubing to the regulators and to the blowpipe as shown, taking care that the acetylene supply is connected to the blowpipe at A and the oxygen supply to the blowpipe at O. Secure the tubing to the connections by binding with wire or with the special clips supplied. Take care that the regulators AR and OR are screwed out until slack before opening the cylinder valves. This should be done to avoid injuring the regulators by a sudden access of pressure.

To test for leakage, close the valve AV or OV and open the cylinder valve momentarily. If the pressure falls there is a leak at the wing-nut connection or the cylinder-valve gland nut. Tighten these if necessary with the key provided. In no circumstances must any oil or grease be used on any of the fittings, whether on the cylinder valves, regulators, tubing, or blowpipe.

Having thus assembled the plant, regulate the blowpipe as follows: Open the cylinder valves at least two full turns. Screw in the milled nut AR (acetylene) to, say, 5 lb. to 10 lb. pressure, as marked, according to blowpipe tip. Screw in the milled nut OR (oxygen) to, say, 10 lb. to 20 lb., according to blowpipe tip, and regulate the gases by the valves AV and OV, then open the acetylene valve AV and light the jet of acetylene at the blowpipe tip. Open AV to the point at which further opening causes the flame to leave the blowpipe tip. See that the valve H on the blowpipe is shut. Open oxygen valve OV, and then carefully open the valve H to adjust the blowpipe flame until the bright portion of flame comes

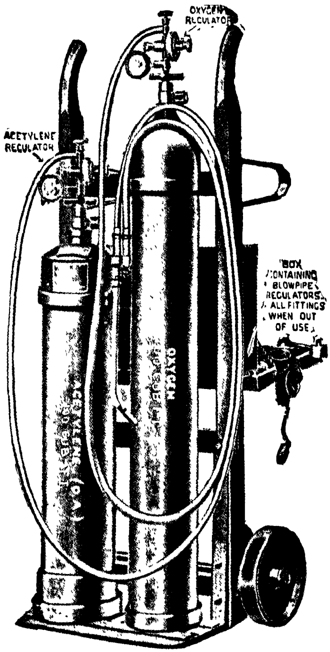



**Fig. 25.—A Portable High-pressure Welding Outfit**

back to a clear cone without any tail, as shown in Fig. 1 (p. 7). The mixture of gases is correct when the tail on the cone has only just disappeared.

A special portable welding equipment supplied by the Acetylene Illuminating Company, Limited, for heavy work, including repairs to railway and tramway lines, points, and crossings is shown by Fig. 25. It is especially suitable for welding the joints of gas- and water-mains, as well as for an endless variety of work, particularly where portability is a great consideration.

It should be stated that plants of various sizes are made to suit every conceivable requirement.

## CHAPTER VI

### Welding Sheet-iron, Wrought-iron, and Mild-steel Plates

IN the welding of sheet-metal, cycle and aeroplane frames, cycle and motor rims, metal hollow-ware, and stamped or pressed metalwork not exceeding $\frac{1}{8}$ in. in thickness, the flame should be directed in a horizontal rather than in a vertical direction, and heat-conducting blocks or sheaths (preferably of copper) should be used on each side of the joint to prevent undue expansion and distortion of the metal. This is rendered necessary on account of the intense temperature of the oxy-acetylene blowpipe flame.

It should be distinctly understood that welding is essentially different from brazing, and this will be appreciated when it is realised that there is a considerable margin between the melting-pot of the brazing spelter and, say, the fusing-point of sheet-iron; whereas the melting-points of the filling rod and the metal to be welded are identical. In brazing, the spelter simply fuses and runs in the joint without losing its identity; but in welding, the joint becomes one homogeneous whole. In a good weld it is difficult to detect where the joint begins and ends.

Instead of adopting a lap edge in the welding of sheet-iron, it is better to employ small flanges by turning the edges of the sheets at right angles, as in Fig. 26, and then the outer edges of these flanges can be welded together. For very thin sheets the familiar grooved seam (Fig. 27) can be recommended, in which case the edges of the seam are fused and thus united. It is in connection with thin sheet-iron that the use of conducting blocks protects the job in hand, by dispersing the heat other than that which is concentrated on the seam, although, with practice and experience, these may, to a very great extent, be discarded.

Fig. 28 shows a former seam applied to a cylindrical shape. In this case, after the outer edges of flanges are welded, the joint affords substantial support to the cylinder; but where this outstanding ridge is at all objectionable, the flanges should be melted down on the cylinder itself. Fig. 29 shows an alternative seam, which, it will be noted, is an application of Fig. 27 to a cylindrical body. Figs. 30 and 31 illustrate these seams as applied to the bottom of a vessel; but where the seam projection is objectionable the one shown in Fig. 32 may be substituted.

These seams may be adapted not only to cylindrical articles, but to articles of every conceivable shape; and on the Continent they are extensively employed in the manufacture of all kinds of useful and artistic sheet metalwork. No flux is required for welding sheet-iron, and when a filling rod is required, this should consist of soft Swedish iron about $\frac{3}{16}$ in. thick. When welding a seam, "tack" it at intervals with the blowpipe to prevent warping, and, if necessary, hold it in position by means of small clips or clamps.

A great future undoubtedly lies in store for oxy-acetylene welding in connection with artistic iron-

Fig. 26

Fig 27

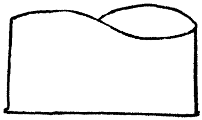


Fig 30

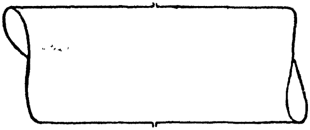


Fig. 28

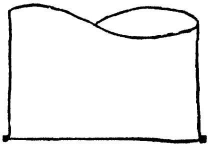


Fig. 31

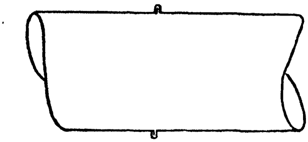


Fig. 29

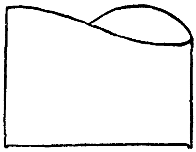


Fig. 32

**Figs. 26 to 32.—Welded Joints for Light Sheet-metal Work**

work such as ornamental gates, altar screens, palisades, column and bracket work for various purposes, and Fig. 33 represents an illustration (supplied by The British Oxygen Company, Limited) showing a spray of roses—oxy-acetylene welded throughout—made by one of the company's workmen. This interesting example of oxy-acetylene-welded artistic metalwork indicates the possibilities immediately ahead in this branch of art where a combination of lightness and strength is essential.

For ornamental metalwork of a light and delicate character, this modern process of welding is peculiarly suitable, since " spot-welding " may be conveniently carried out on those parts which would be practically inaccessible to a workman employing the older and more cumbersome method of welding. Moreover, greater artistic achievements are possible to the workman who can weld his ornamental productions together into one harmonious whole by means of the oxy-acetylene blowpipe flame. After having fashioned each component part of the design to be executed, it is obviously much better to " spot weld " the parts where they are already assembled in position, rather than to disturb them for the purpose of bringing them to a welding heat in the forge, and then being compelled to reassemble them very hastily before the " heat " is lost.

A neutral, or alternatively a very slightly reducing flame, should be employed for very thin metal, and the thinner the metal the more should the blowpipe flame be diverted from the vertical to the horizontal position. A little practice will enable the operator to gauge the rate of fusion a little in advance, so that with a certain amount of intelligent anticipation the welding speed is increased to the maximum.

When welding very thin metal the operator should be quick to detect when the point of fusion is reached, and just at that precise moment the flame should gradually be diverted to the comparatively colder and unwelded metal. A skilled welder will so move the flame that the actual welding is accomplished just as the flame is being moved from one given spot to another. An excess of heat is thus obviated at the place where the welding is being conducted, and in

Fig. 33.—Oxy-acetylene-welded Artistic Metalwork

this way accidental puncturing and burning of the thin metal is entirely prevented.

A satisfactory kind of joint for iron and steel plates up to $\frac{1}{8}$ in. thickness is that known as the butt joint, which is shown by Fig. 34. Although experienced welders can utilise this type of joint for thicknesses up to and including $\frac{3}{16}$ in., it is, nevertheless, a safe rule to bevel all edges whose thicknesses exceed $\frac{1}{8}$ in. The ability and experience of the welder have an important bearing on the foregoing; but unless the blowpipe flame can penetrate between the edges of the metal, and actually fuse the lower edges of the joint as well as the upper portion, the joint cannot be regarded satisfactorily; and the chief point to be remembered is, that unless actual fusion of the metal takes place throughout the entire weld, fracture is liable to occur. The beginner, therefore, should be guided by this consideration, and he should not attempt to weld heavy plates before he can successfully weld lighter ones. Generally, it is better to practise first of all on lighter material, and then to work upwards to the heavier material; but an exception to this practice is made in the case of very thin sheet-iron or steel, which require the practised touch to accomplish the object without puncturing or burning the metal. This, however, should not discourage the novice, since practice begets confidence, and with confidence all the difficulties can be surmounted.

As a rule, great care should be taken to remove all scale and rust, and thoroughly to clean the metal where it is to be welded, although the formation of oxide is no great drawback to the successful welding of wrought-iron by the oxy-acetylene process, since the oxide melts or fuses at a lower temperature than that of the iron itself. Iron is denser than its oxide, consequently the latter floats (when through some reason or other it does not fuse), and thus permits the molten iron to unite with the filling rod to make one uniform and homogeneous mass at the weld.

**Fig. 34.—Butt Joint**

**Fig. 35.—Bevelled Joint**

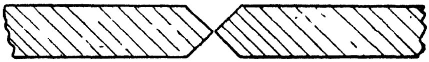


**Fig. 36.—Double-bevelled Joint**

For welded joints varying in thickness from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. the metal is bevelled as shown in Fig. 35 preparatory to welding. A little difference of opinion exists as to the amount of bevel required to obtain the best results, some preferring a steeper bevel than others. Satisfactory results, however, may be obtained by forming the bevel to subtend an angle of 60°. While the bevel should be sufficiently open to admit of the flame fusing the metal at the inverted apex—otherwise a sound weld would be impossible—it should not, however, be sloped too much away from the bottom of the V, because metal that is valuable in that particular locality would be thereby removed. It should be understood that in welding a joint of this description, a considerable economy of both oxygen and acetylene may be effected by pre-heating the plates. According to the nature and character of the job in hand, the saving on the actual cost of welding plates ½ in. and upwards in thickness varies from 25 per cent. to 50 per cent., and in competitive work this factor will be duly appreciated.

Assuming, then, that the edges of the plates have been suitably bevelled, and the plates themselves have been pre-heated, proceed with the welding as follows: First bring the bevelled edges together, and direct the blowpipe flame to the bottom of the V and the converging sides just above the bottom, the object being to fuse the metal for about one-fourth of its thickness, so that it will run down from the sides to the bottom, and with the aid of the filling rod thus make a sound beginning. The filling rod should preferably consist of a strip of the same kind of iron as that which is to be welded, and it should be about 3/16 in. square in cross section. The molten metal should be well stirred and puddled with the filling rod, which in turn becomes fused, and thus helps to build up the weld; but care should be exercised to prevent the fusion of the filling rod and the consequent building up of the weld at a greater rate than that of the fusion of the bevelled edges.

Before the actual weld is filled up entirely, the molten metal is carefully hammered with the pene of a hammer to increase the density of the metal, and thus add strength to the joint. And after the filling process, but before the metal becomes lowered in temperature to a cherry red, the weld should be vigorously hammered throughout its entire length.

Much difference of opinion has been expressed on the subject of hammering, but providing the weld is hammered before the temperature falls below a bright cherry-red heat, the advantages are unquestionable. The best British and Continental practice is emphatically in favour of this treatment as tending to produce a weld of great strength and ductility—equal to quite 90 per cent. of the original bar—and exhaustive experiments have fully established this claim. But the hammering must be done while the metal is of the proper temperature, and it must cease before the metal gets red hot, otherwise more harm than good will result. When the metal is hammered at the wrong temperature it is apt to become " short " and brittle. Excessive strains are thus generated, and sometimes internal fractures result. The weld as a consequence suffers considerably, and the injury is none the less real because it is hidden. It is always better to hammer the weld during the welding process, instead of first welding the metal, and afterwards re-heating it for the purpose of hammering.

A bucket of water is always at hand during welding operations, and the hammer, as well as the blowpipe tip, should be occasionally dipped into the water in order to cool, and thus to some extent preserve them.

The presence of oxide in the joint during welding is betrayed by its comparatively darker colour, and as soon as this is detected the oxide should be converted into metallic iron by means of the application of the effective part of the flame, in conjunction with a vigorous stirring and puddling of the molten metal with the filling rod. A perfectly homogeneous weld of great strength is thus secured.

After the welding operation the metal should be annealed, the method of annealing being dependent on the size and nature of the job in hand. Where a hearth or a furnace is available, and where the work is of large dimensions, the hearth (or furnace, as the case may be) should be used for the annealing process. The plates should be uniformly heated to a cherry red, and then allowed gradually to cool down in the complete absence of cooling draughts or air currents. A smaller job may be annealed with the blowpipe flame similarly. Microscopic examination reveals a crystalline structure in iron that has been welded, but not subsequently annealed, whereas this structure becomes automatically converted into one having distinct fibrous characteristics through the simple process of annealing. Moreover, annealing equalises, and sometimes altogether removes, excessive strains which have originated during the welding process.

It is very difficult, if not impossible, to prevent the formation of excessive stresses in the iron plates during their welding and subsequent cooling; but these stresses may be minimised to a great extent by pre-heating the plates in the vicinity of the weld, and also in its more remote surroundings, and then taking care to anneal them properly after the welding.

Fig. 36 (p. 61) shows a style of double-bevelling the edges of wrought-iron plates exceeding ½ in. in thickness, and this method is employed because experience has proved the finished welded joint to be absolutely reliable. For heavy bars and heavier stocks the double-bevelled joint is much to be preferred, inasmuch as the metal which constitutes the joint is more evenly distributed than would be the case with a single bevel. Further, the nature of the double-bevelling facilitates the fusion of the metal by means of the oxy-acetylene blowpipe flame, since the flame has to penetrate only to a depth equal to one-half the thickness of the stock. A further advantage is that a joint of this description can, if needs be, very expeditiously be welded by means of two blowpipes, whose flames may be directed on both sides of the stock at one and the same time.

The foregoing observations concerning wrought-iron apply equally to the welding of mild steel. For welding mild-steel plates, the filling rod should preferably be a strip of the same metal, or, failing that, Swedish iron would be suitable.

# CHAPTER VII

## Welding Iron and Steel Castings

In all oxy-acetylene welding the composition of the metal is an important consideration. It should be thoroughly understood that mild steel, for example, which consists of iron and carbon, can be appreciably altered as regards its composition in the vicinity of the weld simply by readjusting the proportion of oxygen and acetylene in the blowpipe flame. Thus an excess of oxygen (which is indicated by a shower of brilliant sparks) burns the metal and robs it of its carbon content, whereas an excess of acetylene increases its carbon content, and incidentally lowers its melting point, until it is possible for this to be reduced below the melting point of oxide of iron. It is therefore advisable to use a neutral flame for welding mild steel.

For welding hard steel a different filling rod is required. The joints should be prepared by bevelling in the usual way, and a filling rod with a high manganese content should be employed. This is essential, since a high percentage of manganese in the finished weld imparts to it physical characteristics analogous to those in the steel itself. If desirable, or necessary, the welded steel may be hardened in the usual manner without in any way impairing the welded joint. It should always be remembered that the quality and composition of the filling rod plays an important part in the ultimate strength of the weld, and every endeavour should be made neither to decrease nor yet to increase the percentage of carbon in the iron that constitutes either the original stock or the new weld.

An almost inconceivable variety of cast-iron repair work is now possible to the oxy-acetylene welder, including the repair of cracks, blisters, flaws, etc., generally; the filling in of sand holes and blow-holes in defective castings; the repair of broken spokes, rims, teeth, cog-wheels, cylinders, and structural iron-work, etc. Holes that have been drilled in wrong places may be filled up without detriment to the casting, and parts that have been inadvertently cut away can be welded on to restore the castings to their original shapes. On the Continent and in the United States of America heavy castings are cut, reversed, altered, modified, manipulated, and in some cases entirely remodelled and welded, until they bear little resemblance to the originals—simply by means of the cutting and welding oxy-acetylene blowpipes.

There is a knack in making a strong weld in cast-iron that can be acquired only by exercise of considerable judgment and practice. To those unacquainted with the process, the welding of cast-iron appears to be more difficult of accomplishment than the welding of mild steel or wrought-iron; but such is not the case. In fact, cast-iron is the easiest of these metals to weld.

In the welding of cast-iron, a filling rod having a high percentage of manganese should be avoided for the same reason as that which makes its employment so necessary in the case of hard steel. Cast-iron contains carbon both in a free and a combined state, according to the nature of the iron. Where the percentage of carbon exists in a free state the cast-iron is known as " grey " iron, and this is the iron most commonly used. Where, however, the carbon content of the cast-iron exists in a combined state the cast-iron is known as " white " iron, which, on account of its extreme " hardness " and brittleness, is practically unworkable for ordinary purposes.

Cast-iron also contains varying proportions of manganese and silicon, and the presence of these has a great bearing on the ultimate nature and quality of the cast-iron. Manganese together with a percentage of free carbon in the cast-iron renders the iron hard and brittle; in other words, it has the peculiar ability of transmuting the " grey " iron into " white " iron. Silicon has the opposite effect, therefore silicon should be one of the constituents in the welding rod. Unless a ferro-silicon (iron and silicon) feeding rod be employed in the welding of cast-iron, the weld will surely be hard and brittle. Silicon should always be present, and it should not be allowed to evaporate unduly, otherwise manganese will predominate, with undesirable consequences. Moreover, silicon also performs the functions of a flux, but not to a sufficient extent, therefore a flux in addition is necessary for welding cast-iron.

Many kinds of fluxes for cast-iron are sold by the manufacturers of welding apparatus, and they vary considerably in composition. The principle of all of them is to provide some chemical which, at the high temperature involved, will break up the oxide into its component parts.

The following combinations will perform this function, and can be recommended: (1) Equal parts of carbonate and bicarbonate of soda, to which is added from 10 to 15 per cent. of borax and 5 per cent. of precipitated silica. (2) Carbonate of soda 50 per cent. and bicarbonate of soda 50 per cent. The necessity for using a flux may not be thoroughly appreciated; but if it is attempted to weld cast-iron without a suitable flux difficulty will at once be experienced.

Flux No. 2 is recommended by the British Oxygen Company, Limited. The action of the carbonates is to combine with the oxygen in the slag, or oxide of iron, and this chemical reaction, by reducing the iron, allows the oxygen to pass off in the form of carbon monoxide (CO) or carbon dioxide ($CO_2$).

For those who prefer to obtain a ready-made flux, it may be stated that separate flux powders, suitable for welding copper, brass, cast-iron, and aluminium, may be obtained in bottles containing ¼ lb. or upwards from the Acetylene Illuminating Company, Limited, who also supply filling, feeder, or welding rods for all metals.

In cast-iron welding the edges of the weld should be bevelled when the thickness exceeds $\frac{1}{8}$ in., so enabling the welding to penetrate the entire thickness of the metal. Both edges must be bevelled to an angle of 45°, so as to form a right angle at the weld. The bevelling should be regular, especially at the bottom, so as not to produce holes or excess thickness at the bottom of the bevel. Workers who attempt to effect welds on cast-iron that is thicker than $\frac{1}{4}$ in. without bevelling, invariably obtain poor results, as it is impossible to get regular and thorough penetration.

Edges may be bevelled by chipping, grinding, etc. Grinding wheels made from a carbide of silicon abrasive are very effective for cast-iron. The edges to be welded and their immediate neighbourhood must be free from sand, dirt, and rust.

Internal strains are set up in every process of welding, due to the expansion and contraction when a metal body is heated and cooled. These strains are unavoidable, but their effect may be minimised or nullified. In the case of cast-iron, the tendency to crack will be greatly increased if after confusion the metal is cooled rapidly or irregularly. Consequently, the article to be welded should be pre-heated slowly to about 700° to 1,000° F. (approximately 370° to 540° C.). Generally speaking, the higher the temperature of pre-heating, the less the danger of cracking. Preferably, pre-heating and subsequent slow cooling should be carried out in a muffle, particularly where light and intricate castings have to be dealt with.

If suitable precautions are not taken to minimise the strain or tension on a cast-iron weld after it has cooled down, fracture is liable to occur. How this may be done most effectively depends on the nature of the job and the extent of the fracture. In some cases the best method to adopt is to put the weld under compression during the actual welding process. The cooling and consequent contraction of the metal eases the compression and produces a tendency towards a tension, and thus equilibrium is established.

In the case of a simple fracture, for example, the casting should be entirely heated to a dull red, when the welding should be expeditiously performed, after which the casting should again be heated uniformly and allowed gradually to cool. Or the casting should be heated to a dull red, so that the consequent expansion almost closes the fracture by sheer compression. The casting is then allowed to cool, so that the fracture becomes slightly larger than formerly, after which it is immediately welded, and then transferred to the hearth or furnace to be uniformly heated throughout, and then subsequently allowed to cool gradually.

A larger crack or fracture should be welded at two operations. Begin at the middle of the fracture and weld to one end, then allow it to cool down. Afterwards again start at the middle and work to the other end, then anneal the whole job as previously explained. Subsequent fractures are less liable to occur if this method be adopted.

The fractured spoke of a flywheel, for example, should not be welded until the rim is caused to expand by the application of heat. This will have the effect of enlarging the fracture, which should be made good by the filling rod, otherwise the spoke will be subjected to great terminal strain when the job cools down, and a new fracture may result. The certainties of expansion and contraction should always be taken into due consideration, and precautionary measures adopted accordingly.

Care should be taken to choose the proper size of blowpipe tip to be used on any particular job. The manufacturer's recommendations in this respect should be observed. The total heat of fusion of cast-iron being high, it is necessary to use a blowpipe with a greater power than for the same thickness of welds on mild steel or wrought-iron. In the actual operation of welding, the blowpipe flame should be played on the edges to be welded until the melting of the iron just takes place. It is essential to avoid contact of the white cone of the blowpipe flame with the metal just about to be melted; the point should be kept at a distance varying from $\frac{3}{16}$ in. to $\frac{3}{4}$ in., according to the thickness of the work. The two edges to be joined should melt simultaneously. As soon as the first fusion is obtained, a little flux or scaling powder must be added; this is usually applied by dipping the extremity of the welding rod into the vessel containing the flux, the rod having been previously heated. Avoid throwing the powder into the molten metal whilst executing the weld, as the supply from the welding rod is always sufficient.

Do not add any metal from the welding rod until the bottom of the V is filled from the sides. It is found that by employing silicon in the welding rod, in the form of ferro-silicon, the iron combines with the silicon in preference to the carbon, allowing the carbon to take the form of graphite, and thus facilitate the formation of grey iron. The welding rod should contain about 4 per cent. of silicon and as low as possible in manganese. The proper welding rod may be obtained from the same manufacturers as the flux, and from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. in diameter.

One criticism of cast-iron welding has been directed against the hardness of the weld. This hardness may be due to a number of causes, such as inefficiency of the operator, unsatisfactory fluxes and welding apparatus, rapid cooling, etc. Therefore, as stated previously, in order to get good workable welds there must be slow cooling after the welding is complete; and there is no reason why the worker who carefully follows the instructions given, and applies himself diligently to the task, should not be able to weld cast-iron of any thickness in a workmanlike manner.

This method of welding cast-iron solves an unlimited variety of manufacturing and repair problems in the engineering industry, and can be relied on to make homogeneous work.

It is impossible to enumerate in anything like detail all the work in cast-iron which may be executed by oxy-acetylene welding; but the following are some of its applications: For repairing broken machine parts, gear boxes, motor cylinders, crank cases, tanks, manifolds, flywheels, etc., filling blowholes and defects in castings. Castings impossible or difficult to mould can be made in parts and united. Teeth broken from gear wheels can be renewed, and metal added in any desired quantity to worn parts of cast-iron articles.

As an example of its economical and positive aid to the engineering industry, the following may be of interest. A cast-iron belt-wheel would have gone on the scrap-heap, a total loss, with four of the six spokes broken, three entirely out. It was 5 ft. in diameter, and weighed about 500 lb., but was not worth much as scrap metal. Scrapping it meant the purchase of a new wheel, and perhaps a long delay in getting one cast. But with the oxy-acetylene process the three spokes that were fractured were welded into place and a fourth spoke, broken near the hub, was also welded. There were seven welds, each about 1½ in. by 4 in.; the job was done profitably at a cost of £5, ready for delivery in two days, and was considerably better than buying a new wheel and waiting two weeks or perhaps two months for delivery. The cost of welding a given job depends not only on the thickness of the metal, but on the skill of the workman. For example, the same class of job may vary as much as 50 per cent. when executed by different operators.

# CHAPTER VIII

## Welding Malleable-iron Castings

THE oxy-acetylene process is by far the best process to adopt for repairing broken malleable iron castings; but not infrequently the results obtained are unsatisfactory. Owing to the peculiarities and characteristics of malleable castings it is very difficult indeed to predict what the result will be before the welding is begun. It may be safely said that it is almost impossible to produce a truly homogeneous weld in malleable cast-iron without putting it again through the malleabilising process, and this is seldom possible in ordinary repair work.

Possibly a little thought will show why many unsuccessful attempts have been made to weld the material. Malleable castings are originally in the condition of hard, brittle, white cast-iron, that is subsequently made malleable by heat treatment which effects a chemical change in the structure by decarbonisation. This decarbonisation is nearly complete at the surface, but in a lessening degree towards the centre, giving the outside portion the texture of mild steel, while the inner portion may retain the qualities of cast-iron. It is not necessary here to go farther into the metallurgy of malleable cast-iron, except to say that the quality of a malleable casting depends on the material in which it is packed during the annealing process, on the time to which it is subjected to the heat, on the temperature to which it has been raised, and on the original quality of the material from which it is made.

Should the castings be small, or of thin section, if packed in such a material as hematite, and if subjected for a long enough time to a sufficiently high temperature, a large percentage of the carbon may be eliminated, resulting in the formation of a crude steel. Such castings may then be welded with an ordinary steel welding-rod and very good results obtained. In a thick casting, however, particularly if it was not packed in hematite or oxide of manganese, the action is very different, and the resulting metal is not a crude steel but a form of cast-iron, except on the outside, where there will be a thin layer of steel. Consequently, if the casting is thick, a steely cast-iron weld, hard, brittle, and difficult to machine or work, is obtained. Therefore it is not advisable to follow the welding methods prescribed for either mild steel or cast-iron. For instance, to weld a malleable-iron casting successfully, the welding material should fuse at a lower temperature than the casting, and its adherence, bonding qualities, physical strength and ductility should closely resemble the original casting.

In preparing the work the fracture should be chamfered or bevelled in the form of a V, say, not less than 45° each side of the break, or 90° including angle. The edges to be welded and their immediate neighbourhood must be thoroughly cleaned by grinding, filing, scraping, etc. The parts should then be set up ready for welding, if possible, on a surface plate or iron table. Sometimes it is necessary to set up pieces in the fire (such as a smith's hearth), either because they are too heavy to weld otherwise, or because of expansion or contraction causing them to break if welded cold. In such cases they should be blocked up as if on the surface plate; but take care to see that the heat does not affect the blocking or pieces so as to destroy the alignment during welding.

For all ordinary work it has been found that rolled manganese bronze or tobin bronze rods as a welding material, with borax as a flux, give very good results. The parts surrounding the fracture should be heated to a bright red and the joint sprinkled with a little flux, followed by a few drops of the bronze welding-rod. Should the bronze remain in a little globule it indicates that the work is not hot enough; but if it spreads and adheres to the surface the temperature is correct, and the groove should be quickly filled and at as low a temperature as possible.

In the actual operation of joining the parts together, it will be observed that the behaviour of the bronze affords a guide in regulating the temperature. Hence by this method it is necessary to heat the casting only to the temperature at which the bronze will alloy with it.

On no account must malleable iron be brought to the melting point, or else it will be found that it is detrimental to the strength of the casting. Also, if heated beyond a certain point it will revert to its original state of white or chilled cast-iron with consequent hardness. However, after a little experience the desired temperature can be determined with great accuracy. A neutral flame should be used, and it is generally advisable to reinforce the parts joined.

A special welding metal suitable for malleable cast-iron has been placed on the market under the name of "Ferrox," and it is claimed that excellent results are obtained by its employment. This material can be obtained in rods, in 3-ft. lengths, and of diameter in a range of from $\frac{1}{16}$ in. to $\frac{1}{4}$ in. from the Ferrox Company, Limited. As this material melts at a lower temperature and has much greater fluidity than ordinary welding wire, the operator, until accustomed to its use, should see that the edges of the weld are properly heated and that adhesion does not occur.

Sometimes a welding rod of Swedish iron may be used in conjunction with a good cast-iron flux and a satisfactory weld obtained. This is preferable, for use as a welding material, to silicated cast-iron, as not infrequently, where the latter is used, the welds are very brittle and the results generally unsatisfactory. Similarly, if a weld is made by using a welding rod of malleable iron. Of course, it is possible to obtain a satisfactory weld in malleable iron with a welding material of the same composition by putting it through the malleabilising process again; but, as previously stated, this is seldom possible in repair work.

Experience has shown that the most satisfactory and practical way of joining broken malleable castings is by using manganese bronze or tobin bronze as already explained; but this process cannot be called true autogenous welding. However, a malleable casting mended in this way is practically as good as one piece. It has about the same tensile strength and ductility as the original, and the process has the advantage of being very quickly performed.

The actual cost of repairing malleable-iron castings is not always the most vital feature. In many cases time is the determining factor, especially in cases of broken machinery, where the replacement of a part might involve a long delay.

# CHAPTER IX

## Welding Steel Plates, Pipe Mains, &c.

In welding fractures in boilers or steel shells of various types it is sometimes advisable to drive a wedge into the crack for the purpose of temporarily enlarging it during the process of welding. In practice, the crack is "tacked" here and there by welding a little filling metal in it, so that the wedge may be withdrawn without the crack assuming its original size. Obviously, then, the prospective joint will be under compression which will tend towards equilibrium when the tensional stresses are generated under the influences of the cooling metal after welding.

Where a fracture is very extensive and irregular, and the plate in its immediate vicinity is very much worn, a patch can be welded on with great advantage. Preferably the patch should be either circular or oval-shaped, or, at any rate, it should have rounded instead of sharp corners, so as to minimise the risk of further fracture occurring in the older material. Bearing in mind what has already been stated as regards contraction and expansion, it is advisable, where practicable, to hollow or slightly dish the patch, so as to compensate for tensional strains which will be generated as the metal cools down subsequent to welding.

The patch should not be simply laid on and welded to the old material. It is very necessary that the old material should be cut away, and the patch properly fitted to take its place. Patching by means of the oxy-acetylene welding system is thus rendered much easier of accomplishment (while being thoroughly reliable), inasmuch as repairs can be executed by this method in places which are more or less inaccessible to the workman employing other methods. An old weld should never be re-welded; rather is it better to cut away the old joint and insert a patch.

A matter of considerable importance is the determination of a suitable position for a welding joint, and if it can be at all avoided, the joint should not coincide with what might be termed the junction line of stresses operating in different directions. For this reason, in cylindrical work of a heavy character, for example, the joint should not be placed precisely at the angular junction of the end and the sides of the cylinder. Either the sides of the cylinder should be worked over to form part of the end, or the end should be worked over to form part of the sides. The welded joint will then be definitely either on the sides of the cylinder or on the end, instead of being at the precise angular junction. By adopting this method the newly welded joint will be subjected to stresses which operate in one direction only.

One great advantage of the oxy-acetylene system is that it is possible to weld not only in a vertical but also in an overhead position, although it should be borne in mind that vertical and overhead welding calls for more experience and judgment than does horizontal welding. However, in the case of vertical and overhead welding, the most important consideration is the proper arrangement of the heat. First of all the blowpipe flame should be directed on the plates on each side of the intended weld until they are white hot, while the intended weld is kept relatively cooler. Attention is then devoted to the actual welding. The flame should be directed into the groove or channel that is to be welded, and at the same time the filling rod is introduced, the object in view being the melting of the filling rod by the heat of the surrounding metal, plus the barest minimum of heat from the blowpipe. When the heat has been accurately judged, both as regards the amount and its distribution, it will melt the filling rod sufficiently to cause it to spread and adhere where it is required; but precisely at this juncture a cooling influence operates and prevents the metal forming into globules preparatory to falling away from the seam. It will thus be understood from the foregoing that vertical and overhead welding is essentially a matter of heat judgment. Always endeavour to build up sufficient heat in the plates adjacent to the proposed weld that the stored-up heat will, with the slightest additional heat from the blowpipe, melt the filling rod —and only just melt it—so that it will immediately spread out and cool down before it has time to drop off.

**Pipe Lines.**—The oxy-acetylene process is being extensively developed in connection with cast-iron, wrought-iron, and steel pipe-lines for gas, water, etc. In the United States of America (where pressures far exceeding those employed in this country are dealt with) this is preferred to other methods of jointing. Mains varying in size from 3 in. to 24 in. in diameter—some several miles long—have been successfully welded and have passed the most stringent tests subsequently. In Great Britain the oxy-acetylene welded joint is slowly, but nevertheless surely, winning its way in pipe main work, and this is particularly true in connection with high-pressure work. This, of itself, speaks volumes for the efficiency of the oxy-acetylene welded joint. Usually the "spigot and faucet joint," with its yarn and metallic lead caulking, and the "turned and bored joint" are employed for low-pressure work; but the advent of high-pressure distribution by means of steel pipes has necessitated the adoption of a more reliable joint. The disadvantage of using a caulked lead joint in connection with iron pipes becomes at once apparent when expansion and contraction are taken into consideration. Thus, while the coefficient of linear expansion per degree centigrade is 0·0000280 for lead, it is from 0·000015 to 0·0000175 for cast-iron. Expressed in other words, this means that lead and cast-iron expand and contract at different rates, with the result that the lead becomes gradually loose, and thus tends to destroy the efficacy of the joint.

Referring to the effects of changes of temperature on metals, it may be stated that at a depth of 3 ft. below the surface of the ground the yearly range of temperature is 15° F., that is, from a minimum of 39° F. to a maximum of 54° F. A change of temperature to this extent in cast-iron is capable of producing a stress of nearly a quarter of a ton per square inch.

With oxy-acetylene welded-steel joints and pipes, the co-efficients of expansion of both joints and pipes are practically identical, and the advantages are obvious. Where, however, the pipe line is likely to be subjected to extremes of temperature, corrugated-steel expansion pipes should be interposed at suitable intervals, the corrugations of such pipes being situated at right angles to the axis of the pipe. The action of these expansion pipes under the influence of changes of temperature may be likened to the action of the bellows of a concertina—which latter, of course, is capable of being expanded and contracted at will. In the event of an increase of temperature, linear expansion takes place, and the corrugations close to accommodate it. Conversely, a decrease of temperature causes contraction, and the corrugations open to compensate for it. Some main-layers are content to let expansion and contraction take care of itself by allowing the pipe line to assume a snake-like form, as, when, and where it will; but the interposition of one or more expansion pipes at suitable intervals makes by far the better job.

As regards the preparation and the actual welding of the joints, the thickness of the metal should determine the nature of the joint (as previously explained); but where a bevelled joint is contemplated, the best angle for the ends of the pipe is 60° to the horizontal. The employment of steel pipes and oxy-acetylene-welded joints offer many attractions and advantages. Pipes may be bent *in situ*, tees and siphons may be placed where required, and a variety of other fittings may be made less expensively on the job by means of a simple welding operation. An ideal equipment for this class of work is illustrated in Fig. 25 (p. 53).

In order to demonstrate the possibilities, and incidentally to show the substantial character of this method of main-laying, reference may be made to a successful piece of engineering which has been recently accomplished in the United States. This enterprise involved the laying of a 6-in. high-pressure steel main for a distance of about ten miles, and 700 yd. of this main had to be laid 3 ft. below the bed of the Connecticut River. Altogether 1,413 oxy-acetylene-welded joints were made on this job, and a test of 90 lb. per square inch was subsequently applied, and successfully withstood. This will be better appreciated when it is realised that this pressure is 800 times more than that which is ordinarily applied to consumers of gas in this country. Further, the engineers state: "We are thoroughly convinced that the laying of high-pressure mains with welded joints is the most economical method to date. We realise that this method is still in its infancy; but, nevertheless, we feel sure the time is near at hand when it will be in general use."

So much, then, for the advantages of oxy-acetylene welding in this connection.

# CHAPTER X

## Welding Copper and Its Alloys

OXY-ACETYLENE welding provides a means of effecting welds on copper articles which some years ago were impossible. In fact, hundreds of years' experience had led to the belief that copper is not weldable as iron is. However, with the advent of the oxy-acetylene blowpipe flame, autogenous welding produces a similar joint by similar means in both metals. The process is one that requires a considerable amount of practice in order to effect satisfactory welds; but there is no reason why the worker who carefully follows the instructions given, and applies himself diligently to the task, should not be able to weld copper of any thickness with success.

In preparing the metal to be welded, the edges should be bevelled to enable the welding to penetrate the entire thickness of the metal. Bevelling is not generally practised below a thickness of $\frac{3}{32}$ in. From $\frac{3}{32}$ in. to $\frac{3}{16}$ in., a slight open bevel is sufficient; $\frac{3}{16}$ in. thick and over, the angle of bevel should be about 90°. It is not necessary to go beyond this even with great thickness. The bevelling should be regular, especially at the bottom, so as not to produce holes or excess of thickness at the bottom of the bevel.

The edges to be welded and their immediate neighbourhood should be thoroughly cleaned with a file, scraper, emery, etc. Chemical agents such as spirits of salt or nitric acid are sometimes employed; but it is preferable to precede their use by a mechanical cleaning.

Before beginning the welding the parts should be carefully arranged so that during the welding operation they remain perfectly in position.

Owing to the high conductivity of copper, a relatively larger blowpipe tip must be used than when welding either iron or mild steel of the same thickness. The power of a blowpipe of 225 litres with an approximate consumption of 7·75 cub. ft. of acetylene per hour would be suitable with economical results, for iron or mild steel $\frac{1}{8}$ in. thick, whereas for copper of the same thickness the power of the blowpipe should be of 300 litres, having an approximate consumption of 10·5 cub. ft. of acetylene per hour. Also, a blowpipe that is too strong tends to melt the metal too rapidly. This should be as carefully avoided as that of melting too slowly.

As already stated, a larger tip should be used for welding copper—on account of the latter's great conductivity—and a distinctly reducing flame should be employed. That is to say, the acetylene should be sufficiently in excess to produce a small tail on the dazzling inner cone. Great care should be taken to avoid burning the copper by allowing the inner cone to impinge on it. This, it should be stated, will readily occur if the oxygen instead of the acetylene happens to be slightly in excess.

When copper is burned its physical properties become adversely affected, and its strength is reduced to a minimum. No longer possessing its peculiar characteristics, it becomes rough, brittle, and practically unworkable; hence the necessity for discretion.

Copper possesses a great affinity for oxygen and, when molten, hydrogen. The oxygen unites with the copper to form an oxide, and in the presence of molten copper this oxide is dissolved and absorbed in the molten mass. Unfortunately, however, on cooling, the oxide re-forms, with undesirable effects. Further, in the event of oxygen, hydrogen, and carbon monoxide (CO) being dissolved in the molten copper when the welding operation is being conducted, these gases will surely be evolved as the metal cools down, and the result will be a porous joint of no practical utility.

It should be remembered that under certain conditions all of these gases are present in the oxy-acetylene blowpipe flame, and the chief concern of the welder should be that none of them becomes incorporated in the molten copper, since the ultimate effect cannot be other than detrimental.

In order to accomplish this object, and thus effectively prevent the absorption of the gases under consideration, and also in order to prevent the copper uniting with oxygen to form, and afterwards when molten to dissolve, its own oxide, a welding powder or flux should be employed.

Undoubtedly the best flux to use for welding copper is phosphorus, this element having the desirable ability to reduce any oxide that may be present to its metallic state; and, in addition, the phosphorus tends to prevent the absorption of gases that would be positively detrimental to the work in hand. When phosphorus is used in this connection phosphoric acid is formed, and this floats readily on the surface of the molten metal, and effectively protects it from external undesirable effects.

A point of some importance, however, is the undesirability of allowing phosphorus to become permanently incorporated in the finished weld, since this would have a tendency to make the copper "short" or brittle. A very small percentage would have no ill-effect, but a high phosphorus content in a copper weld should be rigidly guarded against; hence it is always better to employ a special copper welding-rod together with the special copper flux made by a firm that specialises in these matters.

The phosphorus flux is best applied introduced in the form of a welding-rod of phosphor copper; a pure copper welding-rod may be employed, but it is not so effective. The phosphorus is incorporated in a very small quantity, so that none remains in the weld after its execution. A filler rod that contains too much phosphorus lacks fluidity, and melts at a temperature much lower than that of the copper to be welded, thus facilitating adhesion. Moreover, as above shown, the welds in which the phosphorus remains lack elongation, and therefore do not possess the same mechanical properties as pure copper. The welding-rod after $\frac{1}{16}$ in. of its diameter should be about equal to the thickness of the weld, although in practice feeders above $\frac{1}{4}$ in.

in diameter are not generally employed. Welds made on copper without a deoxidising welding-rod properly prepared have a tendency to oxidise, and therefore do not possess the required qualities. In addition, the surface of the metal must be covered with a carefully prepared mixture of potassium phosphate and potassium carbonate to a depth of about $\frac{1}{16}$ in. Upon the application of the flame the mixture will melt and form a glaze over the surface of the copper, thus preventing oxidation and assuring good work.

A flux consisting of chloride of sodium, sodium borate, and boracic acid is also recommended. The flux should be sparingly applied by dipping the end of the welding-rod into the vessel containing the flux. The end of the rod should be warmed in order that the flux adheres.

Before beginning the actual operation of welding it is essential to raise the edges of the weld and the parts in the vicinity to a high temperature. The high conductivity of the metal necessitates this, as any supply of molten welding-rod before the edges are in a molten state inevitably produces adhesion. The flame of the blowpipe should be perfectly regulated and maintained neutral without excess of either acetylene or oxygen. An excess of acetylene produces effervescence or bubbling of the metal, consequently a weld made with such a flame often contains a large number of blowholes. If an excess of oxygen is used it intensifies the oxidation of the metal.

In executing the weld care must be taken to avoid contact of the white jet of the blowpipe flame with the metal just about to be melted. The distance of the white jet should vary according to the power of the blowpipe, say from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. If this distance is increased the gases resulting from the second phase of combustion, carbonic acid and water vapour, influence the weld.

See that the copper is not fused until the edges of the weld and the parts near have been raised to a high temperature. At this moment the welding-rod and the parts to be joined should be melted simultaneously. The welding-rod must be regularly incorporated in the line of welding, and must not be allowed to fall in drops. The operation should be continuous, taking care to attack regularly the two edges of the metal. The welding is thus executed rapidly.

As already made clear, strains are set up in every process of welding, due to the expansion and contraction when a metal is heated and cooled. Copper lacks tenacity when heated. Hence there is contraction of the metal, whose co-efficient of expansion is also fairly high; fractures thereby are often produced, especially in the welding part. However, pre-heating the article to a high temperature, maintaining the heating after the operation of welding, and subsequent slow cooling enable the worker in many cases to avoid fractures due to contraction. It is also necessary to hammer the line of welding and the metal in its vicinity, after which it is essential to reheat the copper, raising it to redness (930° to 1,100° F., or 500° C. to 600° C.). Then plunge into cold water, or cool as rapidly as possible. The structure of the weld is not quite as homogeneous as other parts of the piece welded. This is, however, controlled largely by the skill and workmanship of the operator, who can, at will, make the weld more or less homogeneous.

It is impossible to enumerate in anything like detail all the work in copper which may be executed by oxy-acetylene welding. However, coppersmiths are advantageously making great use of the system, thereby replacing their old methods of brazing and riveting.

**Welding Bronzes and Brasses.**—Copper enters largely into the composition of the various alloys which come roughly under the headings of bronzes and brasses, and for this reason the foregoing observations concerning copper should be remembered when welding any of these. Both brass and bronze filling rods, with suitable fluxes for each, may be obtained from the Acetylene Illuminating Company, Limited, and it is better to rely on these special productions than to attempt to make a filling rod for each particular copper alloy that might come into one's hands.

A method of welding these alloys, and one extensively practised on the Continent, is to place the article on a pre-heated stake or mandrel and then to apply the oxy-acetylene blowpipe to the top of the metal. The stake or mandrel, as the case may be, should be red- or white-hot, in order to economise gas and to facilitate the progress of the work. When the temperature approaches the melting point of the metal to be welded the joint is rapidly hammered by exceedingly small long-shafted hammers, and a satisfactory weld is thus produced.

Borax is a good, all-round flux to use for copper alloys of different composition, but before applying it the water of crystallisation should be driven off by the application of heat. The borax should then be reduced to a fine powder and applied to the weld as required. By pre-heating the borax and then crushing it afterwards the subsequent boiling up of the borax on the weld is entirely obviated.

## CHAPTER XI

### Welding Aluminium

THE most modern method of jointing aluminium is with the oxy-acetylene blowpipe flame. It is common knowledge that oxy-acetylene welding has now assumed the proportions of an important commercial development, and is recognised in the engineering industry as the most reliable means of obtaining a perfect and homogeneous joint in aluminium. The process has solved many problems in the manipulation of aluminium and its alloys, which metals have such a great variety of applications in the industrial arts, and it has largely superseded the processes of soldering, riveting, bolting, screwing, seaming, grooving, etc. It gives a more finished product than is possible by the older methods. Although the process has been employed on certain classes of work during the last fifteen years, its many advantages were not, until the last few years, as fully appreciated by the metalworking industries as its general adaptability warranted; but its possibilities have now been taken advantage of to an extraordinary degree, with the result that aluminium has not only supplanted other metals, but also wood in many branches of industry. As a case in point, large quantities of aluminium sheets and aluminium-alloy castings have been incorporated into all-metal vehicles of various types, in which a few years ago timber was the only material used. In railway passenger-car construction the employment of aluminium lessens the dead weight, provides a fireproof material, and possesses the advantage over steel sheet of being rustless and taking paint better.

Even a slight acquaintance with the properties of aluminium will prepare the reader for the statement that an inexperienced welder finds it to be one of the most difficult metals to weld. This is mainly due to the rapid and insistent formation of oxide on the surface of the metal when heated, and when it is remembered that the melting point of aluminium is 650° C., and that of its oxide 3,000° C., it will be seen that it is possible to melt the metal without melting the oxide. In endeavouring to melt the oxide, the metal is liable to become overheated, and this overheating is found to cause undue expansion. As the thickness of the metal is a negligible quantity, the expansion is superficial, and this inevitably leads to warping. In attempting to avoid overheating the metal, there is always the possibility of imprisoning the unmelted oxide and consequently impairing the joint. Therefore, the proper flux must be used when welding this metal, in order to destroy the oxide without the necessity of unduly heating the joint.

To be able to weld successfully in aluminium even the welder experienced with iron or steel should endeavour to realise that much practice and patience are necessary before the technique can be mastered.

But granted a good insight, practical experience, and a thorough knowledge of the characteristics of the metal, aluminium becomes one of the easiest metals to weld, and in the munitions works thousands of women have been successfully taught to do the work.

The special difficulties to be contended with in aluminium welding are the high rate of expansion and contraction, the low fusion point, the great conductivity and consequent dispersion of heat, rapid oxidation of the metal, high specific heat (being 0·212, more than twice that of copper), and comparative weakness in tension, especially at high temperatures (400° to 500° C.). As already said, the metal has a remarkable affinity for oxygen, and in the melting of the metal under the action of the blowpipe flame a compound with the atmospheric oxygen can be seen to form; this compound is alumina (aluminium oxide), which has great power of resistance to the welding flame, and prevents the metal from flowing as freely as such metals as iron or steel, and which, if allowed to remain, will spoil the joint. The film of oxide can be destroyed by chemical means alone, but as the oxide is exceedingly resistant at high temperatures to the action of acids and alkalies, it has been found very difficult to produce a flux that will destroy the oxide at the comparatively low melting point of the metal and at the same time protect the molten metal from contact with the air.

Fluxes or "welding powders" for aluminium are obtainable from most oxy-acetylene apparatus manufacturers, the British Aluminium Company, etc. The very fine powder is applied to the line of welding, or can be used in the form of a paste by mixing it with cold clean water or alcohol. The paste flux is preferable for vertical welds, and also for sheet aluminium, making possible a greater length of welding at one operation, owing to the fact that it adheres to the surfaces, whereas the powder flux is liable to be blown away by the blowpipe. The paste flux is applied by smearing it all over the parts of the joint to be welded. The application of flux in the form of a varnish on the welding rod is the best method of all.

As in the case of ordinary soft-soldering, the rapidity with which the flux acts is an important factor. The powdered flux is best applied from the welding rod; this can be done by first warming the end with the blowpipe flame and then dipping it into the flux, which readily adheres. Applied in this way, it will flow ahead of the welding flame and prepare the metal. The flux must not be thrown on the metal whilst welding. The supply from the welding rod is always sufficient, as a very small amount of flux is all that is necessary if the joint has been properly prepared.

Many formulæ for aluminium fluxes have been given in text-books. They include the chief ingredients in varying proportions: the chlorides of aluminium, calcium, and sodium; the oxides of aluminium, calcium, potassium, etc. A typical patented flux consists of 60 parts of potassium chloride, 10 parts of cryolite (an aluminium-sodium double fluoride), and 30 parts of calcium chloride; but the proportions may be varied within considerable limits. A flux consisting of the following is also recommended: potassium chloride, 45 per cent.; sodium chloride, 30 per cent.; lithium chloride, 15 per cent.; potassium fluoride, 7 per cent.; and sodium of potassium bisulphate, 3 per cent.

The manufacture of welding powders for aluminium necessitates experience and chemical knowledge, and their preparation is best left to specialists; but should it ever be necessary to make them in the welding shop, it is essential thoroughly to dry and pulverise the ingredients.

The average fusing point for the welding powder must be below the melting point of the aluminium, and the vaporisation point of the powder must certainly not be lower than the melting point of the metal. That is to say, the powder must melt, but must not vaporise during the welding operation. The welding powder should not shrivel up under the action of the blowpipe flame, and must be kept free from dust and dirt, as otherwise faults may occur in the line of welding; the powder, also, must not be exposed to the atmosphere more than is absolutely necessary, as it is hygroscopic (absorbs the moisture from the air), and once it has become moist forms a pulpy mass which does not keep long. It is therefore advisable to keep the powders in closed bottles, preferably with ground-glass stoppers.

Some workers weld the metal without the aid of a flux, by employing what is known as the "puddling system." Generally they use a tool known as the "puddle," this consisting of a steel rod, about $\frac{1}{4}$ in. or $\frac{3}{8}$ in. in diameter, usually flattened at one end, similar to a screwdriver, and filed or ground off smooth, the edges being left fairly sharp. When the edges of the weld begin to fuse, the puddle is brought into operation by agitating or rubbing the molten metal so as to break up the oxide already formed on the separate globules, which allows them to flow into one another. By this method there is no certainty that the weld will be a homogeneous one, as a portion of the oxide remains in the weld and may lead in time to disintegration, and the method is particularly unsatisfactory in the case of thin sections and aluminium sheets.

The welding rod of filling-in material should be an aluminium wire or rod, as pure as possible, and of a diameter slightly greater than the thickness of the metal to be welded, especially when welding thin sheets. A $\frac{3}{32}$-in. diameter rod is suitable for aluminium (where it cannot be readily flanged) up to $\frac{1}{16}$ in. thick; $\frac{1}{8}$-in. rod for thicknesses between $\frac{1}{8}$ in. and $\frac{7}{32}$ in.; while rods of $\frac{1}{4}$-in. or $\frac{9}{32}$ in. diameter may be used for material more than $\frac{1}{4}$ in. thick. Should the welder find himself without the usual welding rods, or if the diameters are unsuitable for the work in hand, strips of sheet aluminium of similar sectional area may be satisfactorily used, but the width of the strips should vary according to the thickness of the aluminium to be welded; that is to say, the width should be about two to three times the thickness of the metal up to $\frac{1}{8}$ in.

thick, and one and a half to twice the thickness for between $\frac{1}{8}$ in. and $\frac{1}{4}$ in. thick. If suitable tools or machines are available, the strips of aluminium can readily be bent or formed somewhat similar to a welding rod, and are then more easy to handle.

In preparing the aluminium parts to be welded, first see that the edges are thoroughly clean. Thin aluminium sheets, up to say a maximum of $\frac{3}{32}$ in. thick, may have their edges turned up or flanged at right angles, the depth of the flange being slightly more than the thickness of the metal. The edges must be thoroughly cleaned and adjusted so that the two lower flanged edges touch exactly. By this method the customary welding rod is unnecessary, the edges being fused and providing the necessary material for the weld, but it is wise to restrict the flange method to very thin sheets which would be difficult to weld by the rod method. Sometimes it is advisable to "tack" the flanged pieces together by fusing the edges of the flange at intervals of about 4 in. before melting down the whole flange.

After the weld has been made it should be hammered level.

Should the work be unsuitable for flanging, as sometimes is the case on intricate shapes, the edges of the metal may be simply butted together, the use of a welding rod being then unnecessary.

When the aluminium is $\frac{1}{8}$ in. or more thick, the edges must be bevelled to enable the flame to come into direct contact with the whole of the surfaces to be united. From $\frac{1}{8}$ in. to $\frac{3}{16}$ in. a slight open bevel is sufficient; from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. to $\frac{1}{2}$ in. the angle may be increased to 100°; for $\frac{1}{2}$-in. or thicker metal, double bevelling (bevelling from both sides to about 90°) is advisable where possible. Expert welders can sometimes effect welds in aluminium and its alloys up to $\frac{3}{16}$ in. thick without bevelling, but this is a matter of individual skill, and the inexperienced should always bevel the edges of metal exceeding $\frac{3}{32}$ in. thick.

The power of the blowpipe should vary according to the thickness of the work, and for welding very thin sheets special low-power blowpipes are extensively used. The following table shows the thickness of the aluminium to be welded and the approximate powers of the blowpipe adapted to the work.

| Thickness in parts of an inch. | Thickness in Millimetres. | Delivery of the Blowpipe. Acetylene per hour. | |
|---|---|---|---|
| | | In litres. | In cubic feet. |
| 0 03125 or $\frac{1}{32}$ in. ... | 0·7937 | 25 | 0 88 |
| 0 046875 or $\frac{3}{64}$ in. ... | 1·190 | 40 | 1 41 |
| 0 0525 or $\frac{1}{16}$ in. ... | 1·587 | 50 | 1·76 |
| 0·09375 or $\frac{3}{32}$ in. ... | 2·381 | 120 | 4·24 |
| 0 125 or $\frac{1}{8}$ in. ... ... | 3·175 | 250 | 8·83 |
| 0·1875 or $\frac{3}{16}$ in. ... | 4·762 | 500 | 17·66 |
| 0 250 or $\frac{1}{4}$ in. ... | 6·350 | 750 | 26.50 |

To overcome the excessive expansion and consequent warping of thin aluminium, heat-conducting blocks may be employed. Preferably, the blocks should be of copper, and of substantial thickness, so that the heat, which would otherwise expand and distort the aluminium may be readily absorbed by the blocks. The sheets to be welded are laid in position on one or more blocks, and other blocks are placed on the sheets on each side of the seam. These blocks should be regarded as part of the welding equipment, and they should be perfectly flat and smooth, so that metallic contact may be obtained all over the surfaces which come next to the aluminium. In the absence of copper, which is nowadays both scarce and expensive, substantial iron blocks may be used to advantage.

Another safeguard against undue expansion and contraction is pre-heating and annealing, but care must be taken not to exceed the fusion temperature, or the metal will be distorted or otherwise injured. Aluminium does not change its colour quickly with increase of temperature, and consequently there is no visible warning of overheating.

Before starting to weld, always see that there is a sufficient supply of both gases to complete the work on hand, as it is injurious to the weld to stop in the middle of a job.

The flame of the blowpipe must be properly regulated, and the correct adjustment of the gases maintained. This is secured where a slight excess of acetylene appears, which is indicated by the extension of the acetylene cone beyond the white cone. As aluminium is sensitive to oxygen, an excess of acetylene is not detrimental, and has the advantage of lowering the flame temperature. The blowpipe flame should be at about right angles to the line of welding, and the white cone or jet must not come into contact with the metal just about to be melted, because the high temperature of this part of the flame tends to produce holes which are by no means easy to mend. The distance of the extremity of the white cone from the work will depend upon the power of the blowpipe and the thickness of the metal, and will vary between $\frac{3}{16}$ in. and $\frac{3}{4}$ in. Two important points to remember are the use of a proper-sized acetylene flame and the saving of gas by pre-heating the work.

In the actual operation of welding, the welding rod and the edges to be united must be melted simultaneously, and on no account must the rod be allowed to fall in globules upon the work. For filling the joint on aluminium $\frac{3}{16}$ in. or more in thickness, one end of the rod should be constantly submerged in the molten metal in the groove; by judicious and rapid movement of the blowpipe flame the worker can completely prevent burning, and at the same time effect a perfect weld.

All welds on aluminium should be expeditiously executed from the moment the first fusion is obtained; the rate of travel should be fast, and must gradually increase as the weld proceeds. Tardiness is generally fatal. The speed at which welding on aluminium can be done depends largely on the nature of the work and the skill of the operator. The cost naturally will be influenced by the prices current for acetylene, oxygen, etc. As an example, an approximate rate at which welding can be carried out on metal, say $\frac{1}{8}$ in. thick, in a straight-ahead job, will be from 24 to 30 lineal feet per hour; whereas in vertical or irregular welding 10 to 12 lineal feet per hour is considered to be a good average.

Vertical welds are often required and can readily be obtained, but only by expert welders. Some operators start at the bottom of the weld and work upwards, while others reverse this order. One advantage of starting at the top is that the flux flows ahead of the welding flame and prepares the metal; whereas, if the welding is done in an upward direction, the flux has to be frequently applied, as it cannot run upwards. A paste flux is advantageous in vertical welding. The blowpipe flame should be held at a suitable angle to the line of welding, and it is advisable for the operator to assume, if possible, a comfortable position, as better welds are generally then obtained. It is important that directly after the welding has been carried out and the joint is cold, the weld and its immediate neighbourhood should be thoroughly washed with clean warm water to remove all traces of the flux, thereby preventing subsequent corrosion of the metal. The writer has seen many cases of injury to the work caused by not completely removing the remains of the flux. Although apparently so small a point, it has been thought well to lay stress upon it.

Internal strains are inevitably set up in the course of welding, because the physical and mechanical properties of the metal have been altered; consequently, in order to relieve a welded aluminium article of these strains and to obtain a perfect and homogeneous weld in the metal, it is desirable, where possible, for the lines of welding and the adjacent parts to be hammered cold and then reheated to a temperature of about 450° to 480° C. (850° F. to 900° F.). This causes molecular rearrangement to take place within the metal, and causes greater homogeneity in the weld zone, consequently improving the quality of the metal. The range of temperatures noted must not be exceeded, as at higher temperatures the metal becomes very fragile, and a piece of work containing a really good weld may be rendered useless by deformation.

Success in welding aluminium depends largely on the intelligence and skill of the operator. It is easy for an inexperiencd welder to mistake for a good weld a joint that is held together merely by superficial adhesion. To be able to make the joints sound throughout, it is necessary to possess skill, training, and a thorough knowledge of the principles of the process, and it is essential that new work should have been specially designed and prepared for manufacture by the oxy-acetylene process. Much depends, too, on the quality and kind of material employed. Sound welds possess a degree of strength only slightly below that of the original section, and by judicious reinforcing or " building up " this can be increased, so that a strength fully equal to that of the original metal can be obtained. The welds present a neat and finished appearance, are sound and homogeneous in structure, and can be easily machined. From every standpoint they are of a very satisfactory character. Hence, welders should not be discouraged if after successfully welding iron and steel, they fail in their early attempts to weld aluminium, as in order to obtain true welds on aluminium a different procedure is obviously necessary. An iron welder invariably finds it difficult to work on aluminium, because it is to him a strange metal. Obviously, there is no good reason why operators who carefully follow the instructions given in this chapter and apply themselves diligently to the task should not be able to weld aluminium with complete success.

Wherever the process of oxy-acetylene welding on aluminium has come into disrepute it is because the work has been performed by unskilled or incompetent welders. The process is no longer in the experimental stage. Properly executed, it must give successful results.

## CHAPTER XII

### Welding Aluminium Alloys

IN the early days of the aluminium industry it was discovered that aluminium unalloyed was too soft for many classes of work, and that structures cast in it lacked rigidity. However, a great many alloys have been developed since then which are harder than the pure metal, and at the same time almost as light. Considering the multiplicity of uses to which these alloys have been put in the automobile, aeroplane, and kindred industries, it is somewhat remarkable how little is known about their properties and treatment, especially in the autogenous-welding shop.

The physical properties of the alloys are influenced by the proportions of the ingredients. Aluminium is commonly alloyed with copper and zinc, less frequently with bismuth, magnesium, manganese, nickel, silver, and tin. These alloys are generally divided into two classes: (1) The light alloys, those containing from 90 per cent. to 95 per cent. of aluminium; and (2) the heavy alloys, those in which aluminium is present up to only about 10 per cent. In the first of these classes, whilst the specific gravity is only raised from about 2·70 to 2·95, the tensile strength can be increased by mechanical working, such as rolling and forging, to more than 20 tons per square inch.

Many readers of this handbook are fully alive as to the progress that has been made in aeronautical construction, which has emphasised the need of strong and hard aluminium alloys. As previously indicated, pure aluminium presents considerable difficulties in working, but alloys of aluminium have been invented in the past few years which are likely to be of very great importance in the building and equipment of aircraft. It may be of interest to give one of the published analyses of the alloys of aluminium used in one of the ill-fated "Zepps":—Aluminium, 90·27 per cent.; zinc, 7·8 per cent.; copper, 0·73 per cent.; with small amounts of iron, silicon, manganese, and tin. However, this analysis, which is from French sources, is believed to be unreliable. Various alloys are used for different purposes in airship construction, that employed for the framework being almost unweldable. The welded parts on a "Zepp" are of pure aluminium or a plain copper-aluminium or zinc-aluminium alloy.

A truly homogeneous weld is seldom obtained, the composition of aluminium alloys being so extremely variable. To be sure of obtaining a perfectly sound weld, it would be necessary for the added metal (welding rod) to be of exactly the same composition as the parts to be welded. Unfortunately, the alloys of aluminium in the form of welding rods are very rarely obtainable, so that many welders resort to the use of pure aluminium as the filling-in material, a practice not to be recommended, because if an alloy containing, say, 20 per cent. of zinc is being welded, its melting point will be approximately 100° F. lower than that of the aluminium, the result being an increased difficulty in working and a lack of soundness in the joint; further, the welded zone will be softer and more flexible than the rest of the work, and this reduced resistance is a defect that ought to be avoided. Moreover, the line of welding, if too soft, will be almost certain to break. The added metal should contain a percentage of zinc, so that the line of welding and its adjacent parts should be approximately as hard as the rest of the material. Pure aluminium rod does not joint easily with zinc-aluminium alloys under the blowpipe flame.

The welder is often in doubt as to the exact composition of the article to be repaired, and even when he does know its composition it is difficult to make a proper mixture to produce a homogeneous weld. It it generally advisable, therefore, to obtain standard alloys of aluminium, which often have a composition resembling that of the material being welded. These alloys are usually known by a particular number, and are obtainable from aluminium manufacturers, who are generally willing to advise customers as to the most suitable alloy to meet their requirements. The standard alloys are generally sold in ingot form or notched bars, but can readily be cast into suitable welding rods or sticks. Alloys are best melted in a small graphite or plumbago crucible, and then run into moulds.

The mechanical properties of the following alloys may be of interest. The figures given are for sand castings, as these are usually the condition of the alloys met with in the welding-repair shop, although many alloys of aluminium are now cast in chill moulds, whereby the tensile strength of the metal is considerably increased. The average tensile strength of the standard No. 6 casting alloy, when run in a sand mould, is 11 tons per square inch; but the same composition, when cast in a chill mould, has a tensile strength of 13 tons per square inch. Far superior results are secured for these alloys when in the form of cold-drawn sections; thus the No. 4 alloy in the following table has, when cold-drawn, a tensile strength of over 40 tons per square inch. The tests, of which the results are given herewith, were carried out at the National Physical Laboratory.

| | Composition per cent. | | | Strength: Yield Point. | Breaking Stress. | Ductility: Elongation per cent. on 2 inches. |
|---|---|---|---|---|---|---|
| | Aluminium. | Copper. | Zinc. | Tons per sq. in. | | |
| 1 | 79·85 | — | 20·15 | 10·00 | 13·07 | 0·7 |
| 2 | 72·00 | 3· 0 | 25· 0 | 5·71 | 18·25 | 2·0 |
| 3 | 96·24 | 3·16 | — | 4·90 | 7·49 | 5·0 |
| 4 | 9·90 | 90·10 | — | 11·30 | 31·70 | 21·7 |
| 5 | 5·76 | 94·24 | — | 4·80 | 17·80 | 67·0 |

In welding aluminium alloys even more difficulty will be encountered than in working on pure commercial aluminium, and great care must therefore be taken during the processes of pre-heating, welding, and annealing, for at temperatures between 450° and 510° C. (850° and 950° F.) the alloys become very friable and their tenacity almost disappears, and without proper support the article under repair may easily collapse while being heated. The work must therefore be well supported, and excessive heating avoided. An indication of overheating is the formation of little beads or globules on the alloys.

Many contrivances are in use for pre-heating, annealing, and maintaining the necessary heat during welding, especially where the work consists chiefly of automobile parts, such as crank-cases, cylinder and engine castings, transmission cases, gear-box covers, radiator frames, etc., which are commonly manufactured from aluminium alloys. Various designs of ovens and furnaces are often employed, using gas, oil, or coke as fuel. Powerful blowlamps, using benzoline or paraffin, and also gas blowpipes are extensively used and are very effective for heating-up purposes; but a coke fire well damped is the best method of all.

An incidental advantage of pre-heating such things as automobile parts is that it expels grease and oil, which generally are retained by the porous metal in considerable quantity. Should a repair be carried out before the oil is expelled the oil will carbonise and adhere to the edges where the weld is to be effected, thus preventing sound work.

The edges to be joined should be prepared as in the case of pure metal; their surfaces and the immediate neighbourhood must be thoroughly cleaned, and no traces of dirt, oil, or grease must remain if a satisfactory weld is desired. The use of hot water containing a little caustic soda, followed by a thorough washing and brushing, is invariably beneficial in removing grease and oil from the surfaces; but sometimes it may be necessary to sweat out the grease from the pores.

A similar flux to that used for aluminium will be found to answer, and its purpose is to destroy the aluminium oxide which forms on the metal at welding temperatures. The use of a flux is not so important as when welding the pure metal, and it is sometimes possible to effect a satisfactory weld by resorting to the puddling system mentioned in the preceding chapter; when adding the metal from the welding rod it should be continually worked into the molten bath of metal, and the puddling tool must be vigorously employed in order to minimise oxidation and to bring the oxide to the surface.

Good autogenous welds are readily secured by following correct methods on aluminium alloys, and, as a matter of fact, the automobile industry has made wonderful progress in the art of joining fractured parts. Oxy-acetylene welding is the one process so far introduced that makes possible the solution of the difficult cost-problems of a few years ago.

## CHAPTER XIII

### Joining Aluminium other than by Oxy-acetylene Welding

**Soft-soldering.** — It appears to be characteristic of aluminium that it behaves badly with other metals; regardless of soldering, the purer it is the better it behaves. Invariably, the aluminium solder introduces alloys of a different character on the electro-chemical scale, setting up galvanic action and all the evils of electrolysis and subsequent corrosion. It must be obvious that this is the reason why the best results have been obtained when the solder is of the same composition as the metal to be joined, the pieces of metal being melted or fused together without the addition of a different metal. This method of joining metals is the "autogenous soldering" or "fusion welding," dealt with in an earlier chapter.

Some of the reasons for the difficulty in finding an effective, reliable and easily-used soft solder for aluminium are as follows:

(1) The formation of an imperceptible but persistent film of oxide on the surface of the metal; this film or coating, which is always present, is intensified at soldering temperatures, and, being very refractory, prevents the intimate union that is so essential between the solder and the aluminium surfaces to be joined.

While, in general, this coating of oxide is beneficial inasmuch as it forms a protection to the metal underneath, it is undoubtedly the chief obstacle in soldering aluminium, as it cannot be reduced by the use of soldering fluxes nor can it be entirely removed mechanically, for however rapid the removal a fresh film is instantaneously formed on the new surface, and as it is white it is not discernible at soldering temperatures. As an American journal a few years ago put it: "It is impossible to expose a fresh aluminium surface for one-hundredth of a second to the atmosphere without the said surface being covered with sufficient oxide to prevent soldering." If it were possible to find an alloy which would instantaneously and molecularly interpenetrate the aluminium surface, or even a substance with which the gathering aluminium oxide film would enter into a solution, that is, one that would reduce it, there would be no difficulty in soldering aluminium with the same speed, ease and reliability with which other commercial metals are soldered.

(2) The high heat conductivity of the metal renders local heating to alloying temperature a slow and difficult matter; this trouble naturally increases as the size of the article increases. Hence, the heat is conducted from the soldering bit and solder so rapidly that they become quickly chilled, and consequently the solder does not become sufficiently liquid to flow readily.

(3) The highly electro-positive nature of the metal sets up galvanic action with low-temperature solders

containing negative metals like lead, with the result that electrolytic action of a destructive nature is apt to set in some time after the joint has been made; especially is this the case if the joint is exposed in a damp situation.

The soft-soldering of aluminium is dealt with in detail in the companion handbook "Soldering, Brazing, and Welding," and will not be described here, lack of space forbidding.

**Cast-welding or Burning Aluminium.**—The art of cast-welding or "burning" is very old indeed. It was extensively used by the Romans for the jointing of lead pipes which were to be put underground. These pipes were made by first bending up a sheet of the metal to form a tube, recurving the edges, and then running molten lead between these curved edges until fusion took place. The process was also employed in Japan several centuries ago, where, in bronze foundries, the vases and ornamental objects were cast in a very simple form, the handles being "burnt" on. During recent years the employment of this method of jointing metal has greatly diminished, mainly owing to the development of oxy-acetylene welding. The process is generally employed in engineering works in which modern methods of welding are not in vogue, and is mostly used for joining fractured parts of machinery, automobiles, etc. Small pieces that have broken off a large casting are sometimes renewed by this process, and by its aid such repairs as are generally known as "wanted at once jobs" can be managed, it being generally out of the question to send to manufacturers for replacements for such urgent repairs. It is often stated that the process is rather costly and should only be employed on expensive castings, and that in some cases the cost of casting a new piece would be less than that of "burning" the broken parts together. The writer agrees to an extent; but in many cases the actual cost of doing a job by cast-welding or burning is not the chief consideration; instead, time is frequently the determining factor, particularly in cases of broken machinery where the replacement of a part would involve a long delay in obtaining and possibly machining a new casting.

Fractured castings of aluminium alloy can readily be repaired by burning or fusing the parts together. Briefly, the process consists in pouring a stream of very hot alloy of the same composition as the work over the surfaces to be joined until they are properly fused, and then stopping the flow of metal and allowing it to cool, surplus metal being afterwards dressed off. The essentials for good work are: properly prepared moulds, into which the work is placed, and into which the molten metal may be poured; the parts to be joined should be firmly secured to prevent distortion during pouring; there must be suitable headers to allow of gases escaping; provision for the first part of the pouring being run out by suitable gates, after passing over and heating the surfaces to be joined; an excess of metal, as anything from 28 lb. to 112 lb. of metal may have to be run through, the amount depending on the size of the pieces to be joined; the exposed surfaces or ends where the join is to take place must be thoroughly cleaned; and provision of sufficiently tall headers to provide a pressure that penetrates the oxide film on the metal faces to be united. Another advantage of tall headers arises from the fact that aluminium and many of its alloys readily oxidise when hot from exposure to the atmosphere, and the metals become drossy as they run. A long header retains this dross, which consequently does not enter the joint.

The melting of aluminium or its alloys for such work should be at a low temperature compared with the heat of a brass-melting furnace. Immediately the metal is thoroughly melted the pot or crucible must be pulled, stirred, skimmed and very promptly poured. In workshop practice it rarely happens that two repair jobs are exactly similar either in form or treatment, although the same general principles apply to all cases. It has been proved that a fractured aluminium casting correctly manipulated by the above process is fully as strong as the original casting, the part seldom fracturing again where the join was made.

**Butt-welded Joints on Aluminium Rods and Bars.**—The butt-welding (not oxy-acetylene) of aluminium rods, bars, and similar sections is perhaps the simplest method of jointing the metal. Briefly, it consists of exposing the ends to be joined to the heat of a blowpipe or blowlamp flame, which causes the formation of a bag or outer case of oxide, inside which is pure molten metal. When in this state the ends are pressed together and the bursting of the bag of oxide allows the two molten ends to come together in pure metallic contact.

There are welding machines on the market which make a special feature of heating up the ends to be welded by means of blowpipes or blowlamps, and then forcing them together under pressure. It is possible to weld aluminium wire or small rods up to $\frac{3}{16}$ in. in diameter by hand simply by holding the two ends in the flame of an ordinary benzoline or paraffin blowlamp about $\frac{1}{8}$ in. apart until the metal begins to flow, the molten ends being then pressed firmly together. For rods or bars of larger dimensions mechanical means are adopted for applying the necessary end pressure; the ends of the rods should be squared up, thoroughly cleaned, placed in a horizontal position and backed with a deflector of asbestos, uralite or firebrick, so as to conserve the heat and concentrate the flame on the joint. A guide or rest is necessary to maintain the rods or bars in correct alignment and prevent lateral movement while the metal is cooling. The aluminium rods or bars should be held about $\frac{3}{16}$ in. apart, so as to permit the flame to come into direct contact with the surfaces to be welded. A powerful benzoline or paraffin blowlamp is suitable for rods up to $\frac{3}{8}$ in. in diameter, while two such lamps with their flames converging at the welding point can be used for rods up to $\frac{3}{4}$ in. in diameter. For sizes over 1 in. in diameter a large gas blowpipe or a powerful generator lamp will be necessary. The surfaces to be welded should be heated uniformly and be kept in the flame until the metal begins to melt and show signs of dropping. When this stage has been reached the rods are squeezed together until sufficient metal has been forced out all round to form an irregular collar, which should be about twice the diameter of the rod itself. The source of heat should then be removed and the pressure maintained until the joint has completely set.

A certain amount of skill and experience is required of the operator, but with practice he should soon determine the best moment to remove the flame. If the heat is cut off too soon the molten metal will not be fused together throughout the diameter of the rod, while, if the heat is left too long, too much metal will flow and spoil the joint. After the actual welding operation the ring of extruded metal may be trimmed off by filing, grinding or chiselling, and the weld may afterwards be polished, if required, and it will then be almost impossible to detect the joint. It is often preferable to leave the joints in the rough condition, as the increased area at the weld may be advantageous and is by no means unsightly if the welding is carefully executed. An overlap of about the diameter of the rod should be allowed. By this system an experienced jointer can easily effect good welds on aluminium wires and rods from $\frac{1}{8}$ in. to 2 in. in diameter, and, with care, it is possible for aluminium tubing to a certain thickness to be so welded. Moreover, aluminium rods, bars, etc., when vertically erected may be readily welded.

The formation of the oxide skin or film which is almost imperceptible when soldering is easily discernible in this butt-welding process. A simple and interesting experiment can easily be performed. Obtain a piece of aluminium from 8 in. to 12 in. in length by about $\frac{3}{4}$ in. in diameter and support it by its two ends, leaving a space of 4 in. to 6 in. in the centre for the flame of a blowpipe or blowlamp to play upon. When sufficient heat has been applied the metal will liquefy and a flexible bag of oxide containing molten metal will sag. If the film or oxide skin is now pierced with a point, molten metal will flow out instantly. The great difference in the melting point of the metal and the oxide as previously referred to is clearly demonstrated by this simple test.

In twelve consecutive welds made by the Cowper-Coles butt-welding machine, and afterwards tested to destruction, the fractures occurred in every case at some distance from the weld, showing that the metal had not deteriorated at the weld. On hard-drawn rod the fracture will always occur just outside the weld at a stress corresponding to the tensile strength of annealed aluminium, the condition of the metal at that place being due to the heat of the blowpipe used in making the weld.

**Jointing Aluminium for Electrical Purposes.**—With the development of electricity for motive power aluminium is fast becoming common for conductor purposes. It has been found that overhead transmission lines of aluminium show a saving in cost of as much as 10 to 25 per cent. compared with copper.

The joining of aluminium cable in the earlier days was a difficult matter, and even now is still regarded as a drawback. However, provided that the joints are carefully made and all moisture excluded, aluminium can be easily and effectively jointed. Some purely mechanical joints have been proved quite efficient. There is the torsion sleeve, for example. In making a joint of this description on aluminium strand, the two ends of the cable are straightened and passed in opposite directions through an aluminium sleeve or tube of figure 8 cross section until they protrude a few inches on each side. The cable and sleeve should be properly cleaned and perfectly free from grease or other foreign matter. Hard-wood clamps are securely bolted together over each end of the sleeve so as to prevent any movement between the cable and sleeve; to keep the cable ends in alignment while being twisted, more particularly on large sizes, they are usually placed in a wooden trough or guide. The clamps are then rotated in opposite directions until the joints contain four to six complete turns according to the diameter of the cable. The sleeve should be of pure aluminium, and is obtainable in various forms from the British Aluminium Co., Ltd. It should fit closely to the cable, and no lubricant should be used in passing the conductors through the sleeve.

For large diameter aluminium stranded cables not subjected to stress, such as feeder connections, furnace leads, etc., the method of welding by means of adding molten aluminium will be found satisfactory. The two ends of the cable are cut off square and cleaned so as to ensure good electrical contact, any insulation being bared for a few inches at the ends and the wires carefully cleaned. The ends are then brought together, a tubular cigar-shaped metal mould clamped round the joint, and some molten aluminium is then poured into the mould through a central aperture. The mould and cable should have been previously heated to avoid chilling of the first lot of metal entering the mould. After the metal has set, the mould is removed and the joint trimmed. To ensure freedom from blowholes, only the purest aluminium should be used, and it must be poured as soon as it has reached its melting point, care being taken not to overheat it or expose it to the action of the hot gases of the stove or furnace for any length of time, as molten aluminium absorbs gases which are occluded when the metal cools down.

For making T-joints and for joining up feeders or service mains, a modification of the foregoing method is employed, the mould being designed to accommodate a third wire at right angles to the main cable. Sections cut through joints made in this manner show that there is a perfect weld, the aluminium of the two cable ends mixing with the molten aluminium to make a solid conductor, the larger area of which gives it a conductivity even higher than the rest of the cable, but the mechanical strength is somewhat impaired due to heat softening. Lengths of cable containing these joints have been subjected to both tensile and torsional tests, and these tests indicate that the position of the break is just outside the joint where the wires have been softened by the heat.

A simple method of jointing two small wires is to twist them together and bend the free ends over several times so as to form a splice.

A method of jointing aluminium stranded cables is by fixing screwed aluminium connectors over the ends to be joined. Each end of the strand is then passed through an aperture and afterwards splayed. This mechanical method gives good electrical contact, though these connectors are not designed to take the full stress of the line.

In jointing aluminium conductors it is customary to make all cast or welded joints at insulators and not under strain, but the torsion-sleeve joints may be subjected to stress.

During calm weather there is no difficulty in making excellent butt-welded joints with blowlamps on aluminium conductors up to 0.25 sq. in. section.

In addition to the methods here briefly referred to, aluminium conductors are satisfactorily jointed by clamping, screwing, riveting, etc.

**Riveting Aluminium.**—Riveted joints in aluminium can be readily made, and are remarkably efficient if the riveting is judiciously done. It is sometimes stated that aluminium cannot be riveted so well as other metals on account of the softness of the metal allowing the rivets to draw out, thus giving rise to leakage, especially under the influence of temperature variations. Such statements, however, are inaccurate. A few years ago the writer assisted in the construction of a large number of all-metal railway vehicles 63 ft. long. The panels and roof plates consisted entirely of aluminium sheets No 14 S.W.G (0.080 in.). Many of the aluminium sheets were formed to the different curvatures required and afterwards riveted to angle, tee and channel aluminium-alloy and steel sections. Naturally there were several thousand aluminium rivets used o: various types in the construction of each vehicle. I: is true that aluminium does not attain the degree o hardness customary in iron and steel, but by continue rolling in the course of manufacture "dead hardness' is produced.

The hardness of aluminium sheets depends upo the amount of rolling that has been put into it in it evolution from the cast slab to the finished sheet an upon whether it has been annealed (softened) at an stage in the process. If worked sufficiently withou annealing, aluminium can be made so hard as to b brittle. In general, for convenience in ordering, thre grades of sheet are recognised: (1) *Dead Sof* (annealed), for spinning and shaping. (2) *Half Har* (annealed during rolling), for drawing, stamping, an light shaping. (3) *Dead Hard* (unannealed in ordinar gauges), for bending and straight work not requirin working.

When flat surfaces have to be riveted the sheet should be "dead hard," but where much hammerin is necessary to produce a piece of work of a compoun curvature the "half hard" is preferable, as such sheet become quite hard when finished. In the actual rive ing of aluminium it is advisable for the worker t forget all he knows about riveting iron and steel, a aluminium will not withstand the ill-treatment to whic the harder metals can be subjected. The same applie to the process of caulking and fullering generally re quired in aluminium watertight tanks and cylinders.

The many shapes of rivets common in copper, iron and steel are obtainable also in aluminium. On no account should rivets made of any other metal be employed, or electrolytic action will be set up. The type of aluminium rivet generally used by engineers is known as the cup, button, spherical or snap-head. Both the head and the riveted end are alike, although countersunk rivets are often used on aluminium plates of the thick gauges in order to secure smooth surfaces, and also on many sections of mouldings. More care, however, is necessary with countersunk rivets, inasmuch as accurate countersinking of the holes is essential; these holes must fit the angle of the rivet head, and it is generally advisable to use a gauge consisting simply of a steel plate to act as a stop when fixed to the side of the countersinking drill, thus preventing the metal being drilled beyond the proper depth, and obviating the necessity of chipping off the projecting portions of rivets.

When using countersunk rivets or aluminium sheets that are thinner than the depth of the angle or slant of the rivet head, it is necessary to employ a punch and die, either hand or machine, to recess the sheet to suit the angle and depth of rivet head.

In punching aluminium sheets or plates for cup and flat-head rivets, especially in repetition work, it is customary for a number of holes to be punched at the same time in multiple-punching machines. Most of the common punching machines produce only one hole at a time, so that the sheets or plates have to be shifted, reset, and sometimes marked for each hole, this leading frequently to the overlapping of the holes. Again, th plotting out of the holes in the templates, howeve accurately performed, with their subsequent punchin or drilling and building up, allows inaccuracies to cree in, and if reamering is dispensed with the overlappin must be only very slight, as aluminium rivets are to soft to lend themselves to draw readily in the sam manner as do iron or steel rivets inserted in thin meta sheets.

The rivets must have ample clearance in the holes to allow for spread in hammering; thus a $\frac{9}{32}$ in. diameter punch or drill should be used for $\frac{1}{4}$ in. diameter rivets. The holes should be set somewhat farther from the edge of the metal than for iron or steel, in order to prevent elongation at the edge, for where rivets are too near the edge the metal invariably shows a tendency to bulge. Therefore, the distance of the centre of the rivet from the edge of the plate should equal $1\frac{3}{4}$ times the diameter of the rivet, so that a single-riveted lap-joint would have a continued overlap of $3\frac{1}{2}$ times the diameter of rivet.

Aluminium plates from $\frac{1}{16}$ in. to $\frac{1}{4}$ in. in thickness are used extensively in the construction of many types of cylinders and tanks for industrial purposes, and the different forms and combinations of riveted joints customary in copper, iron and steel, are equally applicable in aluminium.

A simple way of obtaining the required length of aluminium rivets so as to form a suitable cup or snap-head when finished is to insert a rivet through the hole in the material to be jointed, the tail projecting a distance equal to about $1\frac{3}{4}$ times its own diameter; thus a $\frac{1}{8}$-in. rivet should project about $\frac{7}{32}$ in. and a $\frac{1}{4}$ in. rivet should project about $\frac{7}{16}$ in. On these sizes a cup or spherical head is proportionately formed with a suitable snap tool. The hammering should be somewhat lighter than when riveting iron and steel, and the blows should be delivered in a uniform manner.

Riveting is usually done by hand on aluminium sheets or plates up to $\frac{1}{8}$ in. in thickness, also on aluminium rivets up to $\frac{5}{16}$ in. in diameter, but above these dimensions pneumatic hammers are preferable. Regarding the pitch of the rivets (distance apart, centre to centre) the character of the work is the determining factor. It is obvious that if a riveted joint is to be watertight the rivets must be closely spaced, and, in general, somewhat closer spacing is advisable with aluminium than with other metals.

**Flanging and Seaming Aluminium.**—The flanging and seaming of sheet aluminium is one of the most important mechanical methods of jointing manufactured sheet-metal articles. Owing to its great malleability and ductility aluminium lends itself most satisfactorily to the many forms of mechanical joints that occur continually in sheet-metal work that does not require soldering, welding, or riveting.

In the manufacture of sheet aluminium articles it is essential to have as few joints as possible and to adopt the simplest joint that is consistent with efficiency. Flanging and seaming comes within this range. The parts to be so joined have the edges bent or flanged at angles to suit the work. Suitable allowances should be made (beyond the edges obtained by the geometrical outlines of a developed pattern) according to the nature of the seam required. In plane work, the allowance involves a simple addition to the length or width of the metal sheet to be jointed. Often allowances have to be made in sheet-metal work which do not admit of exact calculation: hence accurate data cannot be deduced when the metal undergoes coercion, as, for example, in the operation of hollowing or raising where shapes are required of compound curvatures.

The double seam or grooved joint is perhaps the most universal form employed. There are, however, numerous modifications of this in practice. In making a double-seamed or grooved joint the edges to be joined are first bent over in the form of a hook, the turned-over parts are then hooked together, and finally the seam is closed by hammering with an iron or steel tool known as a groover, the work being generally placed on an iron bar or other suitable tool.

Where the output of sheet aluminium articles is considerable, ingenious automatic flanging and seaming machines are used.

Jointing by this process on sheet aluminium is almost universally confined to thin gauge stock from about $\frac{1}{64}$ in. to $\frac{1}{32}$ in. thick. The difficulty encountered in the formation of soldered and welded joints owing to the invisible and refractory oxide film on the surface need not be considered in the mechanical method. Not only is the flanging and seaming of sheet aluminium economical, but the joints are also exceedingly strong and easily made.

**Spinning.**—Intricate sheet aluminium articles are sometimes spun in sections in the spinning lathe, and then jointed together by flanging and seaming. The softest sheet aluminium should be used for spinning, and can be worked at speeds up to 3,000 feet per minute. The metal becomes hardened by working, and even annealed aluminium will be almost dead hard when the spinning is finished. In extreme cases it is even necessary to anneal the article during spinning.

**Welding Aluminium Electrically.**—There are three clearly defined methods of electric welding; they are incandescent or resistance, electro-percussive and electric arc. There is nothing mysterious about the use of electricity for welding, as its function is simply to produce heat.

Electric arc welding is a form of autogeneous welding in that welding can be accomplished without pressure, simply by causing the metals to melt under the heat of the electric arc and then to mix and unite them as they cool; the resistance and electro-percussive processes generally require pressure to unite the metals.

Electro-percussive welding is a recent modification of resistance welding, and differs from it in being almost instantaneous, thus allowing of the welding of metals that have widely different melting points, or of metals that are not commonly susceptible of being welded. It is especially suitable for the welding of very small aluminium wires. Although this process is of recent origin it has proved very valuable in the metal-working industry.

The electric arc has a temperature estimated at

6,300° to 7,200° F. (3,482° to 3,982° C.), and is the hottest flame known. It is therefore applicable to the melting of all metals, but there is a great difference between melting and welding commercial metals. In practice the electric arc is most effective for welding wrought-iron and steel; aluminium and its alloys are not arc-welded on a commercial basis.

The resistance method of electric welding is divided into two classes, namely butt-welding and spot-welding.

In *butt-welding* the two pieces are placed in the clamping jaws of the welding machine, with only $\frac{1}{8}$ in. to $\frac{1}{2}$ in. of metal extending beyond the jaws, the ends of the metal touching each other. Immediately the electric current is switched on the abutting ends begin to heat up. When the welding temperature is reached the current is cut off and the weld is completed by operating a lever which applies a sudden increase of mechanical pressure, thus uniting the two ends of the partially molten metal. For welding such small work as aluminium wires, spring pressure is adopted. Special precautions are essential in the welding of aluminium, and automatic welding machines are generally used, the time at which the current is cut off being very closely regulated.

*Spot-welding* is a method of joining or fusing together two or more metal plates in or at spots. Mechanically, it is equivalent to riveting, is equally strong, and can be done much more quickly and economically, especially with the lighter gauges of metal. Metals from 0.015 in. to as much as 0.5 in. thick can be welded by this modern process. The principle of spot-welding is simple. Two electrodes or welding points, which generally take the shape of truncated cones, are brought to bear on the work (one on each side) where the spot-weld is wanted, and a heavy current at a low electrical pressure (voltage) is passed through the electrodes. The metal plates, as they are much poorer conductors of electricity, offer so great a resistance to the flow of the current that they heat to a molten state, and then by applying pressure on the electrodes the metals are forced together and the weld is made. The time taken varies from a fraction of a second on very thin to several seconds in the case of thick metal. The spread of heat and the size of the weld depend entirely upon the area of the welding points, the diameter of which varies from $\frac{3}{32}$ in. to $\frac{1}{2}$ in. according to the gauge of the metal to be welded.

*Seam-welding* is a development of spot-welding. Two thin metal sheets are joined together in an uninterrupted lap-weld under one or between two rotary disc electrodes. It is essential that the sheets or plates, and particularly their edges, be perfectly clean and free from scale, oxide, etc., as impurities offer a high resistance to the passage of current and necessitate a higher electrical pressure, with the result that when the scale or oxide is penetrated a rush of current takes place owing to the drop in the resistance, and the metal becomes burned. Unfortunately, seam-welding is not adapted for use on aluminium, owing to the fact that this metal is a very good conductor of electricity and offers practically no resistance to the flow of the current; hence difficulty is encountered in getting a welding heat. The oxide skin acts as an insulator and prevents a heavy current from flowing, while the low resistance of the metal prevents the small current that does pass from heating up the metal. Moreover, there are precisely the same difficulties to contend with as regards the persistent oxide film as in the case of the other methods of jointing aluminium, and obviously it is practically impossible to eliminate the oxide film from between the surfaces at the moment of contact. Indeed, in a joint made from this process, the presence of the oxide can be clearly traced along the plane of union.

In the case of spot-welding, however, satisfactory results can be obtained with aluminium sheet, this being due probably to the small area affected by the pointed electrodes, as the circular spot of metal rapidly reaches a welding temperature on applying pressure to the electrodes. A characteristic of a spot-weld is a slight depression or recess formed on each side of the work by the pressure of the electrodes. In some cases these may be objectionable, but they are very slight and are not generally detrimental. To obtain a smooth surface on one side of the work it is possible to employ a flat-nosed electrode covering a greater area than the opposite pointed one. The spot-welding machine has proved its value for joining together aluminium sheets.

It is sometimes stated that spot-welding is more successful when the aluminium contains a percentage of zinc (aluminium-zinc alloy). In practice, it is found that the zinc is easily driven off by evaporation before the aluminium has reached its welding temperature. Aluminium may be welded to dissimilar metals, such as iron and brass, by spot-welding, but the welds are apt to disintegrate if exposed to the atmosphere.

**Screw Threads for Aluminium Joints.**—Screws, bolts and nuts are extremely useful for fastening aluminium parts together, especially for work that requires to be taken apart for periodical examination, etc., and also for the building up of intricate parts where other methods of jointing are impracticable. Aluminium screws, bolts and nuts must always be used in securing aluminium parts together, thus eliminating electrolytic action and the risk of corrosion. Some people think that the production of satisfactory screw threads on aluminium is impossible. Admittedly, the pure metal is in some respects more difficult to work than any other of the commercial metals, probably owing to its being so soft and tough that the chips and particles of the metal adhere firmly between the threads and the screw-cutting tool, with the result that an imperfect thread is formed. With care, however, it is possible to produce satisfactory screw threads on this metal, but a suitable lubricant or cutting compound must be used, light cuts only should be given, and the die removed frequently to free the threads. The threads will not bear the rough usage that brass, iron, or steel threads will withstand, and for this reason special aluminium alloys particularly adapted for making up into screws, bolts and nuts have been introduced; they give excellent results with the use of suitable lubricants. The special aluminium alloy generally known as No. 36 or 36a (supplied in rods, etc., by the British Aluminium Co., Ltd.), is, in the writer's opinion, one of the best to use for the purpose. Its specific gravity is low (about 2.85), with an average tensile strength of 10 to 11 tons per sq. in. An alloy composed of aluminium 82 per cent., zinc 15 per cent., and copper 3 per cent. is also good.

The cutting compound or lubricant used in screw-cutting or tapping aluminium or its alloys is of great importance. With an unsuitable lubricant even good screw-cutting tools soon become dulled and perhaps ruined, and the metal is apt to be torn rather than cut; consequently a perfect thread is not obtained. Opinion differs as to the most suitable lubricant for aluminium, and many different ones are used at the present time. Those in chief use are kerosene or paraffin oil, benzine, petrol or gasolene, etc., beeswax, soap and water, turpentine, lard-oil, vaseline, and mixtures of kerosene and gasolene, kerosene and high-grade lard-oil, etc. Patented screw-cutting compounds are also much used. An important point to bear in mind is that the lubricant must not affect the metal after the screw threads are produced, the writer having observed cases in which the aluminium has been corroded by the lubricant.

One of the best lubricants for aluminium or its alloys is kerosene. Many mechanics favour turpentine, but this is open to the objection that when it evaporates it leaves a resinous deposit which tends to cause a screw to bind, whereas kerosene or paraffin leaves a vaseline deposit beneficial to the screw threads.

## CHAPTER XIV

### Oxy-acetylene Cutting

DURING the past few years metal cutting by the oxy-acetylene process has deservedly made rapid strides in engineering practice. By means of the blowpipe flame, holes can not only be fused in wrought-iron and steel plates, but every conceivable kind of cutting operation may be expeditiously performed on wrought-iron and steel structures (not on cast-iron, for reasons made clear on a later page).

Thus it is now possible to fuse holes in steel rails to take the fish-plate bolts that are used in connection with tramway and railway tracks, just as it is possible to cut with ease a hole in a wrought-iron pipe for the purpose of making a branch connection. For work of greater magnitude, some indication of the power and utility of the oxy-acetylene cutting flame may be gathered when it is stated that a square piece may be cut out of a steel block 9 in. thick, and a steel ingot 17 in. square may be cut through with comparative ease.

The oxy-acetylene process is now used for cutting armour plates to any given shape, locomotive frames to any given design, as well as for cutting steel girders, bridges, and similar structures either for constructional or destructional purposes.

**Combustion of Iron and Steel in Oxygen.**—In order fully to appreciate the possibilities of cutting wrought-iron and steel by the oxy-acetylene process, the theory of the process should be understood. The underlying principle involved is a chemical rather than a mechanical one. The oxy-acetylene blowpipe, and, indeed, the acetylene itself, are but mechanical aids to the chemical action, which action is the combustion of iron in oxygen.

It is well known that a glowing splinter of wood will burst into flame if plunged into an atmosphere of oxygen. It is a common classroom experiment. Similarly, a length of thin red-hot iron wire will burn freely in oxygen. But it was reserved for Mr. Thomas Fletcher, of Warrington, to demonstrate in the year 1889 that by largely increasing the supply of oxygen after an iron plate was heated to incandescence by means of an oxy-coal-gas blowpipe flame, holes and slots could be fused in the iron plate. Some years later a German applied the process to the opening up of tuyères, which in blast furnaces had become blocked by the solidification of metal. The use of oxygen in this connection proved so successful that attention was once more directed to its employment for the cutting of metal.

It should certainly not be forgotten, however, that this process was first discovered by an Englishman, not by a German.

Theoretically, when once iron is ignited in oxygen, both the iron and the oxygen chemically combine to form iron oxide, the heat furnished by the combustion of the iron in oxygen being sufficient to maintain the requisite temperature at which chemical combination occurs without any auxiliary source of heat. This scientific fact is taken advantage of in metal cutting by supplying through a specially designed blowpipe a current of oxygen to the incandescent metal, and thus causing continuous combustion where required.

In theory, it is only necessary to provide sufficient local heat to raise the iron to a white-hot state of incandescence, then by supplying oxygen, combustion will begin and continue as long as both iron and oxygen are present. In practice, however, it is found that additional heat is required to that necessary to start combustion. As soon as combustion occurs, oxide of iron is formed, and extra heat is required to melt this oxide so that it can be blown away by the independent stream of oxygen which issues from the cutting blowpipe. Certain heat losses occur during the cutting process, and these losses necessitate the employment of a continuous source of heat in order to pre-heat the metal to the temperature required for combustion.

**Principle of the Cutting Blowpipe.**—In the early days the process of metal cutting was somewhat intermittent, largely through failure to cope with the foregoing practical considerations. But the invention of a specially designed cutting blowpipe surmounted all difficulties; and the maintenance of an independent heating jet in operation during the travel of the cutter, whilst a separate jet of oxygen may be discharged through the centre of the blowpipe, makes the cutting operation continuous. The chief characteristics of a metal-cutting blowpipe consist of one arrangement by means of which the oxygen and the fuel gas issue forth together to raise the metal to the requisite degree of temperature, and another ingenious arrangement by means of which, when this temperature is once attained, a separate stream of oxygen can be directed on the heated metal so as to produce the severance—the so-called "cut."

The invention of the special cutting blowpipe transformed a wasteful process into an economical one. Formerly, through inability to dispose satisfactorily of the oxide, which persistently clung to the metal, thus preventing intimate flame contact, combustion soon failed, and the cutting operation was thereby brought to a standstill. The resultant cutting, with its series of stops and starts, was slow and costly in oxygen, and its results were coarse, wide and irregular.

Nowadays, through the instrumentality of the cutting blowpipe which admits of a separate stream of oxygen being blown through, wrought-iron and steel may be cut as though they were sawn, but very much more quickly. Instead of being intermittent, the process is now continuous, comparatively cheap, very effective, altogether reliable, and possessed of great potentialities.

**Other Fuels.**—Although special reference is here made to the oxy-acetylene process, it should be understood that fuels other than acetylene are frequently employed in metal cutting. Thus hydrogen, coal-gas and benzol are used in conjunction with oxygen to yield respectively oxy-hydrogen, oxy-coal-gas, and oxy-benz. flames; but a special blowpipe is required for each. From what has already been stated concerning the heat generated by the combustion of iron in oxygen, it will be gathered that a lower temperature answers for cutting than for welding; hence a fuel having a lower calorific value than acetylene may be employed. Sometimes the choice of fuel depends on local circumstances, but more particularly on the nature and character of the work to be executed.

Owing to the superior calorific value of acetylene, this gas is generally selected for destructional cutting, and also for work that is required to be done very expeditiously.

Hydrogen yields economical results as regards the quantity of gas consumed for heavy cutting of new work, but the time occupied in the process is longer than would be required if acetylene were used.

Coal-gas gives very good results on the new work up to 1 in. in thickness, the cuts being sharp and clean; but the cutting takes longer to accomplish than with acetylene.

Benzol is used only when no other fuel is available. It is obtainable practically everywhere, and being liquid it is very portable. In its gaseous form it is a compound gas like acetylene, and contains the same elements—carbon and hydrogen—the formula for benzol being ($C_6H_6$), while acetylene is ($C_2H_2$); but the temperature of the oxy-benz. flame is probably about 1,000° F. less than that of the oxy-acetylene flame, although it is somewhat higher than that of the oxy-coal-gas flame. The liquid fuel is automatically fed to the blowpipe, where it is instantaneously vaporised and burnt in oxygen. Petrol is sometimes used as a substitute for benzol with good results. A blowpipe to use liquid fuel must be specially made for the purpose.

**A Typical Cutting Blowpipe Described.**—From what has already been stated, it will be gathered that metal cutting by the oxy-acetylene flame is now a commercial success mainly through the invention of a suitable cutting blowpipe. A well-known blowpipe for this process is that known as the "Universal Cutting Blowpipe," the British patent for which is held by the British Oxygen Company, Limited. Through the courtesy of the company three illustrations of this blowpipe are given by Figs. 37 to 39, as well as the following description.

This blowpipe is known as the "concentric type," which is that most commonly used. The mixed gases for heating are discharged through the annular passage formed by D, and the oxygen for cutting through the central passage C.

The principle on which the "Universal" cutting blowpipe heats is similar to that of the welding blowpipe. The oxygen under suitable pressure is made to draw the combustible gas into the blowpipe and then deliver both gases well mixed, and under sufficient pressure through the nozzle D. In the distributing-box *f* there are passages *k* and *j*, through which the supply of combustible gas and oxygen required for heating respectively pass, and these passages are fitted with a

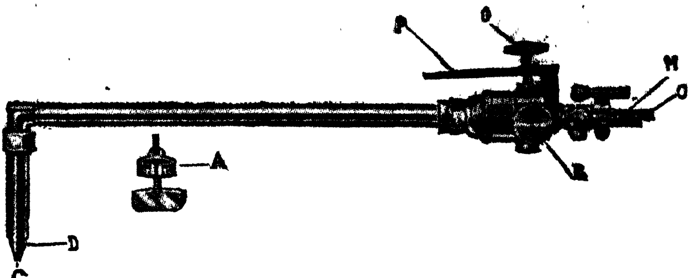


Fig. 37.—The "Universal" Cutting Blowpipe

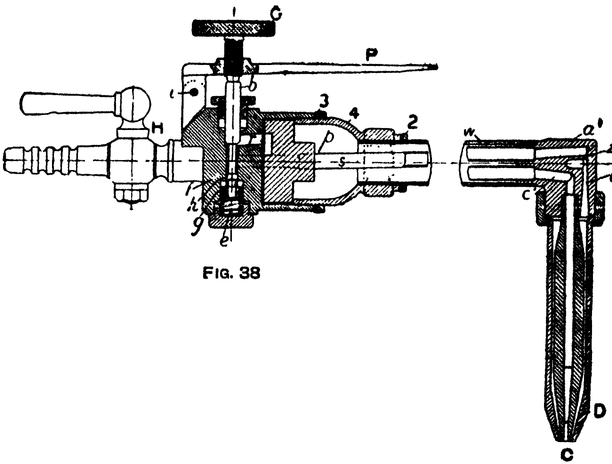



FIG. 38

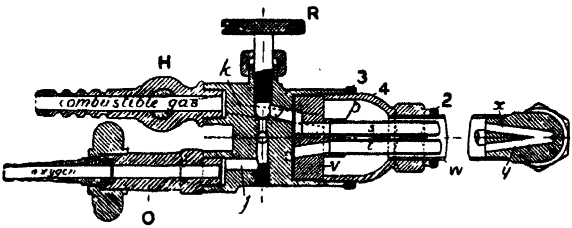



FIG. 39

Figs. 38 and 39.—Sections through the "Universal" Cutting Blowpipe separate tap and valve H and R, by means of which the proportion of the gases for heating purposes can be regulated. The distributing-box is also provided with screwed socket projections at the back, into which the connector O for the main supply of oxygen and the tap H for the supply and control of the combustible gas are fixed, the gases being led to the blowpipe through rubber or other suitable tubing.

The combustible gas is conveyed through the passage *k* to the chamber *p*, while the oxygen is supplied to the under-side of the valves *b* and R, by each of which it is regulated and allowed to travel by the separate passages *j* and *r*, through the pipes *s* and *t* to the nozzles C and D respectively.

The valve through which the supply of oxygen passes to the cutting nozzle is capable of double control, for it can be operated by means of the thumb-screw G, which acts on the valve spindle *b*; or the thumb-screw G can be screwed back in the hand-lever P, after which the valve spindle can be controlled by the lever. In this way great nicety of adjustment can be obtained, and the amount of oxygen passing through the nozzle C for cutting can be regulated as desired.

The valve is held open by the spring *e*, which is contained in the body part of distributing-box *f*. At the end of the spring there is a washer *g*, which presses on the shoulder *h* formed on the extended part of the valve spindle. A cap, which is screwed into a recess formed in the distributing-box *f*, holds the spring in position. The upper part of the valve spindle passes through a stuffing-box, as shown, and projects sufficiently for the thumb-screw G to act on it. On the body part of the distributing-box there is a fork, in which, by means of the pin *i*, the lever P is centred. On the inner side of the distributing-box there is a recess which receives the junction piece *v*, in which are openings communicating with the passages *j*, *k*, and *r*, as shown. The openings which communicate with *j* and *r* are prolonged through *v*, and into this prolongation are fitted the pipes *s* and *t*. The opening corresponding with the passage *k* is carried through the outer side of the junction-piece, and so communicates with the chamber *p*, which is in communication with the tube *w*. It will thus be quite clear that while the separate supplies of oxygen are conveyed through the pipes *s* and *t* for the heating and cutting respectively, the combustible gas is at the same time conveyed outside these pipes, inside the tube *w*, to the elbow piece $a^1$, where beyond the injector nozzle *z* it meets the oxygen supply for heating, by which it has been drawn forward through the passages *x* and *y*. At the expansion orifice $b^1$, which communicates with the annular space between the nozzles D and C, the gases are mixed. The oxygen used for cutting passes through the pipe *t*, which is also fitted to the elbow piece $a^1$. By this means there is a separate supply of oxygen obtained for cutting, which is capable of adjustment and control by means of the thumb-screw G or the lever P, as already explained.

The Universal cutting blowpipe is the outcome of long and special experience. Its particular advantages are, first, that all the controlling valves are kept together at a point farthest away from the heating and cutting nozzles, and under the hand of the operator; second, the combination of thumb-screw and lever control for the valve supplying oxygen for cutting, which enables a very delicate regulation to be effected, a point of special importance in connection with the handling of metal-cutting blowpipes; and third, the facility with which the essential parts of the blowpipe can be detached and reassembled. The inner and outer nozzles, C and D, as well as the spade guide A, occasionally require renewing; but when any repairs or renewals other than these are required it is better to send the blowpipe to the makers, so that the necessary repairs, renewals, and readjustments may be effected.

A few convertible welding and cutting blowpipes have been introduced. Figs. 40 to 42 show a type patented by a German firm. It has an exchangeable nozzle *b* fixed to the burner body *a* by means of a union nut *c*. The nozzle is formed with a number of gas passages *d* and *e*, and can be adjusted to bring just the nozzle passages that are required at the time into coincidence with the gas-supply passages in the body of the burner. The central passage *e* has a branch $e^1$ leading to the burner nozzle, and also has its own cut-off valve *f*, there being an additional cut-off valve common to all the gas-supply passages on the lower part of the burner (not shown). The oxygen is supplied through the gas passages *e* and $e^1$, and the acetylene through the passage *d*. Opposite the central passage *e* is the central cutting gas passage *g* in the burner nozzle, and this, when not required, is shut off by means of valve *f*. In the burner nozzle *b* is a number of mixing tubes, *h*, $h^1$, and $h^2$, having nozzle passages, *k*, $k^1$, and $k^2$, of different diameters which are required for weld-

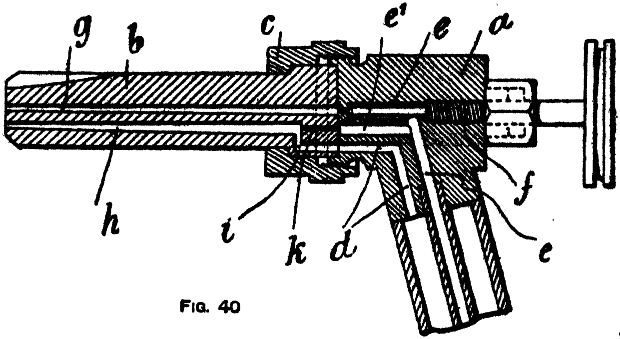



FIG. 40

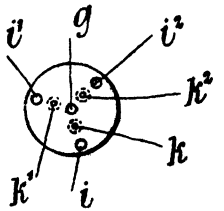



FIG. 41

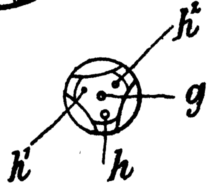



FIG. 42

**Fig. 40.—Section through Nozzle and Gas Passages of Convertible Welding and Cutting Blowpipe. Fig. 41. —Nozzle Face of Joint between Nozzle and Burner Body. Fig. 42.—Outer End of Burner Body**

ing or for heating up the metal preparatory to cutting. Separate lateral passages, *i*, $i^1$, and $i^2$, open into the mixing tubes *h*, $h^1$, and $h^2$. By rotating the nozzle *b* on the body *a*, the burner may be adjusted to work with the various sizes of nozzles and passages as required:

all that is necessary is to slacken the union nut *c*, rotate, and again fix the burner nozzle.

A notable convertible cutting and welding blowpipe, but possessing an enormous number of parts, has been introduced by the Standard Welding and Equipment Corporation, of the United States.

**Pressure Regulator for Cutting Apparatus.**—In metal cutting the outlet pressure of the oxygen is required to be somewhat higher than that usually employed for welding, and on heavy work comparatively large quantities of this gas are consumed. This necessitates the employment of a regulator specially designed to fulfil these requirements. That is to say, the regulator must be provided with stronger springs to work at the higher pressures; it must also have larger passages to accommodate the passage of greater quantities of oxygen; and it must be fitted with two pressure gauges—one to register the pressure of the gas in the cylinder, and the other to register the pressure of the gas proceeding to the cutting blowpipe. Fig. 43 represents the British Oxygen Company's standard-size regulator, fitted with both high- and low-pressure gauges, suitable for use where the cutting does not exceed 4 in. in depth. Other sizes are made which are capable of delivering oxygen up to 400 lb. per sq. in.; but these, of course, are employed on exceptionally heavy work. When the fuel gas (whether it be acetylene, coal-gas, or hydrogen) is stored under compression in cylinders, a pressure regulator will be required to lower the pressure of the fuel gas before it is delivered to the blowpipe. In the event of the acetylene being generated on the spot the pressure regulator may be dispensed with; but it should be borne in mind that a hydraulic back-pressure valve (Fig. 13 on an earlier page) in that case becomes essential, as for welding.

As it is not always practicable to generate the fuel gas on the spot, obviously, the use of compressed

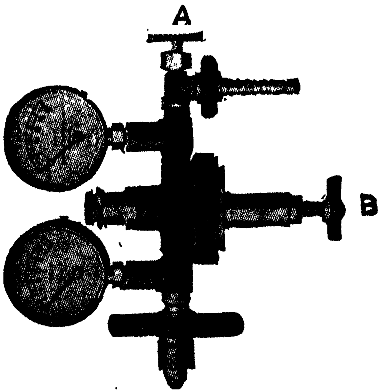



**Fig. 43.—Double Gas-pressure Regulator for Oxygen Cylinder: used with Cutting Blowpipe**

acetylene possesses many advantages on account of its great portability.

**Precautions to be Observed.**—The safety of the workmen employed is the first consideration, therefore those engaged in the actual cutting process should be provided with suitable glasses to protect the eyes from glare, from sparks, and from particles of burnt material. The clothes should also be protected.

A bucket of water should always be in readiness by the side of the operator for the purpose of cooling the cutter occasionally, and also in case of emergency. Only workmen who are physically fit should be allowed to operate inside boilers or other confined places, where they should have the assistance of a mate, another being in charge of the cylinders outside ready to turn off the gas at the shortest possible notice.

Should the nozzle of the blowpipe become obstructed with beads of molten iron, or from any other cause, it should be cleared with a copper wire or a copper brush, and *on no account should a sharp, hard tool be introduced in the hole*, as this will in course of time enlarge the hole.

Every care should be exercised to avoid excessive sparking, that is, showers of sparks during the cutting operation. This indicates the use of too much oxygen. On the other hand, where the metal is blackened or discoloured during the cutting, this indicates the use of too much acetylene or coal-gas, as the case may be.

It is always advisable to use armoured tubing for both the oxygen and the acetylene, in order to avoid kinking, which would cause an interrupted supply. The tubing, however, should be internally clean, and entirely free from grit and dust. If the acetylene is to be generated on the spot, see that the hydraulic back-pressure valve is in order when coupling up the connecting tubes; or if compressed acetylene is to be used, see that a pressure regulator for acetylene is properly fitted to the cylinder. See also that an oxygen regulator for metal cutting is properly fitted to the oxygen cylinder. One connecting tube should then lead from the oxygen regulator outlet to o (Figs. 37

and 39), and the other from the acetylene regulator outlet to H. Now fix the spade guide A to the nozzle D, and adjust it to keep the blowpipe nozzle the correct distance from the work. Assuming that everything is now connected up, open the oxygen cylinder valve, screw in the regulator B (Fig. 43) two or three turns, see that the valve A is open, press down the lever P (Fig. 37), turn on, light the acetylene jet, and adjust the blowpipe as for welding, by means of H and K (Fig. 37). The regulator B (Fig. 43) is now adjusted to the required pressure for the particular work in hand, the lever P (Fig. 37) meanwhile being allowed to rise while this adjustment is made. The raising of this lever turns on the separate jet of oxygen required for the cutting operation, and the amount of oxygen for this purpose is regulated by G (Fig. 37). By depressing the lever P the cutting oxygen is shut off, and the lever is kept in this position when starting a cutting operation.

**Using the Cutting Blowpipe.**—By studying the table (see p. 150) of approximate results (supplied by the British Oxygen Company) the operator will readily be able to gauge (*a*) the size of cutting nozzle required, (*b*) the distance at which the cutting nozzle should be held from the work, (*c*) the oxygen pressure at the regulator outlet, and (*d*) the speed at which the actual cutting should progress when dealing with plates varying from ¼ in. to 17 in.

When cutting a plate the blowpipe flame should be directed well down the metal edge that is farthest from the operator; then when the edge of the metal is well heated direct the flame on the top of the metal until it becomes incandescent, after which allow the blowpipe lever P (Figs. 37 and 38) to rise. This, as previously explained, turns on the separate cutting stream of oxygen, and this starts the cutting operation. The blowpipe is now steadily and gradually drawn towards the operator, but before advancing the blowpipe make sure that the cut has penetrated right through the metal.

Do not attempt to hasten the speed of the cutting unduly beyond that given in the following table, other-

TABLE OF APPROXIMATE RESULTS.

| Thickness of Plate. | Size of Cutting Nozzle. | Distance between Cutting Nozzle and Work. | Oxygen pressure at Regulator Outlet. | Consumption of Oxygen per hour. | Foot run of Metal cut per hour. | Oxygen consumed per foot run of cut. |
|---|---|---|---|---|---|---|
| in. | in. | in. | lb.pr.sq.in. | cub. ft. | ft. | cub. ft. |
| $\frac{1}{4}$ | $\frac{1}{32}$ | $\frac{3}{16}$ | 24 | 48 | 65 | ·75 |
| $\frac{1}{2}$ | $\frac{1}{32}$ | $\frac{3}{16}$ | 28 | 60 | 60 | 1 |
| $\frac{3}{4}$ | $\frac{1}{32}$ | $\frac{3}{16}$ | 32 | 75 | 50 | 1·5 |
| 1 | $\frac{1}{16}$ | $\frac{3}{16}$ | 32 | 88 | 40 | 2·2 |
| $1\frac{1}{4}$ | $\frac{1}{16}$ | $\frac{7}{32}$ | 36 | 95 | 35 | 2·7 |
| $1\frac{1}{2}$ | $\frac{1}{16}$ | $\frac{7}{32}$ | 39 | 105 | 30 | 3·5 |
| 2 | $\frac{1}{16}$ | $\frac{7}{32}$ | 45 | 125 | 25 | 5 |
| 3 | $\frac{1}{16}$ | $\frac{7}{32}$ | 52 | 180 | 20 | 9 |
| 4 | $\frac{1}{16}$ | $\frac{7}{32}$ | 58 | 300 | 20 | 15 |
| 5 | $\frac{1}{16}$ | $\frac{1}{4}$ | 65 | 420 | 20 | 21 |
| 6 | $\frac{1}{16}$ | $\frac{1}{4}$ | 70 | 432 | 18 | 24 |
| $6\frac{3}{4}$ | $\frac{3}{32}$ | $\frac{1}{4}$ | 70 | 468 | 18 | 26 |
| 8 | $\frac{3}{32}$ | $\frac{5}{16}$ | 80 | 504 | 18 | 28 |
| 9 | $\frac{3}{32}$ | $\frac{3}{8}$ | 95 | 510 | 17 | 30 |
| $9\frac{3}{4}$ | $\frac{7}{64}$ | $\frac{3}{8}$ | 100 | 530 | 17 | 31 |
| 11 | $\frac{7}{64}$ | $\frac{1}{2}$ | 115 | 620 | 13 | 48 |
| 12 | $\frac{7}{64}$ | $\frac{1}{2}$ | 125 | 650 | 13 | 50 |
| 14 | $\frac{7}{64}$ | $\frac{5}{8}$ | 125 | 900 | 12 | 75 |
| 17 | $\frac{1}{8}$ | $\frac{3}{4}$ | 130 | 1350 | 12 | 112 |

wise local heat will be lost, and the speed consequently retarded. The correct speed will be gauged with a little practice, but the tendency towards excessive speed will result in back-firing, and this impedes the progress of the work.

If through any cause the requisite heat should be lost, the cutting stream of oxygen should be shut off until the heat is recovered, after which the cutting stream may again be directed on to the incandescent metal in order to resume the cutting operation.

The function of the spade guide A (Fig. 37) is to prevent the nozzle of the blowpipe touching the surface of the plate. Should, however, the nozzle of the blowpipe come in contact with the plate, in all probability the flame will fire back, in which case the fuel gas should be turned off momentarily, then turned on again and relighted. Should either the central hole or the annular opening in the blowpipe nozzle become wholly or partially choked through particles of metal impinging, and then clinging to the nozzle, back-firing may result; but as both the outer and inner nozzles are detachable they may readily be removed for cleaning purposes, although, as previously mentioned, no hard or sharp tool should be used for cleaning the passages.

It should be remembered that when once the cutting operation has fairly started, it may be continued smoothly and regularly without interruption owing to the chemical action of the combustion of iron in oxygen, and it is mainly due to the latter that hard steels can be cut with as great facility as soft iron. A bevelled cut can be made as easily as a straight cut, and any conceivable shape can be cut with comparative ease. It is not necessary to raise the temperature of the metal to its melting point, since the oxides of steel and wrought-iron have melting points below those of these metals respectively. On the contrary, the melting point of cast-iron is lower than that of its oxide, and this fact precludes the application of this cutting process to cast-iron.

When the oxy-acetylene cutting process is applied to wrought-iron and steel the oxide is first melted and then blown through the cut, whereas from the foregoing consideration this is impracticable with cast-iron. With wrought-iron and steel the oxide is effectively disposed of, with the result that the combustion of these metals in oxygen is complete. This is not so with cast-iron, hence, in the light of present knowledge, the application of the oxy-acetylene cutting process to cast-iron is not a practicable proposition.

Notwithstanding this, however, it is possible by means of this process to cut the heaviest armour-plating made, and with as much facility as cutting a piece of wrought-iron plate. The metal on each side of the cut is neither distorted nor injured, a clean narrow cut being effected which leaves the edges sharp and precise. In large engineering establishments a variety of machines, some screw-controlled, are in daily use. By their aid, and by means of suitable guides, iron and steel of varying thickness are cut to every conceivable size and shape by the simple use of the oxy-acetylene blowpipe. It would be difficult to exaggerate the growing importance of this simple method of cutting wrought-iron and steel; but it is safe to state that it will become more and more popular in the immediate future.

**Mechanical Guides**—When cutting circles and other shapes by means of the oxy-acetylene blowpipe flame, mechanical contrivances are often employed. Thus, one contrivance consists of a simple guide rod, one end of which is attached to the blowpipe, while the other end is attached to a lever or to a circular disc, which in turn revolves round a centre. This, of course, is a contrivance of the simplest description; but others are more elaborate and give much more accurate working results. Mechanical aids to metal cutting are necessary, since the slightest deflection of the hand means a multiplied deflection of the actual cut. From what has already been stated it will be seen that mechanical assistance is also essential when a girder or plate is to be cut along a given line. Instead of hoping to follow the line it is more satisfactory to arrange a guide that will automatically and mechanically give the required results.

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*Made and Printed in Great Britain by*
*The Greycaine Book Manufacturing Company Limited Watford*
30.527