

SECTION 4, CHAPTER 5

OXY-ACETYLENE WELDING

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WELDING PRINCIPLES

Introduction

1. Welding is that process by means of which metal parts or surfaces are permanently joined together by heating them to a plastic or liquid condition. If the plastic metals are then hammered together the process is known as "forge welding", but this method has limited use. It is not possible by this method to weld long edges satisfactorily, and tubes

and shaped sections also present serious difficulties. The most commonly used methods employ "fusion welding", where the surfaces to be joined are heated to a molten state, additional molten metal being provided from the fusion of a wire or filler rod to counteract the losses of the base metals during the process, or to add to the thickness of the material at the weld. The heat is

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provided by a gas blowpipe or electric arc, the information in this chapter being confined to gas welding.

2. In fusion welding, the metal in the welded portion may have a different structure to that of the parent metal. The intense heat that has to be used may destroy some of the constituents in the weld, but these can invariably be replaced by a filler metal (welding rod) containing an excess of the constituents. The welding rod may also contain additional elements which neutralize the adverse effect of heating, thus ensuring that the physical properties of the welded portion are similar to those of the parent metal.

3. At high temperatures the oxygen in the air readily combines with molten metal and forms an oxide, which, if trapped in the welded part, will weaken the joint. When the melting point of the oxide is higher than the melting point of the metal itself, flux is used to reduce the melting point of the oxide below that of the metal; the oxide then floats to the surface of the molten metal and is not trapped in the weld. Flux applied to the surfaces of some metals dissolves the oxide by chemical action and/or forms a protective coating over the surface of the metal when heated, preventing further oxidation during welding. For each type of metal, a suitable welding rod, and, where necessary, a suitable flux are available.

Combustion or Burning

4. A flame is caused by combustion, commonly termed burning. Combustion is chemical combination of the combustible substance with oxygen. Oxygen is a colourless gas which does not itself burn, but very readily combines with many other gases and substances. The nature of the burning substances determines the type and temperature of the flame produced.

5. **The Candle Flame.** When a candle is lighted, the wax, which consists of carbon and hydrogen (hydrocarbon), is melted by the heat and travels by capillary action up the wick, where it is vaporized by the flame. Examination of the flame (Fig. 1) reveals at least three distinct regions:—

(a) The dark region around the wick where the wax is vaporized but not yet ignited (A).

(b) A large luminous envelope consisting of burning vapour (B). The hydrogen burns with a blue, non-luminous flame, but the heat generated makes the carbon white hot and incandescent.

(c) The non-luminous area where burning ceases (C). Not all the carbon is burnt. This can be proved by holding a piece of paper above the flame; a deposit of soot will be seen on the paper.

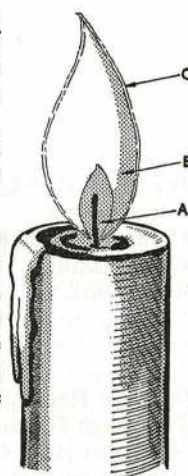


Fig. 1. BURNING OF A CANDLE.

6. There are various forms of hydrocarbons, e.g. solids (candlewax), semi-liquids (grease), liquids (kerosine), and gases such as acetylene.

Acetylene is an inflammable gas which burns in the air with a very smoky flame, the production of smoke being due, as with the candle, to incomplete combustion of the carbon. Complete combustion is achieved by mixing oxygen with the acetylene in approximately equal proportions. The flame produced by the combustion of acetylene and oxygen generates a high temperature (3,100—3,300°C.) suitable for fusion welding. The blowpipe used for mixing the acetylene and oxygen has a small nozzle which restricts the flame to a small area, and, provided the correct amount of oxygen for a given amount of acetylene is used, the flame will not affect the main structure of the metal object being welded. The proportion of oxygen to acetylene is important; the use of an incorrect flame may produce unsatisfactory results.

Gas Welding

7. There is a choice of combustible gases which can be combined in suitable proportions with oxygen to provide the heating flame for welding, but the most suitable and the one most frequently used is acetylene.

8. There are two oxy-acetylene welding systems in general use, known respectively as the high and low pressure systems. Both systems use a high pressure (1,980 lb per sq. in) supply of oxygen stored in steel cylinders. The terms low or high pressure

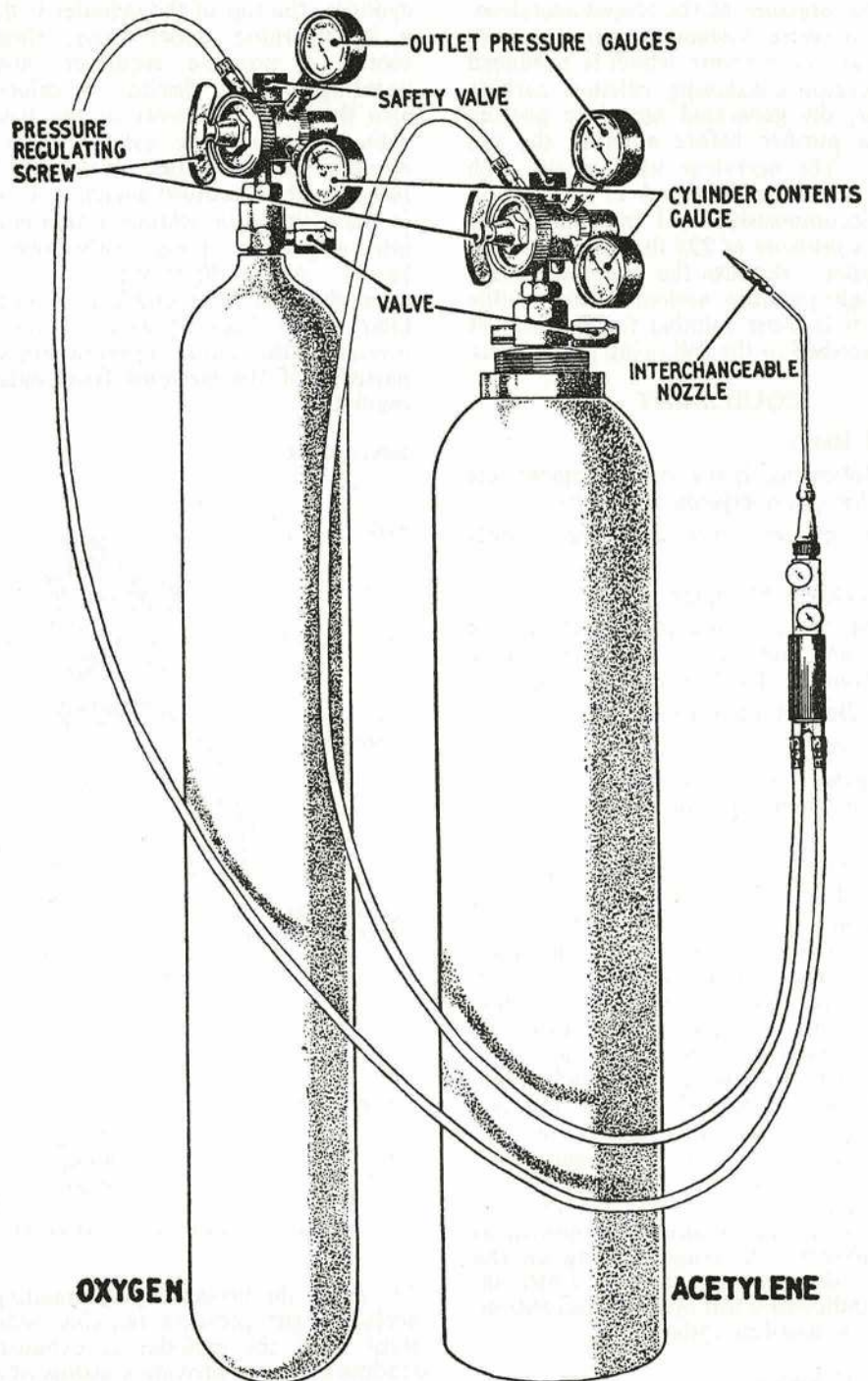


Fig. 2. HIGH PRESSURE OXY-ACETYLENE WELDING OUTFIT

refer to the pressure of the stored acetylene. The low pressure system is supplied with acetylene at low pressure which is produced in a generator containing calcium carbide and water, the generated acetylene passing through a purifier before entering the gas blowpipe. The acetylene used in the high pressure system is dissolved in acetone to prevent decomposition and instability, and stored at a pressure of 225 lb. per sq. in. in a steel cylinder. Because the equipment used in the high pressure system is so readily portable, it is most suitable for Service use and is described in the following paragraphs.

EQUIPMENT

Essential Items

9. The following items of equipment are required for oxy-acetylene welding:—

- (a) The oxygen and acetylene supply system.
- (b) A welding blowpipe.
- (c) Hose for coupling the outlets of the oxygen and acetylene supply system to connections on the blowpipe.
- (d) Welding or filler rods.
- (e) Fluxes.
- (f) Goggles and protective clothing (including gloves) for the operator.

Oxygen Cylinder

10. The cylinder (Fig. 2) is made of high quality mild steel, the base of which is convex in shape to give greater strength. The top of the cylinder is fitted with an outlet valve operated by a key, and is designed to accommodate a pressure regulator. Oxygen cylinders are always painted *black* and the outlet valve has a *right-hand thread*. Four sizes of cylinder, of 80, 100, 150 and 200 cu. ft. capacity respectively, are in general use, and are normally charged, when filled, to a pressure of 132 atmospheres (approx. 1,980 lb. per sq. in.). The gas content of a cylinder is directly proportional to the high pressure gauge reading on the regulator; thus, a pressure of 1,980 lb. per sq. in. indicates a full cylinder and 990 lb. per sq. in. a half-full cylinder.

Acetylene Cylinder

11. This cylinder (Figs. 2 and 3) is also made of high quality mild steel, but the base is concave in shape. As with the oxygen

cylinder, the top of the cylinder is fitted with a key-operated outlet valve, threaded to receive a pressure regulator, and incorporating a safety device. A safety plug is also fitted in the recess in the base of the cylinder. Acetylene cylinders are painted *maroon*, and the outlet valve has a *left-hand thread*. The dissolved acetylene is contained in the cylinder in acetone which is absorbed into a porous spongy substance such as kapok. Above the spongy mass is a granulated charcoal filter and then a brass gauze filter. The filters prevent ingress of any foreign matter and also prevent any displaced particles of the contents from entering the regulator.

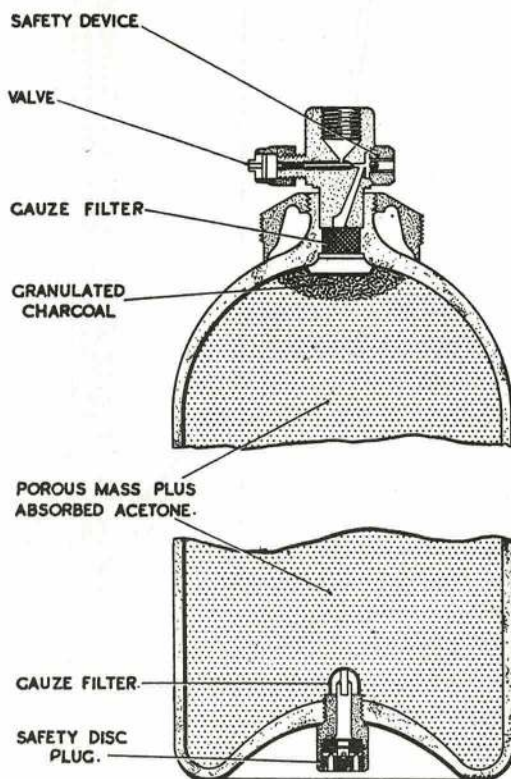


Fig. 3. ACETYLENE CYLINDER

12. Since the pressure gauge reading of the acetylene gas pressure remains nearly constant until the cylinder is exhausted, the reading does not provide a means of estimating either the acetylene content or the amount used on a job. The acetylene content may be found by weighing the cylinder, subtracting the empty weight of the cylinder and

converting the difference in weight into cubic feet of gas (1 cu. ft. of acetylene weighs 1.1 oz.). For practical purposes, the gas consumption for welding is considered to be the same both for oxygen and acetylene; therefore, by noting the oxygen pressure before and after work the quantities used can be readily estimated with reasonable accuracy.

Note.—Cylinders that are damaged, and those in which a safety device has operated, must be returned to the Equipment Section for repair by the manufacturer of the gas. R.A.F. personnel must not attempt to repair these cylinders.

Pressure Regulation

13. The pressure of the acetylene and oxygen stored in the cylinders is much higher than is required for the operation of the blowpipe; therefore, pressure regulators (reducing valves) are fitted to the cylinders to give an even flow of gas at the correct pressure for the particular blowpipe being used.

Two-stage Pressure Regulator

14. The earlier single-stage type of regulator suffered from the inherent disadvantage that, as work proceeded, the drop in pressure in the cylinder caused variations in the pressure at which gas was delivered by the regulator, thus necessitating adjustment of the pressure screw in order to keep a steady flame. With two-stage pressure regulators the gas is at a non-varying pressure when it reaches the second-stage of regulation, irrespective of the cylinder pressure, and the outlet pressure setting is therefore less likely to require adjustment, particularly at the lower working pressures.

15. This type of regulator is attached to the cylinder by a fly nut (Fig. 4) and, as can be seen from the illustration, the two-stages of regulation are obtained by the use of spring-loaded diaphragms. The purpose of the first-stage of regulation is to reduce the gas pressure to a constant value irrespective of changes in the pressure of gas in the cylinder; therefore the spring loading is fixed. Final

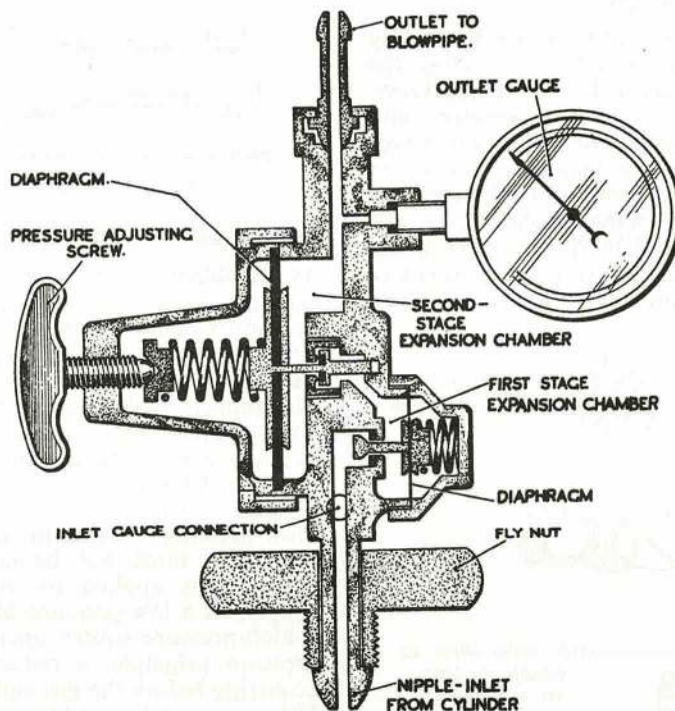


Fig. 4. TWO-STAGE PRESSURE REGULATOR

adjustment of the gas pressure is made at the second-stage of regulation, where the pressure adjusting screw enables the load on the second-stage spring to be adjusted as required.

16. **Operation.** Gas from the cylinder flows directly to the first-stage expansion chamber until the pressure is greater than that of the spring, when the diaphragm will move and close the valve, thus stopping the supply of gas. When gas is supplied to the blowpipe the pressure inside the first-stage expansion chamber will decrease, and the diaphragm will be pushed back by its spring, thus opening the valve and admitting more gas from the cylinder. The gas pressure then acts on the second-stage diaphragm, the spring pressure on which governs the pressure of the gas passing to the blowpipe.

Note.—Pressure regulators for acetylene cylinders are always painted *maroon*, and all external pipe screwed connections have *left-hand threads*. Oxygen regulators are painted *black*, and have *right-hand threads*.

Hose and Hose Clips

17. Only hose approved for use with welding equipment may be used for connecting the acetylene and oxygen cylinders to the blowpipe. *Red hose* is used for acetylene and *black hose* for oxygen; the hoses must never be interchanged. The lengths of hose are connected to the equipment by adapters, the ends of the hose being pushed over the adapters and fastened by hose clips (Fig. 5); union nuts are used to secure the adapters to the welding equipment. The use of wire

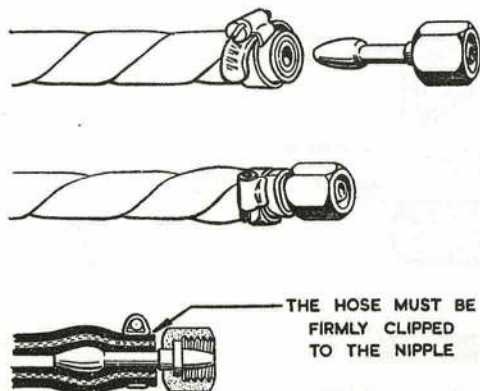
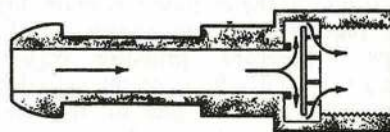


Fig. 5. HOSE CLIP AND ADAPTER

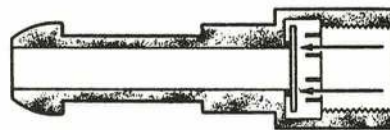
to secure the hose to the welding equipment is strictly forbidden.

Hose Protectors

18. To prevent the possibility of the gas in the hose being ignited by a back-fire from the blowpipe, special adapters termed "hose protectors" (Fig. 6), are used at the blowpipe end of the hose. Each adapter contains an anti flash-back valve, the purpose of which is to stop the flame at the inlet connections of the blowpipe. The device is essentially a non-return valve, and consists of a plate which returns to its seating when a back-pressure is applied from the blowpipe, thus instantly blanking-off the gas in the hose. Normally, the valve offers no restriction to the flow of gas from the regulator to the blowpipe.



GAS FROM CYLINDER—VALVE OPEN



BACK-FIRE FROM BLOWPIPE—VALVE CLOSED

Fig. 6. HOSE PROTECTOR

Blowpipes

19. **Welding.** The function of the welding blowpipe is to mix the oxygen and acetylene in approximately equal proportions and thus provide the desired flame for welding purposes. There are two types of welding blowpipes: high-pressure and low-pressure. The former can be used only with high-pressure gas supply equipment, but the latter can be used with either high or low-pressure systems. The terms "high-pressure" and "low-pressure" used in conjunction with blowpipes must not be confused with the some terms applied to the source of gas supply, as a low-pressure blowpipe fed from a high-pressure source operates on the low-pressure principle, a reduction of pressure occurring before the gas enters the blowpipe. The oxy-acetylene blowpipes used in the Service are of the low-pressure type (Types A and B), and high-pressure (Type G.M.C. 13).

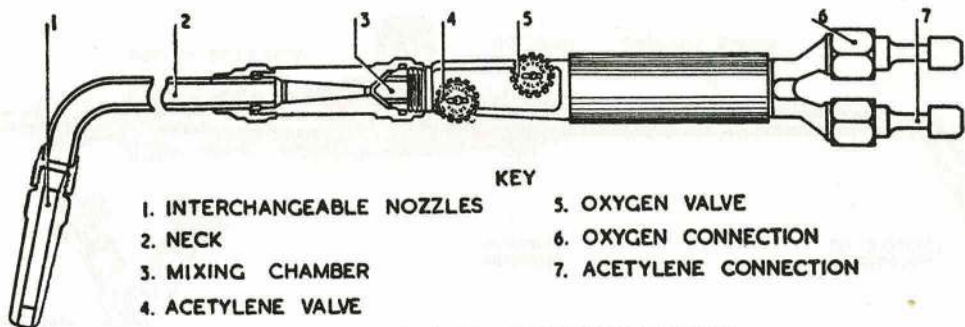


Fig. 7. HIGH-PRESSURE WELDING BLOWPIPE

20. Cutting. The cutting blowpipe has two functions: it provides a flame of acetylene and oxygen for heating the metal to be cut, and an independent stream of oxygen by which the actual cutting is performed.

High-pressure Blowpipe

21. When the supply of oxygen and acetylene is obtained from high-pressure cylinders, both gases are fed to the blowpipe at appropriate pressures, acetylene 2 to 20 lb. per sq. in., oxygen 4 to 30 lb. per sq. in. The high-pressure blowpipe (Fig. 7) is simply a mixing device to supply approximately equal volumes of oxygen and acetylene to the nozzle. The gases enter the blowpipe through two regulating valves, and are conducted to the mixing chamber from which they pass through a single passage to the blowpipe nozzle.

22. The valves enable the operator to adjust the proportion of the gases to obtain the correct type of flame, and are also used for shutting off the gas supply when it is desired to extinguish the flame. Control of the gas pressure supplied to the blowpipe is obtained by adjustment of the oxygen and acetylene pressure regulators according to the work to be done. A range of different sized nozzles is provided for use on differing thicknesses of metal. In addition, various sizes of blowpipes are available, from small and light pipes suitable only for thin-gauge sheet, to heavy-duty patterns.

Low-pressure Blowpipe

23. When acetylene is delivered to the blowpipe from low-pressure generators the pressure of the gas is too low to produce an effective welding flame. Therefore, blowpipes which may be used with this system (Fig. 8)

are designed to enable the oxygen, which enters the blowpipe at high pressure, to accelerate the flow of acetylene; this is done by means of an injector which also acts as a mixer.

24. When it is desired to vary the delivery of the blowpipe to suit the nature of the work, a different injector as well as a different nozzle or welding tip must be used. In practice, it is usual for low-pressure blowpipes to be designed so that the entire forepart is inter-changeable. This part, known as the head, includes the oxygen jet and injector chamber, the mixing chamber and the nozzle, and the heads are given size numbers indicating the differences in the sizes of the tips.

Cutting Blowpipe

25. The blowpipe sets in general Service use are of the combined welding and metal-cutting type, so designed that a full range of injector-type welding heads, or a cutting head, can be fitted as required. When a cutting head is fitted (Fig. 9), the acetylene and oxygen are utilized in the same way as in a welding blowpipe for provision of the flame at the nozzle, and controlled by similar valves. Additionally, there is another valve, usually spring-loaded and lever controlled, which, when operated, releases a stream of oxygen which is the cutting jet proper.

Cutting Guides

26. Guides (Fig. 10) are supplied with the cutting blowpipe to enable a regular and even cut to be made and to relieve the operator of the weight of the blowpipe. Two types of guide are in common use, known respectively as the spade type and roller type. Guides of the double roller type are used when

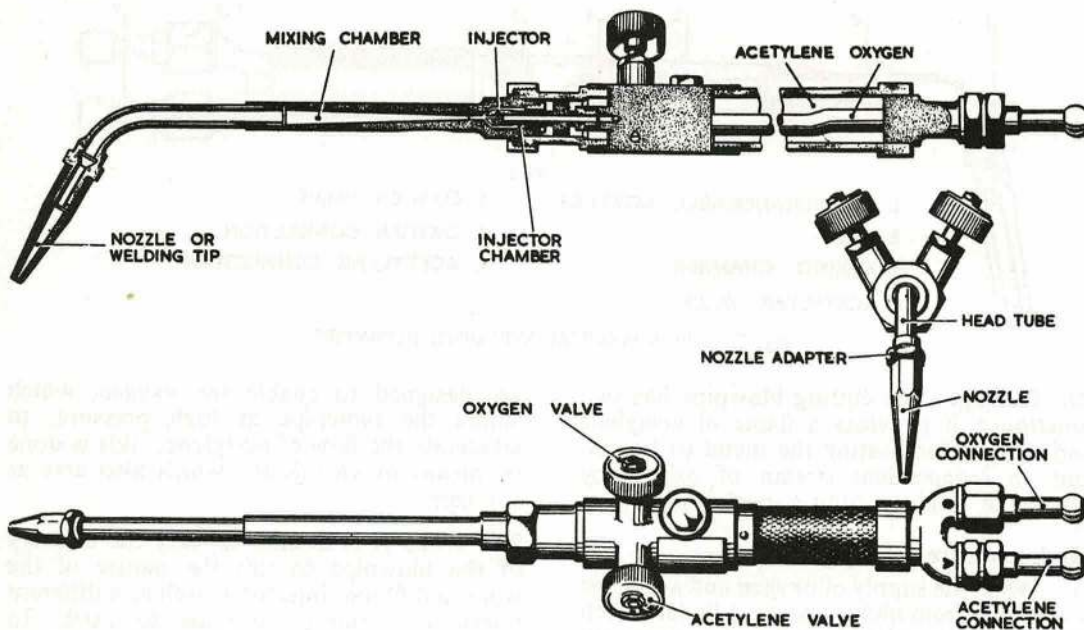


Fig. 8. LOW-PRESSURE BLOWPIPE

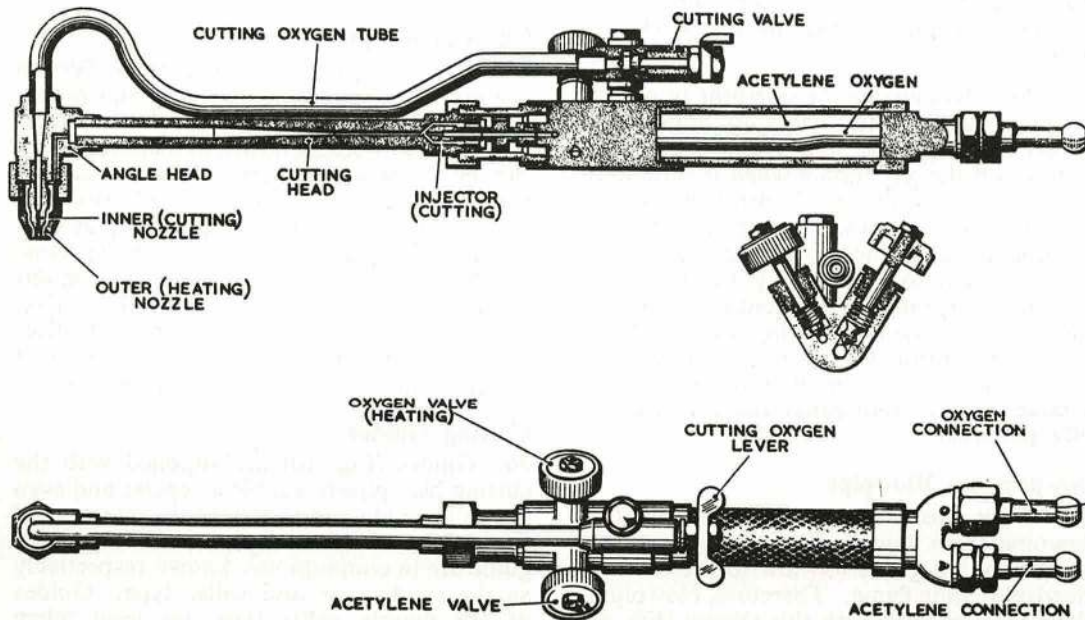


Fig. 9. CUTTING BLOWPIPE

cutting thick metal and when it is desired to cut a bevel. The guides are attached to the head of the blowpipe, the spade or roller being used to follow a template rigidly secured to the work.

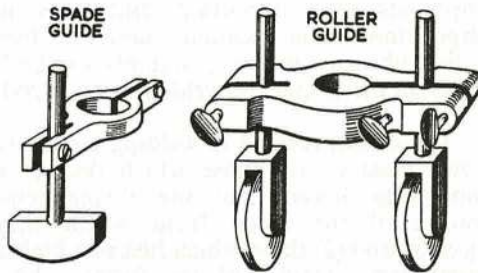


Fig. 10. CUTTING GUIDES

Gas Economizer

27. The consumption of gas can be reduced considerably if the welding flame is extinguished whenever the blowpipe is not actually in use. This is achieved by using an economizer (Fig. 11). Because the valves

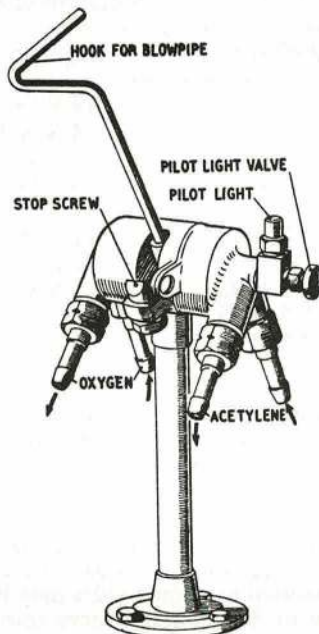


Fig. 11. GAS ECONOMIZER

are left open, the flame, on re-igniting, does not require adjustment, thus resulting in a saving of the operator's time. The two

lengths of hose from the regulator are attached to the inlet connections of the economizer, and the outlets are connected to the blowpipe with additional lengths of hose, the economizer being secured to the work bench in a convenient position.

28. **Operation.** The blowpipe is initially ignited in the normal manner, and, after completing a weld, it is hooked to the lever on the economizer. This action shuts a valve in each supply line and extinguishes the blowpipe flame. The action of removing the blowpipe from the hook allows the spring-loaded lever to open the valves, thus supplying gas to the blowpipe. The blowpipe can be re-lighted without further adjustment to its valves from the pilot light on the economizer.

Welding Wire and Rod

29. Thin sheet and certain other metals may be welded without the addition of filling-in material, but in most welding operations, and at all times when the edges of the parts to be joined have been prepared by bevelling or veing, fresh metal must be added while the operation is in progress in order to fill in or to build up the joint. This added metal, known as the weld metal, is obtained by melting the end of a length of wire or rod into the small pool of molten metal formed directly under the blowpipe flame.

30. Welding wire and rod usually differ slightly in composition from the metal with which they are intended to be used. Allowance is made in their preparation for the changes in composition which result when they are heated and melted; to ensure that the desirable physical qualities of the weld are retained, certain elements may be included in the wire. Steel welding wire or rods, for example, usually have a higher carbon content and more manganese and silicon than the parent metal; the two latter elements are deoxidizing agents and also give improved tensile properties to the weld. De-oxidizing agents are elements having great affinity for oxygen; thus, other elements in the metal are less affected by oxidation.

31. It is essential, therefore, that the composition of the metal to be welded is correctly identified and that suitable welding wire is used. If special welding wire or rod is not available, it is permissible to use strips of the

same material as that to be welded, but such strips should be used only in emergency, as, apart from the fact that they fail to compensate for losses in the parent metal due to heating, they present other disadvantages. Oxide and dirt are liable to be trapped or forced into the metal whilst the strips are being cut, it is difficult to cut strips of uniform width, and burrs on the strips will oxidize readily.

32. It is important that the welding wire is of suitable diameter. If the wire is too thick it will chill the metal of the weld and cause adhesion. If it is too thin it will introduce an undue amount of oxide, because an excessive length of wire must be used and a very large surface is thus exposed to the welding flame. The following table indicates the sizes of welding wire which may

Fluxes

34. Fluxes are used in oxy-acetylene welding to prevent oxidation and other chemical reactions which hinder the making of satisfactory welds. They are chemical compounds with important differences in composition; it is essential, therefore, that the flux chosen for use is suitable for both the parent metal and the welding wire or rod.

35. The oxides formed in welding metal are of two classes: (1) those which fuse at a temperature lower than the fusing temperature of the metal from which they originate, and (2) those which fuse at a higher temperature. Oxides of the former class, those with a melting point lower than that of the parent metal, float as a film on the surface of the molten metal, whence they are easily removed after welding. Metals

Gauge or thickness in inches of metal	Gauge of welding rod (leftward or rightward welding)			
	Steel		Cast iron	Aluminium and Magnesium alloys
	Leftward	Rightward	Leftward	Rightward
20 S.W.G.	16 S.W.G.	—	—	14 S.W.G.
19 S.W.G.	16 S.W.G.	—	—	14 S.W.G.
18 S.W.G.	16 S.W.G.	—	—	14 S.W.G.
$\frac{1}{8}$ in.	15 S.W.G.	—	—	13 S.W.G.
$\frac{3}{16}$ in.	12 S.W.G.	14 S.W.G.	—	11 S.W.G.
$\frac{1}{2}$ in.	9 S.W.G.	11 S.W.G.	11 S.W.G.	11 S.W.G.
$\frac{5}{8}$ in.	9 S.W.G.	11 S.W.G.	11 S.W.G.	10 S.W.G.
$\frac{3}{4}$ in.	6 S.W.G.	8 S.W.G.	11 S.W.G.	6 S.W.G.
$\frac{7}{8}$ in.	5 S.W.G.	8 S.W.G.	6 S.W.G.	—
$\frac{15}{16}$ in.	3 S.W.G.	6 S.W.G.	3 S.W.G.	—

generally be regarded as correct for joints between metals of various thicknesses.

33. When in doubt, it may be taken that the diameter of the welding wire bears the following relation to plate thickness when the plates are bevelled:—

$$\text{Diameter of rod} = \frac{1}{2}T + \frac{1}{8}\text{ in.}$$

Notes. 1. For welding without a bevel, the diameter of the wire should be one-half of the plate thickness.

2. Particulars of welding wires and rods can be found in A.P. 1086, Part 13, Sect. 30A and B.

that produce this class of oxide, e.g. mild steel and wrought iron, do not require the use of a flux during the welding process.

36. Metals producing oxides of the latter class include cast iron, brass, bronze, aluminium and magnesium alloys. Part of the ill-effects caused by these oxides may be cured by the use of fluxes which serve some or all of the following purposes:—

(a) Dissolve and remove oxide present on the surface of the metal to be welded.

(b) Form a protective coating over the surfaces of the metal when they are heated, thus preventing further oxidation during welding.

(c) Float the oxide and other impurities with which it has combined to the surface of the molten metal, where it will not interfere with the free flow of metal in the weld and whence it can easily be removed.

37. Most fluxes are in powder form and are applied to the weld by dipping the heated end of the welding rod into the flux container and transferring the flux to the part of the weld that is in a state of fusion. Paste or liquid fluxes are usually applied with a brush before welding is commenced.

38. Fluxes in general use for non-ferrous metals have a corrosive action if allowed to remain on the welded work. Therefore, when welding is complete, all traces of the flux must be removed. This can be done by washing the welded parts in boiling water; whenever practicable, the parts must also be given a good scrubbing. Most fluxes for non-ferrous metals are also hygroscopic, i.e. they freely absorb moisture from the atmosphere, thus becoming useless. Consequently they must be kept in airtight containers and stored in a dry atmosphere.

Goggles

39. Ultra-violet and infra-red rays, both of which are harmful to the eyes, are emitted when metals are brought into a state of fusion by the blowpipe. It is therefore essential that the welding operator should wear suitable goggles to protect his eyes from these rays and from flying particles of oxide and molten metal. Only goggles of approved type must be used. The goggles supplied are of special construction and consist of tinted glass protected by plain glass. When the plain glasses become pitted they can be renewed.

Gloves

40. Asbestos gloves are worn when the heat radiated from the welding job renders it advisable to have protection for the hands. Such gloves are essential when cutting cast iron, as very great heat is generated during this operation. Gloves should be kept free from oil or grease. If the operator handles any oily or greasy parts, the gloves used must be changed for a clean pair before touching the welding equipment.

Tool-kit

41. A small tool-kit, consisting of keys and spanners, is supplied with each set of welding equipment. Only the keys and spanners provided are to be used when operating the outlet valves of the cylinders, changing blowpipe heads, etc.

Precautions

42. **Acetylene Cylinders.** Acetylene is an inflammable gas, which, if allowed to mix with air, becomes a potential source of an explosion. It is essential, therefore, to ensure that all joints are gas-tight, that hose is in good condition and that the gas is turned off at the cylinder when work is finished. Leaks should be located by using soapy water. When the cylinder pressure drops too low to be suitable for further use, the cylinder will still give off some gas and inflammable vapours; therefore, when the cylinder is taken out of use the valve must be closed. Cylinders should be kept upright both during use and whilst stored.

43. When a cylinder has a leak at the valve or at the base plug which cannot be remedied by firmly closing the valve or plug, it should be moved into the open away from any source of a spark or heat. Smoking or naked lights must be forbidden near the leaky cylinder, and the Equipment Officer must be notified immediately. If, due to leakage at the connection, acetylene catches fire at the valve or regulator, close the valve and securely tighten the joint before further use.

44. If a cylinder becomes hot or fires internally due to excessive backfiring or to the use of faulty equipment, close the valve, disconnect the regulator and immediately remove the cylinder into the open; the valve should then be opened fully to allow the gas to escape freely. A hose should be used to apply water to the body and top of the cylinder or the whole cylinder should be immersed in a tank of water, and the Equipment Officer should be notified of the occurrence immediately.

45. **Oxygen Cylinders.** Never allow oil or grease to come into contact with oxygen fittings. Escaping oxygen will form an inflammable mixture with oil or grease, and

may cause clothing or other articles to burn vigorously if ignited by a spark. The same precautions should be observed for leaks as for acetylene.

46. Pressure Regulators. Always treat a regulator as a precision instrument; do not subject it to knocks, jars or sudden pressure caused by rapid opening of the cylinder valve. Release the pressure on the control spring when shutting down. Do not use regulators with broken gauges, and stand well clear of gauges when opening the cylinder valve. If the regulator creeps, i.e. passes gas when the pressure adjusting screw is released, or builds up pressure on the low-pressure side when the blowpipe is shut, return the regulator to the Equipment Section for reconditioning. If a gauge does not return to zero when the pressure is released, the mechanism is sprung and the gauge must be renewed.

47. Blowpipes. Valve leakage should be remedied by tightening the gland nut. Leakage at the head nut or welding nozzle should be remedied by cleaning the seatings with a soft cloth and re-tightening. If a backfire occurs, with gas burning inside the blowpipe, first shut off the oxygen and then the acetylene valves. After a pause, re-light the blowpipe and check the delivery pressures; if these are correct, persistent backfiring indicates that the blowpipe should be returned to the Equipment Section for reconditioning. Use a soft copper wire or a wood splinter to clean the nozzle of a blowpipe, never a steel wire.

48. Rubber Hose. Hose may be tested for leaks under working pressure by immersing it in water. Leaks may be repaired by cutting out the faulty portion and inserting a coupling. Worn ends should be cut back and the ends re-fitted with proper hose adapters and clips. If this is not sufficient, the hose must be renewed.

WELDING PRACTICE

Introduction

49. Correct preparation of the parts to be joined is of great importance in the production of successful welds. In addition to thorough cleaning to ensure that all oil, grease, paint and oxide are removed from

the surfaces of the parts, preparation for welding may include:—

- (a) Suitable treatment of the edges (shaping) which are to be welded.
- (b) Accurate setting up of the parts in relation to one another.
- (c) Pre-heating or other measures to relieve stresses and avoid distortion.

50. Except where thin sheet metal is to be welded, it is usually necessary to prepare the edges of the parts to be joined. The method of edge preparation to be used depends upon the material, its thickness, and the welding technique to be adopted.

Flanging

51. To weld sheet metal, brass, copper or monel metal up to $\frac{1}{8}$ in. in thickness, the edges may be turned up at right angles to a depth of about twice the plate thickness (Fig. 12). This method of preparation ensures rigidity and welding rod is not necessary. The turned up edges should butt with no gap between them. Aluminium, magnesium or alloys of these metals must be flanged.

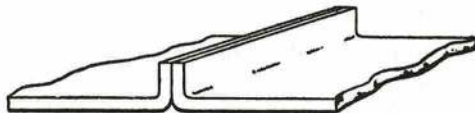


Fig. 12. FLANGING

Gap Rounded Edge

52. For sheet metal and other metals of from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. in thickness, a plain butt joint with slightly rounded edges is generally preferred (Fig. 13). To ensure penetration of the melted welding rod and to allow flux (if used) to flow to the underside of the metal, the edges should be set up $\frac{1}{8}$ in. apart prior to welding.

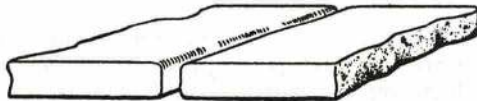


Fig. 13. GAP ROUNDED EDGE

Bevelled Edge

53. Where pieces of metal more than $\frac{1}{8}$ in. in thickness are to be welded the edges must be bevelled. Beveling consists of cutting away

the edges to be joined so that a trough or vee is formed when they are placed together, allowing a $\frac{1}{8}$ in. gap at the bottom of the vee. This ensures that the metal melts throughout the thickness of the parts and also reduces the risk of overheating the metal. The bevelling must be uniform, especially at the bottom of the vee; holes or variation in the thickness of the metal are likely to result in defective welds. Castings and non-ferrous metals over $\frac{1}{8}$ in. in thickness should have edges bevelled to a "flat" or "nose" at the bottom of the vee (Fig. 14); this prevents over-melting and undue penetration of the fluid metal. When both sides are accessible double bevelling should be employed for plates of $\frac{3}{8}$ in. thickness and over, the joint being welded from both sides. The angle of bevel depends on the welding technique, leftward or rightward welding, which will be described later.

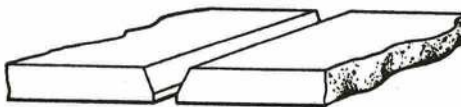


Fig. 14. BEVELLED EDGE

Stresses and Distortion

54. The molten pool of metal in the area of the flame consists of melted parent metal and welding rod. As welding proceeds, heat is lost by conduction through the cooler parent metal outside the welding area and by

radiation. The rate of cooling depends on the thermal conductivity of the parent metal, the temperature and area of the weld metal, and the size of the job welded.

55. Most metals expand when heated and contract when cooled. Thus, as the weld proceeds, there will be areas around the weld in various conditions of expansion and contraction. The consequent forces, termed "residual stresses", may remain when the weld has cooled, and may cause elastic or plastic deformation of the joint. When the parts are ductile these stresses cause distortion, but, if the parts are rigid, fracture may occur immediately or the weld may fail in service. Ductile metals subjected to stresses yield by bending or buckling, but non-ductile metals, such as cast metals break rather than bend because of their relative lack of elasticity.

Prevention of Distortion

56. Prevention of distortion is difficult, but the influence of the following factors should be borne in mind when deciding welding procedure. A large flame increases the amount of local heat; therefore, the use of the correct size of flame will lessen distortion. A narrow weld is better than a wide one because the quantity of heat applied to the plate is smaller. When welding two plates prepared with a vee joint it will be found that the plates distort by bending upwards (Fig. 15). This can be prevented by setting

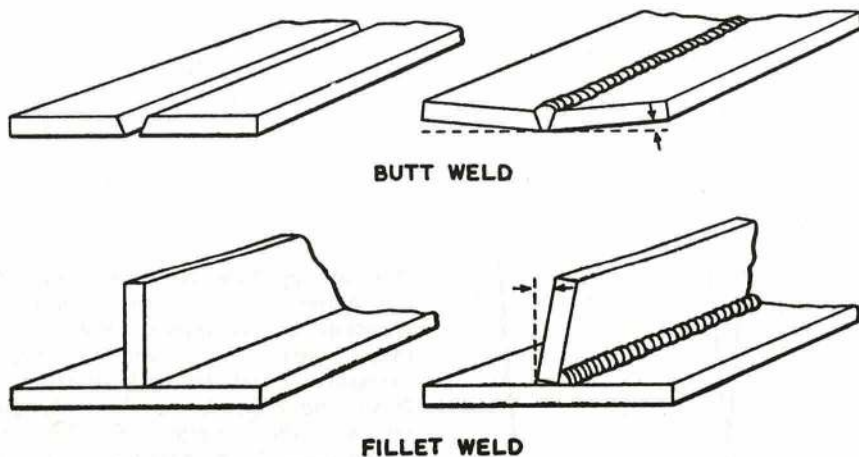


Fig. 15. EFFECT OF DISTORTION

the plates, before welding, at a slight angle to each other, in the opposite direction to that in which distortion will occur. A similar method of avoiding misalignment can be used when welding a plate at right angles to another (Fig. 15). It should be set up, previous to welding, with a slight bias in the opposite direction.

57. Tack Welding. When a butt weld is being made between two plates or sheets of

that considerable buckling may be caused on thin sheet metal, and that irregularities of the surface caused when the weld metal is run over the tack welds may impair the appearance of the work.

58. Where tacking is not advisable, the two plates may be arranged at an angle (taper spacing) which makes allowance for closing up during welding. The gap is maintained by a metal wedge (Fig. 17) which is moved in

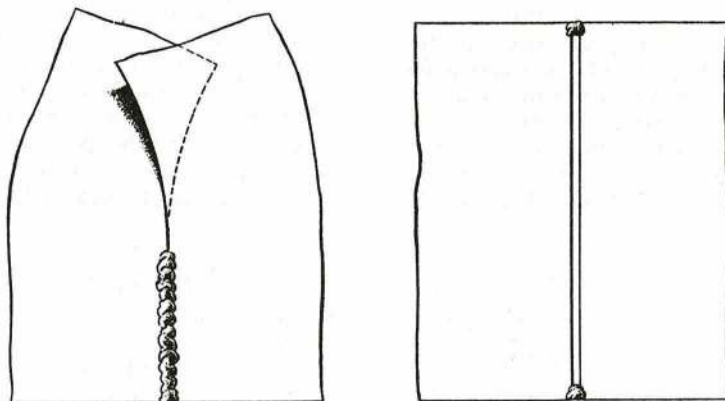


Fig. 16. EFFECT OF DISTORTION—TACKING

metal, the effect of distortion is to draw the parts together as the weld proceeds until they eventually overlap (Fig. 16). One method of preventing this is to hold the parts in position by tack welds along the line of weld (Fig. 16). Tacking is effected by heating the edges of the joint to fusion point and allowing a drop of metal from the welding rod to fall upon the edges. The disadvantages of tacking are

the direction of welding as the work proceeds. The amount by which the plates should diverge is approximately as follows:—

Steel	$\frac{1}{4}$ in. per foot
Brass and Bronze ..	$\frac{3}{16}$ in. per foot
Aluminium ..	$\frac{1}{8}$ in. per foot
Copper	$\frac{3}{16}$ in. per foot

59. When the methods described in preceding paragraphs are not applicable, step welding may be used to minimize distortion. In step welding (Fig. 18) the line of weld is treated as though it was broken into short lengths, each length being welded separately. This has the effect of reducing the heat in any one section of the plate, e.g. when the start of step 2 meets the beginning of step 1, the expansion and contraction areas are adjacent and counteract the effect of each other. Back step welding (Fig. 18), a variation of step welding, consists of welding from one edge for a short distance, then reversing the direction of weld and welding a step towards the first weld. The third and subsequent welds are then made as short steps towards those preceding them.

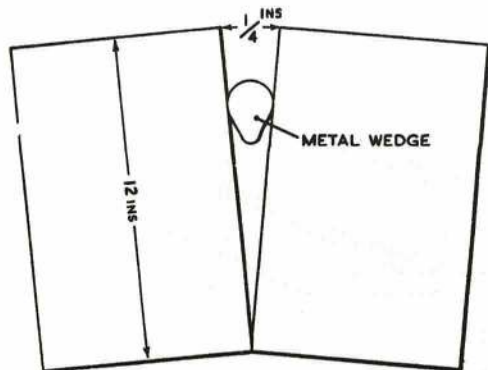


Fig. 17. STEEL PLATES—TAPER SPACING

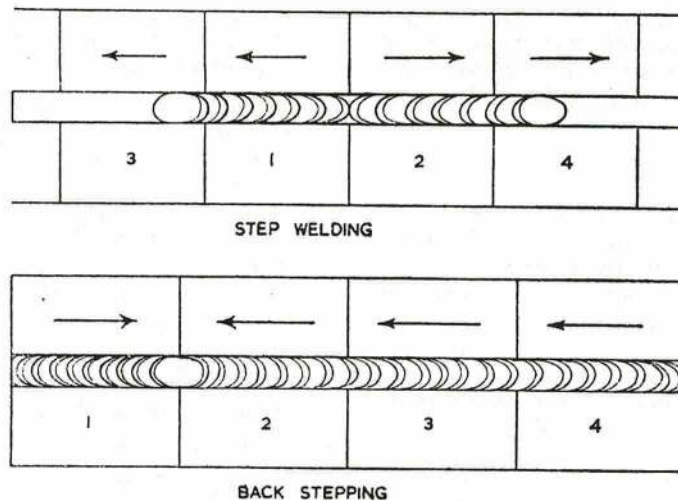


Fig. 18. STEP AND BACK-STEP WELDING

60. When welding thin sheet, an effective method of localizing heat is to clamp a heavier strip of metal along each side of the weld. The strips of metal, known as chills, will minimize the conduction of heat to the parent metal.

61. Pre-heating the work is one of the most important methods of minimizing the effects of expansion and contraction during welding. It can be used successfully where other methods of preventing distortion fail.

62. **Relieving Residual Stresses.** To prevent fracture of welds in cast metals, it is necessary to weld away from a fixed end towards a free end. By this method, the parts welded are able to move relatively to each other, as a result of which the stresses set up on cooling are much less. With some metals, light hammering of the weld and/or the surrounding parent metal is permissible. This relieves the stresses and consolidates the structure of the metal, but must only be done when authorized. Relieving stress in ductile metals is done by heat treatment, e.g. mild steel is normalized after the weld has been completed. The need for heat treatment will depend upon the type of welded structure and the conditions under which it operates. With welds operating under highly stressed conditions, heat treatment is usually essential.

Assembly of Equipment

63. Stand both cylinders vertically. If not on a trolley, the oxygen cylinder needs a stand or support. Oxygen cylinders are painted **black** and acetylene cylinders are painted **maroon**.

(a) Open the valve on the oxygen cylinder momentarily in order to dislodge dirt or obstruction in the cylinder valve.

(b) Open the valve on the acetylene cylinder momentarily.

(c) See that jointing surfaces in the cylinder valves and regulators are free from oil and grease.

(d) Screw the oxygen regulator (painted **black**) into the oxygen cylinder valve. The threads are **right-hand**.

(e) Screw the acetylene regulator (painted **maroon**) into the acetylene cylinder valve. These threads are **left-hand**.

(f) Tighten the regulators; do not use excessive force but make certain that the joints are gas-tight.

(g) Before connecting the hoses (acetylene **red**, oxygen **black**) to the screwed outlets of the regulator, any dust, dirt or chalk when the hose is new, should be blown out by passing a small amount of gas through them.

(A.L. 17, Jan. 64)

(h) Connect the blowpipe, acetylene hose to the connection marked A and oxygen hose to the connection marked O. Keep the blowpipe control valves closed. Fit the appropriate sized welding head to the blowpipe.

Welding Head Sizes

64. The size of the welding head used will be determined according to the skill of the operator, and the type and mass of the metal concerned. The following table is applicable mainly to steel plate.

Welding head No.	Metal thickness (in.)	Oxygen Pressure (lb. per sq. in.)
0	$\frac{1}{8}$	5
1	$\frac{1}{4}$	5
3	$\frac{3}{8}$	10
3	$\frac{1}{2}$	10
5	$\frac{3}{4}$	10
5	$\frac{1}{2}$	15
6	$\frac{3}{8}$	15
8	$\frac{1}{4}$	15
8	$\frac{5}{16}$	20
10	$\frac{3}{8}$	20
12	$\frac{1}{2}$	25
15	$\frac{3}{4}$	30
15	1	30

Lighting the Blowpipe

65. (a) Ensure that the pressure adjusting screw of each regulator is fully anti-clockwise.

(b) Using the correct cylinder key, open the gas cylinder valves slowly; two full turns will give the full opening of a valve. Note the pressure on each inlet or high-pressure gauge.

(c) Open the oxygen valve on the blowpipe one complete turn; note the pressure indicated on the oxygen regulator outlet or low-pressure gauge.

(d) Turn the oxygen regulator pressure adjusting screw clockwise until the pressure indicated on the low-pressure gauge is that recommended for the size of nozzle being used.

(e) Close the blowpipe oxygen valve.

AL-18 (f) Open the blowpipe acetylene valve slowly one complete turn. Ensure that the blowpipe is not pointing towards any flame, spark or hot metal.

(g) Turn the acetylene regulator pressure adjusting screw clockwise until the pressure indicated on the low-pressure gauge is that recommended for the size of nozzle being used.

(h) Light the blowpipe. If the acetylene burns with a lot of smoke, adjust the pressure adjusting screw of the acetylene regulator until a flame free of soot is produced; a smoky flame normally indicates that the acetylene pressure is too low.

(j) Slowly open the blowpipe oxygen valve. Check that a neutral flame is burning at the nozzle tip, otherwise, adjust as detailed in the following paragraphs.

Note.—When looking at the flame always wear the goggles provided.

Adjusting the Flame

66. Correct flame adjustment is one of the most important factors in successful oxy-acetylene welding. The wrong type of flame will result in scaling, or in weak, brittle or hard welds, however great is the care exercised at other stages of the welding process.

67. Examination of a correctly-adjusted welding flame will show that it consists of two parts: a brilliant, sharply-defined inner flame, called the cone, and a slightly nebulous outer flame known as the envelope. This is because the combustion of the gases occurs in two stages, as follows:—

(a) In the cone, the acetylene combines with the oxygen to produce carbon monoxide and hydrogen.

(b) The carbon monoxide and hydrogen pass to the outer envelope and combine with oxygen from the air to form carbon dioxide and water.

68. According to the proportions in which the gases are allowed to mix in the blowpipe, so the sizes of the cone and outer envelope will vary, and three distinctive types of flame are obtainable: the neutral flame; the carburizing, carbonizing or reducing flame; and the oxidizing flame. The welder must regulate the flame to a condition most suitable for the work in hand, and this is done by adjustment of the blowpipe and pressure regulator controls.

Types of Flame

69. **Neutral Flame (Fig. 19).** With few exceptions this is the type of flame most

suitable for welding, because it has the least tendency to change the character of the parent metal or the welding rod. It has a luminous inner cone (A), for the most part sharply defined, but with a slight "haze" or "flicker" at its tip, and a fairly bright outer envelope (B). This flame results from the use of equal parts of acetylene and oxygen.

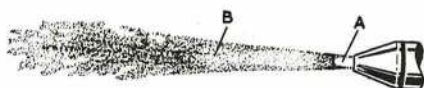


Fig. 19. NEUTRAL FLAME.

70. **Carburizing Flame (Fig. 20).** This flame has a bright inner cone (C) similar to that of a neutral flame, but the outline of the cone is surrounded by a secondary blue-white flame or feather (D). The shape of the whole flame is long and pointed, with an outline not very sharply defined. This type of flame is produced when an excess of acetylene is present in the mixture supplied to the blowpipe, the excess being split up in the inner flame into its constituents, carbon and hydrogen, which pass as such to the outer flame. Some of the carbon thus set free will combine with any ferrous metal being welded and, since this tends to harden the weld and make it brittle, a carbonizing or carburizing flame must usually be avoided. A flame of this type is, however, a definite requirement for hard-surfacing and rebuilding operations.



Fig. 20. CARBURIZING FLAME.

71. **Oxidizing Flame (Fig. 21).** This flame is produced when there is an excess of oxygen in the mixture, some of which passes unchanged into the outer envelope. The cone (E) of such a flame is shorter and thinner than those of the two aforementioned types, and the outer envelope (F) is brighter. Its production is accompanied by a slight hiss from the blowpipe. The free oxygen in the outer envelope of an oxidizing flame may attack the welding rod and the parent metal, tending to burn out their strength-giving elements. A slight excess of oxygen is

desirable when welding brass, but generally an oxidizing flame is to be avoided unless it is specifically recommended.



Fig. 21. OXIDIZING FLAME.

Obtaining Correct Flame

72. Whatever type of flame is required, the blowpipe should first be adjusted to obtain a neutral flame. To obtain this flame, light the blowpipe as described in para. 65 and leave the oxygen valve fully open. Carefully adjust the acetylene valve to reduce the supply until the blue-white feather around the inner cone of the flame is sharply defined. The extreme tip of the cone should have a suggestion of haziness or flicker, but this should be quite small. If the edges of the cone as a whole appear ragged, an excess of acetylene is present and the valve should be adjusted to reduce the supply.

73. If an oxidizing flame is required, further gradual reduction of the proportion of acetylene should be made, causing the inner cone to take on a slightly bluish tinge and to become even smaller and slightly waisted.

74. The difference between the oxidizing and neutral flames is not so marked as that between the carburizing and neutral flames, and some operators may have slight difficulty in recognizing exactly when the flame becomes oxidizing in character. Consequently the adjustment of the flame to neutral should always be made from an excess acetylene (carburizing) flame.

75. **Flame Adjustment During Work.** When the blowpipe has been burning for a short time it will be noticed that the flame tends to become oxidizing in character. This is because heat is being conducted to the walls of the injector chamber, causing the acetylene in contact with them to expand and so enter the oxygen stream at a lower density than when the flame was first adjusted. The oxygen is insulated from the walls of the chamber by the incoming acetylene and thus is not heated to the same extent. In the

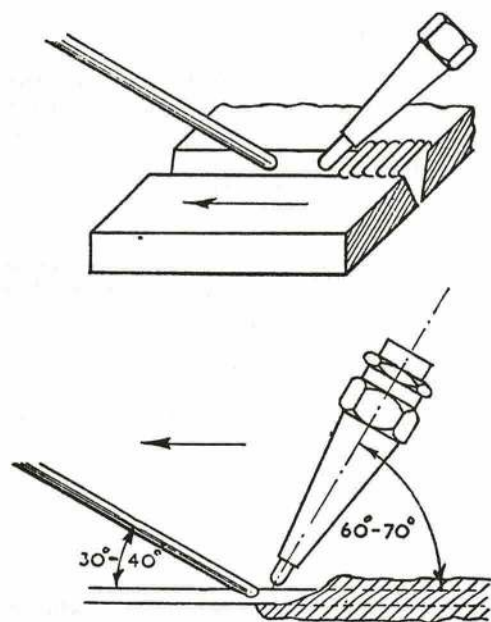
early stages of the weld, therefore, the flame should be kept under observation and the oxygen supply reduced gradually until the blowpipe settles down to steady working.

Making the Weld

76. The method adopted in making a weld is dependent upon the material, its thickness and class of work. The methods of main interest in the Service are the leftward and the rightward welding techniques. In the following brief description of these techniques it is assumed that the operator will hold the blowpipe in his right hand and the welding rod in his left hand.

Leftward Welding

77. This method (Fig. 22) is used for welding metal plate under $\frac{3}{16}$ in. in thickness. The welding rod precedes the blowpipe along the seam, and the weld travels from right to left. The blowpipe is held near the metal and at an angle of 60° to 70° with the plate, while



POSITION OF ROD AND BLOWPIPE.



BLOWPIPE MOVEMENT.

ROD MOVES IN A STRAIGHT LINE.

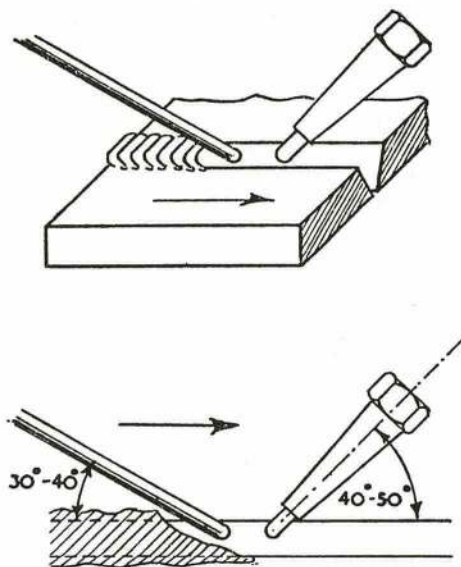
Fig. 22. LEFTWARD WELDING.

the welding rod is held at an angle of 30° to 40° , thus giving an angle of approximately 90° between the rod and the blowpipe. Plates up to $\frac{1}{8}$ in. in thickness need not be bevelled, but material between $\frac{1}{8}$ in. and $\frac{3}{16}$ in. in thickness should be bevelled to an included angle of 80° .

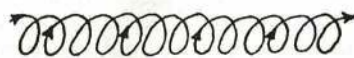
78. The flame is given a circular, or side to side motion, to obtain even fusion on each side of the weld. The flame is first played on the joint until a molten pool is obtained and the weld then proceeds, the rod being fed into the molten pool and not melted by the flame itself. Using the flame to melt the welding rod may result in too much filler metal being introduced into the molten pool of parent metal, thus reducing the temperature to such an extent that good fusion cannot be obtained.

Rightward Welding

79. In rightward welding (Fig. 23), the weld progresses along the seam from left to



POSITION OF ROD AND BLOWPIPE.



MOVEMENT OF ROD.

BLOWPIPE MOVES IN A STRAIGHT LINE.

Fig. 23. RIGHTWARD WELDING.

right, the welding rod following the blowpipe. This method is used with advantage on steel plate which is over $\frac{3}{16}$ in. thick. Its main advantage is that a large blowpipe nozzle can be used without loss of control over the pool of molten metal, and thus makes for greater welding speed. No bevel is necessary for plates up to $\frac{5}{16}$ in. in thickness, but thicker plates must be bevelled to give a 60° included angle. When welding by this method, the blowpipe should be inclined at an angle of between 40° and 50° with the weld surface, and the welding rod at an angle of between 30° and 40° .

80. The weld is started at the extreme left of the work and, after forming the pool of molten metal, the blowpipe is moved steadily to the right. The blowpipe is held so that the cone of the flame is in the vee, just clear of the welding rod, and the nozzle in the same vertical plane as the weld line. No side to side movement of the blowpipe should be made, but the welding rod should be moved forward in a series of elliptical movements, or loops, within the face of the vee.

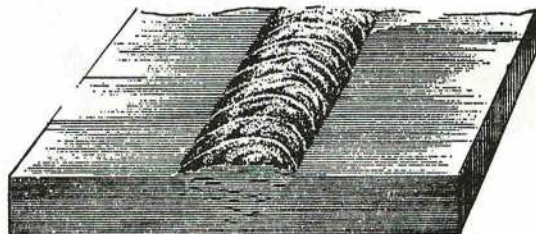
Welding Defects

81. External appearances alone cannot be regarded as furnishing conclusive evidence as to the quality and strength of the weld; a weld with excellent surface finish may contain serious defects. With experience, inferences can be drawn from visual inspection, especially of the underside of a weld, which will enable a person to form a reliable opinion as to whether the work is satisfactory. The information in the following paragraphs will aid an operator to avoid the more common faults.

82. **Carburizing.** This fault is almost entirely confined to welds made in ferrous metals. It is caused by an excess of acetylene in the blowpipe flame, the carbon content of which enters into chemical combination with the metal, making it hard and brittle.

83. **Oxide Trapping.** This defect (Fig. 24) usually occurs when insufficient heat is applied, generally through the use of too small a blowpipe nozzle, or when the molten metal pool is too large to be maintained. In both these instances, an oxide crust forms which is then inadvertently stirred

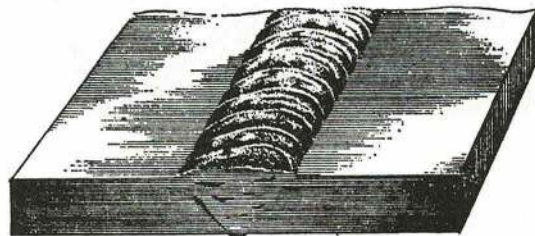
into the weld by the welding rod. Oxide trapping may also be caused by the flame being applied too close to the weld, which results in surface impurities being blown into and trapped in the weld. The use of unsuitable flux may also cause this defect.



Defect revealed by etching

Fig. 24. OXIDE TRAPPING.

84. **Adhesion.** This fault occurs when the added metal adheres, without fusion, to the sides of the weld (Fig. 25). It is caused by the molten metal being allowed to flow, splash, or be driven, on to the sides of the vee before the latter have attained a state of fusion, or by allowing the welding flame to heat one side of the vee more than the other.



Defect revealed by etching

Fig. 25. ADHESION.

85. **Lack of Penetration.** This fault (Fig. 26), failure to fuse the metal throughout the depth of the weld, results in a joint of smaller cross-section than that of the pieces welded. It can be caused by either too great a thickness of metal at the base of the weld, a result of incorrect bevelling, or to hurrying the welding operation and failing to fuse the metal at the base of the vee. This fault is serious because, apart from the reduction in

the cross-section and strength of the joint, it may provide the start of a crack which is liable to continue through the joint.

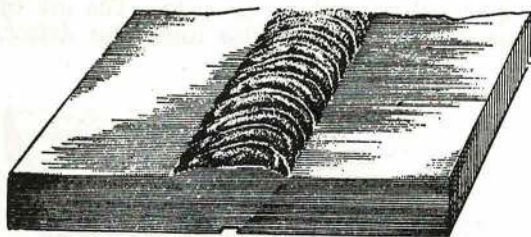


Fig. 26. LACK OF PENETRATION

86. Undercutting or Channelling. If insufficient metal from the welding rod is used in the joint, a channel will form along the line of weld (Fig. 27). This may also be the cause of undercutting of the parent metal, which will also be caused by holding the flame too high when making a fillet weld, or by the application of the flame to a butt weld for an unnecessarily long period. This fault is serious because it weakens the joint.

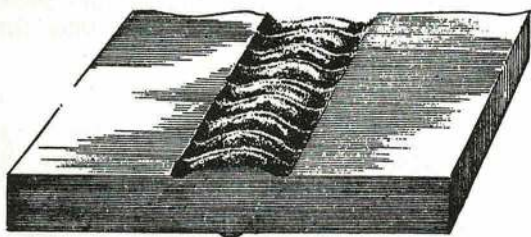


Fig. 27. CHANNELLING.

87. Overheating. Overheating causes grain growth, a coarse crystalline structure, weakness, and brittleness in the weld and surrounding area. It is usually caused by using a too large blowpipe nozzle or by the accumulation of heat due to an excessive amount of welding in a particular area.

88. Oxidation. Oxidation is caused by an excess of oxygen in the gas supply to the blowpipe nozzle. This leads to the formation of a large quantity of oxide on the surface of the metal in contact with the flame. A large amount of this oxide is trapped in the metal with the result that the weld is porous and probably suffers from adhesion and burning.

After-treatment of the Weld

89. When welding is complete, the flux residue must be removed from the surface of the metal around the weld, and the part must receive the appropriate heat or mechanical treatment. The correct anti-corrosive treatment is then applied.

90. Cleaning the Weld. The use of a steam jet or a thorough scrubbing with a bristle brush, followed by immersion in boiling water for not less than half an hour, provides an effective means of removal of the flux residue. To prevent corrosion by the flux residue, all parts must be thoroughly cleaned before cessation of work; cleaning must not be left uncompleted overnight.

91. Restoring Physical Properties. Restoration of the normal strength and other physical properties of the metal, as far as is possible, is effected by subjecting the part to one or more of the processes of heat treatment, sometimes accompanied by a mechanical treatment such as hot or cold hammering. Mechanical treatment of the weld relieves or re-distributes the residual stresses set up in the weld during expansion and contraction. It also refines and improves the micro-structure of both the weld metal and the parent metal.

92. Anti-corrosive Treatment. This is usually a necessity, the type of treatment being dependent upon the material, and the shape and purpose of the component. The treatment may include several processes of acid dipping, water washing and scratch brushing before the final coating or enamelling process is applied.

Welding Various Metals

93. Mild Steel. Mild Steels, which have a carbon content ranging from .1 per cent. to .25 per cent., are among the most easily welded of all metals. Most of the general practice examples given in these notes refer to the welding of mild steel, and the appropriate method of preparation should be selected according to the thickness of the metal. No flux is necessary; a neutral flame only should be used, the tip of the luminous envelope just touching the metal. Hold the tip of the welding rod in contact with the molten pool whilst adding the metal. Heat treatment of mild steels subsequent to welding is not necessary unless instructions speci-

fically state otherwise, but normalizing after welding is essential for welds that are highly stressed in service.

94. Medium and High Carbon Steels. The carbon content of these steels creates difficulties when welding. No flux is necessary, but, as the melting points of these steels and their oxides approach one another, care is necessary to prevent oxide becoming embedded in the weld. A carburizing flame must be avoided as it will increase the carbon content of the metal in and around the weld, rendering it harder, less ductile and less malleable than the surrounding metal. In steels containing about .3 per cent. or more carbon, heat treatment after welding is desirable to modify the tendency to hardness and brittleness at the weld. High carbon steels require pre-heating to produce reasonably soft weld metal and to avoid cracking at the weld.

95. Stainless Steel. The thermal conductivity of stainless steel is only one-half to one-third that of mild steel. This localizes the heat effect and causes undue penetration unless care is exercised. The blowpipe should be played over a wider area, and a slightly smaller nozzle or lower pressure of both gases should be used than for welding mild steel. Thermal expansion is greater than mild steel; therefore, more allowance must be made to minimize distortion or internal strains caused by this factor. The use of a flux is essential, and the flame must at all times be neutral. Whilst welding, the tip of the flame inner cone must be kept in contact with the pool of molten metal, thus preventing oxidation. Pre-heating or heat treatment after welding may or may not be necessary, depending on the specification of the steel. Before welded parts are put into service, oxide or scale must be removed by immersing them in an acid solution of water (50 per cent.), hydrochloric acid (50 per cent.) and nitric acid (2 per cent. of combined volume of water and hydrochloric acid) at a temperature of 50°C. After treatment, the parts are scrubbed in hot water to remove all trace of the acid solution.

96. Cast Iron. Successful welding of this metal requires considerable skill. A process known as bronze welding is widely used instead of fusion welding with cast iron filler rods. Bronze welding has the advantage that much less heat has to be applied as the

parts to be joined are not melted but are bonded by the melting between them of a bronze rod, which has a much lower melting point than cast iron. The process consists of heating the surfaces to be joined to the correct temperature, and "tinning" them by applying a thin film of bronze which adheres firmly to them. The joint is then built up by applying further deposit from the bronze filler rod. Correctly executed, a bronze welded joint is as satisfactory for most purposes as a fusion weld.

97. Copper. Bronze welding is usually employed on copper. This is because the copper supplied to the Service may or may not contain oxygen, the specification not defining the permissible content. The presence of small amounts of oxygen, while hardly affecting the general properties of the metal, may be sufficient to cause unsatisfactory fusion welds, and more satisfactory joints can be made by bronze welding this type of copper.

98. Brass. This metal consists mainly of copper and zinc, but various other metals such as lead, tin, aluminium, iron and nickel are often added to give special properties. If aluminium is present it is necessary to use a flux when welding. To obtain the best results special welding rods should be used. Brass castings should be pre-heated, but local pre-heating is sufficient when welding bars or sheets. Dense white fumes of zinc oxide are given off during the welding of brass; therefore, an approved type respirator must be worn by the welder.

99. Aluminium and Magnesium Alloys. A different technique is required for welding these metals. Their melting points are relatively low, whilst their thermal conductivity is more than four times that of mild steel. The oxides, which form very rapidly as the melting point is approached, are practically infusible, and their density is greater than that of the molten metal. As there is no change of colour to indicate when the metal is approaching fusion temperature it is essential that the parts are suitably supported, because the metal suddenly collapses when the melting temperature is reached. Further, magnesium has a definite fire hazard if correct conditions are not maintained during the welding process.

It is therefore essential to observe the following points when welding these metals. The metal in the vicinity of the weld must be thoroughly clean and free from corrosion, oil and grease. The work must be pre-heated and suitably supported. A blowpipe nozzle one size smaller than that used for welding steel of the same thickness should be used. The flame must be neutral, the pressure of both gases being as low as is consistent with satisfactory operation. An oxidizing flame must never be used on magnesium; it is even preferable for the

flame to have a slight haze of acetylene around the inner cone. The flame must heat the welding rod tip as well as both edges of the joint; the molten pool will not melt the rod as in welding steel; this must be done by the flame. Flux should be applied at frequent intervals while welding is in progress; all traces of this must be removed from the finished weld by washing and scrubbing in boiling water. Welds made on sheet and bar aluminium should subsequently be cold worked by hammering; this refines the coarse-grained structure of the weld.

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